Coaltech

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INTEGRATED ANNUAL REPORT

Annual Report 2025 / 26

Coaltech Research Association NPC. For the year ended 31 March 2026.

ADVANCING THE FUTURE OF SUSTAINABLE COAL

Contents

Coaltech is a voluntary, member funded, non profit research association for the South African coal industry, established in 1999. We coordinate applied research that keeps the industry competitive, safe and sustainable, and share the results across our membership.

Coaltech

SECTION ONE

01

Chairperson's Letter

A year defined by visibility and by delivery, and by a growing conviction that the future of coal will be shaped by evidence and collaboration.

Dear members, partners and friends of Coaltech, I write to you at the close of a year in which Coaltech stepped more firmly onto the national stage than at any point in its recent history.

Phillip Mulder
Chairperson, Coaltech

It was a year defined by visibility and by delivery, and by a growing conviction across the industry that the future of coal will be shaped by evidence, by collaboration, and by research that reaches operations. On behalf of the Board, I invite you to read this letter not only as a record of the year, but as an invitation to build the next one with us.

The clearest marker of that visibility was our presence at the Mining Indaba. To be well represented at the continent's foremost mining gathering was a significant outcome for an organisation of our size, and we are thankful to the organising committee for the strategic partnership. It placed Coaltech's research, and the case for a safe and sustainable coal sector, in front of investors, industry leaders and decision makers from across Africa and beyond. This is what industry visibility looks like, and we intend to build on it.

Visibility means little without substance, and this year the substance was real. We completed a body of research that members can put to work. Our upgrade of the Kloppersbos explosibility laboratory strengthened the national facility at the heart of coal dust safety. Our work on incorporating coal waste into asphalt mixes opened a direct route from discard to usable infrastructure. Research into eutectic freeze crystallisation advanced the recovery of clean water from mine streams, while the growth of kenaf on coal tailings and a regenerative cropping and livestock model reimagined rehabilitated land as productive ground. And our Scope 1 and Scope 2 emissions management work gave the industry a defensible basis for measuring and reducing its footprint. Delivered with the CSIR, Mintek and nine universities, these projects are the proof of our purpose.

> The Board has set a clear direction: to widen our lens to the whole energy system, to shift from the volume of coal to its value, and to keep Coaltech essential to its members and relevant to the nation.

These are steps toward a larger ambition. This is the frontier where the value of coal extends well beyond combustion, and where South Africa's coal endowment can help answer a global question. Our task in the year ahead is to turn that direction into delivery, project by project.

Leadership renewed itself this year in ways that strengthen us. Mr Maynard Lombard (Thungela Resources) resigned as Chairperson of our Coal Processing Steering Committee during the year; we extend our sincere thanks for his leadership and service. The role passed to Ms Vicky van Schalk Wyk, Group Metallurgist at Glencore Coal, as Chairperson, and Ms Sandra Magagula, Group Metallurgist at Genet Mineral Processing, as Vice Chairperson, two distinguished professionals and committed advocates for women in mining. At Board level we welcomed Mr Madder Steyn, appointed in September 2025, thanked Mr Veli Sibiya for his service on his resignation, and elected Ms Lerato Saolose as Vice Chairperson of the Association. We also paused to honour our founding Chief Executive, Johann Beukes, whose vision and humility shaped the organisation we are today, and whose standard we carry forward.

I am pleased to report an unqualified audit opinion from Ranrus Incorporated, prepared under IFRS for SMEs, with the going concern basis affirmed. The control environment that safeguards members' funds was materially strengthened this year: we adopted an Intellectual Property Governance Framework, effective 1 April 2026, to protect Coaltech funded research, introduced Standard Project Cost Guidelines to sharpen cost discipline, and the Board met four times with active steering committee oversight across every programme.

I owe members an honest signal. Research commitments are now growing faster than recurring member contributions. As a first corrective measure the Board approved a 10 percent increase in primary member contributions for 2026/27, and accumulated reserves of R16.8 million provide headroom while our strategy takes effect. That strategy is clear: to reach a self funding research organisation by 2030, to grow our associate base and co funding, and to advance our Memorandum of Understanding with Zambia's Ministry of Energy as a technical partner for sustainable mining research across Southern Africa.

So this is, above all, an invitation. If you are part of the coal industry, or if you believe in its responsible future, there is a place for you in this community. Join us as a member, partner with us on the research that matters to your operations, and help us turn a year of visibility into a decade of impact. The work is demanding, the purpose is clear, and the door is open.

The Board is satisfied that Coaltech is a going concern with a clear strategy and strengthened controls, and I recommend the audited annual financial statements for the year ended 31 March 2026 to members for adoption.

With warm regards and appreciation

PP Mulder
Chairperson, Coaltech Research Association NPC

SECTION TWO

02

Chief Executive's Report

Strong operational growth and a sharpened focus on financial sustainability, closing the year with a clean audit and a resilient balance sheet.

Members, it is my privilege to report on a year in which Coaltech delivered strong operational growth while sharpening its focus on financial sustainability.

Membership and income

Coaltech ended the year with 33 member organisations, being our six primary members, the Minerals Council and 26 associate members, together with three individual members. The associate base has grown from 9 to 26 over two years, broadening our industry reach and inclusiveness. Income from primary member contributions and associate membership fees rose to R15.4 million, up 43 percent on the prior year, supported also by secured project co funding, including High Efficiency Low Emissions (HELE) support from Eskom, the Council for Scientific and Industrial Research (CSIR) and the South African National Energy Development Institute (SANEDI). The Board approved a 10 percent increase in primary contributions for 2026/27. Our priority is not the recruitment of members for its own sake, but the creation of research impact that matters to the industry.

Research delivery

The research portfolio comprised 33 projects across our four programmes, of which 9 were completed, 15 remained active and 9 were newly approved, the new projects including Phase II of the High Efficiency Low Emissions programme, representing a committed research programme of R17.1 million for 2026/27. Direct research expenditure for the year reached R12.7 million, more than double the prior year. Flagship results included completion of Phase I of the Circulating Fluidised Bed clean coal technology project, with a R10 million Phase II for which co funding from the CSIR, Eskom and SANEDI is expected though not yet confirmed; the Kloppersbos explosibility laboratory upgrade; in situ stress measurement trials at Kriel Colliery; eutectic freeze crystallisation for mine brine treatment; and the conversion of coal waste into asphalt and building components. Eight new project contracts were negotiated with cost reductions and signed during the year.

Industry profile and events

We materially raised Coaltech's visibility. The Mine Closure Seminar attracted more than 200 attendees, we continued to build our masterclasses and YouTube channel, and Coaltech was well represented at the Mining Indaba in February 2026. We are thankful to the organising committee for the strategic partnership.

Financial discipline

Management held administrative costs within budget, with discretionary line items at or below plan. The operating result reflects the deliberate expansion of research spend, and investment income of R1.7 million supported a surplus of R367 590 for the year. Cash and investments stood at R23.2 million at year end. We recognise that most research settlement falls in the final quarter, and we manage this timing through disciplined cash planning and, where required, a measured drawdown from reserves rather than any structural shortfall in solvency.

Governance and looking ahead

During the year we implemented the Standard Project Cost Guidelines and the Intellectual Property Governance Framework, and I confirm an unqualified audit outcome. Our forward agenda is equally clear. We are widening our strategic lens, positioning coal within a broader energy system and moving from a volume based view of coal to a value based one. In practice this means concentrating on fewer, larger, co funded priorities that create impact that matters: containing new commitments through selective approval, growing co funding and the associate base, advancing the Zambia partnership, and launching the Youth Innovation Council to build the next generation of talent. These actions set Coaltech firmly on the path to a self sustaining, and increasingly essential, research organisation.

Avhurengwi Nengovhela
Chief Executive Officer

THE YEAR

R15.4m
Contributions and fees, up 43%

R12.7m
Direct research investment

R367k
Surplus for the year

33
Research projects across four programmes

SUBSEQUENT EVENT · INTEGRATED MINING AND PROCESSING

With effect from 1 July 2026, the Mining and Coal Processing portfolios operate as a single Integrated Mining and Processing forum, chaired by Mr Gavin Silver, with dedicated Vice Chairpersons leading the mining and processing technical streams. The integration concentrates oversight across the full value chain and removes duplication, while preserving the technical depth of each discipline. Existing projects, contracts, Service Level Agreements, membership and fees continue unaffected.

AC Nengovhela
Chief Executive Officer, Coaltech Research Association NPC

SECTION THREE

03

Coaltech at a Glance

The year in numbers: growth in membership, a doubling of research investment, and a resilient balance sheet.

03

COALTECH AT A GLANCE

A voluntary, member funded, non profit research association for the South African coal industry, established in 1999. Research needs are raised by members through steering committees, one for each research stream.

MEMBER CONTRIBUTIONS AND FEES

R15.4m

Up 43 percent on the prior year

RESEARCH PROGRAMME

33

Projects: 9 completed, 15 active, 9 new

R12.7m

Invested directly in research, more than double the prior year

R23.2m

Cash and investments at year end

R16.8m

Accumulated reserves

33

Member organisations, including 26 associates

R1.7m

Investment income

200+

Attendees at the Mine Closure Seminar

✓ **Unqualified audit opinion** issued by Ranrus Incorporated, with going concern confirmed and the Association debt free.

03

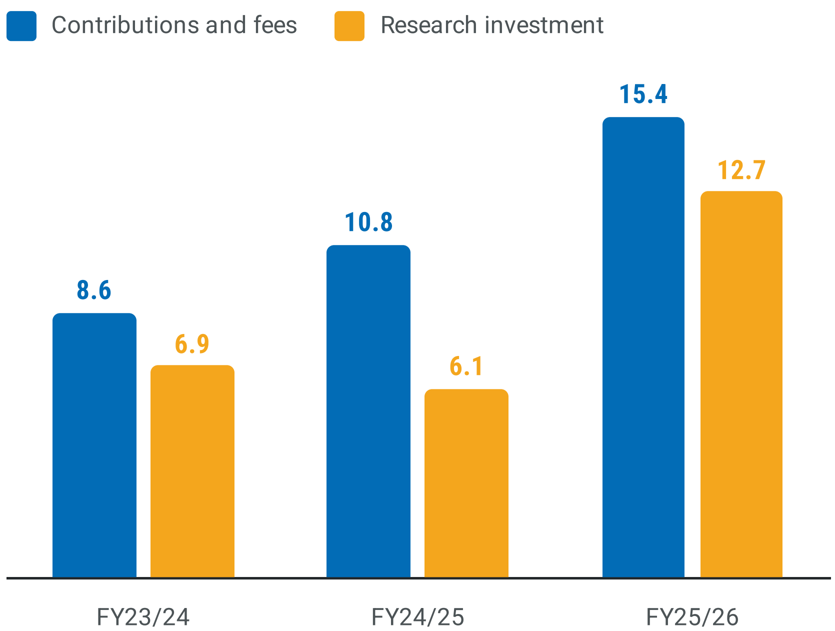
COALTECH AT A GLANCE

Three years of momentum

EXHIBIT 1

Contributions and fees vs research investment

R millions, by financial year



Source: Coaltech audited annual financial statements.

EXHIBIT 2

Research portfolio

33 projects by status

33
projects

Completed	9
Active	15
New	9

EXHIBIT 3

Associate membership growth

Associate members, by financial year

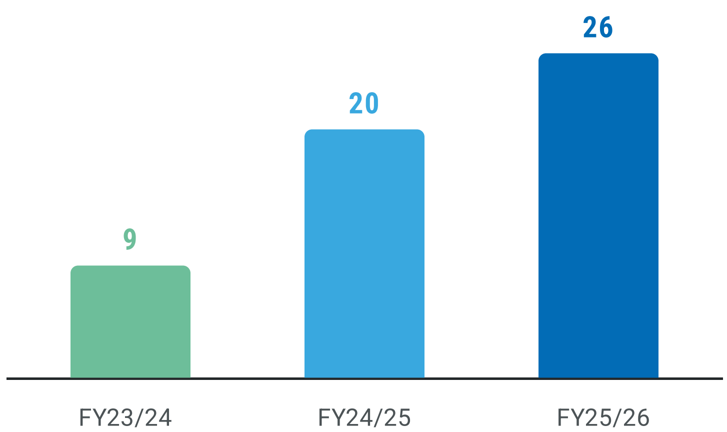
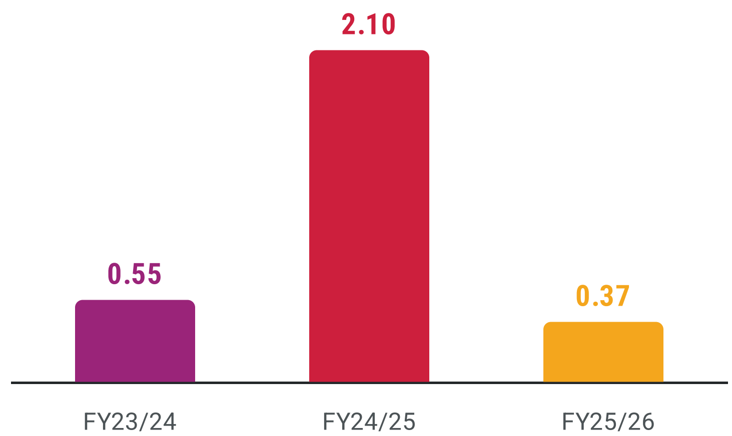


EXHIBIT 4

Surplus for the year

R millions, by financial year



The FY25/26 surplus reflects the deliberate doubling of research investment.

SECTION FOUR

04

How Coaltech Creates Value

One collaborative cycle, shared across the membership. No single company carries the full cost or risk of the research the industry needs.

04

HOW COALTECH CREATES VALUE

Coaltech's model is collaborative by design. Members pool their contributions and share the results, so value moves through a simple, repeating cycle.

EXHIBIT 5 · THE COALTECH VALUE CYCLE

1 Members raise needs

Primary and associate members bring the real problems of mining and processing to the table.

2 Committees prioritise

Each research stream is governed by a steering committee that selects and oversees the work that matters most.

3 Research funded and run

Projects are awarded to universities, science councils and specialist partners, with co funding leveraged where possible.

4 Results shared

Findings, guidelines and technologies are made available across the membership, multiplying the return on every rand invested.

Collaborative research

Exhibit: the collaborative research cycle. Value is multiplied because the cost and risk of research are shared across the membership.

SECTION FIVE

05

The Future of Coal and Coaltech's Contribution

Energy addition and a technology transition: using coal more cleanly, more efficiently and more responsibly while the country builds a broader energy mix.

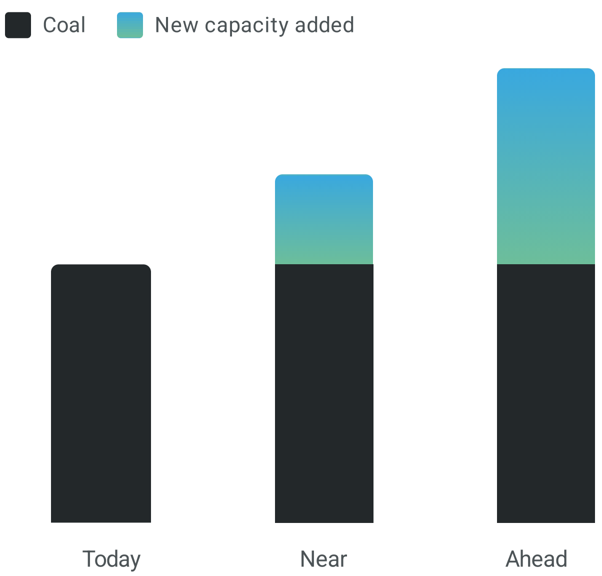
Coal remains central to South Africa's industrial stability, electricity supply and employment. It supplies roughly 70 percent of the country's electricity and underpins a value chain that sustains hundreds of thousands of livelihoods.

The global conversation is shifting, but South Africa's path is one of energy addition: adding new generating capacity alongside coal to meet demand, rather than removing coal before the country can afford to. Where change comes, it comes through a technology transition, using coal more cleanly and efficiently, not through abandonment. The future of coal here is not a binary of use or abandonment; it is a question of using it more cleanly, more efficiently and more responsibly while the country builds a broader energy mix.

EXHIBIT 6 · ENERGY ADDITION AND A TECHNOLOGY TRANSITION

Energy addition

Add new capacity alongside coal to meet demand, rather than removing coal before it can be replaced.



Technology transition

Use coal more cleanly and efficiently through better technology, not through abandonment.

Conventional coal → **Cleaner, efficient coal (HELE-CFB)**

Enabled by Coaltech research

- Clean coal (HELE-CFB)
- Critical minerals from waste
- Mine water treatment
- Rehabilitation and closure

Coal (dark) holds the base while new capacity (colour) is added on top; conventional coal moves to cleaner, more efficient coal through HELE-CFB.

> Coaltech contributes to the future of coal by making the sector safer, cleaner and more efficient, and by supporting a credible technology transition.

Coaltech's contribution is practical and research-led. Through the HELE-CFB clean coal programme, carried out with the CSIR, Eskom and SANEDI, Coaltech is advancing high-efficiency, low-emissions technology that turns coal discards and low-grade coal into dispatchable power while reducing the discard legacy.

Through work on critical minerals and rare earths from coal waste, it is helping to reposition coal residues as a resource. Through mine water treatment, rehabilitation, carbon farming and mine closure research, it is reducing the environmental footprint of the industry. And through its safety and productivity research, it is protecting the people who work in it.

EXHIBIT 7 · COALTECH'S CONTRIBUTION TO THE FUTURE OF COAL

Clean coal technology

HELE-CFB turns discards into dispatchable, lower emission power.

Safety and productivity

Safer blasting, stress measurement, wearables and digital tools.

Safer, cleaner, more efficient coal

Critical minerals

Rare earths and critical minerals recovered from coal waste and ash.

Land and closure

Rehabilitation, carbon farming and regenerative post mining land use.

Mine water

Treatment and reuse of mine affected water; metals from brines.

SECTION SIX

06

Sustainability

Sustainability runs through Coaltech's research agenda rather than sitting beside it, addressing the environmental, social and economic dimensions of coal in direct, measurable ways.

06

SUSTAINABILITY

Four themes, each carried by live research projects that convert environmental pressure into measurable progress.

Environment

Research on mine water treatment and reuse, the recovery of battery metals and critical minerals from brines and discards, waste liner innovation for mine closure, and the rehabilitation of discard dumps all reduce the environmental load of mining and processing. The eutectic freeze crystallisation and biological brine treatment projects target cleaner water and usable by-products from waste streams.

CLEANER WATER · USABLE BY-PRODUCTS

Emissions and clean technology

The sector-wide emissions programme with Promethium Carbon and the HELE-CFB clean coal work address the carbon intensity of the industry directly, moving from measurement to demonstrable reductions and higher-efficiency generation.

6.73M TCO_2E SECTOR BASELINE ESTABLISHED

Land, closure and community

Carbon farming on rehabilitated land, the regenerative crop and livestock work, and the mine closure research connect environmental rehabilitation to community regeneration and post-mining livelihoods, so that closure becomes an opportunity rather than only a liability.

REHABILITATED LAND TURNED PRODUCTIVE

Energy addition and technology transition

Through targeted partnerships, Coaltech supports energy addition and a technology transition that keep development, jobs and energy security in view alongside lower emissions.

SECTION SEVEN

07

Governance

A Board of Directors, supported by steering committees for each research stream and serviced by the Coaltech office as the secretariat.

GOVERNANCE

The Board and team

Coaltech is governed by a Board of Directors, supported by steering committees for each research stream and serviced by the Coaltech office. The steering committees report to the Board; the CEO and office are in attendance in a secretariat capacity.

Phillip Mulder
Chairperson
Seriti Resources

Lerato Saolose
Vice Chairperson
Exxaro Resources

Naadira Haniff
Director
Thungela Resources

Marius Smith
Director
Glencore Operations South Africa

Daniel Thenga
Director
Eskom Holdings

Christian Teffo
Director
Minerals Council South Africa

Madder Steyn
Director
Sasol Mining

Avhurengwi Nengovhela
CEO & Company Secretary
Coaltech office

Carmen Bergman-Ally
Projects Coordinator & Secretariat
Coaltech office

Londolani Rampfumedzi
SACMA Representative
SACMA

SUBSEQUENT EVENT · AFTER YEAR-END

After the financial year had closed, with effect from 1 July 2026, the Board consolidated the Mining and Coal Processing steering committees into a single Integrated Mining and Processing structure. It is chaired by Gavin Silver, with Teboho Dibate as vice chair of the mining stream and Vicky van Schalkwyk as vice chair of the processing stream, retaining a dedicated technical stream and vice chairperson for each discipline.

GOVERNANCE · EXHIBIT A

07

Our organisation during the 2025/26 year

Four steering committees, each reporting directly to the Board. The CEO and Coaltech office are in attendance in a secretariat capacity.

BOARD OF DIRECTORS

Chairperson: Phillip Mulder (Seriti Resources) · Vice Chairperson: Lerato Saolose (Exxaro Resources)

Directors: N Haniff (Thungela Resources) · M Smith (Glencore Operations South Africa) · D Thenga (Eskom Holdings) · C Teffo (Minerals Council South Africa) · M Steyn (Sasol Mining)

EXECUTIVE & SECRETARIAT
in attendance

CEO: Avhurengwi Nengovhela

Projects Coordinator: Carmen Bergman-Ally

MINING

Chairperson
Gavin Silver
Seriti Resources

Vice Chairperson
Teboho Dibate
Exxaro Resources

COAL PROCESSING

Chairperson
Vicky van Schalkwyk
Glencore Operations South Africa

Vice Chairperson
Sandra Magagula
Genet Mineral Processing

SURFACE ENVIRONMENT

Chairperson
Marthinus W. van Wyk
Thungela Resources

Vice Chairperson
Dr Kelley Reynolds-Clausen
Eskom Holdings

FUTURE TECHNOLOGIES

Chairperson
Festus Leteane
Seriti Resources

Vice Chairperson
Mfundo Verby
Eskom Holdings

Exhibit A. Coaltech organisation structure during the year ended 31 March 2026.

GOVERNANCE · EXHIBIT B · SUBSEQUENT EVENT

Our organisation with effect from 1 July 2026

Created after the reporting year closed. Mining and Coal Processing consolidate into one Integrated Mining and Processing forum with two technical streams. Steering committees report to the Board; the CEO is in attendance. No change to members, projects, contracts or fees.

BOARD OF DIRECTORS

Chairperson: Phillip Mulder (Seriti Resources) · Vice Chairperson: Lerato Saolose (Exxaro Resources)

Directors: N Haniff (Thungela Resources) · M Smith (Glencore Operations South Africa) · D Thenga (Eskom Holdings) · C Teffo (Minerals Council South Africa) · M Steyn (Sasol Mining)

EXECUTIVE & SECRETARIAT

in attendance

CEO: Avhurengwi Nengovhela

Projects Coordinator: Carmen Bergman-Ally

INTEGRATED MINING & PROCESSING

Chairperson
Gavin Silver (Seriti Resources)

Vice Chair, Mining stream
Teboho Dibate (Exxaro Resources)

Vice Chair, Processing stream
Vicky van Schalkwyk (Glencore Operations South Africa)

SURFACE ENVIRONMENT

Chairperson
Marthinus W. van Wyk (Thungela Resources)

Vice Chairperson
Dr Kelley Reynolds-Clausen (Eskom Holdings)

FUTURE TECHNOLOGIES

Chairperson
Festus Leteane (Seriti Resources)

Vice Chairpersons
Mfundo Verby (Eskom Holdings)
Sandra Magagula (Genet Mineral Processing)

Exhibit B. Subsequent event, effective 1 July 2026, after the reporting year closed.

SECTION EIGHT

08

Members and Partners

Thirty-three member organisations and three individual members, working with the country's leading science councils and research partners.

A collaborative membership

08

PRIMARY MEMBERS

exxaro POWERING POSSIBILITY

SERITI

sasol reaching new frontiers

Eskom

thungela

GLENCORE

MINERALS COUNCIL SOUTH AFRICA

ASSOCIATE MEMBERS 26

THE VUNA GROUP

MINOPEX

genet MINERAL PROCESSING

FRASER ALEXANDER

NAMANE RESOURCES

AGREENCO

Jones & Wagener Engineering & Environmental Consultants

GCS

nafasi water

CEM mining

EXM EXM ENVIRONMENTAL SCIENCE

gravitas

ACRUX SORTING TECHNOLOGY

FlowCentric MINING TECHNOLOGY

mcs.

MAPTEK

DMT DMT Kai Batla (Pty) Ltd

BLUGREY Occupational Hygiene (Pty) Ltd

TR TIMRITE

KLE ADVANCE

razorlabs

ENPROTEC ENGINEERING THAT INSPIRES

AshResources Fly ash products

PHATSEMA

CDC DUST CONTROL

JCI MINING

Universities and research partners

UNIVERSITIES

- University of Cape Town
- University of Pretoria
- University of the Witwatersrand
- North-West University
- University of the Free State
- University of Johannesburg
- University of South Africa
- University of Venda

RESEARCH AND INDUSTRY PARTNERS

- CSIR
- Mintek
- Water Research Commission
- Agricultural Research Council
- Mandela Mining Precinct
- FutureCoal
- SACMA
- SANEDI
- SACESHA
- Nkangala Chamber

33 member organisations: six primary members, the Minerals Council South Africa, and 26 associates. Three individual members are counted separately.

JOINED AFTER YEAR-END

Hlela Energies and MPBIASA joined as members after the reporting year closed on 31 March 2026.

SECTION NINE

09

Events of the Year

A year in which Coaltech stepped more firmly into the national and industry conversation, through seminars, partnerships and the launch of the 2026 research portfolio.

EVENTS OF THE YEAR

8 April 2025

Mine Closure Seminar

More than 200 members, researchers and partners gathered to help shape a sustainable future for the coal sector.

6 May 2025

Sector-wide emissions project with Promethium Carbon

A sector-wide project launched to tackle carbon emissions across the coal value chain.

August 2025

Annual Ideation Summit

Members and partners gathered to shape the next research programme, raising the priorities that will guide Coaltech to 2031.

28 November 2025

2026 Research Portfolio launch

Coaltech unveiled its 2026 research portfolio, positioning South Africa for leadership in clean coal innovation and critical minerals.

19 February 2026

New Coal Processing committee leadership

Vicky van Schalkwyk (Glencore) appointed Chairperson and Sandra Magagula (Genet) Vice Chairperson, both advocates for women in mining.

Delegates gather at a Coaltech seminar under the banner, Advancing the future of sustainable coal.

From the Mine Closure Seminar and the Ideation Summit.

SUBSEQUENT EVENTS · AFTER 31 MARCH 2026

The HELE-CFB Localisation Programme launched on 1 April 2026 in support of the Integrated Resource Plan 2025, with Coaltech at the centre, and the Coaltech Colloquium followed on 28 May 2026. Both fall after the reporting year and are noted here for context only.

SECTION TEN

10

Research in Action

The following project summaries are reproduced as supplied by the research teams. They are the substance of Coaltech's year.

Mining · Coal Processing · Surface Environment · Future Technologies

RESEARCH IN ACTION · FOCUS AREA

Mining

Coal dust explosibility characterisation and in-situ stress measurement: research that protects the people who work underground.

Kloppersbos explosibility laboratory upgrade · In-situ stress measurement in South African coal mines

MINING · PROJECT M2020-2

Kloppersbos explosibility laboratory upgrade

Researcher: Riaan Bergh (CSIR) · Reviewers: Prof. Bekir Genc (University of the Witwatersrand), Prof. Jan du Plessis (University of Pretoria), Alan Cook (Latona Consulting)

10

Introduction

Underground coal mining involves significant safety hazards, including methane ignitions and coal dust explosions. These events have historically caused fatalities, injuries and extensive damage to mine infrastructure. Reliable characterisation of coal dust explosibility is essential for assessing explosion risk and determining appropriate prevention and mitigation measures.

In South Africa, coal dust explosibility has traditionally been characterised using a 40-litre explosion vessel. The result is expressed as the Explosibility Index, Kex, in units of bar/s. This index has been used for many years to classify South African coal dust according to its ability to propagate an explosion underground. When the 40-litre apparatus was commissioned, calibration was performed using German reference coal samples and comparison with a similar apparatus in Germany. Later, South African reference coals were used for verification. Over time, these reference materials became unavailable or had to be replaced, and there has not been a means of independently calibrating the 40-litre apparatus for several years.

The 20-litre Siwek explosion vessel is widely used internationally and is available at the Kloppersbos explosibility laboratory. It has important advantages, particularly annual manufacturer-administered round-robin calibration, technical support and broad international acceptance. However, because South African coal dust classification was developed around the 40-litre apparatus and Kex index, the relationship between Kex and the 20-litre apparatus Explosion Index, Kmax, had to be determined if the 20-litre apparatus is to be used in future.

This study was undertaken to determine whether the 20-litre apparatus can replace the 40-litre apparatus for future South African coal dust explosibility testing, while still allowing results to be evaluated against existing South African classification limits. The study also investigated the effect of in-mine atmospheric conditions on coal dust explosibility. Standard laboratory tests are performed under laboratory temperature and humidity conditions and without methane in the vessel. Actual mine conditions may differ. Temperature, humidity and methane may influence explosibility and should therefore be considered when interpreting laboratory test results.

Coal dust explosion risk

It is common for methane to be released from coal seams during mining and methane can accumulate where ventilation is inadequate. Coal dust is generated by cutting, drilling, transport and handling of coal, and will settle on exposed mine surfaces. If this dust becomes airborne and is ignited, it can propagate a destructive explosion through the mine.

Historical explosion incidents show the severity of the hazard. South African explosion statistics from 1983 to 1993 recorded 93 injuries and 218 deaths. The Middelbult coal mine disaster of 13 May 1993, where a methane ignition resulted in a coal dust explosion that killed 53 mine workers, illustrates the destructive potential of such events.

FIGURE 1

Laboratory technician depositing a dust sample into the injection chamber of the 20-litre explosion vessel. Depositing of a dust sample into the injection chamber of the 20-litre explosion vessel is demonstrated in Figure 1.

Coal dust explosion mechanism

A coal dust explosion requires the five elements of the explosion pentagon: combustible dust, air as oxidiser, an ignition source, dispersion of the dust cloud and confinement. Important risk factors include ignition sources, coal explosibility, presence of methane in air, mine temperature and humidity, ventilation, particle size distribution, dust concentration, and the balance between combustible and incombustible material. Dry dust is more explosive than moist dust, and fine particles increase explosion severity because their greater surface area allows faster combustion. Coal dust with a mean particle size of approximately 20 μm and a top size of 125 μm was found to be representative of dust produced in underground coal mining.

The initiating event in underground coal mine explosions is often the ignition of a methane-air mixture. Methane is explosive in air between approximately 5% and 15% concentration by volume, with the most powerful explosions resulting from the stoichiometric concentration of about 9.5% methane. Ignition sources may include frictional ignition from cutting machinery, electrical sparks and blown-out shots during blasting. Ignition of methane produces an outwardly expanding flame front and a pressure wave. The pressure wave from the methane ignition may lift settled coal dust from mine surfaces and disperse it into an airborne dust cloud. The methane flame can then ignite the suspended coal dust. Heat from the flame front causes coal particles to release volatile combustible compounds, which burn and sustain flame propagation. As the explosion progresses, more dust can be lifted into suspension, allowing the explosion to increase in strength and extent. Secondary coal dust explosions therefore tend to be more destructive than the initial methane ignition.

Coal dust explosion propagation can be prevented or limited by inerting with stone dust. Stone dust absorbs heat, screens thermal radiation, obstructs oxygen and combustible gas diffusion, and some types of stone dust may release carbon dioxide when heated. Research using the 200 m explosion gallery at Kloppersbos showed that 80% total incombustible content is required to stop a full-scale coal dust explosion. Lower levels may reduce propagation and overpressure but may still allow coal dust to participate in the explosion.

Explosibility characterisation and classification of coal dust

Coal dust explosibility testing is performed in closed laboratory explosion vessels to determine the explosion potential of the coal dust. The explosibility test using the 40-litre apparatus produces the Kex explosibility index, which is the industry standard for coal dust explosibility characterisation in South Africa. The explosibility index of the coal dust informs decisions on explosion prevention measures, including stone dusting and explosion barriers. The classification of coal dust explosibility into three broad categories based on the explosibility index is shown in Table 1.

Table 1. Classification of coal dust explosibility.

Explosibility index, Kex (bar/s)	Dust explosion risk classification
Kex < 70	Non-explosive. Will not propagate an explosion.
70 ≤ Kex ≤ 95	Transition region. Large-scale testing in 200m explosion gallery recommended to confirm explosion propagation risk. Alternatively, treat as explosive.
Kex ≥ 95	Will propagating an explosion.

Testing in the 20-litre Siwek explosion vessel reports explosibility index Kmax, in units of bar.m/s. In this study, coal samples tested in the 20-litre apparatus were prepared to the same particle size specification used for the 40-litre apparatus, to represent underground coal mine dust and allow direct comparison. The 20-litre apparatus offers several advantages, chief among which are annual round-robin calibration, manufacturer support and international acceptance. These advantages made it the preferred future option, provided the relationship between Kex and Kmax is established.

Methodology

The experimental programme consisted of two parts. First, a side-by-side comparison was performed between the 40-litre and 20-litre explosion vessel methods. This was done to determine the relationship between the Kmax values obtained from the 20-litre apparatus and the Kex values obtained from the 40-litre apparatus. Second, the 20-litre apparatus was used to investigate the effects of temperature, humidity and methane on the explosion index of coal dust.

The comparison tests were performed in both vessels under laboratory atmospheric conditions. Temperature ranged from 20°C to 24°C and relative humidity from 43%RH to 56%RH. Coal samples were collected from 16 South African coal mines to include a range of explosibility values. For the investigation of the effect of atmospheric condition on coal dust explosibility, one parameter was varied while the others were kept constant as far as practical. The dust concentration was fixed at the concentration that had produced the maximum Kmax during earlier explosibility testing.

Experimental results

The results of comparison between the 40-litre and 20-litre apparatuses, based on 16 coal samples, are summarised in Table 2. Using the mean ratio Kmax = 0.97Kex, the historical South African Kex limits can be restated in terms of Kmax as shown in Table 3.

The tested samples set did not include very strong explosibility samples. None produced Kmax values above 300 bar.m/s, and the intended range from weak to very strong was only partly achieved. This supports the need for further comparison testing using samples over a wider explosibility range.

Temperature testing using the 20-litre apparatus, conducted at three temperature steps between approximately 23°C and 63°C, showed a moderate correlation between increasing temperature and increasing Kmax, with coefficient of determination $R^2 = 0.59$. It was found that a 1°C increase in temperature can be expected to increase Kmax by approximately 0.4 bar.m/s.

Humidity testing showed a moderate correlation between increasing humidity and decreasing Kmax, with $R^2 = 0.43$. It was found that a 1% increase in relative humidity resulted in a 0.3 bar.m/s decrease in Kmax. Methane testing was performed at concentrations from 0% to 2% by volume in 0.5% increments. The results showed a moderate correlation between methane concentration and Kmax, with $R^2 = 0.58$. It was found that KMax increase by 22 bar.m/s per 1% increase in methane concentration.

Methane is the dominant atmospheric variable. A 10°C temperature increase changes Kmax by about 4 bar.m/s, and a 20% relative humidity reduction increases Kmax by about 6 bar.m/s. In contrast, 1% methane increases Kmax by about 22 bar.m/s.

Table 2. 40-litre vs. 20-litre comparative testing.

Minimum Kmax/Kex ratio	**0.82**
Maximum Kmax/Kex ratio	**1.11**
Mean Kmax/Kex ratio (n = 16)	**0.97**
Standard deviation (n = 16)	**0.08**

Table 3. Classification restated in terms of Kmax.

Kmax (bar.m/s)	Classification
Kex < 68	Non-explosive.
68 ≤ Kex ≤ 93	Transition region. Large-scale testing recommended, or treat as explosive.
Kex ≥ 93	Will propagating an explosion.

MINE-CONDITION ADJUSTMENT

$$Kmax_{mine} = Kmax_{lab} + 0.4(T_{mine} - T_{lab}) - 0.3(H_{mine} - H_{lab}) + 22(M_{mine})$$

T_{lab} = 23°C, H_{lab} = 50%RH. The laboratory explosibility test result can be adjusted to take into account the effects of temperature, humidity and methane concentration in the mine.

Conclusion and recommendations

The risk of methane and coal dust explosions remains present for as long as coal is mined underground. The severe consequences of coal dust explosions justify periodic testing of the coal being mined so that appropriate explosion risk controls may be selected and implemented. The 40-litre vessel and Kex index have served the South African coal mining industry for several decades. However, the 20-litre Siwek chamber provides important advantages, and should be used in future. The comparison tests done in this study established a provisional mean relationship of Kmax = 0.97Kex from 16 coal samples.

Adjustment factors have also been determined for temperature, humidity and methane so that laboratory Kmax results can be adjusted for actual in-mine atmospheric conditions. Additional comparison testing using coal samples that represent a wider range of Kmax values is recommended, along with further testing to improve confidence in the atmospheric adjustment factors. Given the dominant effect of methane on Kmax, further testing should also be conducted at methane concentrations above 2% to better define the relationship between methane concentration and explosibility index.

In-situ stress measurement in South African coal mines

Trials at Kriel Colliery · DCDA and CCBO methodologies

10

Measurement of the stress field components as mining approaches a geologically complex area will contribute to quantify the impact of these structures on the magnitude and / or orientation of the field stress components and allow remedial action to be implemented timeously.

Executive summary

To be able to solve this gap in the knowledge of mining areas, the development of a method that will be cost-effective, practical and provide a good enough estimate of the magnitude and orientations of Principal field stress components is essential. From publications on work done on hard rock mines in South Africa, the DCDA method (diametrical core deformation analysis) methodology was selected as a possible solution.

Milestone 1 included the execution of planning and contracting activities to allow the rest of the project to be executed.

Milestone 2 focused on establishing whether the Diametrical Core Deformation Analysis (DCDA) technique could plausibly be applied in the South African coal mining environment, where stress magnitudes are low and rock masses often exhibit significant anisotropy and poor core quality. The primary objective of this milestone was therefore not to derive absolute stress values, but rather to determine whether stress-induced core deformation could be measured reliably enough to justify further investigation.

A structured data-gathering process was undertaken at Kriel Colliery, including site selection, drilling strategy development, core recovery, and laboratory preparation. Site selection considered multiple operational and geological factors, including depth, proximity to geological disturbances, excavation geometry, groundwater presence, and anticipated stress magnitudes. From a range of possible drilling locations, a single borehole (Hole A, Block F, BF-3, LH181_Split 08) was selected as the most suitable candidate for obtaining DCDA test material with minimal external bias.

Core drilling was executed using standard exploration drilling equipment. Although this allowed the collection of sufficient coal and sandstone samples, the process highlighted several inherent limitations: mechanical breakage of coal core, laminated sandstone horizons, and signs of core damage due to drilling practices. These factors were later shown to have a direct influence on DCDA result reliability.

To assess whether DCDA measurements would be technically viable at shallow coal mining depths, historical coal-industry stress measurements and rock elastic property databases were used to estimate expected stress differentials and corresponding elastic strain relief. Calculations demonstrated that even at low stress magnitudes, the expected diametrical diameter changes in both coal and sandstone core samples should exceed the minimum resolution threshold of the DCDA measurement equipment. The milestone concluded that, in principle, DCDA-measurable strain relief should occur in both coal and sandstone at Kriel Colliery depths. However, it also established that core quality and drilling methodology are critical success factors, and that results from poorly recovered or mechanically damaged core would inevitably be questionable.

Milestone 3 evaluated the first DCDA laboratory results obtained from core samples shipped to Japan. These tests represented an important proof-of-concept stage aimed at assessing whether DCDA could reliably capture stress-related deformation characteristics under coal mining conditions. The sandstone samples generally exhibited large diameter variations and strong elliptical deformation. However, closer examination indicated that much of this deformation was likely associated with mechanical effects rather than stress relief alone. Evidence of barrel scraping, tapered ends, and uneven core surfaces suggested that drilling-induced damage had significantly distorted the sandstone core geometry.

As a result, the differential stress values derived from sandstone DCDA measurements were excessively high and inconsistent with historical in-situ stress data. While sandstone samples showed reasonable agreement in the orientation of maximum deformation, their stress magnitude estimates were considered unreliable. Coal samples displayed more modest diametrical deformation, and in several cases the magnitude of differential stress derived from DCDA measurements fell closer to historically expected ranges for similar mining depths. This suggests that coal core experienced less mechanical overworking during drilling, allowing some stress-related deformation to be preserved. Nevertheless, orientation results for coal samples were highly variable, reflecting the strong anisotropy, bedding plane effects, and potential time-dependent relaxation behaviour of coal material.

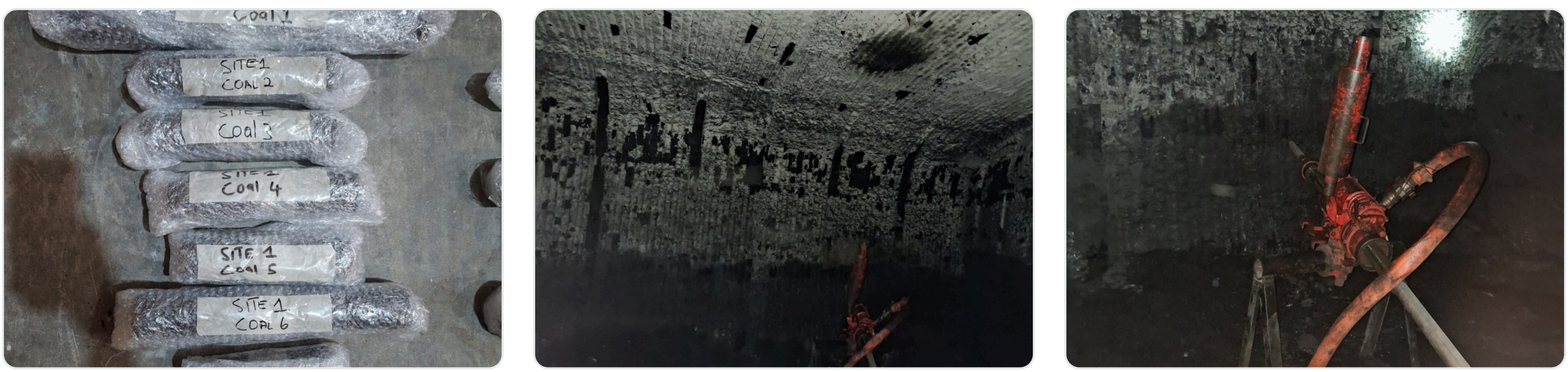
Overall, the DCDA results confirmed that diametrical deformation can be measured in coal-environment core, validating the fundamental premise of the method. However, the results also made it clear that core integrity and handling dominate data quality, and that stress orientation determination in coal is particularly sensitive to material anisotropy. Milestone 3 therefore concluded that DCDA holds promise as a coal-industry stress screening tool, but that its use requires strict drilling and sample-handling controls and should be supported by complementary stress measurement techniques.

Milestones 4 and 5 shifted the focus from laboratory testing to direct underground stress measurement using the Compact Conical-ended Borehole Overcoring (CCBO) technique. The primary objective was to generate a reliable benchmark stress dataset against which DCDA results could be evaluated, while simultaneously collecting additional core samples for further DCDA testing. After the originally proposed sites became operationally unavailable, alternative sites were selected in adjacent splits (Splits 40 and 41) within the BF-E7 panel at Kriel Colliery. The close proximity of these sites allowed comparison of results under similar geological and stress conditions, increasing confidence in the correlation process.

Four boreholes were drilled, two targeting coal seam material and two intersecting the sandstone roof. CCBO strain cells were successfully installed and overcored at multiple measurement points within each hole, generating a substantial dataset of strain relief measurements. Although groundwater presence and laminated roof conditions introduced challenges, strain gauge responses were recorded at all planned measurement points, indicating operational success.

Initial strain-to-stress conversions showed stress magnitudes significantly higher than expected from historical coal-industry data. Subsequent analysis identified the elastic constants used in the initial conversions as a major source of uncertainty. A re-evaluation of coal and sandstone elastic properties using historical and site-specific data revealed that the initially applied moduli were near the upper bounds of reasonable values for these materials. By adopting elastic property ranges rather than single point estimates, recalculated CCBO stress magnitudes promises to aligned more closely with expected shallow-depth stress conditions. These milestones demonstrated that CCBO stress measurement is feasible in the Kriel coal environment, but also underscored the necessity of careful rock property characterisation to avoid over-estimation of stress magnitudes.

Milestone 6 is planned to integrate the laboratory DCDA findings and underground CCBO measurements to assess the degree of correlation between the two methodologies. Final DCDA measurements on the samples sent to Japan, has not yet been received. In this evaluation, the emphasis will be placed on determining whether DCDA could provide meaningful estimates of stress orientation and relative magnitude when calibrated against conventional overcoring data.



Core recovery, CCBO strain-cell installation and overcoring at Kriel Colliery.

RESEARCH IN ACTION · FOCUS AREA

Coal Processing

Turning coal discard into usable infrastructure: circular innovation that repurposes coal waste for the road-building sector.

Repurposing of coal waste for asphalt applications

COAL PROCESSING · PROJECT P2024-2

Repurposing of coal waste: coal-based circular innovation for asphalt applications

Prepared by the Council for Scientific and Industrial Research (CSIR) in collaboration with Coaltech. Key CSIR contributors: Reatile Pitso, Freeman Masuku, Mvikeli Mpofu, Stephen Mapanamana, Johan Hanekom, Hartmut Brodner.

Introduction

The incorporation of coal waste into road construction materials represents a significant opportunity for South Africa's circular economy. South Africa generates approximately 60 million tonnes of coal waste annually, creating substantial environmental, safety, and land-use challenges. At the same time, the road construction sector consumes large volumes of natural aggregates, which are becoming increasingly scarce and expensive to source and transport.

The asphalt industry faces rising material costs and environmental pressures to reduce the consumption of virgin aggregates. While international studies (particularly from the USA, China, Iran, India, and Korea) have shown promising results using coal waste ash and fines in hot mix asphalt (HMA), limited local research existed to validate performance under South African conditions, standards, and materials.

This project was initiated to address this gap. The project investigated whether coal waste fines and coal fly ash could serve as viable substitutes for natural aggregates and active fillers in medium continuously graded asphalt wearing courses. The ultimate objective was to develop technically sound, cost-effective, and environmentally compliant asphalt mixes that reduce reliance on virgin aggregates while maintaining or improving the asphalt performance.

The research

The project was conducted in a phased approach and finalized in December 2025. It combined a comprehensive literature review with laboratory material characterisation, mix design optimisation, performance testing, leachate analysis, and cost-benefit evaluation. Conventional materials were sourced from industry partners, with coal waste samples obtained from a coal mine in the Middelburg area of Mpumalanga in South Africa.

Research from the Virginia Department of Transportation (VDOT) and studies in China, Iran (Modarres and Rahmanzadeh), India, and Korea demonstrated that coal waste could enhance Marshall stability, indirect tensile strength, resilient modulus, rutting resistance, and moisture damage resistance. In the South African context, the project addressed the high coal waste volumes and the testing was done according to the Southern African Bitumen Association (SABITA) and South African Bureau of Standards (SABS).

Conventional aggregates (dolomite stone, filler sand, and crusher dust), 50/70 penetration-grade bitumen, hydrated lime, and coal waste were fully characterized according to SANS 3001 and Sabita Manual 35. Coal waste exhibited suitable grading, high silica-alumina content, pozzolanic activity (tested through XRD and FTIR), and chemical stability. Three main asphalt mix designs were developed and tested: a conventional control mix, a coal waste mix with full lime, and a coal waste mix with reduced lime.

Performance testing included Marshall Stability, Indirect Tensile Strength (ITS), Dynamic Creep (rutting), Air Permeability, the Hamburg Wheel Tracking Test (HWTT), the Four-Point Bending Beam (fatigue) and the Modified Lottman Test (moisture susceptibility).

Figure 1: Asphalt mix development process used in all three mixes.

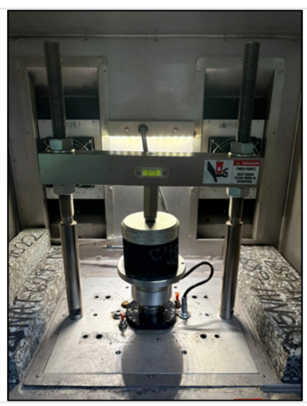


Figure 2: (a) ITS Test, (b) Dynamic Creep Test.

Key findings

Laboratory results showed that mixes incorporating coal waste (coal waste mix with full lime) matched or outperformed the conventional control mix across most performance indicators, as illustrated in Table 1. The Indirect Tensile Strength (ITS) results confirmed that the coal waste mixes achieved strong tensile performance as compared to the conventional mix. Coal waste improved stiffness, deformation resistance, impermeability, and moisture resistance when combined with appropriate lime dosages. Geochemical and mineralogical analyses confirmed the pozzolanic properties of coal waste, making it suitable as an active filler. Challenges noted included optimising lime content and ensuring consistent material quality.

Economic analysis

The study quantified significant material and transport cost savings, particularly when coal waste sources are located near asphalt plants. Sensitivity analyses confirmed financial viability, with potential annual transport savings of R105 million at reduced haul distances. Normalised savings per kilometre of road were calculated, along with avoided disposal costs. Annual coal waste utilisation potential in asphalt was estimated at approximately 452,000 tonnes (about 0.75% of national generation).

Environmental impact

The heavy metal leachate test (acetic acid and HCl extractants) was conducted as part of the environmental assessment. Leachate test results classified the material as Pollutant Class A, indicating minimal environmental restrictions for beneficial use. Using coal waste in asphalt supports reduced landfill loads, lower demand for virgin aggregates, and is aligned with circular economy principles. The environmental impact appears low under current paving levels, but could be substantial if high-risk waste piles are prioritised. The approach also offers potential for reduced carbon footprint and carbon credit opportunities.

Conclusions

The Coaltech project successfully demonstrated that coal waste fines and fly ash can be safely and effectively incorporated into asphalt mixes without compromising and, in several cases, enhancing mechanical performance, durability, and environmental compliance. The mixes met or exceeded South African standards and showed strong potential for practical implementation. The project provides a technically feasible, economically attractive, and sustainable solution for South Africa's road construction sector, and laid a strong scientific foundation for broader adoption and more sustainable infrastructure development in South Africa.

Table 1. Indirect Tensile Strength (ITS) results.

Conventional control mix	Coal waste mix with full lime	Coal waste mix with reduced lime
698 kPa Lowest absolute strength, but good durability through TSR.	**1184 kPa** Very high tensile strength; coal waste and full lime improved cohesion and adhesion.	**838 kPa** Higher than control, but TSR <0.80 shows poor retention under moisture.

RECOMMENDATIONS

Develop strategies for regional implementation, focusing on proximity between coal waste sources and asphalt plants; conduct further laboratory and pilot-scale trials to validate results under operational conditions; modify coal waste to increase the quantity incorporated in asphalt without compromising performance and durability; expand utilisation beyond asphalt to include concrete, bricks, and mine backfilling for broader coal waste valorisation; encourage collaboration among transport, energy, and construction sectors; and develop national guidelines with additional testing across different geological and climatic regions.

COAL PROCESSING · PROJECT P2024-01

Circular transformation of carbon ore residues to building components: technical feasibility and LCA

10

Investigators: Dr Orevaoghene Eterigho-Ikelegbe (Postdoctoral Research Fellow) and Prof. Samson Bada, University of the Witwatersrand, School of Chemical and Metallurgical Engineering. Prepared for the Coaltech Research Association.

Executive overview

South Africa generates millions of tonnes of coal-processing residues each year, creating long-term environmental liabilities and lost value opportunities. At the same time, increasing pressure exists across the mining and industrial sectors to develop practical waste utilisation pathways that support sustainability, resource efficiency, and circular economy objectives.

This project investigated the conversion of coal waste and associated industrial residues into value-added composite materials through a structured technology-development programme. Multiple binder systems, including polymer-derived ceramic and organosilicon technologies, were evaluated and optimised through laboratory testing, thermal processing studies, durability assessment, environmental validation, and pilot-scale manufacturing trials.

Initial pilot-scale investigations successfully demonstrated the feasibility of producing larger composite components but also identified scale-up challenges associated with cracking and dimensional stability. These findings guided the development of a second-generation mineral-assisted composite system incorporating coal waste, PGM tailings, recycled glass cullet, and a low-cost Water Glass binder. The resulting composite system successfully produced crack-free pilot-scale components and demonstrated favourable mechanical, durability, and environmental performance.

The project therefore establishes a technically feasible pathway for transforming multiple industrial waste streams into value-added engineering materials suitable for further industrial evaluation.

TECHNOLOGY DEVELOPMENT PATHWAY

1. **Binder development** — Multiple binder systems evaluated for composite manufacture.
2. **Thermal optimisation** — T1 and T4 routes to improve densification and performance.
3. **Environmental validation** — Durability, chemical resistance and leaching confirmed stability.
4. **First pilot-scale** — Validated manufacturability but revealed scale-up limitations.
5. **Second-generation composite** — Coal, PGM tailings, glass cullet and Water Glass overcame scale-up challenges.

KEY POINT

The project progressed through a structured technology-development pathway that systematically reduced technical, environmental, and scale-up risks. The successful transition from laboratory-scale development to crack-free pilot-scale composite production established a strong foundation for future industrial demonstration and commercial evaluation.

Technical performance and validation

The developed composite systems were subjected to comprehensive physical, mechanical, thermal, durability, and environmental performance evaluations. The results demonstrated strong relationships between formulation composition, thermal processing conditions, densification behaviour, and final composite performance. The best-performing formulation, S1, produced crack-free pilot-scale components with a compressive strength of 29.53 MPa and low water absorption.

Environmental validation, ESG and circular economy

Environmental performance was a critical component of the technology-development programme. Comprehensive chemical resistance, durability, Toxicity Characteristic Leaching Procedure (TCLP), and leaching assessments were conducted. Environmental assessments demonstrated generally low contaminant mobility under neutral exposure conditions, while matrix densification and silicate network development contributed to effective immobilisation of inorganic constituents within the composite structure.

The project demonstrated that coal waste and associated industrial residues can be converted into environmentally stable engineering materials, advancing ESG objectives, resource recovery, waste reduction and circular economy outcomes.

Strategic roadmap and next steps

The project successfully progressed from laboratory-scale development to pilot-scale validation. Laboratory development, environmental validation and pilot-scale demonstration are complete; industrial demonstration is the next phase, with commercial evaluation to follow. Next-phase requirements include industrial-scale demonstration, product certification and compliance testing, long-term field performance validation, and industrial partnership development.

Performance highlights

Pilot-scale component	**240 × 60 × 18 mm**
Best compressive strength (S1)	**29.53 MPa**
Structural integrity	**Crack-free**
Environmental validation	**Completed**

Feedstocks: coal waste, PGM tailings, recycled glass cullet and a low-cost Water Glass (sodium silicate) binder.

VALUE PROPOSITION

The technology converted coal waste, PGM tailings, recycled glass and Water Glass binder into structurally stable composite products. Pilot-scale validation confirmed the feasibility of producing value-added engineering materials from predominantly waste-derived feedstocks, with clear potential for future industrial deployment within the mining, construction and waste-management sectors.

RESEARCH IN ACTION · FOCUS AREA

Surface Environment

Cleaner water, recovered resources and productive rehabilitated land: research that reduces the environmental footprint of mining and reimagines closure.

Micro-algal carbon capture · Carbon farming model · Regenerative crop and livestock model · Continuous eutectic freeze crystallisation

Micro-algal systems for carbon capture and energy recovery from mine wastewaters

Karen Ssekimpi, Juarez Amaral-Filho, Nodumo Zulu and Susan T.L. Harrison. Centre for Bioprocess Engineering Research (CeBER), Department of Chemical Engineering, University of Cape Town.

Micro-algae, found commonly in coal mining regions can be used to lessen environmental burden of CO2 emissions, mine water acidification and metal deportment and losses, while also potentially providing additional products, including bioenergy. This is shown diagrammatically in Fig. 1.

Coal-based energy production is recognised to contribute significantly to carbon dioxide (CO_2) emissions while mining and processing the coal may lead to mine wastewater and leachate streams contaminated with dissolved metals and salts. These wastewater streams, particularly acid mine drainage (AMD), present a major environmental challenge. This research investigates microalgal technology as a sustainable approach to mitigate CO2 emissions through carbon capture into microalgal biomass and cycling through bioenergy forms with simultaneous remediation of metal-contaminated mine waters (Fig. 2). The energy and metal recovery provide a circular economy framework, with potential for other secondary products.

Our work has characterised more than 50 microalgal isolates from the Mpumalanga and Gauteng regions to identify key endemic species with high CO2 uptake rates and the ability to concentrate metals from solution (Figure 3). This study builds on the characterisation of endemic microalgae by focusing on using an indigenous microalgal polyculture composed of four strains isolated from the Mpumalanga and Gauteng regions, selected for their potential to rapidly assimilate carbon into biomass and to accumulate metals. An isolate with particularly efficient use of the nitrogen source was also included.

The polyculture was cultivated under varying metal concentrations. A representative metal-laden mine water sample from the region was shown to contain 1.07 mg/L Al, 0.01 mg/L Cd, 0.004 mg/L Cr, 4.02 mg/L Fe, 0.07 mg/L Pb, 4.0 mg/L Mn, 0,01 mg/L Hg, 0.12 mg/L Ni and 0.45 mg/L Zn. Simulated metal-laden waters were used containing one-fold, five-fold and 10-fold these concentrations in the polyculture cultivation, using both airlift photobioreactors and outdoor raceway pond systems. Through these cultivations, we evaluated the resilience of the microalgae to metal stress, their ability to accumulate metals, and the feasibility of converting the resulting biomass into renewable energy or other valuable products.

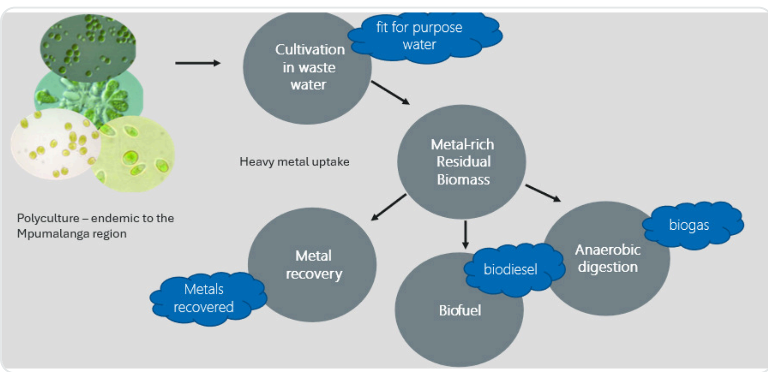


Figure 1. Microalgal polycultures have potential to remediate metal-laden mine waters to fit-for-purpose water, enable carbon capture and cycling to bioenergy and recover metals.

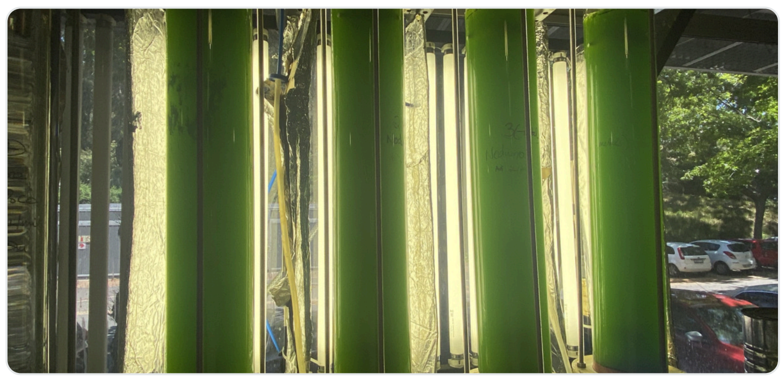


Figure 4. Microalgal polycultures growing in lab-airlift bioreactors, pilot raceways and large-scale raceways.

Experimental results showed that the formulated polyculture showed sustained growth at metal concentrations up to five times higher than those present in the original AMD sample with no decrease in biomass concentrations and carbon assimilation realised compared with the control. At tenfold metal concentrations, a decrease in growth rate and biomass accumulation was observed, accompanied by changes in the algal biomass profile. It is expected that Adaptive Laboratory Evolution (ALE) of the microalgal polyculture will enable even better tolerance of metals. Testing this is planned in continuation studies. Similarly exposure to increasingly acidic waters forms part of our planned continuing work.

Metal uptake into the algal biomass of the polyculture was demonstrated across all tested metal concentrations. Bioconcentration factors of the metals of 2.5 to 5 were found for the metal mix representing the mine water sample, shown in Fig. 5. These were maintained in the range 1.5 to 4 for five-fold metal concentration and for 10-fold concentration with the exception of Mn, Hg and Ni where concentration was lower. These results show an increasing loading of metals onto the algal biomass with increasing metal concentration. It can be assumed that the biomass reached capacity for the 10-fold concentration for Mn, Hg and Ni. These bioconcentration levels are consistent with much improved water quality, both in terms of metal concentrations and pH.

The microalgal biomass generated was characterised to determine potential for processing to products, in addition to metal recovery. The polycultures varied between 30 and 45% protein when grown in the presence of no to five-fold metal content, raising potential for protein recovery. At 10-fold metal content, the protein content decreased to 15 to 25%. Similarly the pigment content lay in the range 2.0 to 4.5% when grown with no metals or with a metal concentration typical of AMD, but decreased in the presence of five-fold metals and was negligible at 10-fold metal, suggesting that simultaneous pigment production and metal removal in not practical.

The potential to use the biomass formed as a feed for bioenergy was considered. Four potential routes were evaluated: anaerobic digestion to a biogas product, transesterification to biodiesel, hydrothermal liquefaction to biodiesel, and catalytic hydrothermal gasification to biogas. Bioethanol production by fermentation was not evaluated owing to the low conversion of microalgal carbon to ethanol carbon. Hydrothermal liquefaction of an algal slurry of >14% biomass is expected to yield a quality biocrude product, with metals reporting to the solid phase for recovery, offering a promising processing route.

IN CONCLUSION

Indigenous microalgal polycultures have significant potential for use in integrated systems that combine carbon capture, wastewater remediation, metal recovery and biomass valorisation, especially to bioenergy. Remediating AMD using algal biotechnology produces fit-for-purpose water without developing copious sludge in the waterways. Simultaneously, it assimilates CO2, and the biomass produced can be used to produce bioenergy, providing a further carbon offset. Through these, compliance for closure is enhanced, with active contribution to SDG 6 (clean water and sanitation), SDG 7 (affordable and renewable energy) and SDG 13 (climate action).

Outdoor raceway pond cultivation of the microalgal polyculture.

SURFACE ENVIRONMENT

Carbon farming model for rehabilitated coal mined land

Prof Wayne F. Truter and Dr Emmanuel Cele (AF4RICA Lab, Enterprises University of Pretoria) and Mr Albert van Zyl (Terrasim).

Introduction

South Africa's coal mining industry faces increasing pressure to develop mine closure strategies that extend beyond legislative compliance and deliver meaningful environmental, social and economic value. Although conventional rehabilitation practices have successfully re-established vegetation cover on many mined landscapes, these areas often remain characterised by poor soil health, low soil organic carbon (SOC), limited biological activity and restricted post-mining land-use opportunities. At the same time, growing commitments to climate change mitigation, renewable energy generation, environmental, social and governance (ESG) performance, carbon sequestration and South Africa's Just Energy Transition have created opportunities to rethink the future use of rehabilitated mine land.

This research developed and evaluated the Carbon Farming Model, an innovative rehabilitation framework that integrates biomass production, renewable energy generation, carbon sequestration, soil regeneration and nutrient recycling within a circular carbon economy. The model further incorporates the Enterprises University of Pretoria Smart Farm Incubator, providing a mechanism for community participation, enterprise development and skills transfer on rehabilitated coal mine land. The primary objective was to determine whether rehabilitated mine land could be transformed from a long-term environmental liability into a productive environmental and socio-economic asset capable of supporting sustainable mine closure while generating renewable energy, storing carbon and creating new livelihood opportunities.

The research

The study was undertaken using a controlled research-bin system designed to simulate rehabilitated coal mine soils under replicated experimental conditions. Mini-lysimeters containing reconstructed topsoil, subsoil and coal spoil were established and planted with three high-biomass species selected for their complementary characteristics within the Carbon Farming Model: vetiver grass (Chrysopogon zizanioides), forage sorghum (Sorghum bicolor) and Rhodes grass (Chloris gayana).

To evaluate regenerative soil management practices, two secondary carbon inputs generated from renewable energy systems were investigated. Biochar, produced through biomass pyrolysis, and anaerobic digestion digestate were incorporated into rehabilitated mine soils to assess their ability to improve soil quality, increase biomass production and enhance long-term carbon sequestration. Treatments were arranged in a randomised block design with five replications, allowing robust statistical comparison between untreated control, biochar-amended and digestate-amended systems.

Comprehensive baseline soil analyses confirmed that the rehabilitated mine soil exhibited the typical limitations associated with reconstructed mining landscapes, including low soil organic carbon, acidic pH, poor nutrient status and limited cation exchange capacity. These conditions provided an ideal platform to evaluate the regenerative potential of carbon farming interventions.

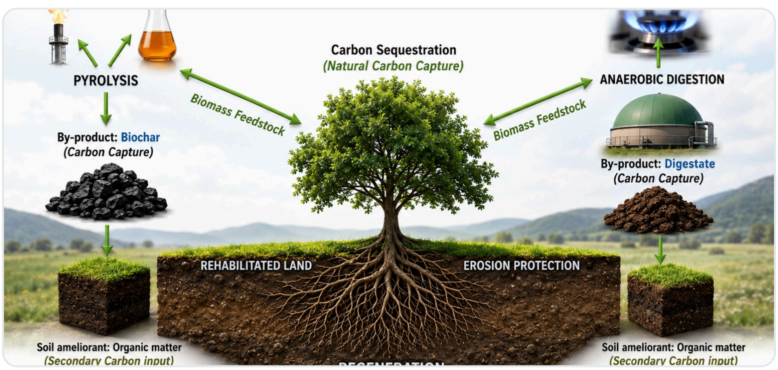


Figure 1: Carbon Farming Model as an integrated land-management framework combining biomass production, soil regeneration, renewable energy generation and carbon recycling.

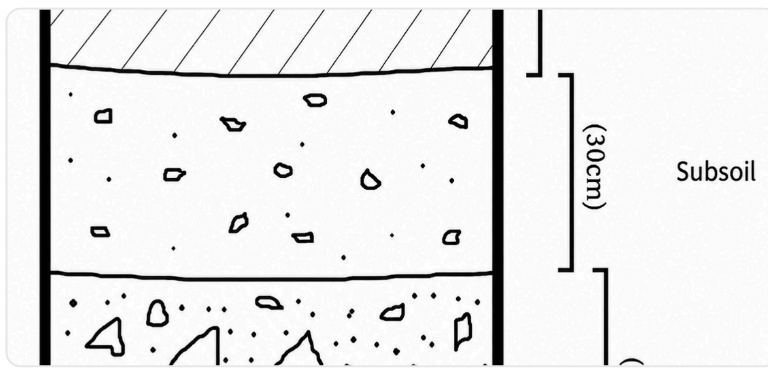


Figure 3: Vegetation species selected for primary carbon inputs. a. Vetiver grass, b. Annual sorghum, c. Rhodes grass.

The research demonstrated that rehabilitated mine land can successfully support productive biomass systems when appropriate soil regeneration strategies are implemented. Across all species, digestate and biochar significantly improved plant performance compared with untreated controls. Digestate consistently produced the greatest biomass response owing to improved nutrient availability and enhanced microbial activity. Vetiver achieved the highest above-ground biomass production, reaching approximately 41 t ha^{-1}, while Rhodes grass produced approximately 29 t ha^{-1} and forage sorghum approximately 19 t ha^{-1} under optimal treatment conditions.

One of the most significant findings of the study was the exceptional contribution of below-ground biomass to ecosystem restoration. Vetiver developed the largest and deepest root systems, producing more than 85 t ha^{-1} of root biomass under digestate treatment. These extensive root systems substantially increased below-ground carbon inputs, improved soil aggregation, enhanced water infiltration and accelerated soil organic carbon accumulation. Rhodes grass also demonstrated strong root development, while sorghum provided moderate root biomass combined with superior renewable energy characteristics.

The renewable energy component further demonstrated that rehabilitated mine land can contribute meaningfully to South Africa's low-carbon energy future. Biomethane potential testing showed that forage sorghum produced the highest methane conversion efficiency, achieving biomethane yields exceeding 2 700 m^3 CH_4 ha^{-1} under digestate treatment. Rhodes grass generated the greatest overall energy output owing to its combination of high biomass production and favourable feedstock quality, while vetiver also produced substantial renewable energy despite its higher lignin content.

The study also confirmed the important role of biochar and digestate as regenerative soil amendments. Digestate enhanced nutrient cycling, microbial activity and vegetation productivity, whereas biochar improved soil structure, water-holding capacity, pH buffering and long-term carbon stability. Their combined application demonstrated how renewable energy by-products can be recycled back into rehabilitated soils as valuable resources rather than waste products, thereby closing nutrient and carbon cycles within a circular carbon economy.

Perhaps the most important innovation was the successful validation of the Carbon Farming Model itself. The research demonstrated a complete circular carbon pathway in which atmospheric carbon is captured by vegetation through photosynthesis, converted into biomass, transformed into renewable energy through anaerobic digestion or pyrolysis, and then returned to the soil as digestate and biochar. Beyond the environmental benefits, the model creates opportunities for biomass production enterprises, renewable energy generation, biochar production, carbon credit development, feedstock supply chains and regenerative agriculture. Through integration with the Smart Farm Incubator, rehabilitated mine land can become a platform for enterprise incubation, community participation, skills development and employment creation.

Table 1. Biomethane production potential of the three test species.

Species	Renewable energy outcome
Forage sorghum	Highest methane conversion efficiency; >2 700 m^3 CH_4 ha^{-1}.
Rhodes grass	Greatest overall energy output.
Vetiver grass	Substantial energy despite higher lignin; best for carbon sequestration.

Figure 5: Seasonal soil organic carbon (SOC) % of species treated with biochar and vetiver. Means with the same letter are not significantly different at P>0.05 (Tukey's Studentized Range Test).

CONCLUSION

Rehabilitated coal mine land can be transformed into productive landscapes that simultaneously support environmental restoration, renewable energy generation, carbon sequestration and socio-economic development. The Carbon Farming Model provides a scientifically validated framework, positioning rehabilitated land as a valuable contributor to South Africa's climate resilience, circular economy and sustainable rural development.

A regenerative integrated crop and livestock model for sustainable mine closure

Prof Wayne F. Truter and Dr Emmanuel N. Cele. AF4RICA Lab, Enterprises University of Pretoria.

Introduction

South Africa possesses thousands of hectares of rehabilitated surface coal mines that were historically productive agricultural land. While legislative mine rehabilitation requirements have successfully established stable landforms and vegetation cover, many rehabilitated areas remain underutilised and fail to generate meaningful long-term economic value for surrounding communities. Consequently, there is an increasing need to transform mine closure from a compliance exercise into a process that restores productive landscapes capable of supporting agriculture, biodiversity, rural livelihoods and regional economic development.

This Coaltech project investigated the feasibility of implementing regenerative integrated crop–livestock production systems on rehabilitated mine land with different land capability classes. The study evaluated whether rehabilitated pastures can sustainably support livestock production while simultaneously improving ecosystem functioning and creating viable post-closure business opportunities. By combining ecological assessment, forage quality evaluation and economic modelling, the research provides a practical framework for converting rehabilitated mine landscapes into productive agricultural assets.

The research

The project consisted of two complementary research components undertaken across several rehabilitated coal mines within the Mpumalanga Coalfields. The first component assessed grazing capacity and veld condition across rehabilitation sites of different ages. Vegetation surveys were undertaken using recognised South African veld assessment methodologies to determine ecological condition, basal cover, species composition and grazing potential.

Soil fertility, nutrient availability and pasture productivity were evaluated to determine how rehabilitation age influences agricultural capability. Results demonstrated that ecological condition generally improved with rehabilitation age, with older rehabilitation sites exhibiting greater basal cover, improved species composition and higher grazing potential than younger sites. Basal cover exceeded accepted South African rehabilitation benchmarks across most sites, indicating that well-managed rehabilitated grasslands can successfully develop into functional grazing ecosystems.

The second component evaluated the productivity and nutritional value of rehabilitated grazing systems through detailed forage quality assessments. Parameters including crude protein, fibre fractions, mineral composition, digestibility and constituents of potential concern were analysed using conventional wet chemistry techniques together with near-infrared spectroscopy (NIRS). The study demonstrated that NIRS produced results closely comparable to conventional laboratory methods, validating its application as a rapid, cost-effective field monitoring technology for mine rehabilitation programmes.

Figure 3: A. Zero grazing, no stocking rate; B. Optimal grazing system stocking rates; C. High-density grazing system stocking rates.

Figure 1: Location of surface coal mines (A, B and C) in Mpumalanga Province, within which differently aged, rehabilitated sites were chosen.

Nutritional analyses indicated that forage quality varied according to rehabilitation age, seasonal conditions and grazing management. Protein concentrations generally reflected maintenance-quality grazing for beef cattle, although supplementary nutrition would be required for high-producing livestock enterprises. Fibre fractions, mineral concentrations and digestibility remained within acceptable ranges for extensive grazing systems, supporting the potential use of rehabilitated pastures as productive livestock resources when managed appropriately.

The project also investigated potential accumulation of constituents of potential concern (CoPC) within forage species. Accumulation factor analyses demonstrated that essential nutrients such as potassium, magnesium and phosphorus were readily absorbed by plants, while potentially hazardous trace elements remained below phytotoxicity and livestock feed safety thresholds. These findings provide confidence that rehabilitated pastures can be utilised safely under appropriate monitoring programmes.

Key outcomes

- Older rehabilitation sites consistently exhibited improved ecological condition, grazing capacity and pasture stability.
- Rehabilitated pastures can support productive livestock enterprises when appropriate grazing management principles are applied.
- Near-infrared spectroscopy provides a reliable and cost-effective technology for routine forage quality monitoring on rehabilitated mine land.
- Concentrations of constituents of potential concern remained below levels likely to present significant livestock or environmental risks.
- Integrated crop–livestock production systems present a realistic opportunity to convert rehabilitation liabilities into productive agricultural assets.
- The developed business case provides mining companies with a practical decision-support framework for sustainable post-closure land use planning.

An integrated techno-economic assessment was subsequently undertaken to evaluate the commercial viability of crop–livestock enterprises established on rehabilitated mine land. Production potential, capital investment, operating costs, revenue streams, financial performance and socio-economic impacts were modelled to determine long-term business feasibility. The resulting business case demonstrated that regenerative agricultural systems have the potential to generate sustainable post-mining economic activity while simultaneously improving land stewardship and supporting successful mine closure.

A risk matrix serves as a critical decision-support tool in evaluating the potential challenges associated with implementing integrated crop–livestock production systems on rehabilitated mined land. By visualising risks across ecological, agronomic, climatic and governance dimensions, the matrix supports informed planning and resource allocation, essential for ensuring the long-term sustainability and productivity of post-mining agricultural landscapes.

Figure 5: Constituents of potential concern (CoPC) within forage species; accumulation factor analyses.

CONCLUSION

Rehabilitated coal mine land possesses considerable potential to support regenerative integrated crop–livestock production systems when rehabilitation quality and grazing management are aligned with ecological principles. Beyond its technical findings, the project establishes a practical business model that transforms mine closure from a rehabilitation obligation into an opportunity for landscape regeneration, agricultural production and socio-economic development, providing Coaltech and the South African mining industry with an evidence-based framework for productive post-mining land uses.

Continuous eutectic freeze crystallisation for mine brines

Novel materials and directed crystal engineering for continuous Eutectic Freeze Crystallization (EFC). Professor Alison Lewis, Bridget Mushava, Madimetsa Matau, Senzo Mgabhi, Lerato Motsepe and Jemitias Chivavava (University of Cape Town).

Introduction

South Africa's coal mining industry produces large volumes of highly saline wastewater that must be managed safely. Traditionally, these brines are stored in evaporation ponds or treated by evaporative crystallisation. Both approaches have drawbacks. Evaporation ponds require large areas of land and carry the risk of groundwater contamination, while evaporative crystallisation is energy intensive, expensive to operate and prone to scaling and corrosion.

Eutectic Freeze Crystallization (EFC) offers a different approach. Instead of evaporating water, EFC freezes it, allowing pure ice and valuable salts to crystallise separately from the brine. Because freezing requires far less energy than evaporation, EFC has the potential to reduce operating costs while recovering useful products from what is currently regarded as a waste stream.

Researchers at the University of Cape Town have spent more than two decades developing EFC for industrial wastewater treatment. Previous studies demonstrated that the technology works well at laboratory scale, but two challenges have continued to limit its commercial application. The first is the formation of ice on the heat exchange surfaces inside the crystalliser. As this ice layer builds up, heat transfer becomes less efficient and the process eventually stops. The second challenge is separating the ice and salt crystals efficiently enough to produce high-quality water and salt products.

This project focused on overcoming these remaining barriers. It investigated whether a new heat exchange material could reduce ice scaling and explored how operating conditions affect ice production, crystal growth and product separation.

Ice scaling

Ice scaling has long been recognised as one of the biggest obstacles to continuous EFC operation. Conventional systems often rely on mechanical scrapers to remove ice from cooling surfaces. Although effective, these systems increase both the cost and mechanical complexity of the process and require regular maintenance. The research team investigated an alternative approach by replacing conventional stainless steel heat exchange surfaces with a novel polypropylene graphite (PP-GR) composite. This material has a smooth surface and low surface energy, making it less likely for ice to adhere strongly during crystallisation.

PP-GR consistently reduced the amount of ice that accumulated on the heat exchange surface compared with stainless steel. The improvement was particularly noticeable for magnesium sulphate-rich brines, where ice adhered less readily and detached more easily from the surface. The material was then tested using industrial brines from the Tweefontein and eMalahleni Water Reclamation Plants. The Tweefontein brine produced especially positive results: as the concentration of dissolved salts increased, permanent ice scaling decreased while production of suspension ice increased. The eMalahleni brine behaved differently because both ice and sodium sulphate crystals formed simultaneously, yet the PP-GR material continued to perform well.

Continuous EFC

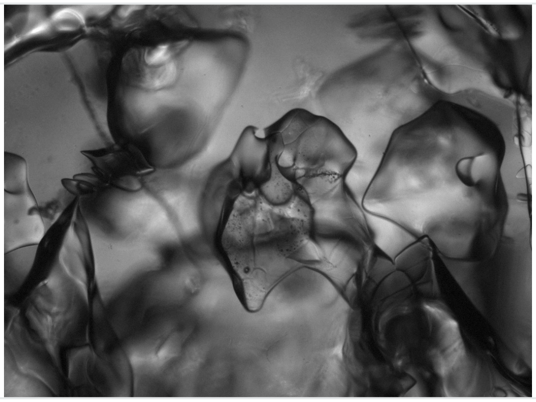
Reducing ice scaling alone is not sufficient to make EFC commercially viable. The process must also produce sufficient quantities of ice while generating crystals that can be separated efficiently from the remaining brine. The research team carried out a detailed study of the operating conditions inside the crystalliser, systematically varying heat transfer driving force, mixing intensity, crystallisation time and settling time.

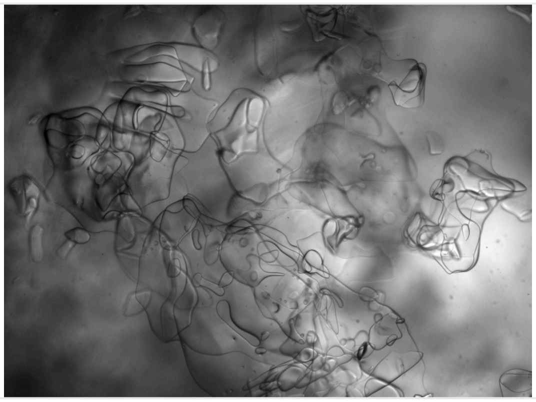
One of the clearest trends was the strong influence of heat transfer driving force. Increasing the temperature difference between the cooling surface and the brine increased the overall rate of heat removal and therefore increased ice production. Although larger temperature differences initially promoted greater ice formation on the cooling surface, the PP-GR material allowed much of this ice to detach naturally before permanent scaling developed. This enabled sustained production of suspension ice for periods exceeding one hour without blocking the crystalliser. Increasing mixing improved heat transfer and disrupted the thin boundary layer where ice normally accumulates.

Cleaner water and high quality salt

Producing crystals is only one part of the process. Those crystals must also be separated efficiently if clean water and marketable salt products are to be recovered. To investigate this stage, the researchers developed a two-stage crystallisation system. The primary PP-GR crystalliser produced ice and salt crystals, while a secondary crystalliser provided additional time for crystal growth and gravitational separation.

The study showed that increasing mixing within the secondary crystalliser improved overall ice recovery. However, the purity of the recovered ice remained lower than desired: optical analysis showed that the ice crystals were extremely small and often trapped concentrated brine and fine salt particles. Recognising these limitations, the researchers investigated washing the recovered ice with cold deionised water. This simple additional step removed much of the trapped brine and fine salt, producing a substantial improvement in ice purity.





Continuous EFC performance with the polypropylene graphite (PP-GR) crystalliser on South African industrial brines.

CONCLUSIONS

This project has taken Eutectic Freeze Crystallization an important step closer to practical application for the treatment of hypersaline coal mine brines. For the first time, polypropylene graphite was shown to resist ice scaling during continuous operation with South African industrial brines, overcoming one of the major barriers to commercial implementation. These findings provide the engineering knowledge needed to design the next generation of pilot-scale EFC systems, and reinforce South Africa's international leadership in Eutectic Freeze Crystallization research.

RESEARCH IN ACTION · FOCUS AREA

Future Technologies

High efficiency, low emission clean coal technology and a defensible basis for measuring and reducing the sector's emissions.

HELE Circulating Fluidised Bed clean coal technology · Scope 1 and 2 emissions management in the coal sector

High Efficiency, Low Emission (HELE) Circulating Fluidised Bed (CFB) technology: clean coal technology for South Africa

Mike Masukume, Ashton Swartbooi, Adam Luckos and Simphiwe Ncwane. A collaborative programme with the CSIR, Eskom and SANEDI.

Abstract. This study assessed the feasibility of establishing a 500 kW (thermal) circulating fluidised bed (CFB) combustion test facility to de-risk high-efficiency, low-emissions (HELE) coal technology for South African conditions. The headline conclusion and decision basis are summarised below.

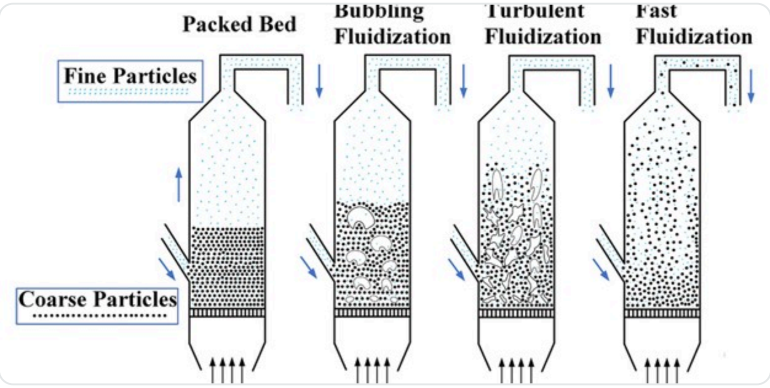
R75.78m
Total owner's cost (±30%, incl. 20% contingency)

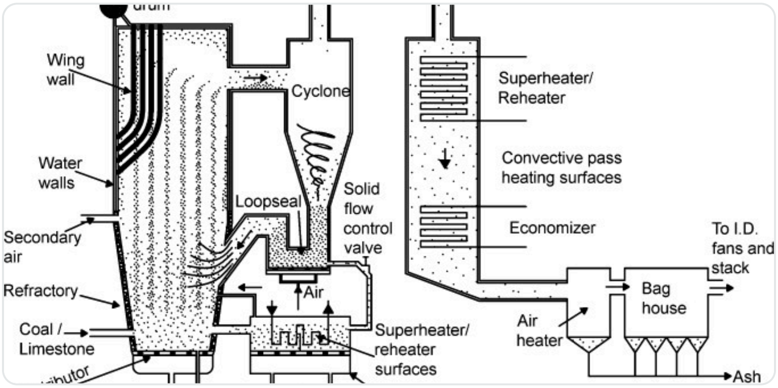
R3.91m
Annual operating cost, ten 3-day campaigns

89.0%
Eskom Rosherville site score (next-ranked 72.4%)

Decision summary

Finding	A 500 kW CFB test facility is technically feasible and is the appropriate scale at which to de-risk the technology before any commercial deployment. Phase 1 is complete; the study supports proceeding to Phase 2 (detailed engineering, procurement, construction and commissioning).
Preferred site	Eskom Rosherville Research, Testing and Development facility (Johannesburg), weighted score 89.0%, against 72.4% for the next-ranked site. A brownfield host with existing combustion-research infrastructure, reducing cost and schedule.
Funding model	Research and development facility; not intended to be financially self-sustaining. Returns are non-monetary: technology validation under local conditions, skills and supplier development, and beneficiation of coal discards.
Top risk	Reputational and funding risk, future phases compromised by negative perception of coal technologies (residual rating: HIGH). All other risks reduced to low or moderate after mitigation.
Strategic value	Generates engineering, scientific and regulatory data well ahead of 2030 to inform South Africa's post-2030 cleaner-coal policy, while building local capability for responsible deployment.





Introduction

Coal supplies about 70% of South Africa's electricity and underpins a value chain employing close to 100,000 people, drawing on an estimated 9.9 Gt of reserves. The Integrated Resource Plan (IRP) 2025 confirms that coal will remain integral to the energy mix into the 2030 to 2050 period because it remains affordable, stable, reliable and dispatchable relative to the alternatives, even as renewables and storage grow. At the same time, conventional pulverised-coal (PC) combustion releases SO_x, NO_x, particulate matter, mercury and greenhouse gases, and tightening minimum emission standards are reshaping the outlook for coal.

CFB combustion is an internationally mature HELE technology, with over 4,000 units in operation and single units now reaching 660 MWel. It offers in-furnace SO_2 capture using limestone, low-temperature combustion and air staging that reduces NO_x formation, and CO_2 emission reduction through co-firing with biomass and oxy firing. It provides exceptional fuel flexibility, including low-grade coals, coal discards, biomass and refuse-derived fuels, making it well matched to South Africa's coal endowment, including an estimated 1.5 Gt of discards which currently have no use. Despite these advantages, all 15 of South Africa's coal-fired stations use PC technology, and CFB combustion has never been tested locally on local fuels under local conditions.

In July 2025, CSIR, Eskom, SANEDI, and Coaltech commissioned a collaborative programme to de-risk the CFB combustion technology, to be implemented in three phases: a feasibility study (this phase, to 30 June 2026); detailed engineering, procurement, construction and commissioning; and demonstration.

Summary of findings by work package

Work package	Principal outcome
1. Technology review	Confirmed CFB as a mature, bankable HELE technology across wide fuel and scale ranges. International references (Łagisza 460 MW supercritical; Samcheok 4×550 MW; Turów repowering; China's 660 MW ultra-supercritical unit) demonstrate reliable compliance with stringent emission limits and fuel flexibility extremes.
2. Test-unit specification	Specified a 500-kW thermal unit balancing data quality, cost and regulatory requirements; design fuel is high-CV Grootvlei coal with provision for discards and biomass; limestone sorbent; 800 to 900°C operating window.
3. Process design (facility)	Defined facility configuration, utilities, basis of design and overall mass and energy balances. Performance targets: >95% SO_2 removal (in-situ limestone), low NO_x (air staging), reduced CO_2 (biomass co-firing).
4. Site selection	Four sites evaluated on weighted regulatory, strategic and infrastructure criteria. Eskom Rosherville selected (89.0%).
5. Special design considerations	HAZOP study identified nine principal hazard scenarios, each with assigned design actions; full instrument specifications developed for process monitoring, interlock protection and emissions compliance.
6. Process design (unit level)	Unit-level mass and energy balances completed and used to size all major equipment; P&IDs, plot plan and line list delivered.
7. Techno-economic assessment	Total owner's cost of R75.78 m (±30%) and annual OPEX of R3.91 m was estimated.
8. Risk register	Technical, business, financial and SHE risks identified, assessed and mitigated; most reduced to low residual risk. Dominant residual risk is reputational and funding-related (HIGH).

Design basis

Thermal capacity	**500 kW**
Design/supplementary fuel	**Coal (Grootvlei) / biomass**
Operating temperature	**800 to 900°C**
Oxidising agent / sorbent	**Air (20% excess) / limestone**
Higher heating value	**20.37 MJ/kg**
Coal feed / bed circulation rate	**~91.24 / ~7.233 kg/h**
Target SO_2 removal	**>95% (in-situ, limestone)**

Site selection (weighted score)

Eskom Rosherville (selected)	**89.0%**
CSIR Main Campus	72.4%
CSIR Kloppersbos	50.8%
CSIR Paardefontein	48.0%

CONCLUSION

Establishing a 500-kWth CFB combustion test facility is technically feasible and strategically warranted. The study provides a sound foundation for proceeding to Phase 2, generating decision-useful data well ahead of 2030 to inform South Africa's post-2030 cleaner-coal policy while building local capability to deploy the technology responsibly.

FUTURE TECHNOLOGIES · PROJECT F2025-3A

Enhancing Scope 1 and Scope 2 emissions management in the South African coal mining industry

10

A sector-wide programme delivered with Promethium Carbon.

The South African coal mining industry is operating within a rapidly evolving regulatory and commercial environment where greenhouse gas (GHG) emissions management is becoming an increasingly important component of operational performance, regulatory compliance and long-term competitiveness. In addition to South Africa's Carbon Tax Act and the recently enacted Climate Change Act, international disclosure frameworks such as the IFRS Sustainability Disclosure Standards and the Task Force on Climate-related Financial Disclosures (TCFD) are shaping stakeholder expectations for transparent and consistent climate-related reporting.

The research establishes the first consolidated baseline of Scope 1 and Scope 2 GHG emissions across participating South African coal mining companies. This was done by assessing current emissions management practices against recognised international frameworks and identified priority opportunities to strengthen emissions management across the sector. The assessment establishes a common starting point against which future progress can be monitored.

Establishing the sector emissions baseline

The assessment established a consolidated operational emissions baseline of approximately 6.73 million tonnes of carbon dioxide equivalent (tCO2e) for participating companies during the 2024 calendar year. This comprised approximately 4.38 million tCO2e of Scope 1 emissions and 2.35 million tCO2e of Scope 2 emissions. The analysis identified three principal operational emissions sources that collectively account for the majority of reported emissions: mobile diesel combustion (mining and fleet vehicles); fugitive methane emissions (from coal mining and stockpiles); and purchased electricity (grid electricity consumed in mining, processing, ventilation and material handling).

The concentration of emissions within a relatively small number of operational sources provides a clear indication of where future mitigation efforts should focus to deliver the greatest benefit. Improvements in fleet efficiency, fuel switching, methane management and electricity decarbonisation therefore represent the highest-priority opportunities. A high-level screening of selected Scope 3 categories indicated that downstream emissions associated with the use of sold coal are substantially larger than operational emissions, at approximately 385 million tCO2e across participating companies.

OPERATIONAL BASELINE, 2024

6.73m

tonnes CO_2e (Scope 1 + Scope 2)

4.38m

tCO_2e Scope 1

2.35m

tCO_2e Scope 2

Sector readiness and current practices

The research demonstrates that participating companies have made meaningful progress in establishing the systems required to quantify and manage operational GHG emissions. All participating companies were able to compile activity-based Scope 1 and Scope 2 emissions inventories, providing the foundation for consistent sector-wide reporting.

The assessment identified a growing range of operational initiatives aimed at improving energy performance, including process optimisation, improved energy monitoring, conveyor system optimisation, equipment shutdown automation, occupancy-based controls and broader energy efficiency initiatives. Several companies have also begun investigating renewable electricity procurement and self-generation. Advanced energy monitoring systems and mine digitalisation platforms are enabling companies to identify operational inefficiencies and integrate emissions information into routine operational decision-making.

Climate-related governance arrangements are becoming more established, with responsibility for emissions management increasingly shared across operational, environmental, finance and management functions. Many participating companies are strengthening alignment with internationally recognised reporting frameworks, including IFRS S2, the GHG Protocol and ISO 14064-1:2018.

Key opportunities for improvement

The most significant opportunity relates to fugitive methane emissions. Although methane is one of the largest contributors to reported Scope 1 emissions, relatively few companies have progressed beyond measurement toward large-scale methane capture, utilisation or flaring projects. A second priority is the continued improvement of measurement, reporting and verification (MRV) systems aligned with recognised international standards. The assessment also identified continued opportunities to reduce electricity-related emissions through improved energy efficiency, renewable electricity procurement and self-generation, and highlighted the importance of strengthening long-term transition planning.

Looking ahead

The research establishes an important foundation for improving GHG emissions management across South Africa's coal mining industry, providing participating companies with a common framework through which future reporting cycles can measure progress. Future reporting will focus on improving MRV systems, strengthening consistency in emissions accounting methodologies, and supporting improved year-on-year performance evaluation.

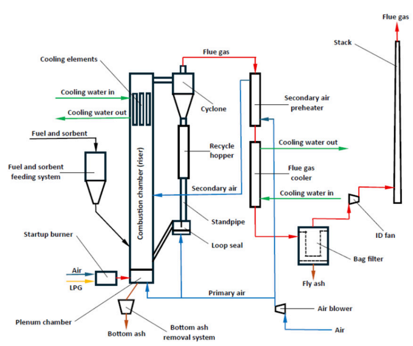


Figure 1: Sector decarbonisation implementation roadmap, progressing from strengthened emissions measurement and governance, through operational decarbonisation, to longer-term technology transformation.

SECTION ELEVEN

11

Financial Statements

For the year ended 31 March 2026. Audited without qualification by Ranrus Incorporated, with going concern confirmed.

11

FINANCIAL STATEMENTS

The annual financial statements for the year ended 31 March 2026 were audited by Ranrus Incorporated, who issued an unqualified opinion, confirming that the statements present fairly, in all material respects, the financial position of the Association in accordance with the IFRS for SMEs standard. The statements were approved by the Board and signed on 13 July 2026. The primary statements are reproduced below.

Statement of Financial Position (R)

	2026	2025
Property, plant and equipment	13,400	24,993
Trade and other receivables	1,591,444	32,771
Cash and cash equivalents	23,189,710	20,780,717
Total assets	**24,794,554**	**20,838,481**
Accumulated surplus	16,761,246	14,977,545
Non-distributable reserves	–	1,416,111
Total equity	**16,761,246**	**16,393,656**
Trade and other payables	8,033,308	4,444,825
Total equity and liabilities	**24,794,554**	**20,838,481**

Statement of Comprehensive Income (R)

	2026	2025
Revenue	15,436,268	10,800,583
Other income	813,053	1,310,689
Operating expenses	(17,557,052)	(10,756,987)
(Deficit) / surplus from operating activities	(1,307,731)	1,354,285
Interest received	1,675,321	745,048
Surplus for the year	**367,590**	**2,099,333**

Statement of Cash Flows (R)

	2026	2025
Net cash flows from operating activities	2,408,993	2,005,519
Cash flows used in investing activities	–	(34,781)
Net increase in cash and cash equivalents	2,408,993	1,970,738
Cash and cash equivalents at end of year	**23,189,710**	**20,780,717**

The figures above reproduce the primary audited statements. The complete audited annual financial statements, including the accounting policies and notes, are available from the Coaltech office.

AUDIT OPINION

Unqualified

Issued by Ranrus Incorporated, confirming that the statements present fairly, in all material respects, the financial position of the Association in accordance with the IFRS for SMEs standard. Going concern confirmed; the Association remains debt free. Signed 7 July 2026.

R15.4m
Member contributions and fees

R12.7m
Direct research investment

R367.6k
Surplus for the year

R23.2m
Cash and investments

SECTION TWELVE

Looking Ahead

Coaltech enters the coming year with a deliberate strategic direction: to widen its lens from improving coal in today's context to shaping the role of coal within South Africa's whole energy system, and to move from a volume based view of coal to a value based one.

The next research programme, spanning 2027 to 2031, is being shaped now with members and industry, on a single conviction: that Coaltech must be essential to its members and relevant to the nation.

THE STRATEGY FROM HERE

12

A broader lens for the future of coal

The strength of Coaltech has never been in question; three decades of research have proven it. The opportunity now is to widen the strategic lens. The question is no longer only how to make coal safer, cleaner and more efficient, but how coal works within a broader energy system, alongside renewables, storage, grid investment, water stewardship, critical minerals and industrial demand. Positioned this way, coal is not defended, its role is defined, and its value is secured within a resilient, balanced energy mix for South Africa.

FOUR SHIFTS THAT SHAPE OUR THINKING

Either / or → Both / and

Not coal versus renewables. Coal and renewables, working together to power a reliable, affordable and cleaner South Africa.

Volume → Value

New value across the coal value chain, from byproducts and waste to beneficiation and the critical minerals a modern economy needs.

Defending coal → Defining its role

Positioning coal where it adds the most value in a balanced energy system, so Coaltech stays central to national energy strategy.

Many small projects → Sector shaping priorities

Fewer, larger, co funded priorities that address South African challenges directly and deliver practical impact at pace.

Responsible energy security, and the future value of coal

12

RESPONSIBLE ENERGY SECURITY

Coal remains essential to the national energy system and industrial base. Coaltech will keep driving zero harm, lower emissions, cleaner mine water and stronger environmental performance, so that reliable energy is delivered in a responsible manner.

FUTURE VALUE OF COAL

Building on a South African legacy of innovation, Coaltech will strengthen its Future Technologies focus, finding practical, sustainable uses for coal, its byproducts and its waste, and unlocking value across the whole coal value chain.

SECTOR SHAPING PRIORITIES, 2027 TO 2031

Clean coal technology
Building on the High Efficiency Low Emissions programme

Water and brine management
Turning a liability into clean water and value

Value from discard and ultra fines
Waste materials as energy and products

Digital tools, safety and AI
Monitoring, optimisation and protecting people

Closure and land legacies
Rehabilitation and productive after use

Delivering this agenda calls for collective action: Coaltech as the vehicle through which members connect, align at senior level and co fund the pre competitive research that no single company would undertake alone. Data, energy and water, worked in harmony, are the cornerstone of that shared future.