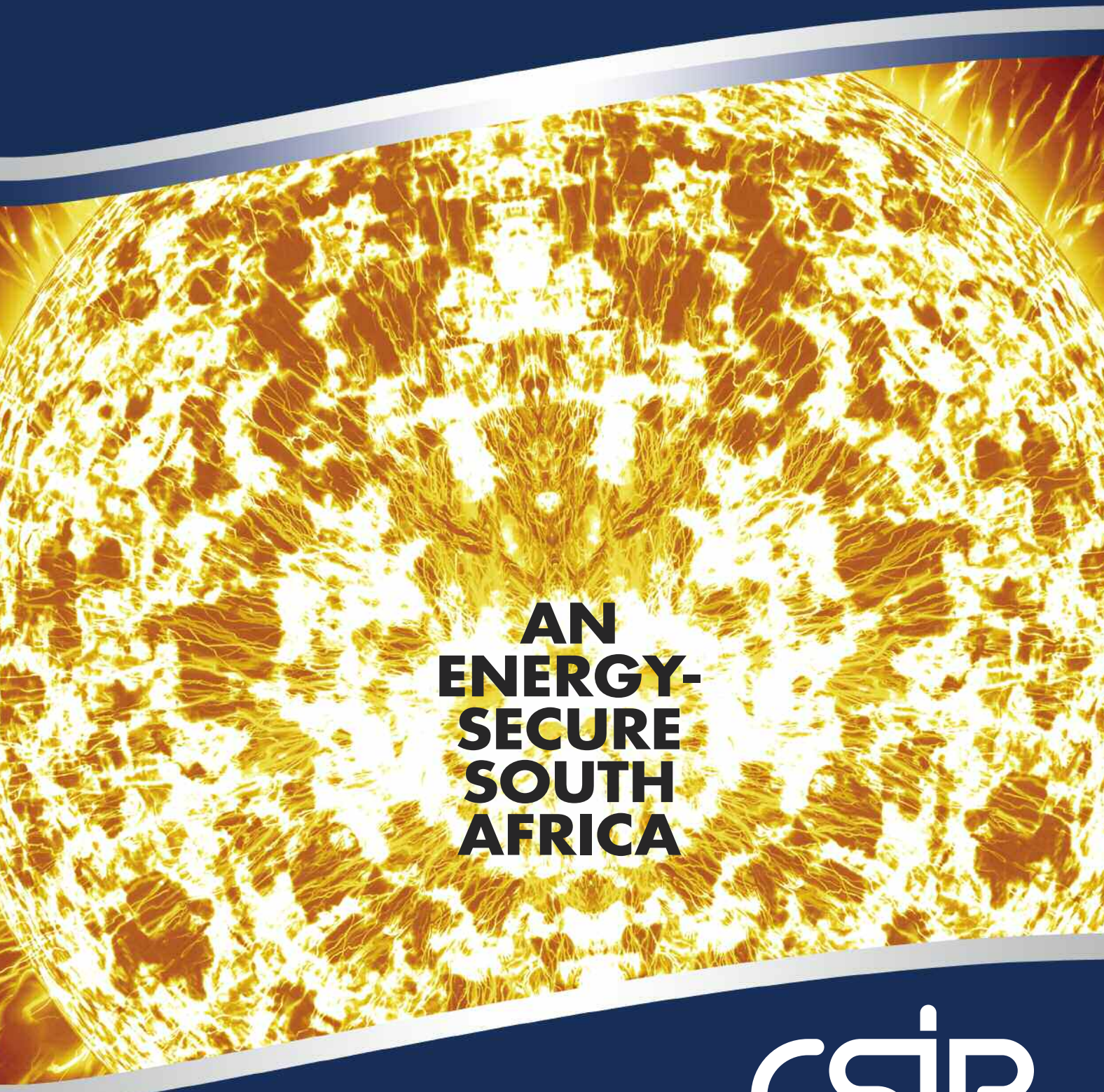
# ScienceScope

QUARTERLY PUBLICATION OF THE CSIR | VOLUME 4 | NUMBER 1 | JUNE 2009
SOUTH AFRICA'S COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH
www.csir.co.za



## AN ENERGY-SECURE SOUTH AFRICA

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# AN ENERGY-SECURE SOUTH AFRICA

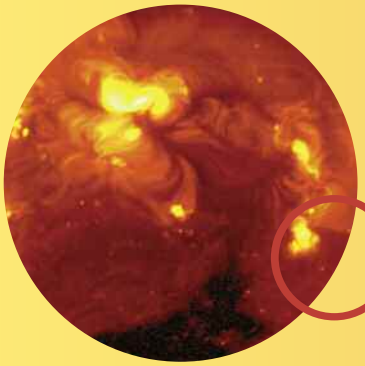


# TENTS









# OVERVIEW

## THE RACE FOR ELECTRICITY PROVISION

BY THOMAS ROOS

MUCH HAS BEEN SAID ABOUT THE SOUTH AFRICAN ENERGY SITUATION. THE REALITY IS THAT THE COUNTRY FACES FOUR CHALLENGES WITH RESPECT TO THE PROVISION OF ELECTRICITY TO SOUTH AFRICAN CONSUMERS AND INDUSTRY: • SECURITY AND SUPPLY, I.E. OUR GENERATION AND DISTRIBUTION INFRASTRUCTURE, POWER STATIONS AND THE RISK OF LOAD SHEDDING • ENERGY INTENSITY, I.E. THE AMOUNT OF ELECTRICITY WE USE AS A NATION TO GENERATE GDP • EMISSIONS AND THE ENVIRONMENTAL IMPACT, SEEN AGAINST THE BACKDROP OF CLIMATE CHANGE • ELECTRICITY ACCESS (OR LACK THEREOF) OF OUR POPULATION.

### SECURITY OF SUPPLY

The construction of new power plants has not been authorised by government for about 15 years. A contributory reason for this approval delay was a decision to open the electricity generation space and invite independent power producers (IPP) to invest in South Africa, which has the cheapest industrial electricity tariffs in the world and the second cheapest (after India) residential tariffs. Unfortunately, IPPs were not forthcoming as, without an increase in allowed tariffs, IPPs did not see a business case for investing.

Subsequently, government gave approval for new coal-fired power station construction. Unfortunately, this approval came too late. The year-on-year growth of the economy pushed demand to levels approaching maximum available supply.

The subsequent load shedding resulted in cutbacks of electricity use by the mining sector of 10% and restrictions on future housing and other construction projects – slowing down the economy. Lead times on new generation capacity of several years will inhibit economic growth for the foreseeable future. Eskom is now building the Medupi coal-fired power station in Lephalale, Limpopo province, and has built peaking power gas turbine plants at Atlantis and Mossel Bay, running on diesel.

### ENERGY INTENSITY

In a survey of the world's 30 largest economies, South Africa is second only to Russia in using the highest amount of electricity to produce US$1000 GDP (see 1st figure on next page). Firstly, this is because the economy has a large, energy-intensive mining and resource extraction component. Secondly, South Africa's electricity price for industry is the cheapest in the world, a disincentive for energy saving and attracting energy-intensive industry (such as aluminium smelters).

The energy-intensive nature of the economy has led to an Energy Efficiency Hub being set up at the University of Pretoria, an incentive programme by Eskom for industry to replace older design electrical motors with more efficient motors, and a national energy efficiency campaign led by government.

### EMISSIONS

The evidence of man-made greenhouse gas emissions being linked to climate change has been accepted as compelling and convincing by mainstream institutions. The South African cabinet responded favourably to the Stern report on climate change, acknowledging the need for action.

How is South Africa faring? In the same sample of countries mentioned earlier, this country is beaten only by China and Russia in emitting the most carbon dioxide for every thousand US dollars made in GDP (see 2nd figure on next page). This exposes South African energy-intensive exports (aluminium, ferrochrome) to the risk of protectionist tariffs in markets subject to green legislation. South Africa is the 12th largest $CO_2$ emitter on the planet, but only the 30th largest economy.

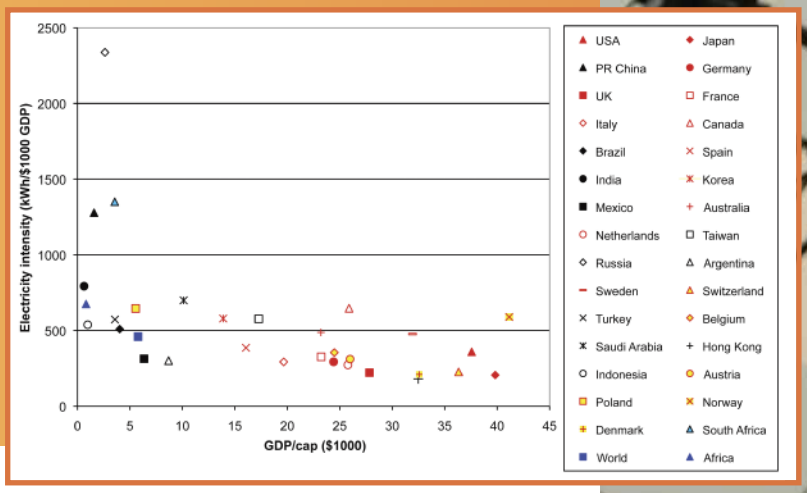
This is due, firstly, to the energy intensity of the economy and, secondly, to the fact that South Africa is overwhelmingly dependent on coal for energy, compared to other fuels:

- 87.2% of electricity generation capacity by Eskom is based on coal-fired stations
- 30% of liquid fuel is made from coal by Sasol using the Fischer-Tropsch process, making the Sasol Secunda plant the biggest single point source of $CO_2$ on the planet.

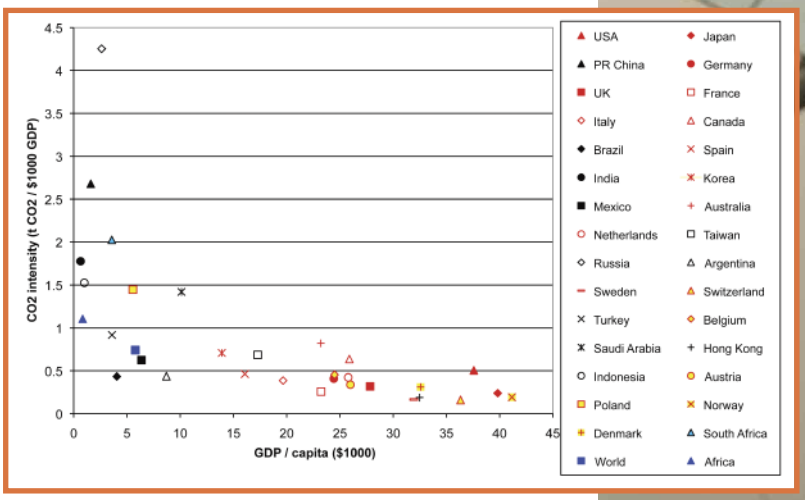
Potential solutions include the introduction of systems that are carbon lean (i.e. clean coal technologies that emit less $CO_2$), carbon neutral (bio-energy that releases the same $CO_2$ it used to grow the plants) and carbon free (renewable and nuclear emitting no $CO_2$).

This will only happen if it is economically beneficial to do so, which may involve the introduction of higher carbon taxes, on the one hand, and incentives for renewable power production on the other, such as feed-in tariffs. A feed-in tariff adds a levy to the general electricity price, allowing extra money to be recovered from consumers (not tax payers) to pay more to electricity providers who make use of renewable energy technologies.

The publication of a generous feed-in tariff in Spain has seen an explosion of projects to build solar power stations, using tracking mirrors to generate heat to drive steam turbines. Germany and Spain have been followed by France, Portugal, Greece and Israel in publishing solar feed-in tariffs. A South African feed-in tariff was published in March




Electricity intensity of the world's 30 largest economies (OECD countries in red). South Africa is second only to Russia.




$CO_2$ intensity of the world's 30 largest economies (OECD countries in red). South Africa is beaten only by Russia and China.

The CSIR's Thomas Roos in front of the 25 m² target-aligned heliostat, the first part of a CSIR hybrid solar/ fossil fuel gas turbine distributed research programme. Read more about it in *ScienceScope* (Volume 2, Number 3, December 2007)

this year, allowing electricity providers to earn 90c kWh if their power was generated from landfill gas, R1,25 kWh if generated from wind and R2.10 kWh if produced from concentrated solar with six hours of storage.

## ENERGY ACCESS

Residential access to electricity increased from some 30% of the population in 1994 to 73% in 2005. The 27% of South Africans who still do not have access to electricity tend to live in smaller, more remote communities. Only about 46% of rural households are connected to the national grid.

All things being equal, communities receive priority for connection to the national electricity grid when they are:

- Close to the grid
- Large and dense
- Located in accessible topography.

It is unlikely that the grid will reach most areas in the short to medium term, owing to the low load demand, the dispersed nature of these settlements and the high fixed costs of grid extension. This suggests that a distributed approach may be more appropriate if a suitable cost recovery mechanism could be found: the articles on pages 36 and 42 illustrate the difficulty of funding renewable and off-grid systems. The feed-in tariff may present a solution to this problem.

In general, feed-in tariffs only apply to large-scale, grid-connected renewable systems of around 10 MW. If a modification were to be made to the South African tariff to allow smaller scale off-grid systems (200 to 800 kW), the following benefits would accrue:

- More independent companies would enter the energy sector
- Eskom can concentrate on large scale power provision
- These small power stations would be financed from private or institutional capital (not the fiscus) and revenue, hence repayment of loans to institutions, is guaranteed
- All consumers, not just the off-grid community, are paying for this higher-cost power, reducing tariffs
- Power stations would use renewable energy with diesel for back-up use
- Companies can be held accountable to guarantee power availability, requiring on-site technical staff.

The article on page 20 describes IRIP, an integrated CSIR project addressing the four energy challenges discussed in this article.

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ALTERNATIVE ENERGY RESEARCH

# ADVANCED OPTICAL MATERIALS

## TO IMPROVE SOLAR ABSORPTION

DRS ANDREW FORBES AND GIFT KATUMBA

NOW MORE THAN EVER THERE IS A NEED TO TURN TO RENEWABLE, COST EFFECTIVE AND SUSTAINABLE ENERGY RESOURCES. IN RESPONSE, CSIR RESEARCHERS HAVE EMPLOYED THE USE OF PHOTONIC MATERIALS.

IN RURAL AFRICA, in particular, the demand for domestic energy is very high and is exacerbated by inadequate grid electricity infrastructure. This state of affairs has culminated in massive deforestation and desertification of some parts of Africa.

One technology solution is to harness the energy from the sun through solar absorbers. This has applications in domestic heating – such as heating water (solar geysers) and cooking.

Early solar energy technologies were not readily accepted in Africa because of high initial investment cost and low efficiency, particularly so for the not so rich rural populace. Presently, there is a re-look into the solar energy technologies with emphasis on cost effectiveness and sustainability.

One of the key factors in solar energy is the material used to absorb sunlight. The requirements of selective solar absorber materials used for low to moderate temperature applications such as domestic water heating collectors are high absorption in the solar wavelength range and an accompanying low thermal emittance in the near-infrared (NIR) and far-infrared (FIR) wavelength ranges.

The idea is simply that the material be such that it absorbs as much of the solar energy as possible, thereby getting very hot. Once it gets hot, it would tend to re-emit, following a grey or black-body spectrum. An ideal solar absorber would not re-emit any radiation, thus maximising transfer of energy by other means, such as heating by conduction (e.g. heating water in a rural village).

These requirements translate to a material that has low reflectance of less than 10% in the wavelength range from 300 nm to 2500 nm and a high reflectance of greater than 90% for wavelengths greater than 2500 nm. Today, no intrinsic material is capable of this selectivity.

## ENTER THE PHOTONIC SPECIALISTS

CSIR researchers specialising in advanced photonic materials have succeeded in tailoring the optical and structural properties of materials to achieve the desired wavelength selectivity. Our novel selective solar absorber comprises carbon nano-particles embedded in a NiO (nickel oxide) matrix on an aluminium substrate. It shows enhanced solar radiation absorbance and low thermal emittance properties: laboratory tests show that it is approximately 30% more efficient than the best alternative on the market.

Furthermore, the sol-gel recipe that is used to manufacture the composite material has additional advantages of being environmentally friendly and has a low production cost. Control of the spectral selectivity in the coating is achieved by adjusting various parameters of the coatings, such as composition, thickness, porosity surface morphology and nanostructure, among others.

This technology is set to impact the lives of the poorest people in South Africa by providing them with a reliable energy source for domestic heating applications. For example, boiling water without the need for electricity or making a fire would have a huge impact on a rural household's safety and health and would generally result in a better quality of life for such communities.

A consortium of local universities, the private sector and NGOs, led by the CSIR's laser experts, has started a three year implementation programme to see that this laboratory research is realised in local communities for cleaner, safer energy.

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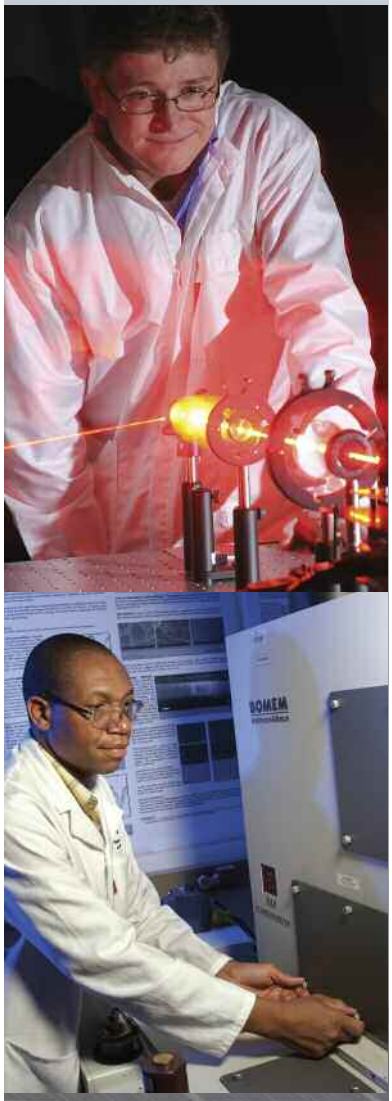
Drs Andrew Forbes and Gift Katumba



**"Lab results show that CSIR laser researchers have developed a novel selective solar absorber that is about 30% more efficient than the best alternative on the market."**

ALTERNATIVE ENERGY RESEARCH

VERY FEW PEOPLE KNOW THAT THE CSIR MADE SIGNIFICANT CONTRIBUTIONS TO THE DEVELOPMENT OF THE LITHIUM ION BATTERY – THE ONE BEING USED IN MOST CELLULAR PHONES THESE DAYS. NOW, A BATTERY CENTRE OF COMPETENCE WILL BE SET UP AT THE CSIR, EDGING SOUTH AFRICA ONE STEP CLOSER TO PLAYING A MEANINGFUL ROLE IN THE ADVANCEMENT OF BATTERY RESEARCH AND INNOVATION.

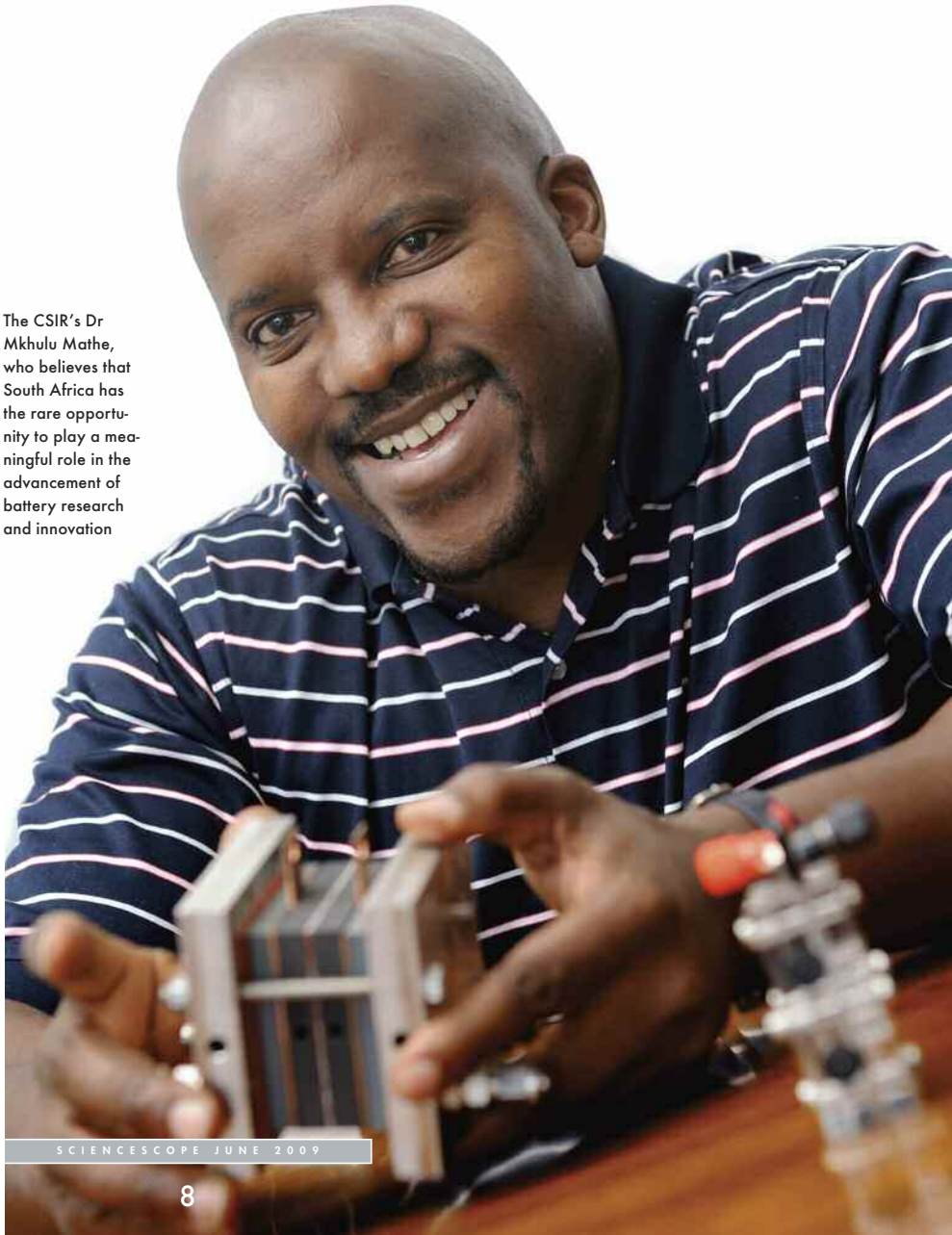
# ALL SET FOR A BATTERY CENTRE OF COMPETENCE

WORLDWIDE, LARGE INVESTMENTS are being made in research that will enable us to find a realistic alternative to the internal combustion engine. To this effect, several hybrid and other electric vehicles have been launched. These vehicles rely on battery power and mostly make use of lithium-ion batteries. However, in some cases the cost of these batteries can account for up to 25% of the cost of the entire vehicle.

Research into batteries that will be low-cost, safe and long-lasting is therefore an almost automatic spin-off of the electric car industry. According to Dr Mkhulu Mathe, who heads up the CSIR's research group for energy and processes, this turn of events also presents South Africa with the rare opportunity to play a meaningful role in the advancement of battery research and innovation.

"This is the reason why a Battery Centre of Competence (BatCoC) will be established at the CSIR," says Mathe. "In fact, the BatCoC will form part of a stakeholder group working on the development of a national strategy on battery research."

Among others, these stakeholders currently include the Industrial Development Corporation (IDC), who has commissioned a study on the feasibility of the battery industry in South Africa; Optimal Energy, the makers of South Africa's first electrical car (the Joule); the Innovation Fund and the Department of Science and Technology (DST), both stakeholders in the Optimal Energy project; and the universities of Limpopo, Witwaters-rand and the Western Cape.



The CSIR's Dr Mkhulu Mathe, who believes that South Africa has the rare opportunity to play a meaningful role in the advancement of battery research and innovation

## Pioneering a national strategy

The first 'battery research interest group' meeting took place in March this year. It was held under the joint leadership of the CSIR and Professor Phuthi Ngoepe of the University of Limpopo. According to Mathe, the meeting was largely on how to coordinate and share information on battery development and research. "However, the most important item on the agenda was to discuss possible mechanisms for the development of a national strategy that will lead to the start of a battery industry targeted at electric vehicles," he says.

A follow-up meeting was held a mere ten days later, this time with Dr Phil Mjwara, Director General of the DST, also present. In this meeting, the development of a national strategy was endorsed and the need for a preliminary business plan, an immediate challenge for possible submission to the Medium Term Expenditure Framework (MTEF), was identified and highly encouraged.

"The CSIR plans to play the leading role in the formulation of this business plan, as well as the national strategy. We will need the valued input of all stakeholders though," says Mathe.

The various stakeholders are now all on a fact-finding mission. Representatives from the IDC and Optimal Energy, for instance, attended the Advanced Automotive Battery and Electrochemical Capacitor conference, held in Long Beach, California, in June this year.

The CSIR had two immediate missions: attending the Electrochemical Society (ECS) meeting in May, held in San Francisco, California, and a visit to the Argonne National Laboratory in Illinois, USA, where Dr Michael M Thackeray heads up the battery technology department.

## Back to the future

Thackeray was in charge of the CSIR's battery research group back in the early 80s, when the CSIR made significant contributions to the development of the lithium ion battery. Mathe believes that Thackeray's experience and high-tech laboratories at the Argonne National Laboratory are good starting points for the CSIR's BatCoC plans. "A visit there helped us to establish what trends and skills are needed to leapfrog the BatCoC."

He continues: "The ECS meeting was an opportunity to listen to high-level talks on batteries, fuel cells and energy conversion while we were able to meet with international experts in the field. At the same time we aimed to recruit some of the skills we will need for the BatCoC."

## Wider application possibilities

While the national strategy will focus mostly on battery development for electric cars, Mathe says that research into battery technology has much wider applications, especially in a country like South Africa.

"Certainly, the largest application opportunity currently lies in the automotive industry. Yet there is also scope for several other applications," he says. "Think of solar energy that has to be stored in a battery, to name but one example. BatCoC will aim to find ways of producing batteries that last longer, store more energy, are cheaper to manufacture and environmentally friendly to dispose of. Who knows what our research will deliver?"

According to Mathe, the centre will initially focus its research on high-capacity materials anode and cathode development, thin film/smart structures batteries, battery characterisation, testing and diagnostics and battery electronics. It will also seek national and international collaborations while striving to develop human capital in this field.

"We want BatCoC to be a leading world-class characterisation, testing and battery materials development laboratory that provides state-of-the-art research facilities. I believe that the establishment of this centre is just one step closer to the ideal of becoming an energy-efficient country," concludes Mathe. – *Petro Lowies*

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## THE WONDER OF LITHIUM ION BATTERIES

**Lithium ion batteries were first proposed in the 1970s. Several researchers soon made significant discoveries that led to its current refined development. While the American, Professor John Goodenough, is widely credited with its invention, he was assisted by several research teams. It was in 1983 that a CSIR team, lead by Dr Michael Thackeray, assisted Goodenough in discovering manganese spinel as a cathode material for these batteries. Manganese spinel is currently used in commercial cells.**

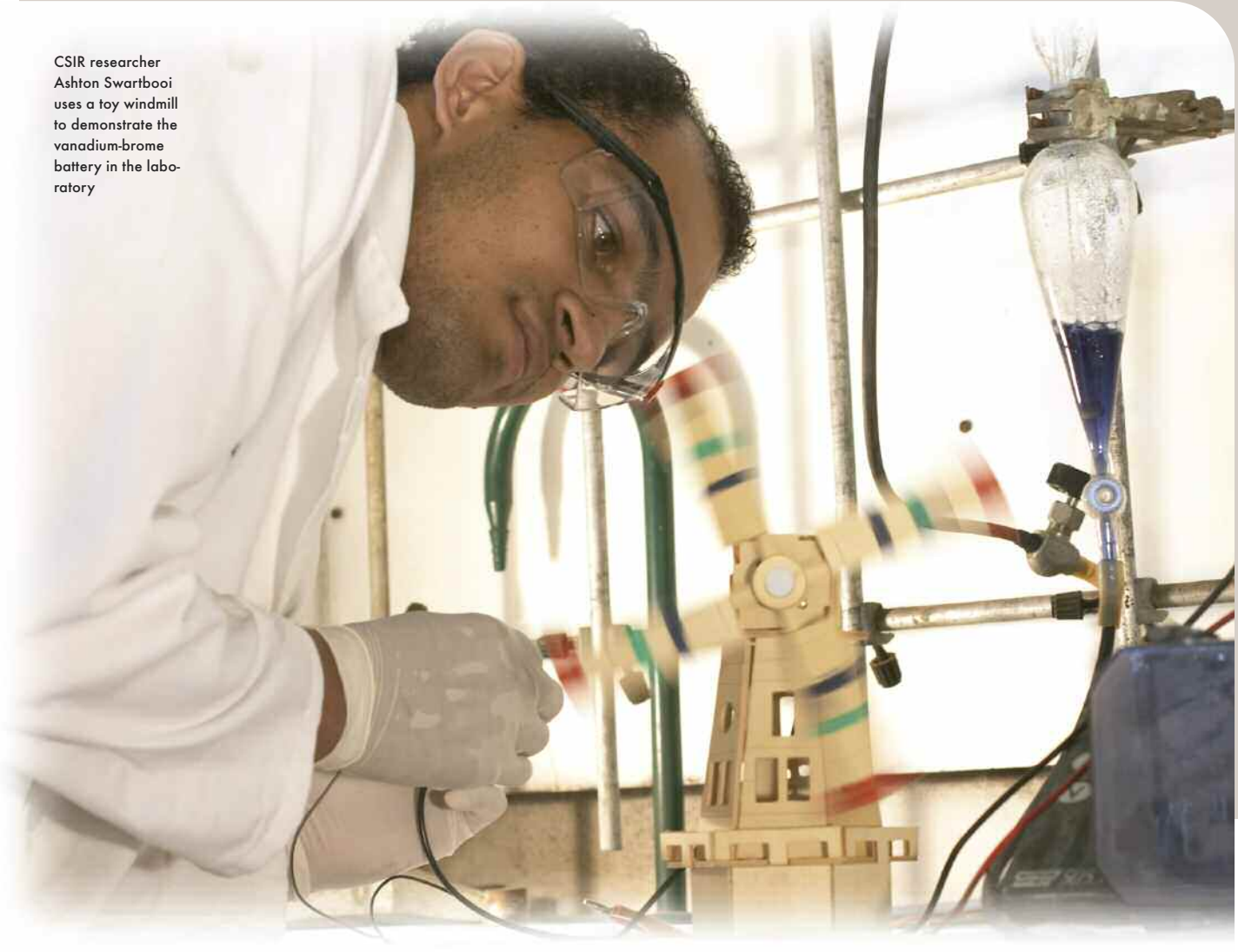
**Since Sony first commercialised lithium ion batteries in 1991, it has revolutionised the consumer electronics industry. They are especially popular for use in portable electronics, with one of the best energy-to-weight ratios, no memory effect, and a slow loss of charge when not in use. Lithium-ion batteries are also growing in popularity for defence, automotive and aerospace applications due to their high energy density.**
*(Adapted from Wikipedia.org)*

Optimal Energy's Joule, a full electric multi-purpose urban passenger vehicle unveiled at the Paris Autoshow in 2008, is the first South African designed and manufactured electric car

ALTERNATIVE ENERGY RESEARCH

# BETTER, CHEAPER BATTERIES

ELECTRICITY GENERATED FROM RENEWABLE RESOURCES SUCH AS WIND, SOLAR, TIDAL OR WAVE ENERGY USUALLY NEEDS TO BE STORED IN A BATTERY. WHILE LEAD-ACID BATTERIES HAVE LONG BEEN THE FAVOURED AND MOST ECONOMICAL OPTION TO USE FOR THIS PURPOSE, THEY ARE NOT ENVIRONMENTALLY FRIENDLY AND CAN ONLY BE APPLIED ON A SMALL SCALE. CSIR RESEARCHERS ARE INVESTIGATING REDOX FLOW BATTERIES AS AN ALTERNATIVE FOR THE LARGE-SCALE STORAGE OF ELECTRICITY.



CSIR researcher Ashton Swartbooi uses a toy windmill to demonstrate the vanadium-brome battery in the laboratory

# FOR BETTER ELECTRICITY STORAGE

AS FOSSIL FUEL RESOURCES become depleted and concerns about global warming increases, the focus on renewable energy sources becomes more urgent. The sources are, however, intermittent by nature. The electricity generated by them usually needs to be stored in energy storage devices such as batteries, until such time as it can be used.

It has always been the cheapest option to use lead-acid batteries for this purpose. But lately more interest has been shown in batteries known as reduction-oxidation (redox) flow batteries. According to the CSIR's Ashton Swartbooi, however, the low power densities of redox flow batteries means that they can only be applied as large-scale storage devices that are generally not portable. It is also more expensive to produce than lead-acid batteries. This is what he aims to change.

"We have done studies on redox flow batteries that are aimed at improving them so that they would cost less to produce and perform better," he says.

## Redox flow batteries explained

Up to date only pilot plant tests have been completed for redox flow batteries. It is envisioned that these batteries could be applied in the telecommunications industry at exchange sites and data centres, to supply electricity to remote communities, hospitals and schools that are not on the national electricity grid with energy from solar and other renewable resources, and to level loads in uninterrupted power supplies.

It is constructed in much the same way as conventional batteries. Swartbooi explains the main difference: "In redox flow batteries, electrodes are inert and act merely as current collectors, whereas they are the active components in a conventional battery. This has the added advantage of decoupling the capacity and power rating in redox flow batteries; thus a large capacity, high power battery can readily be produced to use for load levelling purposes."

## Experiments to lower the cost

There are two types of redox flow batteries commercially available: the zinc-bromine (Zn-Br) battery (a pseudo redox flow battery) as well as the all-vanadium (V-V) battery. Although these batteries provide efficiencies greater than or equal to those of lead-acid batteries, they need some improvements.

Swartbooi explains why: "The Zn-Br battery could suffer from efficiency losses due to uneven zinc deposition on the electrodes at high charge rates. The cost of the V-V battery is high due to the expensive vanadium that is used as reagents."

His experiments were based on a combined version of these two batteries: a V-Br redox flow battery. It involved finding possible redox couples that would not only reduce the costs significantly, but would also improve the power densities of the battery itself, thus broadening the market applications for redox flow batteries."By just replacing one half of the V-V battery with a bromine redox couple, the cost is reduced by as much as 40%. Also, the battery gives double the theoretical energy density than the V-V battery. Even more encouraging, we have tested a chrome-brome battery, and this reduces the cost by as much as 80%, compared to the V-V battery."

According to Swartbooi, one of the major obstacles that would have to be overcome when using mixed electrolytes is the cross-contamination of the species across the membrane. In the case of the V-V battery, this cross-contamination is negated because of the use of the same species on both sides. Cross contamination directly results in a loss of efficiency.

"For the V-Br and Cr-Br battery to be competitive in the market, it would have to give similar efficiencies to that of the vanadium battery, thus providing a battery of the same functionality, but at a significantly reduced cost," he explains.

Preliminary results have indicated that these new couples could provide a battery that competes well with the current commercially available redox flow batteries. "There is definitely room for improvement on the commercially available V-V battery, especially with regard to manufacturing costs. I'm doing further optimisation tests to produce a battery that has low internal resistance and thus favourable voltage and current efficiencies. Once this optimisation is complete, the battery should be subjected to continuous charge-discharge cycles so as to complete a thorough comparison with other available technologies." – *Petro Lowies*

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ALTERNATIVE ENERGY RESEARCH

# SOLAR DYE CELLS

## A DIFFERENT APPROACH TO SOLAR ENERGY

BY LUKAS LE ROUX AND FRANSCIOUS CUMMINGS

THE 'BUSINESS END' of most solar panels consists of silicon-based photovoltaic (PV) cells. These are the cells that convert solar light into electrical energy. This happens when the electrons within silicon are energised by sunlight. All molecules, including those found in silicon, are surrounded by energy layers containing electrons. When these electrons are energised by sunlight, they move to the outer layer of the molecule where they become available for the creation of an electrical current through electrical contacts.

A cheaper and more attractive alternative to silicon-based cells, however, is to use dye solar cells.

Dye solar cells are photoelectrochemical and use a liquid electrolyte or other ion-conducting phase as a charge transport medium. The process is similar to photosynthesis in plants; with the major difference being that electricity is produced (with the aid of a ruthenium dye) whereas plants produce oxygen and 'sugar' (with the aid of chlorophyll).

Dye solar cells use dye-absorbed, large-band-gap metal oxide materials such as titanium dioxide ($TiO_2$) to absorb the solar light. They have a visible difference to conventional PV cells, in that they are semi-transparent. Hence they can be installed in place of glass windows in buildings.

There are many excellent reasons why dye solar cells are preferable to silicon cells. These include the fact that its performance increases with temperature and that it is easy, clean and cost-effective to produce. The biggest drawback in using dye solar cells is that it is not as efficient as silicon cells in converting sunlight into electricity. Dye solar cells will convert around 7% of the sunlight into electricity whereas silicon cells will convert between 10% and 15% of the sunlight.

## CURRENT RESEARCH AT THE CSIR

Researchers at the CSIR are currently focusing on four projects pertaining to dye solar

WHAT IF SOME WINDOWS IN YOUR OFFICE BUILDING OR HOME COULD ACTUALLY ACT AS SOLAR PANELS? THESE WINDOWS WOULD BE TINTED AND HAVE THE DUAL TASKS OF PROVIDING SHADE FOR THE OCCUPANTS OF THE BUILDING AS WELL AS GENERATING ELECTRICITY. THIS TECHNOLOGY EXISTS BUT NEEDS TO BE REFINED AND COMPLETELY UNDERSTOOD FOR IT TO BE AN ATTRACTIVE AND CHEAPER ALTERNATIVE TO CURRENTLY USED SOLAR PANELS.

The CSIR's dye solar cell team: Franscious Cummings, Nonhlanhla Mphahlele and Lukas le Roux. In front are two dye solar cell panels used in their research, with Cummings and Mphahlele both holding test cells that were manufactured in the dye solar cell laboratory.

# ALTERNATIVE ENERGY RESEARCH

**Fuel cells can contribute to energy security, because they can convert potentially renewable fuels such as hydrogen, methanol or ethanol cleanly and efficiently into electrical energy. They are of particular interest to South Africa, as they incorporate catalytic metals, such as platinum, of which three-quarters of known reserves are found here.**


cells. These include using $TiO_2$ nanotubes to increase efficiency, dye synthesis, improving stability through reverse bias and recovery and doing comparative studies.

## THE PROMISE OF $TIO_2$ NANOTUBES

One of the main causes for the low efficiencies reported for the dye solar cells is the ineffective transport of electrons through the cell. This is caused by the rough surfaces and disorder at the interface of $TiO_2$ nanoparticles.

The CSIR's research aims to overcome this problem by synthesising smooth surfaced, highly-ordered $TiO_2$ nanotubes. These structures are of particular interest because their predominantly one-dimensional nature creates a direct route for electrons to travel unhindered from their point of generation, at the dye/$TiO_2$ surface interface, to the conducting glass substrate.

Furthermore, $TiO_2$ nanotubes have a more open structure that allows for more dye molecules to be chemically absorbed onto the surface while simultaneously facilitating the penetration of the electrolyte. This means that iodide diffusion inside the cell is improved.

Initial reports have shown that dye solar cells that use nanotubes outperform traditional nanoparticle-based dye solar cells in terms of charge transport and, ultimately, light-to-electricity conversion efficiency.

A study is currently in progress to determine the extent of the effect of voltage, time and electrolyte on the morphology of $TiO_2$ nanotubes. Preliminary results show that it is capable to control the outer diameter, wall thickness and length of these nanotubes by simply having accurate control over the mentioned experimental parameters. Future research will be aimed at investigating the effect of the structure of the $TiO_2$ nanotubes on their optical and electric properties, which is crucial in determining whether they will be suitable for use within a dye solar cell.

## DYE SYNTHESIS

CSIR researchers focused on synthesising ruthenium dye, also known as N3 dye, to be used in dye solar cells. This has been done successfully by using ruthenium residues that accumulated over years of research. The final purification step is currently being optimised. The product will be tested in cells that are assembled in the CSIR's laboratories against commercially available dyes from Switzerland and Australia.

## STABILITY TESTS UNDER REVERSE BIAS AND RECOVERY OF CELLS

Solar cells tend to behave differently when they are exposed to shade instead of sunlight. They reverse their electricity charge back into the cell and cause it immense damage. This process is called reverse bias. To prevent reverse bias from happening, solar modules have diodes built into their design.

Dye solar cells are not as susceptible to damage from reverse bias but the boundary conditions should be clearly understood and defined. Modules can then be built at even lower cost.

CSIR researchers subjected dye solar cells to various reverse bias voltages and their efficiencies were monitored with time. The degradation as well as the regeneration were plotted against time and the cells analysed. Chemical analysis on the cells is now underway to determine the chemical changes that the cells underwent during the reverse bias experiments.

## COMPARATIVE STUDIES

Toyoda R&D in Japan did comparative studies in actual atmospheric conditions that had dye solar cells outperforming silicon cells by approximately 20% per month over a six-month period. CSIR researchers started a similar project in local conditions, as South Africa has significantly more sunshine than Japan. Parameters such as the effect of temperature, humidity, wind speed and light intensity will be logged to determine the effects on the efficiency of the different cells.

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# GENERATION USING FUEL CELLS

A FUEL CELL is a device that converts the chemical energy of a fuel directly to electrical energy. In this respect, it is similar to a battery. However, the chemical energy for a fuel cell is not necessarily stored inside the cell. Rather, it can be supplied externally, and the fuel cell can continue to operate as long as it is supplied with fuel.

A fuel cell, explains CSIR senior researcher Dr Mark Rohwer, has two compartments: in the anode, fuel such as hydrogen gas is oxidised, while in the cathode, oxygen (either pure or in the form of air) is reduced. In the process, the fuel cell delivers an electrical current to an external circuit.

"While fuel cells can generate electricity directly from fuel, conventional production of electricity from fossil fuels involves a stepwise conversion of the chemical energy in the fuel – first to thermal energy, then to kinetic energy and only then to electrical energy. Each of these steps involves losses. Fuel cells, being direct energy converters, therefore have much potential as highly efficient energy sources, provided that they can be operated at high efficiency," he says.

## OPTIMISING FUEL CELLS FOR GREATER EFFICIENCY

To make fuel cells truly efficient and cost effective energy converters, a number of aspects must still be optimised. These include catalysis, mass transport, ionic and electric conductivity and water management.

Direct methanol fuel cells, for instance, are one of the most promising power sources for portable devices such as laptops and cellular phones. They do, however, have drawbacks – the relative toxicity of methanol being only one. The already commercialised hydrogen fuel cell, on the other hand, is quite expensive. It generally uses a costly polymer called Nafion as its membrane material and the precious metal, platinum, as its catalyst. "Ultimately, we want to develop fuel cell components and products with new and improved features," says Rohwer. "To achieve this, the CSIR's fuel cell research team is focusing on developing, evaluating and improving the key electrochemical components (catalysts, membranes, gas diffusion layers and electrodes) of hydrogen fuel cells and, lately, alcohol-based fuel cells."

Currently, several projects aim to improve different aspects of fuel cells. These are:

- Developing a novel method for making 'designer catalysts' for fuel cell electrodes
- Optimising catalysts in hydrogen fuel cells
- Developing more efficient catalysts for direct alcohol fuel cells
- Investigating different membranes for use in alkaline direct alcohol fuel cells.

Among others, the team experimented with different types of alcohol fuels (including ethylene glycol and glycerol) instead of the methanol that is commonly used in these cells. They also tested various catalytic inks used in hydrogen fuel cells and developed three ammonium-doped membranes.

"We also modified and improved a test cell design from Helsinki University of Technology. It now has a larger active surface area, can be upgraded from a single cell to a stack, and allows for measuring and controlling temperature," says Rohwer.

He believes that there is still much work to be done, "We have had promising results so far, especially with direct alcohol fuel cells, where we are looking to control the size of catalyst nano-particles and include carbon nanotubes as catalyst support, as well as with developing and optimising the ammonium-doped membranes that should be investigated further in alkaline direct alcohol fuel cells."

The multi-faceted nature of fuel cell research is also ideally suited for interdisciplinary collaboration. Rohwer explains: "Fuel cell science can be viewed as a hub science. It combines various disciplines, e.g. electrochemistry, polymer and membrane science, catalysis, surface science, nano-particle physics, mechanical design and engineering, fluid dynamics, electronic control systems and even computer modelling. As such, it is a complex field, but this also makes it suited to interdisciplinary collaboration, both within the CSIR and with external partners."
– *Petro Lowies*

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Left: Dr Mark Rohwer, here with two halves of a fuel cell, believes that the interdisciplinary nature of fuel cell research makes it ideal for collaboration

The CSIR's fuel cell research team is focusing on developing, evaluating and improving the key electrochemical components of hydrogen fuel cells and, lately, alcohol-based fuel cells. The team comprises (from left) Thembi Masombuka, Dr Mmalewane Modibedi, Dr Bolade Agboola, Dr Haitao Zheng, Dr Mkhulu Mathe, Dr Mark Rohwer, Dr Luo Hongzee, Tumaini Mkwizu, Tendamudzimu Ramulifho, Senzile Guliwe and Dr Shakes Nonjola.

ALTERNATIVE ENERGY RESEARCH

# WIND ATLAS TO ESTABLISH VIABLE LOCATIONS FOR WIND FARMS

Steve Szewczuk, CSIR project leader of the wind atlas initiative, with photos of wind generators and a wire model of a traditional water pumping windmill

## RENEWABLE ENERGY GENERATION IS HIGH ON THE AGENDA IN THE FACE OF DECLINING FOSSIL FUEL RESOURCES, THE IMPACT OF BURNING THESE ON THE CLIMATE AND GROWING EFFORTS OF COUNTRIES TO DECREASE THEIR CARBON FOOTPRINTS.

DENMARK AND SOUTH AFRICA have entered into an agreement for capacity development and research cooperation through the development of wind resource mapping for the Western Cape and areas of the Northern and Eastern Cape provinces.

Denmark is the world's top harvester of wind energy at present, obtaining 20% of its electricity from wind. In its Energy Grand Challenge, the Department of Science and Technology anticipates that by 2018 South Africa will have 5% of the energy used coming from wind and other sources of renewable energy.

The cooperation agreement encompasses research that will obtain data on wind speeds and frequency along the South African coastal and escarpment regions, in aid of updating South Africa's current wind resources map. Partners in the project include the wind energy group of the Danish Technical University (Risø DTU), the South African National Energy Research Institute (SANERI), the CSIR, the University of Cape Town (UCT) and the South African Weather Service (SAWS).

Risø DTU has been active in wind energy assessments for decades and has developed the WAsP software, a micro-scale modelling tool for wind farm energy calculations, and the KAMM/WAsP method, for the calculation of wind resources over large areas.

"The Danish will provide South Africa with expertise to do wind measurement and to develop a Numerical Wind Atlas for South Africa that can lead to viable, 'bankable' wind farm projects," explains Steve Szewczuk, CSIR project leader of this initiative.

The CSIR will undertake wind measurements in the three provinces and capture data at its Stellenbosch regional office, while researchers in Pretoria will do micro-scale modelling of the data to Danish standards and look at possible applications.

"Previous wind measurements done by the CSIR were taken using masts of about 10 m high, which are not accurate enough to predict wind activity for wind turbines. We'll be responsible for, among other tasks, designing the wind measuring system, site selection and overseeing the erection of 10 masts at the average height of wind turbines, about 60 m high," explains the CSIR's Eric Prinsloo.

A database system will be set up in Stellenbosch on a server and online web display software will give data access to all the relevant partners.

Wind measurements over a period of at least one year are necessary for a feasibility study. The measurements will continue over the lifespan of the three-year project. Multi-year data are required to establish the variable wind patterns on an annual basis, as wind activity varies from year to year.

The planned sites for the masts are coastal regions and the escarpment in the three provinces. "We'll erect the first masts in the Western Cape where we can monitor the performance of equipment on a regular basis," comments Prinsloo.

"As soon as useful amounts of data become available, we'll start with micro-scale modelling. This will cover wind speed and direction

Eric Prinsloo and Eugene Mabille with an anemometer (front) and a wind vane

# ALTERNATIVE ENERGY RESEARCH

distributions, terrain elevation, terrain roughness, sheltering obstacles, WAsP modelling, micro-scale results versus measured data, the creation of the atlas for selected measurement sites in South Africa, and WAsP training. One of the aims of the collaborative project is to establish the CSIR as a national resource centre for wind monitoring and micro-scale modelling," says Szewczuk.

UCT will be involved in meso-scale modelling of the data, while the SAWS will look at extreme wind conditions. All aspects of the research are dependent on the data obtained through the measurements.

"Wind energy has a short development lead time and can strengthen distribution networks. Potential applications of wind energy in South Africa include large grid-connected wind farms; small off-grid systems in rural areas; and the provision of energy sources close to the point of use (distributed energy)," explains Szewczuk. The CSIR will also develop a micro-scale resource map for 30-50% of the modelled areas in the three provinces, including its integration as a geographic information system layer.

"South Africa is still way off the mark regarding the national target of 10 000 gigawatt hours (GWh) of renewable energy per year by 2013," he says. "The Renewable Energy Feed-in Tariff announced in March 2009 by the National Energy Regulator of South Africa will aid wind energy initiatives in the country. Renewable energy is relatively expensive to generate; the new tariff allows a reasonable profit margin to be added to the cost of energy generation, which makes it an attractive option for developers to invest. This will also boost the process of reaching the 10 000 GWh target," he says.

The wind atlas will aid bankers, developers and prospective wind farmers in deciding on the location of viable wind generation projects, saving the risk of investment in unproductive areas. "The wind atlas will be made available in the public domain for all interested parties to have access to, and will accelerate investment in wind energy," concludes Szewczuk. – *Hilda van Rooyen*

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Wind generators in Denmark, the world's top harvester of wind energy

# SEARCH FOR RENEWABLE ENERGY **HEATS UP**

Thomas Roos

THE CSIR IS MAKING INROADS IN ITS BID TO FURTHER RESEARCH ON RENEWABLE ENERGY. A RECENTLY PROCURED 100 kW GAS TURBINE HAS BEEN DELIVERED AT THE CSIR, AND COMMISSIONING WILL BEGIN SHORTLY.

THOMAS ROOS, a principal research engineer at the CSIR, says the newly acquired 100 kW gas turbine will be the prime mover of an envisaged solar power station on the CSIR premises in Pretoria. The objective, he says, is to demonstrate renewable energy provision at medium scale, in this case from concentrated solar radiation. "When people think about renewable energy, they often think of wind turbines and photovoltaic cells," he says. "Generally speaking, they do not think of concentrated solar technologies, largely because these have not been used in South Africa."

He says these systems use heat from the sun, suitably concentrated, in contrast to photovoltaics that uses light from the sun.

"This heat is normally used in a conventional heat engine such as steam turbine or a gas turbine," says Roos, adding, "It has the advantage that when the sun does not shine, power can still be generated using fossil fuel or heat from storage."

He adds that it is cheaper to store heat than to store electricity in batteries. How it works, he continues, is that the field of mirror collectors is oversized to produce more heat than instantaneously required by the turbine. "Excess heat is sent to storage, which can be drawn out and used to drive the turbine during periods of cloud passage or during night time," says Roos.

He says interest has increased in concentrated solar technology since the National Energy Regulator of South Africa published the renewable energy feed-in tariff rates. An independent power producer using renewable energy to generate electricity will be paid 90 cents/kWh if generated using landfill gas, R1.25/kWh if generated from wind and R2.10/kWh if generated using concentrated solar power with six hours of storage.

To concentrate the solar rays, a new lightweight 1.25 $m^2$ focusing heliostat mirror panel has been designed and manufactured. The second generation heliostat panel weighs 14 kg instead of the first generation 20 kg for a panel of the same size.

Impact on mirror panel of 45 mm diameter hailstone fired at 78 m/s

Mechanical vibration testing of mirror panel

The CSIR target-aligned heliostat, mentioned in a previous edition of *ScienceScope* (Volume 2 Number 3 December 2007), uses 19 such panels. Roos and his team designed a 25 $m^2$ target-aligned heliostat using low-cost components and simple systems. This was touted as the first part of a hybrid solar/fossil fuel gas turbine distributed power research programme with the goal of supplying appropriate technology for electricity supply to off-grid South African and African communities.

According to Roos, the second generation heliostat mirror panel has successfully undergone 1 million mechanical cycles (representing storm wind conditions) as well as exceeding by far the hail storm impact test requirement of both the South African solar water heat specifications and a United States specification for large area heliostats.

"Our next step will be manufacturing 19 such panels and retrofitting these onto the heliostat," he says. – Mzimasi Gcukumana

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# INTEGRATED MODELS TO AID SMALL TOWN MUNICIPAL SERVICE DELIVERY

BY DR LOUIS WALDECK

PROVIDING MUNICIPAL SERVICES SUCH AS ELECTRICITY AND WASTE WATER TREATMENT IS A MAJOR CHALLENGE FOR SMALL TOWNS THAT OFTEN LACK THE INSTITUTIONAL CAPACITY TO MANAGE AND MAINTAIN THE NECESSARY INFRASTRUCTURE. HIGH LEVELS OF POVERTY IN THESE TOWNS ALSO PRESENT COST-RECOVERY CHALLENGES.

AIMING AT ASSISTING RURAL MUNICIPALITIES, THE CSIR HAS BEEN INVESTIGATING ALTERNATE MODELS OF SUSTAINABLE AND INTEGRATED MUNICIPAL SERVICE DELIVERY THAT COULD BE OPERATED AS VIABLE BUSINESS CONCERN, INDEPENDENT OF THE MUNICIPALITY'S ABILITY TO RECOVER COSTS, WHILE NOT DEPRIVING THE MUNICIPALITY OF A KEY SOURCE OF INCOME.

CSIR RESEARCHERS set themselves a challenge of developing alternative solutions to municipal service delivery problems in particular to mitigate and adapt to climate change while at the same time contributing to food, energy and water security and creating local economic opportunity.

With the recent completion of a comprehensive feasibility study, the CSIR came one step closer to the establishment of an integrated research platform on its campus consisting of a number of outdoor laboratories and associated research programmes, collectively known as IRIP, which will be used to develop alternative solutions to municipal service delivery problems.

The project subscribes to an industrial ecology approach, which is the sustainable combination of the environment, economy and technology in such a way that the waste from one process becomes the input of another process. In this context, the term 'industrial' is a general reference to how humans consume resources to sustain life and produce goods and services. The processes being considered include municipal service delivery processes such as the provision of energy, clean water and the collection and treatment of waste water and solid waste. In its preparatory work, the CSIR has considered the application of an industrial ecology approach at two scales – a small town of about 5 000 households and a large building or building complex.

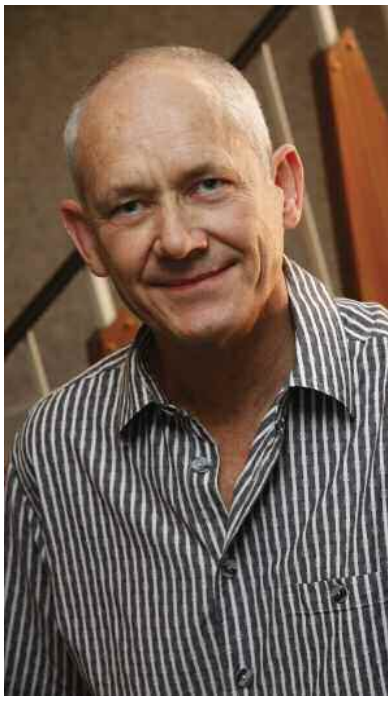
At the scale of a small town, a typical application built in close proximity to the existing waste water treatment works would comprise the following factors: A heliostat array concentrates sunlight on a solar collector and the heated air drives a gas turbine to generate electricity. The heliostat field is designed to capture more energy than the turbine requires and the excess heat is stored so that electricity can be generated at night (see article on page 19).

Sludge from the primary waste water treatment plant is pumped into an anaerobic digester where it is digested by bacteria to produce carbon neutral biogas to generate additional electricity. The biogas yield can be improved by the addition of animal slurry and other forms of organic solid waste separated at source. Using the carbon dioxide from the combustion process, nutrients from the waste water and sunlight, micro-algae are grown and harvested to produce carbon neutral biodiesel to also fuel the gas turbine. Economic opportunity and food security are promoted by using the various waste streams (water, heat and nutrients) to produce food through intensive farming activities including aquaculture and hydroponics. Vast amounts of waste heat are available for maintaining such operations within an optimum temperature range, as well as for producing distilled (bottled) water and ice, providing cold storage based on absorption chillers and promoting water security by desalinating brackish groundwater.

Recognising that small municipalities can hardly afford to lose any of the income derived from selling water and electricity, and that few might have the expertise required to build and operate the relatively sophisticated plant described above, the question is whether the private sector would be interested in building and operating the plant on behalf of the municipality. The feasibility study investigated this by simulating the annual income statement of a fictitious company by taking account of income generated from the sale of electricity, carbon trading and food produced by intensive farming, the cost of labour and capital, operation, maintenance, security, insurance, etc.

Thanks largely to the feed-in tariff of R2,10/kWh recently announced by NERSA for solar energy, the results of the simulation confirmed that such an operation could be financially viable from income sources limited to selling electricity, surplus biodiesel, carbon trading, aquaculture (based on Tilapia, a type of fish) and bottled water. With considerable scope for optimising the design, achieving better economies of scale and augmenting income by considering other means of food production such as hydroponics, it is likely that the operation could be made even more attractive.

At the scale of a large building or building complex, a different configuration of more compact components will be required based on membrane bioreactor technology for self-contained waste water treatment and parabolic trough or linear fresnel collectors to capture heat for space heating and cooling purposes. An advanced construction technology laboratory is envisaged for developing material, production and assembly technologies for the construction and operation of buildings with improved resource efficiency through their entire lifecycle.



**Dr Louis Waldeck, project leader of the CSIR's integrated research platform aimed at developing alternative solutions to municipal service delivery problems**

The four other laboratories to be established at the CSIR will be dedicated to investigating and refining anaerobic digestion, aquaculture (including algal culture), concentrating solar power and membrane bioreactor-based waste water treatment.

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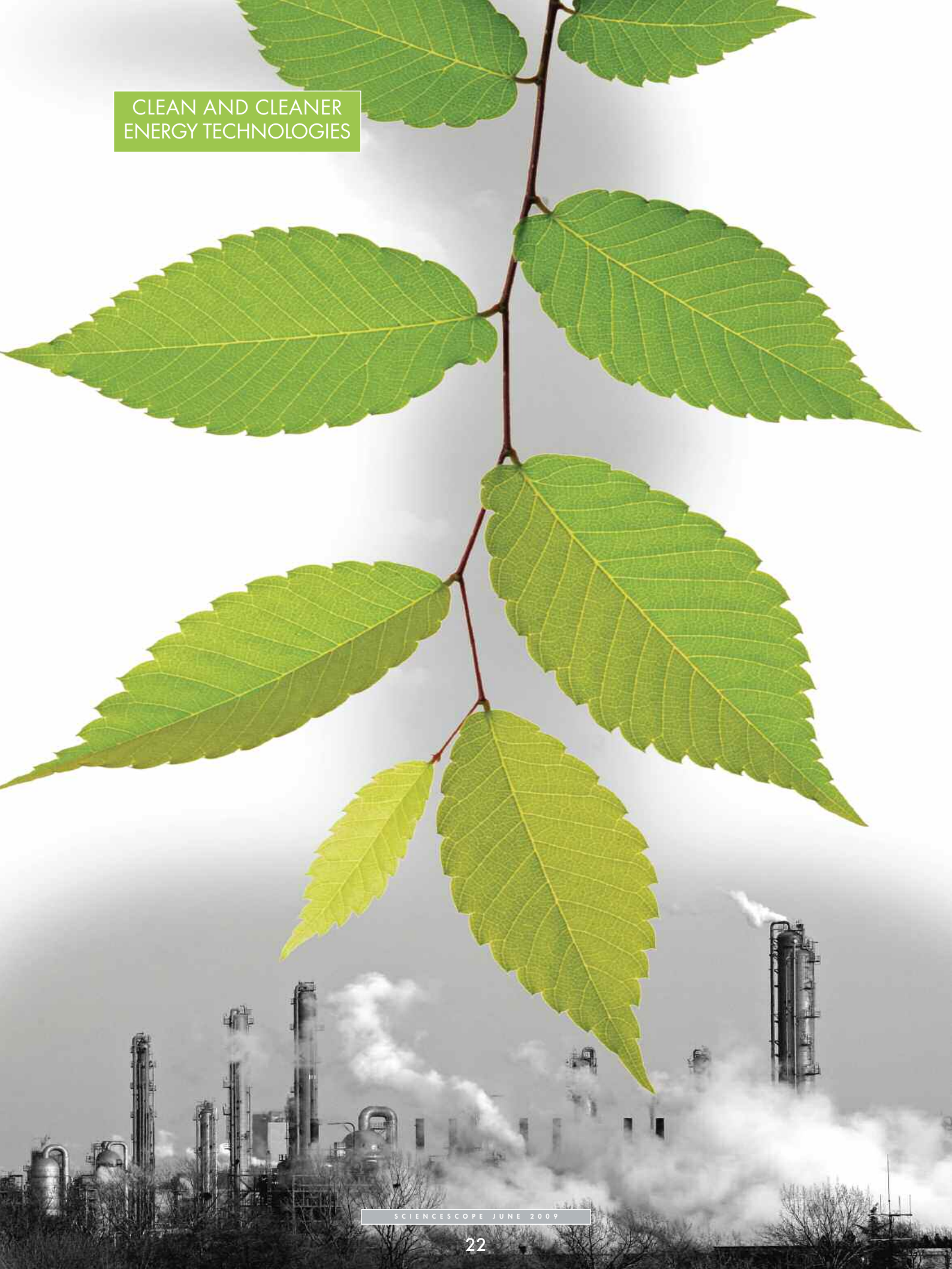
# CLEAN AND CLEANER ENERGY TECHNOLOGIES



BY DR ALAN BRENT

# EXPLORING A CLEAN DEVELOPMENT MECHANISM METHODOLOGY FOR BIODIESEL

FUNDING AND BACKING OF THE CLEAN DEVELOPMENT MECHANISM (CDM) OF THE KYOTO PROTOCOL COULD HELP THE BIOFUEL INDUSTRY TO REACH MATURITY AND FORM A SUSTAINABLE PART OF THE WORLD ENERGY LANDSCAPE.

However, at present, biofuel production systems are not eligible to receive financial support through the CDM due to the phenomenon of double counting, whereby more than one entity can claim credits for the same greenhouse gas emissions. The CSIR, in collaboration with the Graduate School of Technology Management of the University of Pretoria, undertook an investigation into biodiesel production and how the CDM could enable such production.

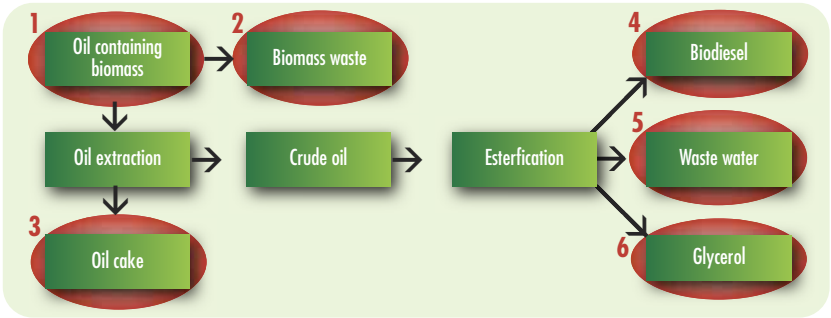
The study identified six typical embedded CDM projects in the larger biodiesel production process. The study further investigated the CDM regulatory environment for the biodiesel value chain and aimed to propose a consolidated methodological approach for CDM biodiesel projects.

## EMBEDDED CDM PROJECTS

The study proposes the combination of all six possible embedded projects in a single biodiesel framework. These are:

- Growing the oil containing biomass as part of an afforestation/reforestation project
- Utilising the energy content from forest waste and primary biomass separation
- Utilising the energy content from mechanically processed oil cake
- Claiming emission reductions from the primary biodiesel product
- Processing the waste water fraction to prevent methane from escaping to the atmosphere
- Utilising the energy content from glycerol produced.

Figure 1: Biodiesel process flow diagram and possible CDM projects embedded in biodiesel production




**Various incentives exist for green house gas (GHG) emission reduction as means to address climate change concerns. The United Nations Framework Convention on Climate Change drives one such incentive, the Clean Development Mechanism, whereby industrialised countries, through the companies within these countries, could earn GHG emission reduction credits.**

**Developing countries stand to benefit from participation in the CDM by acquiring technology, foreign capital and by accelerated growth. The CDM aims to mitigate GHG emissions by offering a trading platform for proven emission reductions in developing countries through technological interventions by developed countries. Emission reductions are quantified in so called Certified Emission Reduction (CER) units that are tradable on the open market at a price driven by supply and demand. The trends in the carbon market are reported by the World Bank.**

**The CDM process is governed by the executive board of the UNFCCC, while the trading of the CERs is facilitated by the Carbon Finance Unit of the World Bank.**

Approximately four methodologies will then be used for a single, but comprehensive, biodiesel CDM project. Applying two CDM methodologies in a single CDM project is quite common, but applying four methodologies is unusual.

A problem that can very easily arise with applying so many strategies is the possible non-compatibility of project boundaries. For example, the steps used to produce biodiesel in the initial stages could also be considered within the boundaries of agricultural production. In such a situation the multiple methodologies will either include the same section in the project boundary or not at all. This will necessitate the further development of approved methodologies, which is a tedious and time-consuming process.

Historically, the executive board of the United Nations Framework Convention on Climate Change (UNFCCC) developed approved consolidated methodologies for sectors where various, but broadly similar, CDM projects are developed. Various approved methodologies can be combined to produce the approved consolidated methodologies for biodiesel.

The consolidation must be broad enough to include the whole value chain as an 'off the shelf' biodiesel methodology. This broad consolidation will alleviate possible conflicting project boundaries.

Figure 2 illustrates a possible framework that could be followed to consolidate the various applicable methodologies and establish the approved consolidated methodologies for biodiesel.

## TAKING CARE OF DOUBLE COUNTING

An alternative approach to prevent double counting has been proposed that will be much simpler in implementation and auditing than the current proposed UNFCCC system. All CDM projects have to be registered before such projects can claim carbon credits. The registered projects all form part of open source literature available from the UNFCCC web site.

Moreover, the site also provides information on the progress of projects through the registration process. With all this information freely available, little research is necessary to pinpoint whether a CDM methodology exists and which projects employ that methodology.

It is then simply required to investigate if any project upstream in the value chain, with respect to a prospective CDM project, exists that already claims CERs for that specific emission reduction. If no such registered project, or project in the approval phase, exists, then the prospective new CDM project is allowed in principle to claim that emission reduction without the possibility of double counting.

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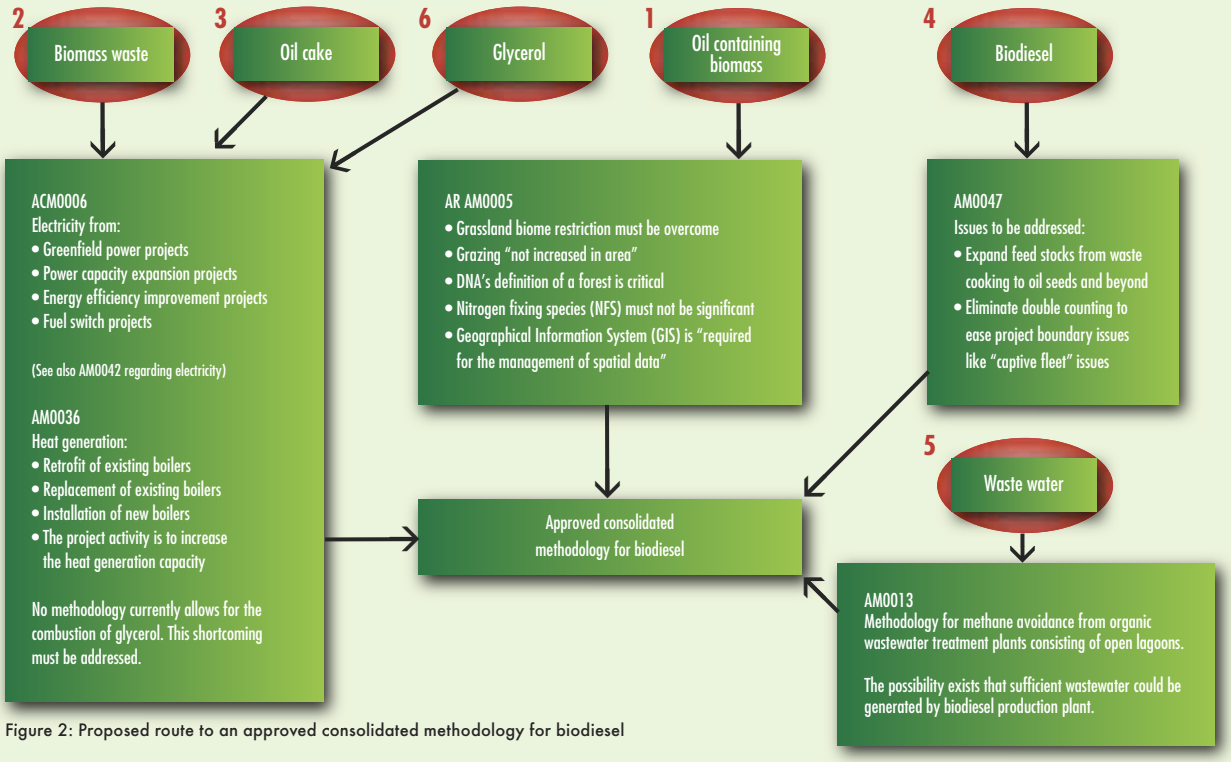


Figure 2: Proposed route to an approved consolidated methodology for biodiesel

# ENSURING SUSTAINABLE **BIOFUEL FOR THE FUTURE**

BY LORREN HAYWOOD

BY ENSURING the correct planning and engagement with stakeholders, biofuel can contribute to a sustainable supply of fuel in the future. The CSIR is investigating sustainability assessment framework methodologies.

The sustainability of biofuel production is becoming a key concern and is being considered as a requirement for market access. This is due to potential negative elements such as loss of biodiversity, changing land use patterns, social economic impacts and green house gas emissions.

For example, in 2008 the United Nation's two leading food agencies both issued warnings that the demand for biofuel is in danger of leaving the poor hungry.

This has emphasised the need for setting standards and establishing certification systems. A process that promotes vigorous planning for sustainability for the life span of the biofuel plan or project could also help strengthen trade agreements.

The CSIR is currently involved in a European Union-funded project known as Re-Impact, which has started to test planning for sustainability assessment framework methodologies in India. The CSIR is also looking for opportunities to test this in South Africa.

Sustainability assessment is an emerging science. The current principles have developed through a long history of environmental impact assessment and strategic environmental assessment in the environmental sector. The framework presented will improve and mature over time as its application is tested on actually planned biofuel production projects.

Sustainability assessment is expressly to prepare and design a development policy, plan, programme or project with sustainability as the desired outcome, rather than merely to prevent or mitigate potential environmental impacts. The approach is inherently positive as well as prospective. It is about considering the relationships between social, ecological and economic factors. Sustainability assessment must be focused on these interrelationships and their character, resilience to change and adaptability.

Since sustainability is an integrative concept, it is important to design sustainability assessments as an essentially integrative process that can act as a framework for better decision making at all levels of development planning that may have lasting effects. These relationships need to be characterised and explored at the earliest stages of a sustainability assessment process to inform the accurate formulation of appropriate sustainability criteria.

If a common vision for biofuel development cannot be created among the stakeholders and there is no consensus on the vision, then this is where the sustainability assessment process stops.

The specific project for biofuel development may thus not be appropriate for the specific area or national context, and the desired state of sustainability will not be achieved.

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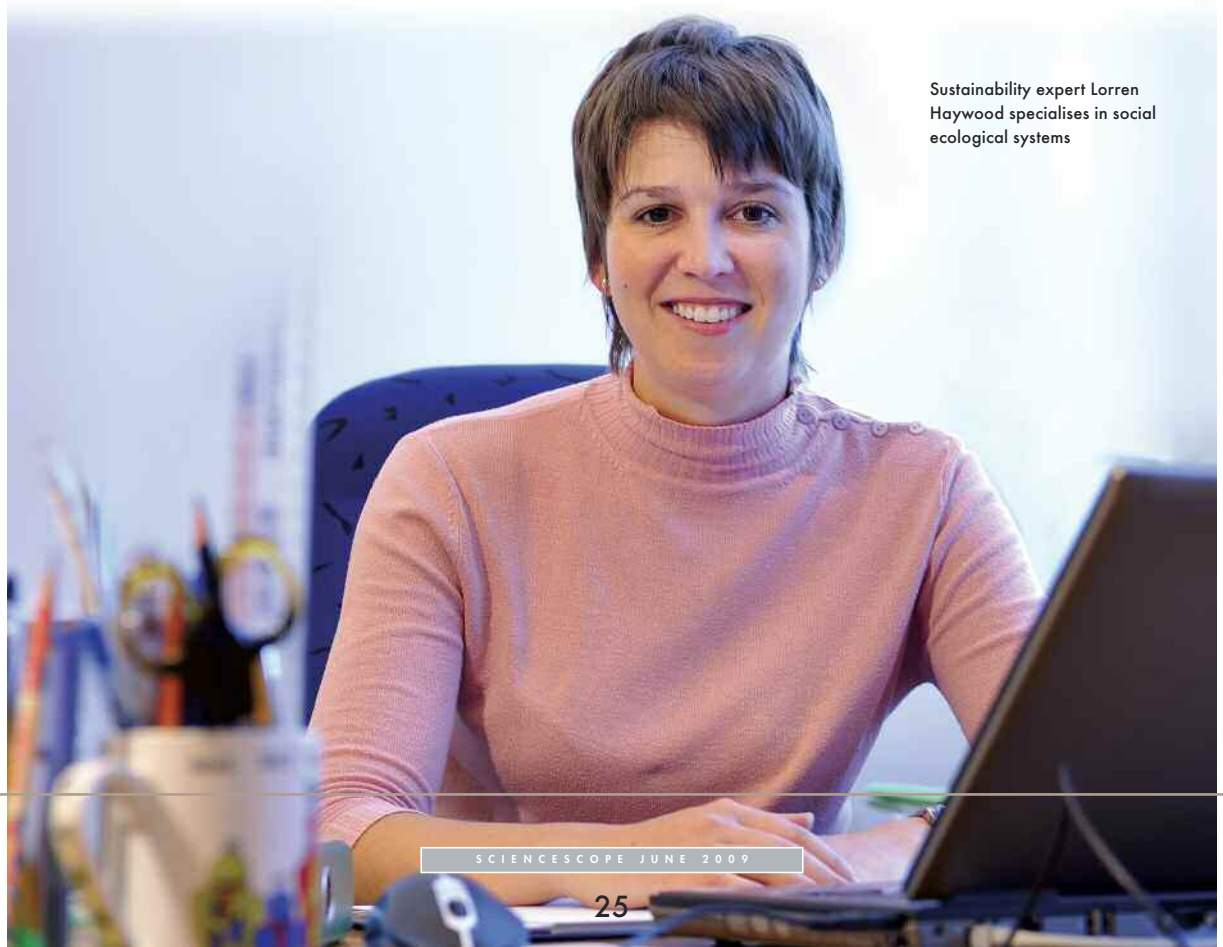

Sustainability expert Lorren Haywood specialises in social ecological systems

# SIZE NO LONGER MATTERS IN BIODIESEL MANUFACTURING

FASTER REACTION RATES, higher productivity, smaller plant footprint, improved conversions and selectivities, and lower raw material costs are some of the benefits of producing biodiesel in microreactor systems.

Researchers in the CSIR's chemical technologies group led by Subash Buddoo, have been developing expertise in the microreactor technology and have been investigating the production of biodiesel using various sources of vegetable oils such as soya, sunflower, canola, Jatropha, palm and peanut.

"These reactions were successfully scaled up to pilot plant scale using conventional, batch, stirred tank, jacketed reactors and biodiesel standards were produced for the SABS (~100L of each oil)," he says.

Recently an investigation was launched into the production of biodiesel using commercially available microreactors.

"The laboratory investigation and optimisation phase of the project has been completed and we are now in a position to conduct a comparative study of the conventional reactor system versus microreactor systems. The next phase includes construction of a pilot demonstration unit and commercialisation of the process," says Buddoo. – *Asha Speckman*

Jatropha

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# LIFE CYCLE INVENTORY SHEDS LIGHT ON BIOFUEL IMPLICATIONS

BY DR ALAN BRENT

THE SOUTH AFRICAN GOVERNMENT HOPES TO ACHIEVE A 2% PENETRATION LEVEL OF BIOFUELS IN THE NATIONAL LIQUID FUEL SUPPLY BY 2013. HOWEVER, LIFE CYCLE ASSESSMENT (LCA) STUDIES HAVE NOT YET BEEN CONDUCTED TO UNDERSTAND THE ENVIRONMENTAL IMPLICATIONS OF THE SOUTH AFRICAN BIOFUELS INDUSTRIAL STRATEGY.

Field of canola flowers

Life cycle assessment studies, also known as cradle-to-grave analysis, address the environmental aspects and potential environmental impacts throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal. The procedures of life cycle assessment are part of the International Standards Organisation's environmental management standards.

CSIR scientists, in collaboration with the Graduate School of Technology Management at the University of Pretoria and the Department of Chemical Engineering at the University of Cape Town, investigated commercial-scale seed extraction biodiesel production (SEBP) by taking 19 500 ton of 100% biodiesel produced per year as a unit of product. This is equal to a 2 500 kg/hr production facility, which is deemed an optimum biodiesel plant size for commercial purposes in the South African context.

The study came to the following conclusions:

- It is clear that the inputs and outputs of the farming unit process are sensitive to the type of crop and region of produce. Water, for example, is a highly variable parameter, which emphasises the importance of rainfall and irrigation to the overall burden of the biodiesel system on water resources.
- The oil and meal/cake content of the seed proves to be the most important parameter that influences the upstream unit processes.
- The uncertainties associated with logistics in the value chain have major implications. For example, should the distances from the farming activities to the different processing units increase by a factor or two, then the energy balance may be negative. Indications are that average distances should not exceed 300 km in the product value chain.
- With respect to air emissions, the life cycle inventory compares reasonably to other studies. However, the emissions of $N_2O$ (nitrous oxide) are very high with a contribution to global warming potential of at least five times that of $CO_2$. This highlights the necessity to also refine the accuracy of the conventional flows in the life cycle inventory for the South African context.

The researchers make a number of recommendations to refine LCAs for South Africa and thereby provide for better decision and policy making pertaining to the biofuels industrial strategy.

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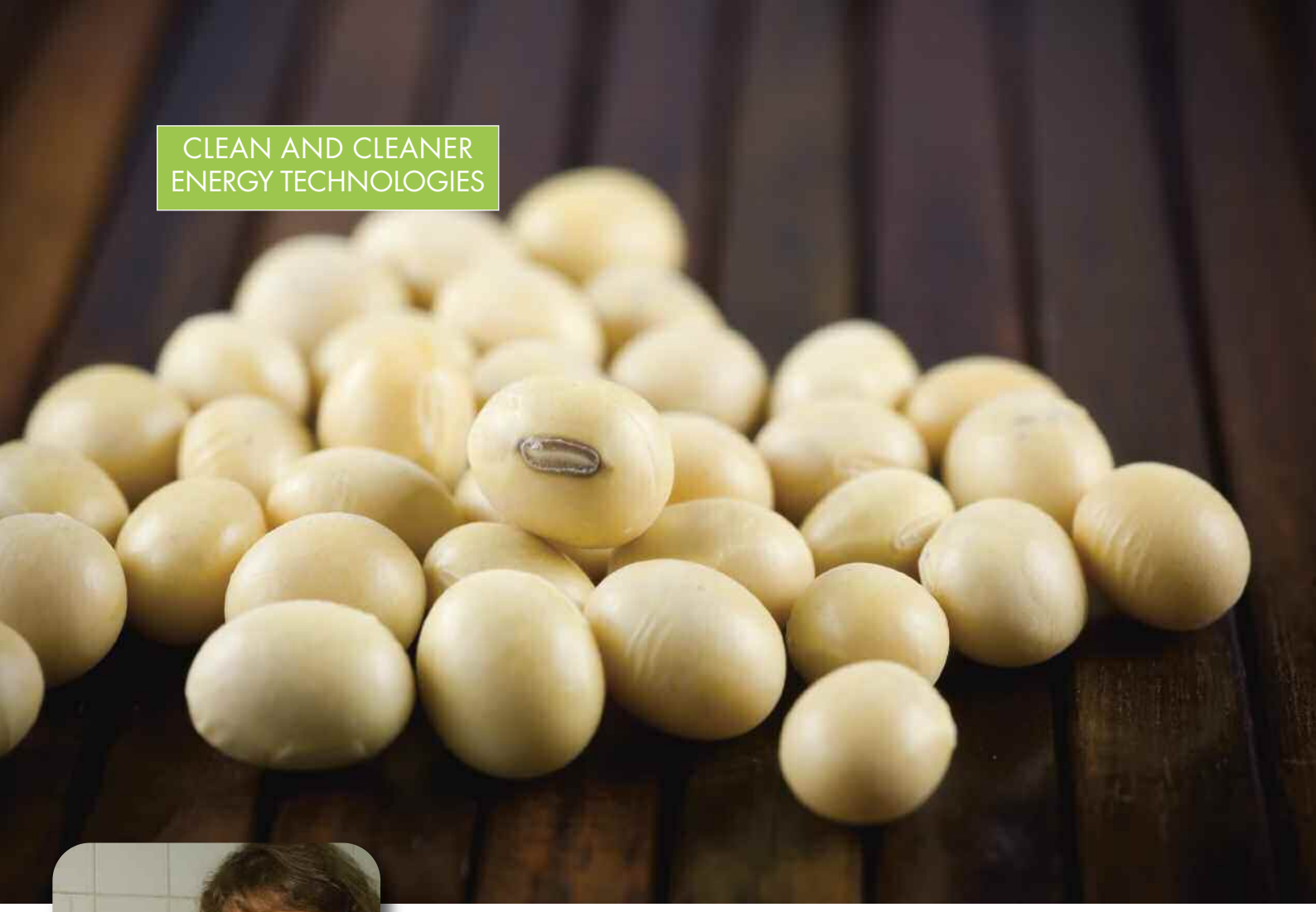


To assess current processing properties of existing South African oilseeds cultivars, DST also invested in supplying equipment. Dr Corinda Erasmus is pictured here with a DeSmet Rosedowns for pressing oilseeds for the evaluation of oil yield and cake quality studies.

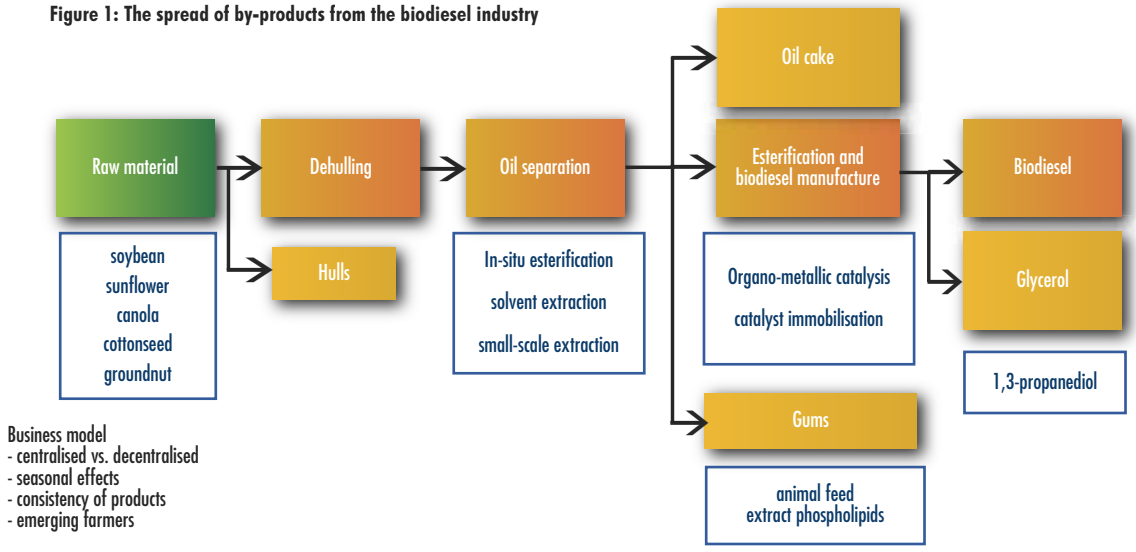
# ADDING VALUE TO BIODIESEL BY-PRODUCTS

TO ACHIEVE SUSTAINABLE BIODIESEL PRODUCTION IN THE FUTURE, EVERY COMPONENT OF THE VALUE CHAIN WILL HAVE TO BE INVESTIGATED. ONE SUCH A FOCUS IS A CSIR INVESTIGATION INTO ADDING VALUE TO BIODIESEL BY-PRODUCTS.

THREE YEARS AGO a local consortium embarked on a project to seek as many options for potential applications of the nearly one million ton of oilcake that South Africa currently imports per annum. As the project matured, researchers discovered that there is more to biodiesel by-products than meets the eye.

In 2005, the Department of Science and Technology (DST) approved and committed to funding a plan submitted by a DST-governed body guiding the role local science plays in the emerging biodiesel industry, which will have the potential to replace and exceed these oilcake imports.

**Figure 1: The spread of by-products from the biodiesel industry**




The CSIR was selected to lead the project and in collaboration with the Agricultural Research Council (ARC) began evaluating soya bean and sunflower oilcakes as currently available from the biodiesel processing industry for its potential use. The ARC focused on using the oilcakes in feed and feed supplements for cattle and sheep as well as chicken and pigs, while the CSIR focused on industrial applications for these products including specialised products such as manufactured fish feeds.

The study found that although South Africa imports almost one million ton of oilcake per annum (2009 predictions) into the country, the market for oilcake is virtually unlimited as the amount of oilcakes that can be used in dairy cattle feeds alone can almost triple the market size. In the case of pigs and poultry, the use of oilcake depends heavily on the fibre content, but prediction models for optimised usage of a specific oilcake have been studied and will be available for use by the feed industry. Specific focus was given to the Apparent Metabolisable Energy models, to develop a laboratory model for chicken feeds, eliminating the need for expensive trials in animals when the potential performance of an oilcake from a biodiesel manufacturer is to be evaluated.

During biodiesel production, due to cost and processing requirements, oilseeds are often not dehulled, resulting in oil cakes with lower protein levels and higher fibre levels. For most animal feed applications, it is desirable to have low fibre content and high protein content thus increasing the sales value of the cake.

The CSIR focused on value addition to oilcakes by using various processing techniques


Fish feed prototypes with soya bean oilcake base. Left: Feed for Dusky Cob. Right: Feed for Tilapia.

as well as genetic transformation feasibility studies. One specific focal area and potential future market is the use of oilcakes as ingredients in novel feeds for finfish. Food security has in recent years become an issue in many countries, exacerbating the need to develop new sources of nutritious foods. Fish can provide both high class protein and essential fatty acids for humans.

However, there is a global depletion of wild fish resources, necessitating the development of fish culture as an increasingly important sustainable alternative. The economics of commercial fish farming require low cost, good quality feeds. Bioscientists developed two prototype feeds that can be produced on pilot scale and both feeds are using soya bean oilcake as the main ingredient. Feeding studies were conducted on the Dusky and Silver Cob (*Argyrosomus spp*), White Stumpnose (*Rhabdosargus globiceps*) and Mozambique Tilapia (*Oreochromis mossambiccus*) species. A technology package describing the processing systems for both feeds is currently being written. No similar plant-based feed exists on the market except for expensive products for ornamental fish, which are unsuitable in fish farming due to cost.

The research has not only provided cost effective alternatives for the use of oilcake but has also resulted in establishment of technology expertise for laboratory modification of soy and sunflower.

For additional information on current South African animal feeds markets and the demands for protein, the Protein Research Foundation web site can be visited on www.proteinresearch.net.

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# CLEAN COAL TECHNOLOGY:
# GASIFICATION OF SOUTH AFRICAN COALS

THE GASIFICATION OF COAL IS ONLY ONE TYPE OF CLEAN COAL TECHNOLOGY BEING DEVELOPED FOR POWER GENERATION AS A POTENTIAL ANSWER TO REDUCE ITS ROLE IN GLOBAL WARMING. BUT HOW SUITABLE IS THIS PROCESS FOR SOUTH AFRICA'S COAL RESOURCES? THE CSIR INVESTIGATES.

BASED ON SCIENTIFIC ANALYSIS it is generally accepted that a link exists between climate change and the use of fossil fuels such as coal. The development of clean coal technologies (CCTs) has therefore received increased attention worldwide.

"CCTs are defined as 'technologies designed to enhance both the efficiency and the environmental acceptability of coal extraction, preparation and use'," says CSIR researcher André Engelbrecht. He forms part of the CSIR research team investigating CCTs and researching their optimisation for South African conditions.

He explains: "74.1% of South Africa's primary energy supply is derived from coal. The rest comes from imported oil (12%), renewable energy (7.4%), nuclear (4.2%) and gas (2.3%) – all of which are either expected to decrease or experience limited growth because of cost constraints, decreasing reserves and safety concerns. Our abundant and cheap coal reserves will, therefore, almost certainly remain our most important energy resource for the foreseeable future."

As electricity demand in South Africa is increasing at a rate of 1000 MW per year, this statement cannot be easily refuted, even while there is increasing pressure to adopt non-fossil fuel electricity generating technologies. The challenge in the future is to enhance both the efficiency and environmental acceptability of coal use by adopting CCTs.

## CHOOSING THE RIGHT CCT

The five most prominent CCTs currently being developed for power generation are: Integrated gasification combined cycle technology (IGCC), ultra supercritical pulverised coal combustion (SCPCC), oxy-coal combustion, circulating fluidised bed combustion (CFBC) and post combustion capture.

According to Engelbrecht, the CSIR has identified IGCC as a potential clean coal technology that could be applied in South Africa to increase efficiency and achieve near zero emissions of greenhouse gases, which is likely to be a requirement for electricity producers towards the middle of the 21st century.

But those are not the only reasons why the CSIR is concentrating its research efforts on this particular CCT. Another reason is because IGCC holds the advantage of reduced water consumption and the potential for co-production of liquid and gaseous fuels and chemicals.

## INCREASED EFFICIENCY WITH IGCC

During a conventional coal power generation cycle all the energy in the coal is used to generate steam, which is then exhausted through a steam turbine to generate electricity. The exhaust steam has to be recondensed and recycled to the boiler. Due to large energy losses during condensation, the overall efficiency (coal to electrical power) of an Eskom conventional power station is between 33% and 38%.

"With an IGCC power generation cycle the overall efficiency can be raised to between 45% and 55% with lower emissions of pollutants," says Engelbrecht. He explains how: "In an IGCC power station a coal gasifier is incorporated. During gasification coal is reacted with oxygen/air and steam to produce a combustible gas (syngas). This gas stream has a low volume compared to flue gas resulting from conventional coal combustion, and therefore gas clean-up systems can be reduced in size. The cleaned gas is combusted in a gas turbine that produces electrical power while heat is recovered from the turbine exhaust gas by means of a conventional steam turbine cycle."

## INCORPORATING A COAL GASIFIER THAT CAN HANDLE FINE COAL

An IGCC power generation cycle preferably needs a coal gasifier that works with fine coal. There are several different fine coal gasification processes that can be used. One of these is fluidised bed gasification, the process the CSIR chose as the one to incorporate into future IGCC plants. Much of the current research being done on CCTs within the CSIR now focuses on this process.

Engelbrecht explains why: "Coal gasification is not new to South Africa since Sasol operates 72 Lurgi gasifiers at its synfuel plants in Secunda. The Lurgi gasifier, however, is more suited to synthetic fuel and chemicals production since it cannot utilise fine coal (less than 12 mm in diameter). This process also produces by-products, which include tars and oils."

## BUT CAN THEY HANDLE SOUTH AFRICAN COALS?

To fit the choice of a fluidised bed gasification process into IGCC plants, however, a better understanding of the gasification characteristics of South African coal is important. Therefore, the CSIR, in collaboration with the South African National Energy Research Institute, characterised and tested four different types of South African coals – all of which have been identified as being possible fuels for power stations that would operate for

three or four decades, towards the middle of this century. These coals are currently used as fuel for the Lethabo (New Vaal coal from Vereeniging), Matla (Kriel), Matimba (Grootegeluk coal from Ellisras) and Duvha (Witbank) power stations and are typical of South African power station feed coal.

"These are all low-grade coals with a high ash content of between 32.5% and 40.4%. Generally, high-ash coals have high densities and low porosities that decrease the reactivity of the coal. This means that, under gasification conditions, the carbon conversion of the coal is lower than during combustion."

The team's research found that fluidised bed gasifiers are able to utilise these high-ash South African coals and are a potential candidate for being incorporated into IGCC power stations. Due to the relatively low reactivity of these coals, a secondary combustion stage may be required after the fluidised bed gasifier to convert the residual carbon into ash.

According to Engelbrecht, this is something the CSIR's team is now further researching. "We are specifically looking at ways to improve the electricity output potential of IGGC power stations using high-ash coals. As we have only proved the technology in a small scale pilot plant so far, we are also focusing on the development of a mathematical model that will assist with predicting the performance of a large scale IGCC power station using high-ash coals." – *Petro Lowies*

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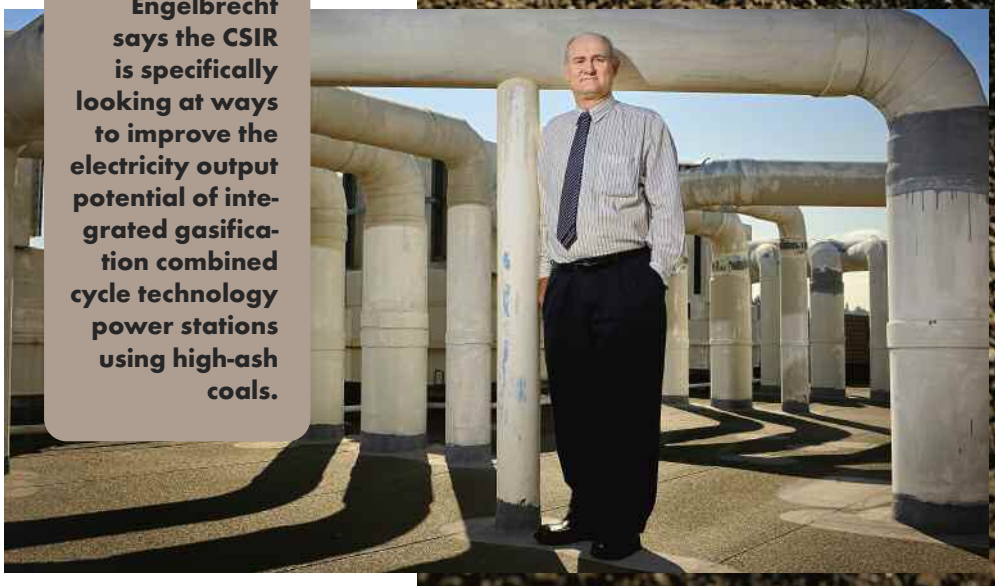
**André Engelbrecht says the CSIR is specifically looking at ways to improve the electricity output potential of integrated gasification combined cycle technology power stations using high-ash coals.**

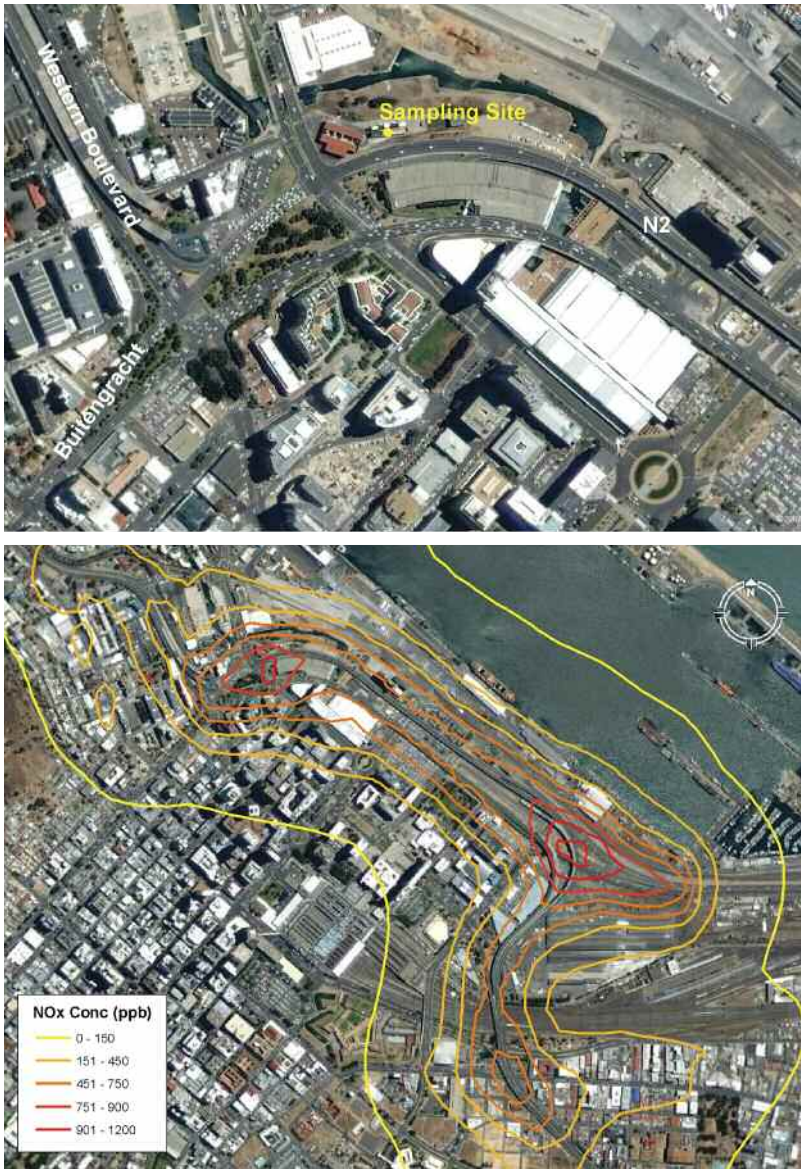


André Engelbrecht with some of the coal samples that are characterised and tested in the CSIR's pilot coal gasification plant

# EMISSIONS FROM ENERGY USE IN TRANSPORT

## LOOKING AT JOHANNESBURG AND CAPE TOWN

IN LIGHT OF THE EFFECTS OF AUTOMOBILE ENERGY USE ON THE ENVIRONMENT, THE CSIR COMPARED THE ENVIRONMENTAL IMPACT OF THE AUTOMOBILE SECTOR ON CAPE TOWN AND JOHANNESBURG.




In Cape Town the sampling site was set up close to where the M2 intersects with Buitengracht and Western Boulevard

The transport sector is the major consumer of liquid petroleum fuels, and a major source of pollution, contributing 11% of total national greenhouse gas emissions.

In 2000, 74% of the transport energy used in South Africa was for land transport and this proportion is on the increase. The problem is further aggravated because in cities more people are exposed to these emissions than in the countryside.

Funded by the South African National Energy Research Institute (SANERI), the CSIR embarked on a project to compare the environmental impact of the automobile sector on Cape Town and Johannesburg.

The project provided a 'snapshot' of ambient air quality at selected monitoring sites and provided useful comparative data between the two cities.

The research found that in general, pollutant concentrations recorded in Johannesburg and Cape Town were not comparable (with the exception of carbon monoxide – CO).

Significantly higher sulphur dioxide ($SO_2$), hydrogen sulphide ($H_2S$), nitrogen oxide (NO), nitrogen dioxide ($NO_2$), benzene, toluene and ammonia ($NH_3$) concentrations were recorded in Cape Town – compared to Johannesburg – while ozone concentrations were lower.

Pollutant concentrations showed a strong correlation with the prevailing meteorological conditions, as periods of increased pollutant concentrations were associated with conditions promoting the stagnation of pollution in Cape Town (conducive to brown haze conditions).

Air quality impacts associated with emissions from vehicles can therefore be determined to be based on location-specific conditions such as the prevailing local meteorology and underlying topography, which influence the dispersion of pollutants.

Simulations were undertaken to determine the impact of emissions from vehicles at the monitoring sites. Both locally derived emission factors (where available) and British emission factors built-in to the modelling software were used to determine oxides of nitrogen (NOx), sulphur dioxide, particulate matter of less than 10 microns in diameter (PM10), carbon monoxide (CO), and benzene concentrations.

Good agreement was observed between predicted oxide of nitrogen concentrations using local and British emission factors in both Johannesburg and Cape Town. Hourly nitrogen concentrations exceeded the respective guideline in both Johannesburg and Cape Town while daily nitrogen concentrations were below the guideline in Johannesburg.

Predicted sulphide dioxide and PM10 concentrations were low in Johannesburg and Cape Town, when compared against their respective guidelines. Ambient hourly carbon monoxide concentrations were below the guideline in Johannesburg.

According to CSIR senior energy specialist Maxwell Mapako, the project also looked at the strategies of the two cities to cope with the environmental impact of the automobile industry: "Most of the strategies are not yet implemented, but Cape Town seemed to be ahead of most cities in its efforts at building a sustainable transport system," he said.

Cape Town has unveiled a multi billion rand public transport plan to alleviate traffic congestion, reduce transport times and stimulate new developments. Currently the city is planning to construct bus lanes and cycle lanes on Koeberg Road and the R27 as far as Blaauwberg Road and beyond.

The project findings will be presented as a conference paper at the International Conference on the Industrial and Commercial Use of Energy in June 2009.

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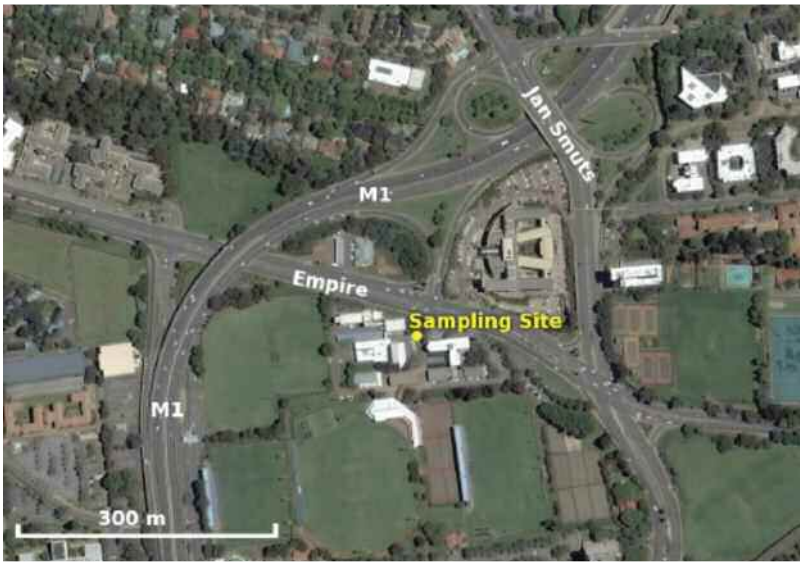
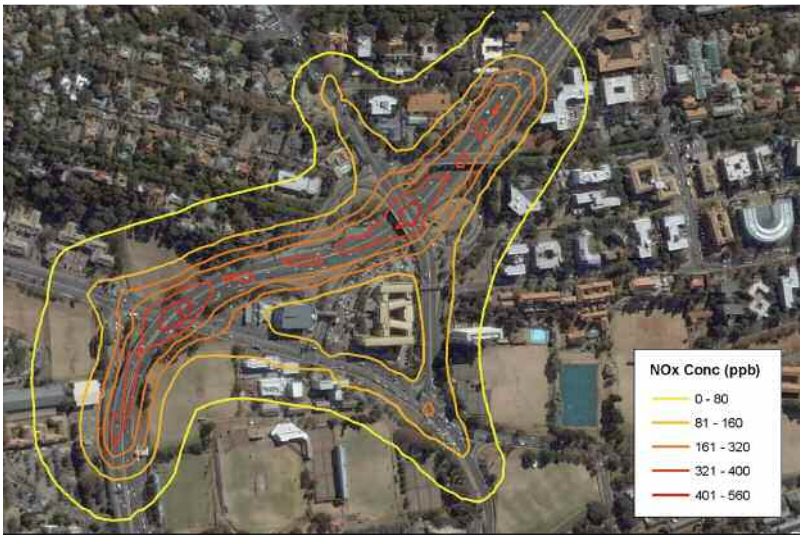
Maxwell Mapako is a senior energy specialist at the CSIR in Pretoria

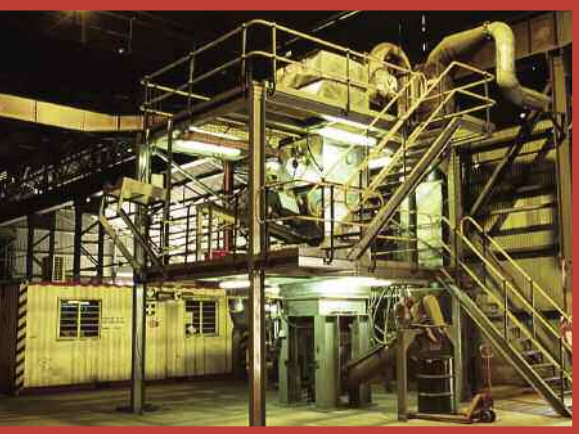



The sampling site in Johannesburg was at the busy intersection where the M1 meets with Empire and Jan Smuts

# FLUIDISED BED TECHNOLOGY ENJOYS LONG TRACK-RECORD

FLUIDISED BED TECHNOLOGY HAS BEEN A MAJOR INITIATIVE WITHIN THE CSIR FOR OVER TWO DECADES. RESEARCH FIRST CONCENTRATED ON COMBUSTION, BUT LATER EXPANDED TO INCLUDE MINERALS TREATMENT AND GASIFICATION.



The multi-purpose fluidised bed established in 2000 at the Fluidised Bed Centre of Competence

A fluidised bed is a bed of inert solid material suspended in an upward-moving air stream. The result is a turbulent mixing of gases and solids. The tumbling action, resembling a bubbling fluid, promotes more effective chemical reactions and heat transfer. For this reason the technology has found many applications such as drying, combustion and minerals treatment.

"The CSIR started investigations into fluidised bed combustion of coal in the 1970s already. For this purpose an initial refractory-lined bubbling fluidised bed test rig was constructed," says Brian North, who heads up the CSIR's research team for clean coal technologies. "The research became more focused in the early 1980s when the CSIR was appointed custodian of the Department of Minerals and Energy flagship project – the National Fluidised Bed Combustion (NFBC) boiler."

A key feature of this work was to utilise discards coal in an environmentally acceptable manner, by capturing the sulphur contained in the coal by injecting sorbent (e.g. limestone) into the bed. Fluidised bed combustion was proved to be a suitable technology for the utilisation of these low grade fuels.

## DEVELOPMENT OF TEST FACILITIES

The need became apparent for a replacement facility for the initial test rig – one that would incorporate the functionality and freeboard height of the NFBC with the flexibility of the smaller initial test rig. Hence, in 1992, the Multi-Purpose Fluidised Bed Combustor (MPFBC) was commissioned.

According to North, the MPFBC's versatility led to a wide range of process development work. This work, often undertaken with Mintek, included ilmenite oxidation and reduction, marine shell calcination, zinc and nickel sulphide ore oxidation and paper residue processing.

In the late 1990s the CSIR and Iscor Limited, (the latter, in 2001, listed its mining operations as Kumba Resources, which in turn re-listed as Exxaro Resources in 2006) identified and capitalised on a synergy in the fluidised bed treatment of minerals. They joined forces in 2000 and established the Fluidised Bed Centre of Excellence (FBCoE). An upgraded and automated MPFBC now forms part of a range of facilities hosted by this centre of excellence.

"The marine shell calcination work highlighted the need for a smaller and more flexible fluidised bed test facility with a high degree of heat recovery," says North. "Thus the Fluidised Bed Calcination Rig (FBCR) was developed where projects such as calcination of calcium carbonate and magnesium chloride were conducted."

The 'fleet' of test facilities has been expanded to include two bench-scale fluidised beds, of 25 mm and 50 mm diameter, where small-scale exploratory research can be carried out. These have been used to produce carbon nanotubes from plastic waste and other hydrocarbons and to obtain a better understanding of the transformation process from coal to char and ash during gasification.

"Based on the research and development carried out at our test facilities, the CSIR has been able to design industrial-scale fluidised bed systems, which have been supplied to South African industry," says North. These include:

- The Slagment Hot Gas Generator, a 10 MW plant for the combustion of duff coal at greater than 98% burnout, to provide hot gases for the drying of slag. It won the South African Institution of Mechanical Engineers Projects and Systems Award in 1990.
- A biomass sludge boiler for a multinational food producer. This is a 20 MW

The high sulphur pitch incinerator built for a South African petrochemical company

plant for the incineration of a stream of 12 ton per hour coffee grounds (at 85% water) while raising 26 ton of process steam with the off-gases. The project won the South African Institution of Chemical Engineers Innovation award in 1994.

- A high sulphur pitch incinerator for a petrochemical company. It is designed for 85% sulphur capture by the addition of limestone and could potentially be used for thermal soil remediation.
- A deodoriser designed for a food producer that deodorises a stream of gas from dryers, while generating hot gases and ultimately process steam. This plant has been in operation since late 1997.

## THE WAY FORWARD

Current research at the CSIR concentrates on fluidised bed gasification of fine, low-grade South African coal. This research has been conducted in collaboration with the South African National Energy Research Institute, SANERI.

Says North: "The continuation of this research will involve major modifications to the plant, for example to eliminate heat losses and to allow it to operate under pressure. The bench scale units will be modified and upgraded. We want to develop a better understanding of how the process and the parent coal contribute to the quality of the gas produced and the degree of carbon utilisation."

He concludes: "We will shortly begin research on solar-driven methane reforming and coal gasification, the goal being to reduce the carbon footprint associated with these processes." – *Petro Lowies*

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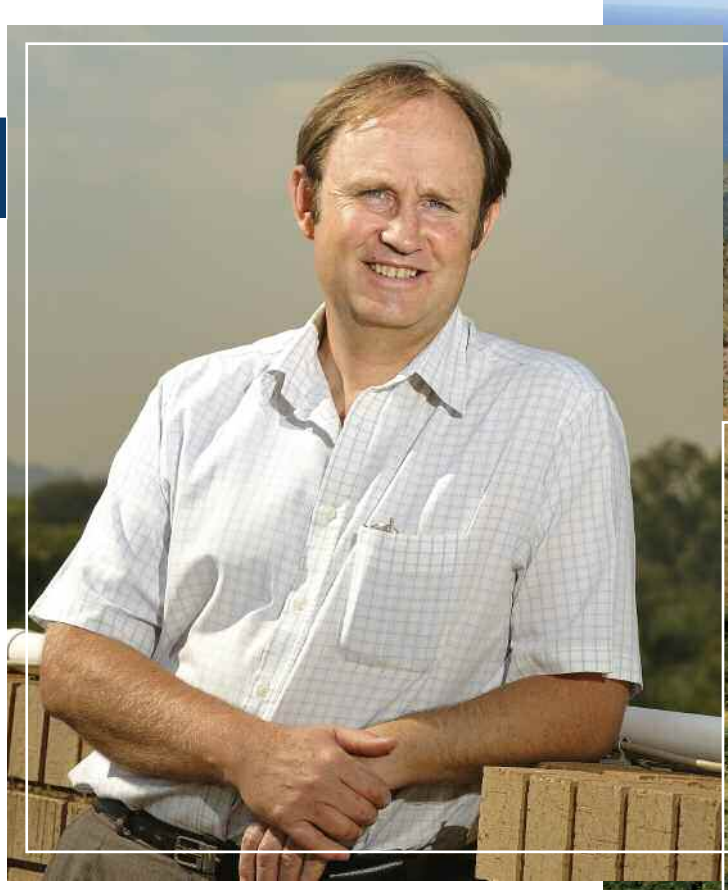
Brian North, who explains that the CSIR has a rich history and wealth of experience in fluidised bed technology

ENERGY AND RURAL SOUTH AFRICA/AFRICA



Dr Dave Rogers who, together with CSIR colleagues, conducted a 'sustainability science thinking' case study on renewable energy sources in a rural village that is not on the national Eskom power grid

# IS RENEWABLE ELECTRICITY A SUSTAINABLE SOLUTION FOR RURAL SOUTH AFRICA?

IN 2003, THE DEPARTMENT OF MINERALS AND ENERGY (DME) EMBARKED ON A PROJECT TO TEST THE VIABILITY OF RENEWABLE ENERGY FOR LOCATIONS NOT ACCESSIBLE TO THE NATIONAL GRID. CSIR RESEARCHERS TESTED 'SUSTAINABILITY SCIENCE THINKING' ON THIS PROJECT, WITH THE OBJECTIVE OF UNDERSTANDING HOW TO SPEED UP THE RESEARCH AND IMPLEMENT NEW ENERGY TECHNOLOGIES. IN THESE TWO ARTICLES, TWO OF THE CSIR'S RESEARCHERS SHARE THEIR PERSPECTIVES AND LESSONS LEARNT.

WORLDWIDE, RENEWABLE ENERGY as a sustainable alternative to 'carbon-intensive' energy sources is a hot topic. The post Kyoto 2012 commitments to low carbon technologies, to mitigate the effects of climate change, are based on renewable energies that are to be supported by a carbon tax. At the same time, the objective of South Africa's Millennium Development Goals is to reduce widespread poverty between 1990 and 2015. This includes the provision of access to energy for all South Africans.

A popular assumption is that, to achieve sustainable development, renewable energy must be supplied for basic needs. Can the Kyoto and Millennium objectives be solved in one project? Can we simply eradicate poverty and reduce carbon emissions by supplying renewable energy sources?

510 solar panels, each with a peak output of 0.113 kW, were erected at a site within the OR Tambo Lucingweni Village

## A CASE STUDY

CSIR engineering and energy specialists Drs Dave Rogers and Alan Brent, together with students Nontando Vena and Wikus Kruger, had the task to assess the sustainability of the DME's renewable energy village project from an ecological and social-economic point of view. The case study was performed in the OR Tambo Lucingweni Village and its four neighbouring villages, as well as a nature reserve, situated in rural Eastern Cape.
Says Rogers: "We took into account factors such as the household electrification and energy grant of R55 per household, which is administered by the Department of Provincial and Local Government to local municipalities. Other factors to consider included the sources and quantities of renewable energy, the cost of energy provision and the demand versus the production thereof."

They then applied the assumptions of the main sustainability paradigms to identify elements within the socio political, social ecological, socio economic and energy systems described for the villages.

The sustainability paradigms included:

- The World Bank Millennium Development Goal model, to which South Africa has subscribed for energy consumption per unit of gross domestic product
- The World Commission on Environment and Development, which has provided the first and only global consensus on conditions for sustainability
- The Stern Review, which has provided the most widely accepted techno-economic model for mitigation against climate change due to energy consumption.

## THE RESULTS ARE OUT

"Unfortunately, the findings were not very encouraging," says Rogers. "For 2007 the total system cost turned out to be R7.76 per kWh for 119 000 kWh per annum. This is a cost of approximately 50 times higher than the Eskom costs for 2006/07 of R0.16 per kWh – a considerable difference."

He explains that there are four main reasons for this: "Firstly, energy conversion losses of about 30% occur between the source of the electricity and the consumer. These losses are mainly due to battery storage and conversion from DC generation and AC distribution. Eskom losses are expected to be closer to 10%."

"Secondly, capital costs of lead acid DC storage and DC to AC conversion make up 70% of the capital and running costs. For Eskom, pumped storage is closer to 1% of the capital cost. Thirdly, capital costs of renewable electricity generators have low capacity factors, i.e. 25% and 19%. These compare unfavourably with coal fired power stations that can operate at 85% of maximum rated output."

"Lastly, Eskom capital costs are typically based on old and depreciated plants. New renewable energy generators have yet to be written off." Another problem is that the R55 grant for poor households is only enough to provide for between 10 and 30 kWh per month from the available renewable energy options identified in the study. "This is below the basic need of 50 kWh per month, which makes the use of renewable energy sources unaffordable for these households," says Rogers.

The climate change mitigation strategy will also not come into play until 2025. Subsidies for renewable energy and carbon tax will be phased in slowly so as not to hinder the current application of the Millennium Development Goal model and modernistic development models. Neither sustainability frameworks support a standalone renewable energy grid.

He explains: "The main reason is economic unsustainability due to the more productive use of capital on large grids, where scales of economy and usage patterns allow much lower storage and access to base load capacity."

## SO WHAT NOW?

Getting 'power to the people', so to speak, is not impossible. Today, however, the answer does not lie with renewable energy.

"One of the main technological innovations of the National Electrification Programme is single wire earth return technology," says Rogers. "A 13 km, 5000 kW line extension from nearby Mdumbi village, with 112 household installations, will cost about R1.3m with the standard Eskom grid controller. It would then cost households around R0.31 per kWh (peak demand), which is only two times the Eskom national charge cost. It would also meet the affordability constraint of the national target of 50 kWh per household."

This answer will address the goal to reduce widespread poverty. It will not, however, assist with the post Kyoto 2012 commitments. – *Petro Lowies*

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**FACT BOX**

**THE PROJECT IN NUMBERS**

**The wind turbines and solar panels erected outside the village could deliver:**
- **97 kW at peak**
- **125 watts (continuous)**
- **To 112 households.**

**Energy provision:**
- **Just over 3 kWh per day for each connected household.**

**In comparison, the average:**
- **Kettle uses 1800 watts to boil**
- **Fridge uses about 100 watts continuously**
- **Nokia cell phone uses between one and four watts to charge.**

Children from the OR Tambo Lucingweni Village and surrounding villages walk past the six wind turbines erected for the project

# RETHINKING RENEWABLE ENERGY SYSTEMS FOR RURAL AREAS

**An alternative energy village project in the rural Eastern Cape failed to prove viable, emphasising the intricate relationship between social expectations and economic viability.**

THIS RENEWABLE ENERGY PROJECT in the OR Tambo Municipality in the Eastern Cape formed the basis of a perfect case study to determine the viability of renewable energy for locations outside the national grid. It formed part of the national government's larger programme to supply energy for basic needs.

An in-depth analysis by the CSIR showed that not only was the renewable energy system unsustainable because of social demand, but also in terms of stability of supply.

## WHEN CONSUMER DEMAND EXCEEDS CAPACITY

According to CSIR engineering and energy specialists Drs Alan Brent and Dave Rogers, the community expected the same performance from the alternative system as that provided by the national electricity grid: "However, the capacity and reliability of the technological system proved insufficient to meet these expectations. Observation from

the site was that the average household demand far exceeded the average generation capacity of 3 kWh per day," they said.

It seems that people's electricity demand doubles soon after installation when they want stoves and refrigerators. In the Lucingweni Village, household connections were provided with trip switches, but many households simply bypassed these trip switches.

For the researchers, the failure of the system was rooted in its original design: "The lack of awareness at the design stage for the most important non-technical aspects resulted in an overall unsustainable system. The uncontrolled connections by the community resulted in system overload, disputes between all parties, and disconnections of power by the service provider.

"The system was disconnected within one year of commissioning. Overall, the management of the technological intervention did not improve the conditions of the social sub-system in the rural village or meet any of the sustainability performance aspects sought by the stakeholders and designers. The result was the breakdown of trust between the traditional societal structures and the formal government structures, and the technology developers," they wrote in an article to be published in the journal *Renewable Energy*.

According to Brent and Rogers the case study highlights the importance of the principles of sustainability science to design and manage renewable energy technologies.

## RENEWABLE OFF-GRID ELECTRICITY SYSTEMS NOT VIABLE

When comparing the outcomes of this case study with a South African sustainable development framework, it is clear that renewable off-grid electrification systems for specific villages are not viable.

According to Brent and Rogers the economies of scale for renewable energy supply technologies favour national grids. "At the time of the study, electricity selling costs from the national grid was approximately 50 times lower than that of the renewable energy supplies." (See: 'The results are out' on page 37)

Public funded electricity supply systems depend upon a high level of integration to meet the social, technical, economic and environmental goals of the Millennium Development Project, which South Africa supports. The complexity of energy supply systems for basic needs can result in uncertainties for social and technical systems planners. In the case of renewable off-grid systems in traditional rural areas, robust technical systems are required. A good example has been the learning in the successful national electrification programme that has supplied grid electricity to half of SA's population between 1990 and 2007.

A learning model for the sustainability of energy provision has been proposed in the journal *Renewable Energy*.

In the article Brent and Rogers propose several alternative options, such as linking renewable energy with the national grid, as well as a carbon tax to place renewable energy technologies on the same footing as coal.

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ENERGY AND RURAL SOUTH AFRICA/AFRICA

# DECISION SUPPORT TOOL ASSISTS WITH **DELIVERY OF ENERGY SERVICES**

BY MAXWELL MAPAKO

THE CSIR HAS ESTABLISHED COLLABORATIVE RESEARCH LINKS WITH IMPERIAL COLLEGE LONDON TO ADAPT A DECISION SUPPORT TOOL PILOTED IN LATIN AMERICA TO IMPROVE DELIVERY OF ENERGY SERVICES IN SOUTHERN AFRICA.

THE GLOBAL DEVELOPMENT AGENDA has become increasingly focused on poverty reduction in response to the dire state of the populations of most developing countries, particularly in sub-Saharan Africa.

The New Partnership for Africa's Development and the Southern African Development Community have poverty reduction as the overarching goal of their programmes. The incoming government in South Africa also is set to have an increased focus on service delivery to fight poverty. Scientific research must pay attention to addressing increasingly urgent issues around poverty; and engage closely with policy makers.

Modern energy services have a pivotal role to play in the upliftment of poor communities. A correlation has been demonstrated between per capita modern energy consumption and development indicators such as GNP per capita. There have been numerous initiatives to deliver modern energy services to the poor in many African countries, but these have generally failed.

The central issues in successful delivery of modern energy services to the poor include clear understanding of the needs and circumstances of the poor, and communication of the positive and negative implications of any intended interventions to the poor. A common cause of failure is the top-down approach to the planning and implementation of projects, resulting in failure to address the needs of the intended beneficiaries.

The mere provision of energy services does not by itself cause development. To meet the needs of the rural poor, many other services need to be provided, including clean water, sanitation and healthcare.

Governments and development agencies typically approach rural development in a sectoral fashion with each sector (water supply, education, health and telecommunications, for example) working independently. However, the needs of the target population are not compartmentalised to correspond to these sectors. Therefore, a more holistic approach that offers integrated packages of interventions would be more appropriate.

Some of the important issues to emerge from past experience are:

- Given the need to deliver packaged interventions tailored to the needs of the recipient communities, an interdisciplinary approach to the design and implementation has much to recommend it.
- Different situations may warrant different approaches, depending on factors like the country, technology and target population. Understanding the context into which any given technology is to be introduced is a critical initial step.
- Approaches to the delivery of renewable energy and energy efficiency have components such as information dissemination, financing arrangements, training and maintenance. Some of these components are more critical than others to the success of the delivery models.
- How critical a given component is may change depending on the point at which the dissemination process is. For example, financing is generally critical in the early stages when beneficiaries need to acquire devices whereas maintenance becomes more important later.
- Local knowledge is important for the long-term success of initiatives. Climate may affect the usability of improved stoves, as can local preferences and customs. In general, devices that require users to significantly adapt their routines to accommodate the demands of the device are less likely to be accepted even if technically sound.
- Supportive and consistent policies are important to the long-term success of dissemination initiatives.

## TOWARDS MORE SUCCESSFUL IMPLEMENTATION

Clearly, research needs to respond to the identified shortcomings. Despite the pointers to more appropriate approaches to community service provision, top-down and highly sectoral approaches remain the typical way to plan and implement interventions.

This may be partly explained by territorial behaviour among the various implementers including government departments and donor agencies.

The CSIR's sustainable energy futures research group initiated collaboration with Imperial College London through a training workshop in July 2008 on a decision support tool for use in planning community energy service initiatives. The sustainable rural energy decision support system (SURE DSS) is a pre-selection model designed to support research and policy making, as well as assisting investment decisions. It aims at providing a complete inventory of livelihood assets (social, natural, human, physical and financial capital) in a given rural community with a particular focus on energy services, and forecasting and comparing the impact on livelihoods of different sets of energy interventions.

SURE DSS allows a comprehensive understanding of local conditions and requirements to define and select appropriate energy supply options. The tool was developed by Imperial College under a project funded by the UK Department for International Development and has been piloted in South/Central America.

The CSIR has been approached to assist with energy services planning in a community being resettled in the Northern Cape province and will pilot the SURE DSS tool in this and other communities facing different circumstances. This is expected to culminate in integrated, responsive and sustainable solutions to the energy needs of communities.

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ENERGY AND RURAL SOUTH AFRICA/AFRICA

# FINDING A MODEL FOR FINANCING RENEWABLE ENERGY TECHNOLOGIES

BY DRS ALAN BRENT AND BAMIKOLE AMIGUN

ACCESS TO ENERGY IN THE FORM OF ELECTRICITY AND FUELS IS A NECESSARY REQUIREMENT FOR SUSTAINABLE DEVELOPMENT. HOWEVER, DESPITE THE ABUNDANCE OF RENEWABLE ENERGY RESOURCES IN AFRICA, ITS POTENTIAL IS STILL UNDEREXPLOITED. THE CSIR IS INVESTIGATING THE POTENTIAL FOR RENEWABLE ENERGY TECHNOLOGIES IN SOUTHERN AFRICA DEVELOPMENT COMMUNITY (SADC) COUNTRIES BY EMPHASISING THE ENERGY GEOGRAPHY IN AFRICA, FINANCIAL ASPECTS THEREOF, AND LIMITATIONS TO ADOPTION.

IN LIGHT OF the United Nations Climate Change Conference in Copenhagen in December this year, renewable energy technologies is a focal point in the response to global challenges such as climate change and energy security.

Furthermore, the investment landscape in renewable energy technologies and energy efficiency has recently undergone considerable transformation. To realise its potential, investment in renewable energy technologies infrastructure is critical for southern Africa. However, the development of sustainable energy in the region is curbed by the lack of adequate and secure finances. A plethora of generic technological and non-technological restrictions, such as scarce political support and poverty, impede (financial) support and adoption of renewable energy technologies. A deeper understanding of the consequences of different energy policies could positively influence stakehol-ders, gain investor confidence, and subsequently contribute to the global community.

## IDENTIFYING WHAT WILL WORK FOR SADC

For developed countries, renewable energy sources primarily serve as a means to diversify the national energy supply and reduce green house gas emissions. However, for developing countries such as those in Africa, renewable energy technologies play a very different role, namely improving the quality and magnitude of energy services and addressing poverty.

At the moment, an African uses only one eleventh, one sixth, and one half of the energy used by a North American, a European, and a Latin American respectively. There is thus an urgent need for substantial increases in energy consumption in Africa as a whole if it is to become competitive with other developing regions of the world. At the same time, the appropriate technologies should be provided. Southern Africa is rich in natural energy resources. With abundant hydropower potential in the north, vast coal fields in the south, oil reserves off the west coast, and fertile land, there is a definite potential to supply low cost energy in the region.

However, the disparate distribution of natural, human and capital resources in the region, as observed in any other transitional country, necessitates regional coordination and cooperation to ensure the development of an efficient and reliable (regional) energy system.

The CSIR is investigating the potential for renewable energy technologies in SADC countries by emphasising the energy geography in Africa, financial aspects thereof, and limitations to adoption. In an article published in the proceedings of *Energy and Sustainability* 2009, future energy paths, with an increased share of renewable energies in the African energy mix, are suggested.

## INTERNATIONAL INVESTMENT CLIMATE

The Global Environment Facility (GEF), the financial mechanism for the UNFCCC, currently represents the largest source of funds for renewable energy to developing countries. About $900 million have been assigned to 110 projects in 50 countries leveraging nearly $6 billion of added co-financing. However, its role is in need of redefinition. The design of a future global carbon finance market is yet to be defined.

To support the adoption of renewable energy technologies, developing countries need investment. The Pew Center on global climate change sketches a technology funding framework for the period after 2012. The establishment of a clean energy fund in the African region, the African Biofuels and Renewable Energy Fund (ABREF), also addresses the uncertainty about the post-2012 carbon market setting.

Africa strongly lags behind other regions such as India, China and Brazil. Energy in southern Africa is largely underexploited, but at the same time the continent presents an unprecedented opportunity to choose a cleaner development pathway *via* low-carbon energy alternatives.

The current state of South Africa's renewable energy sector, for example, is marked by pilot projects. While some renewable energy may incur higher capital costs, immense savings can be achieved in operating costs as compared to fossil fuels or nuclear energy. For example, comparing cost, energy supply and job creation for solar water heaters and the pebble bed nuclear plant, the difference in cost is R2.6 billion compared to R10 billion for the latter.

## BARRIERS TO ADOPTION

Both technological and non-technological barriers hinder the adoption and commercialisation of renewable energy technologies in Africa. They are institutional or policy hurdles, technical, economic, financial, information and capacity hurdles.

Countries can be categorised as Type A to D depending on the number and value of the hurdles. For example, South Africa is classified as a Type A country – it is a technologically advanced developing country, with well diversified and fairly comprehensive industrial, energy and R&D infrastructures. At the bottom of the scale one finds Type D countries – Ethiopia, Chad, Burundi, Mozambique, Ivory Coast, Niger, Somalia, Mali and Sudan – described as technologically least developed countries.

The study finally suggests two methodologies to assess the sustainability of the different energy paths, namely the sustainable value and real options approach.

## DYNAMIC MODELLING TECHNIQUES

The sustainable value approach assesses the contribution of a company in terms of sustainability and the efficiency with which it uses its capital, environmental and social resources. Whenever a resource is used in a better way than possible alternative uses, financial value is created.

The real options approach assesses economic performance by evaluating alternative uses, but focuses only on financial measures. A financially sound energy path for the SADC region can be developed using these two approaches within a system dynamics modelling framework that is flexible enough to incorporate future changes.

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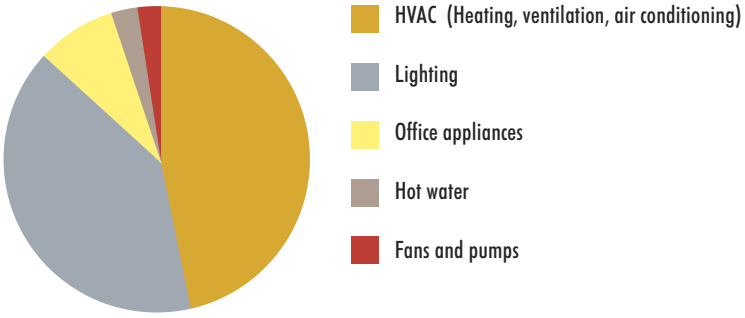
# ENERGY-EFFICIENT BUILDINGS ON THE HORIZON

BUILDINGS CONSUME ENERGY throughout their lifespan, including during construction, operation and demolition. Legislation in South Africa will in future require buildings to be more energy efficient, with new standards on energy efficiency being developed by the South African Bureau of Standards (SABS). Municipalities such as the City of Joburg and the City of Tshwane are looking at by-laws and incentive schemes to reduce energy consumption in buildings.

A DIRECT LINK EXISTS BETWEEN BUILDINGS, CARBON EMISSIONS AND THE ABILITY OF THE NATURAL ENVIRONMENT TO ABSORB CARBON DIOXIDE. GLOBALLY, THE BUILT ENVIRONMENT IS RESPONSIBLE FOR 40% OF ENERGY USE, 17% OF FRESH WATER USE, 25% OF WOOD HARVESTED AND 40% OF MATERIAL USE.

Figure 1 Energy consumption in a large air-conditioned office building




The CSIR and the City of Joburg collaborated on a project to produce a set of policy guidelines for the city to use in the design of new buildings that are energy efficient. The document, which was completed at the beginning of 2009, provides practical guidelines that have been developed through international studies and local research.

"We looked at a range of building types, from offices to residential buildings. We concentrated on passive environmental control, day lighting and renewable energy such as solar power rather than mechanical systems such as air conditioning," explains Dr Jeremy Gibberd, an architect at the CSIR.

Energy is required in buildings for lighting, heating and cooling, hot water and for powering equipment and appliances. This varies between buildings – the approximate proportions of energy used in a conventional Johannesburg office building appear in Figure 1.

## DESIGN FOR ENERGY EFFICIENCY

"One should look at energy aspects as early as possible in the design process. It should impact all aspects of the building, including the choice of site, the size and shape of the building, detailed design of the building envelope (external elements such as walls, windows and roofs) and type of mechanical systems specified as well as interior layouts. An integrated approach during design development can be used to obtain energy efficiency," comments Gibberd.

Environmental conditions such as temperature, humidity, daylight and ventilation have a direct bearing on human health and productivity. In achieving energy efficiency, it is important not to provide unhealthy or unsafe environments.

## SOLAR RADIATION

Solar radiation levels in South Africa are among the highest in the world. Research shows that average daily solar radiation varies between 4,5 and 7 kilowatts per hour (kWh) per $m^2$. Even in winter, parts of the country receive more than 6,5 kWh/$m^2$ per day. The duration of sunshine is also high. "For the study, we look specifically at Johannesburg, which receives bright sunshine for some 70% (of possible duration) in summer and 80% in winter. This compares to London (33%), Sidney (49%) and Haifa (73%).

"These figures indicate that Johannesburg has excellent and reliable solar energy. This free resource can be used in passive environmental control strategies, solar water heaters and photovoltaic systems to improve energy efficiency in buildings," says Gibberd.

Dr Jeremy Gibberd, researcher in sustainable buildings




Modelled air flow in and around buildings

## ENVIRONMENTAL CONTROL

The choice of environmental control strategy depends on factors such as cost, technical capacity, building function, client requirements, climate and the local external environment. A number of passive environmental control strategies are applied in the design to increase the ability of the building to cope with different weather conditions. For instance, both a cross ventilation and a stack effect system may be used to cool the building.

During normal conditions when there is a breeze, the cross ventilation system will be effective. During hot, still conditions when cross ventilation may not be effective, ventilation and cooling can still be achieved through the stack effect system. This system uses tall vertical spaces and the physical tendency of warm air to rise, to ventilate and warm or cool buildings. Rising air within a vertical space, which could be an atrium or solar chimney, is used to draw air into buildings.

## LOCATION

Buildings should be orientated to avoid unwanted heat losses or gains. In general, the long section of buildings should be orientated to about 15 degrees of due north. The extent of the facade facing north should be maximised and the length of facade facing east and west minimised. This enables good access to sunlight for the north facade, good access to daylight through the north and south facades and reduces unwanted heat gain from early morning and late afternoon sunshine on the east and west facades.

Shading devices should be used to avoid unwanted heat gains. The design of shading devices are normally based on calculations and modelled to ensure that windows or glazing are shaded from direct sunlight at specific times. In general, horizontal shading elements are appropriate on northern facades and vertical moveable louvers are suitable on east and west facades.

## LIGHTING AND EQUIPMENT

Electrical lighting systems vary and it is important to select the most appropriate system for applications. One should consider light level requirements, safety, energy efficiency of systems, colour rendering and maintenance. The use of tungsten and halogen lamps should be minimised as these are the least energy efficient. Dust and dirt on light fittings and lamps can reduce their effectiveness by up to 40%.

Increasingly, office equipment has energy ratings and includes energy saving features. "Flat screen monitors emit less heat, use less energy and space than conventional monitors, while laptops use about 25% of the energy used by conventional desktop computers," recommends Gibberd.

"Compliance with tightening legislation and standards is not the only driver for designing energy-efficient buildings – other reasons include global warming, reducing operating costs, limiting the need for additional power, and market and client demands," he concludes. – *Hilda van Rooyen*

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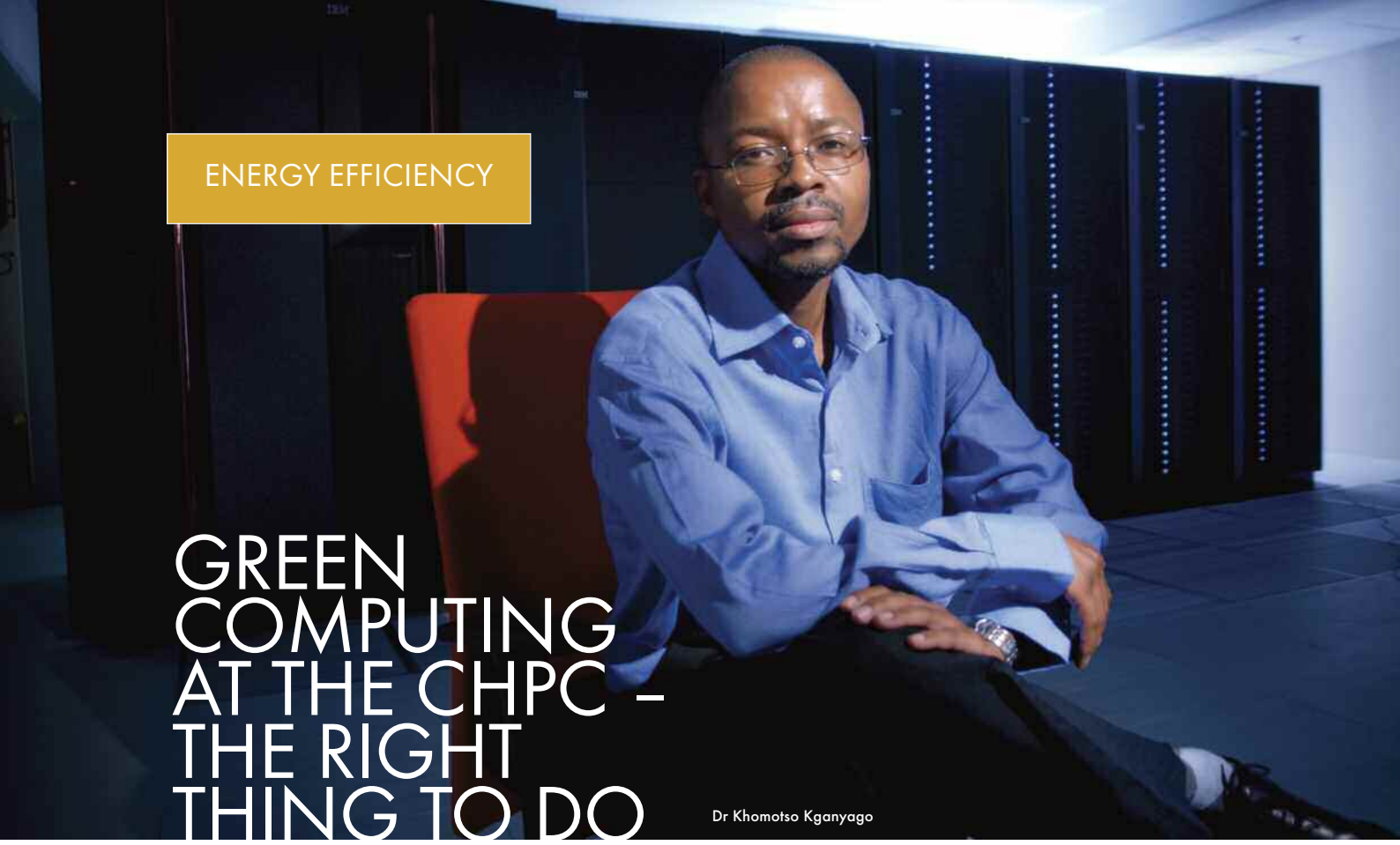

# GREEN COMPUTING AT THE CHPC – THE RIGHT THING TO DO

Dr Khomotso Kganyago

GREEN COMPUTING HAS FEATURED HIGH ON THE AGENDA IN THE PLANNING AND CONSTRUCTION OF NEW COMPUTING FACILITIES WORLDWIDE AND AT THE CSIR'S CENTRE FOR HIGH PERFORMANCE COMPUTING (CHPC).

THIS EXPANSION positions South Africa as a beacon of computational research on the African continent and meets the CHPC's mission to enable South Africa to become globally competitive through the effective use of high-end HPC infrastructure.

As the cost of electricity rises in tandem with the increased demand for powering and cooling of computing systems, power costs begin to outstrip the costs of hardware in supercomputing facilities. A good alternative definition to green computing is, therefore, 'energy-efficient computing'.

In anticipation of the installation of its newly acquired Sun SPARC Enterprise M9000 server with SPARC64 VII quad-core processors (64), and a cluster of four Sun blade 6048 modular systems, the CHPC has taken the imperative to match computing power by energy efficiency seriously. Sun blades X6250 server modules (48) will be based on Intel Xeon E5450 processors and the dual-node Sun blades X6275 server modules (144) powered by the ground-breaking Intel Xeon processor 5500 series (code-named Nehalem) within the C48 chassis. The newer Sun blade 6048 chassis accommodates the Sun cooling door modules, which are securely mounted on the rear of the Sun cabinet.

## FEELING THE HEAT

The heat generated by a single laptop is quite significant as anyone who has tried laptop computing for any length of time, will attest. Most laptops contain a dual-core processor. By comparison, each blade within the architecture of the new system has 16 dual core processors and generates a considerable amount of heat, as more processors are now located within a small space.

The energy output of a quad-core processor is similar to that of a clothes iron at its highest setting. It is therefore little wonder that power consumption for two vital purposes – to operate and to cool – can be viewed as a potentially limiting factor to future growth in HPC.

The Sun hybrid architecture provides an estimated 27 teraFLOPS of peak computing power. As a proactive measure, the CHPC team has incorporated green computing interventions in the planning and construction of the new computing and research facility.

This idea was conceived after a visit to the National Centre for Supercomputing Applications in Illinois, by Dr Khomotso Kganyago, Dr Jeff Chen and Chris Petzer where they attended a workshop on 'Building the Data Center of the Future: Effective Energy-Efficient Design'.

Recently installed chilled-water infrastructure

Dual-node Sun blades 6275 server module

## CHPC'S STATE-OF-THE-ART DATA CENTRE

September 2008 marked the beginning of Phase II of the refurbishment on the CHPC site. It has added more supporting infrastructure to sustain the new computational facilities for housing of the Sun hybrid system.

A newly installed sub-station will ensure that the CHPC's increased demand of one megawatt of power will be met. The one-megawatt diesel generator coupled with two 500 kilowatt uninterruptible power supply (UPS) units will form a complex and sophisticated automated mechanism to ensure completely uninterrupted power.

This has been matched by a highly economical cooling system in the server room, the implementation of which is uniquely South African. The principle on which it operates is the equivalent of putting the computer 'in a fridge'. Although conventional air conditioning is used to cool the ambient temperature, the greater and more effective cooling of the machine will be done by means of water. Both the racks that store the blades and the central processing units are water-cooled with pipes that run through the machine.

The new Sun cooling door systems, which have only been installed in six sites around the world, offer six times more efficient rack cooling than standard data centre cooling systems to significantly reduce energy consumption and increase effective compute density by up to 70 percent over in-row cooling options.

Designed with an unprecedented capacity of up to 35 kW per rack, the Sun cooling door system fits in the rear of the updated Sun Blade 6048 modular system. It has the highest cooling efficiency and capacity in a 100% passive design that does not require additional fans or electrical power to function. CHPC will be implementing the Sun cooling door 5200, which leverages the recently installed chilled-water infrastructure. These advanced cooling systems remove heat at the source, require minimal data centre footprint and will help avoid costly data centre makeovers.

Achieving this advancement in green computing has required smart planning on the part of the architect responsible for designing the data centre. Charl Esterhuysen of Triocon Consulting Engineers was tasked to incorporate these requirements into the design of the centre. In brief, these involved ensuring that the infrastructure for power supply and water cooling could be run side by side without any interference. The CHPC is now a Tier 3 data centre, composed of multiple active power and cooling distribution paths, but only one path active; it has redundant components, and is concurrently maintainable, providing 99.982% availability.

The chilled-water reticulation system inside the HPC is isolated from the main chilled-water supply network with a system of plate heat exchangers. This has the benefit of minimising the total amount of water that could potentially enter the computer room in case of mechanical breakdown of, for instance, a rear door heat exchanger or pipe. The total amount of water in the internal system is such that in the unlikely event of a leak, it will drain away through a floor drain system with minimal damage and interruption.

The externally located chilled water system comprises a redundant set of high efficiency chillers (N+1 configuration). The chillers operate with elevated supply water temperature to further increase the efficiency of the overall system. During lower ambient temperature time periods, such as during night time and winter periods, the system is at its most efficient due to the higher temperature differences.

Network cabling is run in trays below the ceiling. This results in a flexible layout that allows for easy HPC system infrastructure upgrades over the lifetime of the system. Electrical power is fed from below directly into the HPC system racks. The physical separation of network cabling (reticulated above) and power cabling (reticulated below) is good practice and limits the possibility of electro-magnetic interference.

Not only does this investment ultimately contribute to the quality of research and related human capital at the CHPC, it is also a showcase of South African ingenuity and design mastery in achieving green computing. It is envisaged that these upgrades will be completed by mid-2009, paving the way for new ideas, problems, solutions, innovation and growth. – *Biffy van Rooyen*

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# RECOVERING COAL FROM SLURRIES FOR MORE ENERGY

THE FUTURE OF SOUTH AFRICAN ENERGY STILL LARGELY DEPENDS ON COAL. EVEN WITH THE POSSIBILITY OF ALTERNATIVE ENERGY SUCH AS SOLAR POWER AND NUCLEAR POWER, THE PLAYING FIELD IS NOT LEVEL AS COAL WILL REMAIN A MAJOR ENERGY SOURCE FOR YEARS TO COME.

Coal reserves are running low in the Highveld area, Mpumalanga. This area has been the main source of coal for many decades and most power stations are situated here.

The likely scarcity of coal threatens the future of electricity in South Africa. In response, the CSIR, in cooperation with Coaltech, has embarked on numerous projects to ensure that the country's coal reserves are optimally used.

Researchers are involved in collaborative projects to develop technologies for better and cheaper dry-coal beneficiation technologies. They are also looking for the reclamation of coal and slurry (fine coal) from discard dumps and slurry ponds to be used for energy production.

Johan de Korte, a CSIR researcher and a member of the coal preparation committee of Coaltech, says there are potentially large tonnages of recoverable coal in dumps and slurry ponds. He says utilising this coal not only produces coal for electricity generation but also aids in removing potential pollution hazards.

De Korte says that the briquetting of fine coal has also been investigated – mainly as a means to improve the transportation of fine coal. The technology has been developed and proven to work. It is, however, expensive to produce the briquettes from the slurry and the technology is not cost effective for most coal users like Eskom.

## COAL BENEFICIATION, THE BETTER OPTION

Beneficiation (cleaning) of low-grade coal reserves remains the better option to obtain more and better quality energy. De Korte explains that coal beneficiation is the process of removing the contaminants and the lower grade coal contained in the raw coal as mined to achieve a product quality that is suitable to the needs of the end user – either as an energy source or as a chemical feedstock.

"When coal is extracted it is mixed with shale and other contaminants from the roof and the floor of the coal seam that are required to be separated from the coal," he says. He says coal cleaning also helps in reducing sulphur in the coal, reducing the extent of pollution that the coal may cause during combustion.

A method of coal cleaning that may be used in the future is dry-beneficiation, as it does not use water and does not create fine coal that goes to slurry dams – a positive environmental aspect. This technology is currently being investigated.

## ADDITIONAL BENEFITS OF HIGH-GRADE COAL

In the future, most of South Africa's coal will be mined in the Waterberg and Limpopo coalfields. Coal beneficiation will be necessary for exploitation of the coal from these areas since the coal occur mostly as thin seams interlaced by rock.

Briquetting Press: The machine used to produce briquettes

The Waterberg area will supply coal to new power stations. Currently, Matimba power station is functional and Eskom is in the process of building the new Medupi power station.

De Korte says the aim of coal beneficiation is to improve low-grade coal to provide a high-grade coal that is more efficient during power generation and produces less pollution. Beneficiation of low-grade reserves also means that more of South Africa's coal reserves become available for use as this coal may previously have been unused.

"With high-grade coal you use less as there are no extra contaminants like rocks and shale to transport, this means there are less trucks on the road," he explains, adding that, "Power stations also need to handle less ash afterwards."

He says this collaborative initiative will develop technology and apply research findings to enable the South African coal industry to remain competitive, sustainable and safe well into the 21st century.

Coaltech is a research association with shareholders from various coal mines, including Anglo Coal, BHP Billiton, Xstrata Coal, Exxaro Coal and Sasol Mining as well as other coal-consuming businesses such as Eskom. – *Kamogelo Seekoei*

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**"The aim of coal beneficiation is to improve low grade coal into high grade coal as it burns efficiently and produces better power."**

A coal discard dump where slurry will be mined for coal

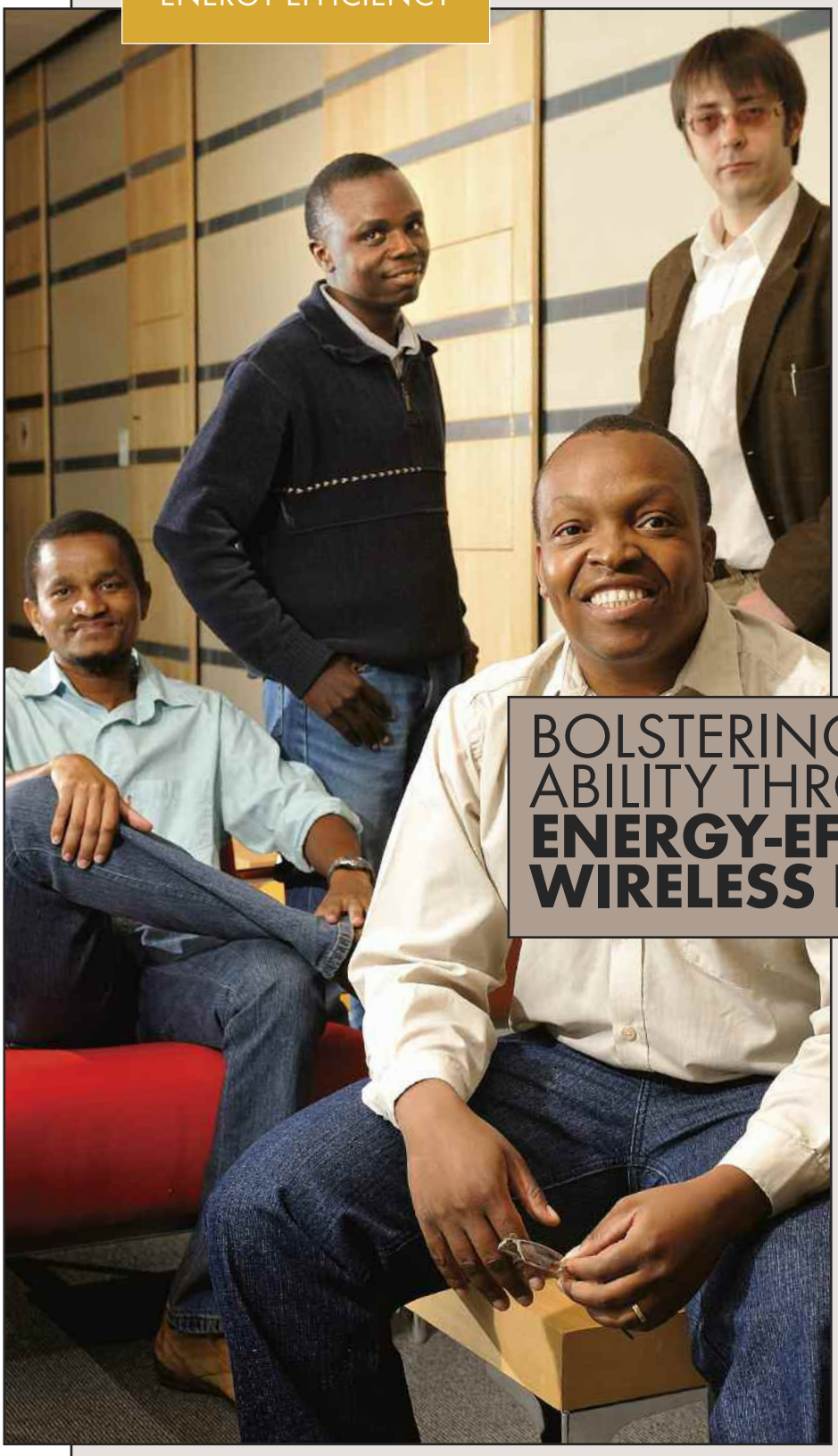
# MAPPING THE STRUCTURE OF THE WATERBERG FOR FUTURE COAL

COAL MINES IN SOUTH AFRICA, especially in the Highveld area, are becoming depleted of resources and the need to mine other areas to sustain the coal industry has become increasingly important.

CSIR scientists have interpreted airborne magnetic and radiometric data, and acquired additional airborne data, to produce the first detailed structural map of the Waterberg Coalfield. This is the first step in the process to allow mines to explore and mine more effectively. This research is set to prolong the life of the South African mining industry and, therefore, the energy supply.

The Waterberg Coalfield is said to have the capacity to host eight power stations and there should be enough reserves to mine for the next 150 years.

*See the ScienceScope, Volume 3, Number 3, of January 2009 for the full story.*



Dr Ntsibane Ntlatlapa (seated right) with (from left) Clemence Kyara, Thomas Olwal and Albert Lysko

RESEARCH BY THE CSIR'S MERAKA INSTITUTE INTO ENERGY EFFICIENCY WILL BOLSTER THE REACH AND IMPACT OF WIRELESS MESH NETWORKS IN AFRICA.

# BOLSTERING SUSTAINABILITY THROUGH **ENERGY-EFFICIENT WIRELESS NETWORKS**

THIS RESEARCH THRUST comes on the back of a successful track record by the wireless Africa research group in turning theory into real and sustainable projects – not only locally but also in sub-Saharan Africa.

Mesh networking is a method by which incremental connectivity is achieved through adding wireless mesh nodes to existing hotspots, which then relay the signal to extend the coverage. These networks can be expanded by communities. By nature of its novel qualities, the network configures itself (should extra nodes be added) and heals itself (should a node fall away).

The particular focus of the energy-efficient research thrust is twofold:

- The development of a wireless mesh routing algorithm to dynamically influence the routing process based on the energy remaining in each node in the network

- The development of a smart beam-forming antenna to optimise usage of the energy consumed by radio transmission.

## TRAILBLAZING THE CONCEPT OF LOW ENERGY CONSUMPTION

Dr Ntsibane Ntlatlapa first presented a research paper, titled 'Energy-efficient wireless mesh networks', during an international meeting of wireless experts at the 18th meeting of the Wireless World Research Forum (WWRF). The WWRF has over 140 members from five continents, representing all sectors of the mobile communications industry and the research community.

Ntlatlapa sketched the context as rural infrastructure-deficient parts of the African continent where nodes operate on batteries. He explains, "As a result, energy consumption must be minimised while achieving high throughput and low delay. Our research focuses on various projects to design a transmission strategy to minimise the total energy consumption."

### CIER

**Research on energy-efficient wireless network has been included in the Global Research Alliance's FP7 project proposal on Converged Infrastructure for Emerging Regions, placing a specific accent on the energy efficiency in wireless communication systems for emerging regions, like the African continent.**

Subsequently, two students in Ntlatlapa's group have taken on topics in support of this research thrust. Thomas Olwal's PhD thesis focuses on dynamic power control for energy savings. It considers a scalable choice on the transmission power level of every mesh node so that network interference within a common wireless channel, energy residing in each node of the network and the network connectivity are properly managed.

It also considers how to minimise the energy transmitted by a node in the presence of other communicating nodes, without disturbing the data flow. Martin Mhlanga is engaged in a Master's study on energy-aware routing. He considers maximising the network lifetime as a fundamental goal. Given alternative routing paths, his algorithm selects a routing path that has the most remaining energy in the nodes.

## GLOBAL RESEARCH COOPERATION

A visit to the CSIR by a team of Hungarian researchers from the Institute of Informatics at the University of Szeged in mid-2008 provided strong impetus to collaboration in the domain of wireless mesh networks for rural areas. Ntlatlapa explains, "Similar problems regarding rural network connectivity exist throughout the world. The demand for extra bandwidth is universal. A crucial challenge in South Africa is the gap in reliable energy supply, which researchers must consider when designing wireless mesh networks." This realisation translated into the research decision to add a simulator to monitor energy usage on the wireless mesh test bed facility at the Meraka Institute. Clemence Kyara, a Master's student, is writing a network simulator code to estimate power usage within a network. This will complement physical measurements; Ntlatlapa explains, "By using an algorithm we can model and optimise the power usage between nodes."

## SMART ANTENNAS TO AID ENERGY SAVINGS

An antenna is an essential element of a wireless network. It radiates and receives high frequency signals helping to move information between nodes. The process of radiation consumes energy. Optimisation of this process has, therefore, become an important component of the research, as the percentage of power consumed by radiation is becoming significant.

Adaptive beam-forming antennas (also called smart antennas) are able to form the shape of their radiation patterns, and are able to point the beam in any required direction, focusing the radiated energy. In doing so, an adaptive antenna offers high energy efficiency of directional antennas as well as the flexibility of omnidirectional antennas.

**An algorithm is a finite sequence of instructions – an explicit, step-by-step procedure for solving a problem, often used for calculation and data processing.**

Albert Lysko works on smart antennas. His current research focus is on parasitic array antennas, where the most elements of the array re-radiate incident radio waves. By controlling the phase of reflection, the reflected waves may be gathered coherently in a desired direction or at a receiving antenna element, providing a steerable beam of high gain.

The choice of this concept was based on the considerations of power consumption and cost; stemming from recent advances in CMOS technology. Lysko is working on implementing this technology for other components of energy-efficient wireless mesh networking. This offers another way of achieving power savings.

## INCREMENTAL BENEFITS FOR RURAL COMMUNITIES

While the project will contribute to building sustainable low-cost wireless networks in rural under-serviced areas where there is little market incentive to install wired infrastructure, the envisaged system to promote energy efficiency will have a key role in enhancing the usability of internet services in this environment.

This relates particularly to how the end users experience the reliability of these services. Real-time media such as voice are often the first basic requirement of these areas and this work will make it possible on low-cost infrastructure. This will, in turn, significantly lower the entry costs for business entrepreneurs to establish local village telephony and data networks.
– *Biffy van Rooyen*

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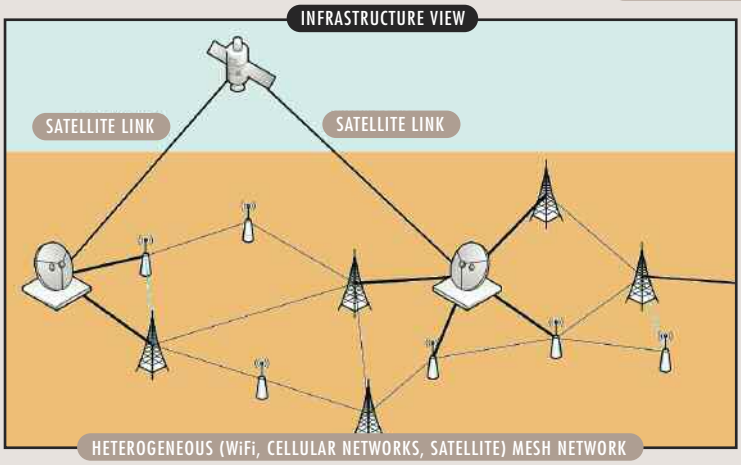

In these samples of cadmium selenide quantum dots (liquid form), the size of the quantum dots can be seen through its light absorption across the light spectrum. The lighter it appears, the smaller the size of the quantum dots. This is because smaller quantum dots absorb more light on the infrared side of the spectrum. These cadmium selenide quantum dots can typically be used in neon lighting.

# THE POWER OF QUANTUM DOTS

AS MOST QUANTUM DOTS ARE SEMICONDUCTORS, THEIR USE IN ENERGY SOURCES TO ENHANCE EFFICIENCY IS OF PARTICULAR INTEREST TO SCIENTISTS. AT THE CSIR'S NATIONAL CENTRE FOR NANO-STRUCTURED MATERIALS (NCNSM), QUANTUM DOTS, AS THEY PERTAIN TO ENERGY, FEATURE LARGELY IN TWO SPECIFIC PROJECTS.

## QUANTUM DOTS IN POLYMER SOLAR CELLS

As solar is an expensive source of electricity generation, cheaper means of converting solar energy into electricity is sought.

First generation solar cells, the most common type available, are made of silicon. They are quite effective but very expensive. Their cost led to the development of second generation solar cells, or dye solar cells. These are somewhat less effective but also less expensive to manufacture. Now, scientists are pursuing quantum dot and polymer solar cells – the so-called third generation solar cells.

The CSIR's Nosipho Moloto, who is currently doing her PhD in quantum dot technology, explains the research: "Pure quantum dot solar cells are not really viable, as the minute size of quantum dots makes it difficult to produce on the large scale needed for solar cells. Scientists are therefore pursuing solar cells made from polymers, which is much cheaper to produce, and we are looking at ways to add quantum dots to the polymer solar cells in order to enhance their performance."

Quantum dots are added for a number of reasons, all of which adds to the efficiency of polymer solar cells.

"Firstly, as quantum dots are semiconductors and very, very small (we're talking nano-scale here), they can absorb light from across the entire light spectrum and not just a limited range such as current materials used for solar cells can. They, therefore, absorb much more light energy," says Moloto.

"Then, they can conduct light energy into electricity much better. The quantum dots essentially assist the polymers to conduct the energy more optimally than the polymer would have been able to do on its own."

"Thirdly, the light that quantum dots absorb can be maintained for much longer periods than that absorbed by polymers. This means it can generate electricity over a longer period of time from the same light source."

"Lastly, adding quantum dots to the polymer mix make them last longer in the harsh sunshine. As polymers are essentially plastics, they don't last very long in exposure to sunshine. The quantum dots improve their stability in direct sunlight."

Of course, polymer solar cells are much cheaper to produce than silicone or dye solar cells, which make it a viable option for future electricity generators.

## QUANTUM DOTS IN LIGHT SOURCES

Another project involving quantum dots that scientists at the CSIR are investigating is the use of quantum dots in light sources to increase energy efficiency.

Once again, the semiconductive nature of quantum dots means it can replace certain materials within current light sources to produce brighter lights that use much less energy.

Professor Thembela Hillie, principal researcher, NCNSM, uses the example of a light bulb to explain how it works: "Instead of burning the filament in a light bulb, quantum dots are used within the light source's phosphor. The quantum dots' ability to produce a far better light source through energy transfer within the phosphor means that a room that would normally require four light bulbs now would only require one. Quantum dot incorporated hybrid light sources would furthermore last much longer than traditional light bulbs since they will not have a filament that often burns out."

The same applies for other light sources such as neon lighting or fluorescent light bulbs.

– *Petro Lowies*

**QUANTUM DOTS: a particle of matter so small that adding or removing a small number of atoms changes its properties in some useful way ... a semiconductor where electron and hole pairs are confined in all three dimensions.**

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