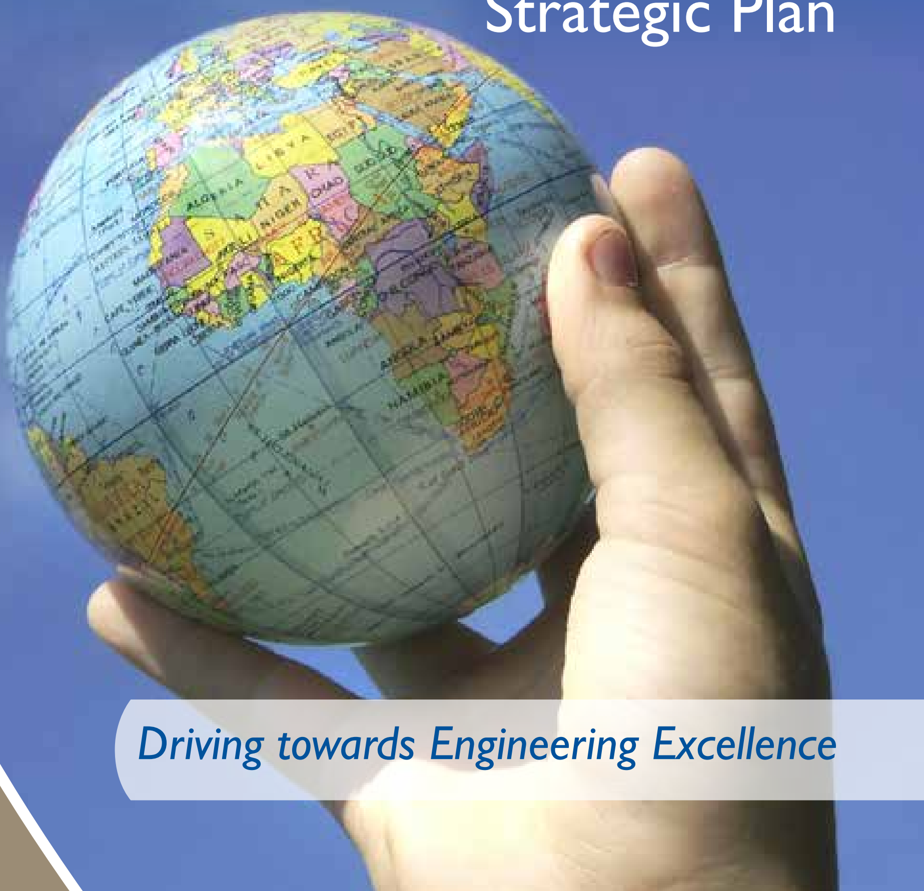
Eskom

Eskom Power Plant Engineering Institute

EPPEI

2012-2016 Five-year Strategic Plan



Driving towards Engineering Excellence

Eskom

Produced by Eskom Power Plant Engineering Institute – January 2014
1st Draft

Contents

Tribute

> “Education is the **most powerful weapon** which you can use to **change the world.**”

Nelson Rolihlahla Mandela
18 July 1918 - 5 December 2013

Foreword by Matshela Koko
on the EPPEI five-year strategic plan

I

Given the triple challenges of unemployment, poverty, and inequality in South Africa, the government has prioritised job creation through economic growth and skills development. The government is determined to act decisively to ensure that the South African economy remains resilient and robust in spite of global volatility. In this regard, power production and constant power supply are lifelines to economic growth and development. Investment in engineering skills is, therefore, paramount to ensure that we achieve the above to position South Africa as a manufacturing hub in Africa.

The need to reduce the negative impacts that industry imposes on the environment was highlighted at COP17, which was held in Durban in 2011. It is vital that our carbon footprint is reduced and that polluting emissions are better controlled. The technologies to service these needs, as well as the development of the power system, have to be implemented. The significant amount of work that must be done is an opportunity to develop technical abilities within South Africa.

The development of skills to achieve these goals requires mechanisms where citizens are given the opportunity to learn about the industry. South Africa has world-class universities, with a strong heritage in the engineering fraternity, which was developed to service the mining industry. In 2012, the Eskom Power Plant Engineering Institute (EPPEI) started its operation to investigate in depth, and contribute to solving, the challenges that Eskom is facing. It uses a research-based methodology that provides the EPPEI students with a deeper understanding of the challenges and trains individuals to strategically solve more complex problems.

The synergies between the practical experiences gained while working at Eskom, together with the expert input from academic experts, facilitate further development of information hubs in the fields relevant to the power industry. EPPEI started its operation by establishing eight specialisation centres in six lead universities, together with eight additional partner universities within South Africa. Eskom management has put together a team of specialists to mentor students from an industrial standpoint, while being guided by academic specialists, who also teach courses in Eskom.

During the first two years of the programme, the team, led by Malcolm Fawkes and Professor Louis Jestin, has established a platform for the long-term development of EPPEI within South Africa.

After this, I am happy to present the five-year strategic plan for research that EPPEI is conducting in close cooperation with Eskom Research, Testing, and Development and the associated South African universities. The interaction between industrial specialists from Eskom Centres of Excellence (CoEs), academic specialists, and EPPEI management has resulted in the strategy presented in this publication.

Foreword
by Barry MacColl

Eskom Research, Testing, and Development (RT&D) business area, within the Sustainability Division, is a multifunctional organisation that offers a diverse range of products and services in the field of research, consulting, and testing to Eskom Holdings SOC. Next-horizon technologies are selected, researched, and developed to help Eskom achieve its strategic intent in a sustainable manner. Specialised technical testing and inspection services are provided to ensure optimum plant management and to "keep the lights on". Pilot and demonstration plants for new technologies are designed, built, and operated to demonstrate technical and economic feasibility.

As Eskom's research and development hub, with world-class facilities and expertise in the power industry, RT&D is well positioned to partner with, and support, EPPEI. With a clear view and understanding of both the Eskom business and relevant technologies, RT&D can ensure that research work conducted by EPPEI students is aligned with Eskom needs. Specialists in a wide range of fields, with world-recognised experience and expertise, act as industrial mentors to ensure that student deliverables are relevant and aimed at solving current and future technical challenges. In addition, these specialists are called on to teach courses to fast-track knowledge of the power industry. Through collaborative research and consulting activities with original equipment manufacturers, local and international academic institutions, and other specialist suppliers, RT&D is in the position to unlock resources to support EPPEI students. Through appropriate motivation, funds can be allocated to financially support EPPEI students using the existing RT&D governance model as vehicle.

Foreword
by Malcolm Fawkes and Louis Jestin

The EPPEI programme was created to add value to the power plant engineering industry in South Africa, which includes Eskom, independent power producers (IPPs), manufacturing, engineers, and universities. Graduate engineers will be able to increase their understanding of the technical challenges faced by the power industry. With a greater understanding of the problems and the tools gained through the programme, engineers will be able to help solve operational and design problems within their working environment. The eight specialisation centres created at six lead universities, form the hub of activity in the power plant industry to assist in servicing the training needs for the South African and greater African power sector.

These eight specialisation centres will support the further development of the intellectual property (IP) that Eskom purchases for the future plants as well as for the retrofits to existing plants. This IP will be further developed thanks to the continued EPPEI research done in collaboration with South African universities. South Africa is currently designing, and will soon manufacture, products such as burners and desulphurisation plants that Eskom will implement, commission, and operate in its power plants to fulfil the targets set by the new Environmental Protection Act.

Malcolm Fawkes
Senior Manager, EPPEI

Louis Jestin
EDF Senior Manager, EPPEI

2 Introduction
Eskom's status and development

South Africa is the largest economy on the African continent. The country's rich mineral wealth and associated industries, as well as a climate that supports a large farming sector, have facilitated significant development as a modern economy.

The South African government is committed to growing the economy for the benefit of all citizens. One essential precondition for prosperity is the development of relevant supporting infrastructure, in which sustainable supply of electricity is key. The development of a sustainable power supply system will facilitate increased industrial activity and increased supply to South African citizens and will support the mechanisation of a number of industry branches.

The power supplied to the economy must not only be cost-effective, but must also have a neutral and controllable environmental impact. As a state-owned utility, Eskom is actively working towards improved cost efficiency and environmental protection and partners closely with the government to attain the National Development Plan goals.

Eskom was established 90 years ago as a state-owned power utility to provide low-cost energy and supported the growth and development of all South African industries. Between 1960 and 1990, Eskom initiated a very rapid build programme that ramped electricity production to exceed 35 GW. Eskom also developed the relevant transmission infrastructure to transport and distribute electricity. Currently, Eskom supplies 95% of all electricity in South Africa. The utility is the owner and operator of about 44 GW of power generation assets, consisting of 13 large coal pulverised fuel (PF) power plants equipped with 87 units, two nuclear pressurised water reactors (PWRs), as well as hydraulic plants and open-cycle gas turbines (OCGTs) that complement the generation system.

Eskom develops, owns, and operates the integrated power transmission network spread across South Africa. This transmission network is interconnected with neighbouring countries. The distribution network delivers power to final customers and local municipalities. The figure below illustrates the locations of the power generation plants, as well as the transmission network main lines, on the map of South Africa.

Base load stations		
Coal-fired	*MW (No. units)*	
1 Arnot	2 400	(6)
2 Camden	1 600	(8)
3 Duvha	3 600	(6)
4 Hendrina	2 000	(10)
5 Kendal	4 116	(6)
6 Kriel	3 000	(6)
7 Lethabo	3 708	(6)
8 Majuba	4 110	(6)
9 Matimba	3 990	(6)
10 Matla	3 600	(6)
11 Tutuka	3 654	(6)
Nuclear		
12 Koeberg	1 800	(2)

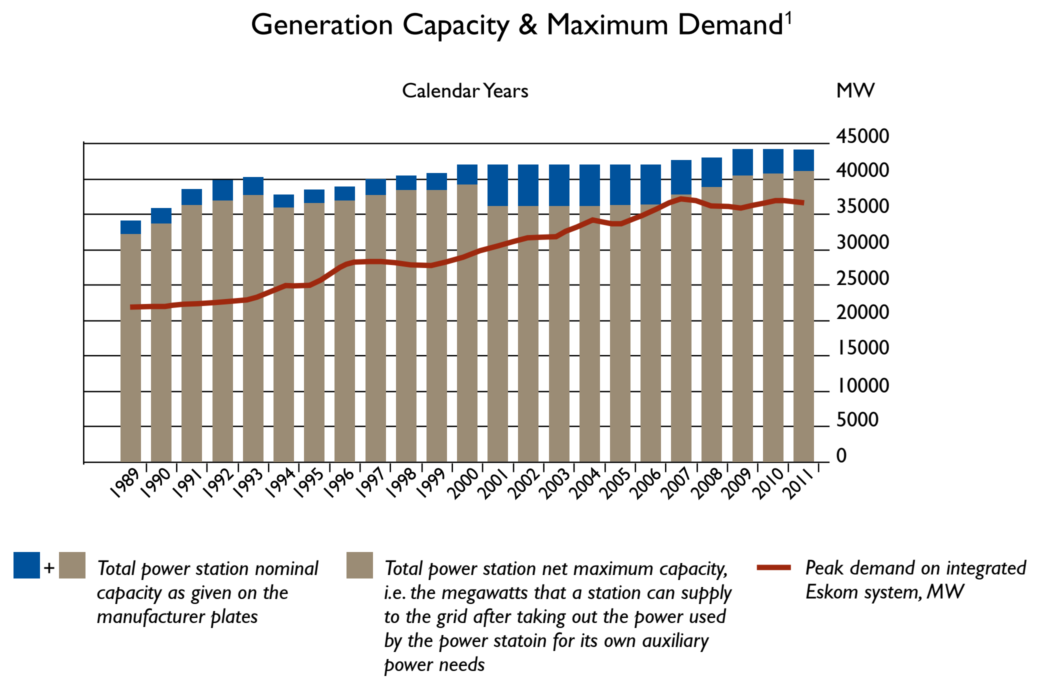
Renewable energy		
Windfarm	*MW (No. units)*	
13 Klipheuwel	3.2	(3)
Distribution		
Hydroelectric		
14 First Falls	6.4 MW	
15 Second Falls	11 MW	
16 Colley Wobbles	42 MW	
17 Ncora	2.4 MW	
National grid		

Peak demand stations		
Hydroelectric	*MW (No. units)*	
18 Gariep	360	(4)
19 Vanderkloof	240	(2)
Pumped storage		
20 Drakensberg	1 000	(4)
21 Palmiet	400	(2)
Open cycle gas turbine		
22 Acacia	171	(3)
23 Port Rex	171	(3)
24 Ankerlig	1 350	(9)
25 Gourikwa	750	(5)

Return-to-service		
Coal-fired	*MW (No. units)*	
26 Grootvlei	1 200	(6)
27 Komati	1 000	(9)
New build		
Base load, coal-fired		
28 Medupi	4 788	(6)
29 Kusile	4 788	(6)
Pumped storage		
30 Ingula	1 332	(4)
Renewables		
31 Sere Windfarm	100	(50)
32 Solar 1 (CSP)	100	(1)

Grid map and power station location for Southern Africa

As illustrated below, despite the aforementioned Eskom activities, South Africa has been experiencing a shortage of power generation since 2007 due to successful economic development and a rising demand for electrical energy.



Source: RT&D, Group Sustainability, Eskom

[1] *Data for the period before year 2000 was sourced from Eskom Statistical reports 1985-1996 and Eskom Annual reports 1985-2000. Data from the period year 2000-2010 was sourced from the Eskom Annual reports.*

South African power supply and demand since 1989

Consequently, an ambitious strategy was developed, in collaboration with the government, to "keep the lights on". The four main components of this strategy include:

1. improved energy management and energy savings in cooperation with customers;
2. improved asset maintenance to ensure early detection and correction of faults and inefficiencies to increase plant availability;
3. plant modifications for operation beyond their original design lifetime and fulfilment of new environmental regulations;
4. power supply growth through additional generating capacity development.

The following paragraphs briefly outline some of the current flagship projects under this strategy. Some of the projects were decided on approximately 10 years ago and are close to delivery.

Gas I (2442 MW)

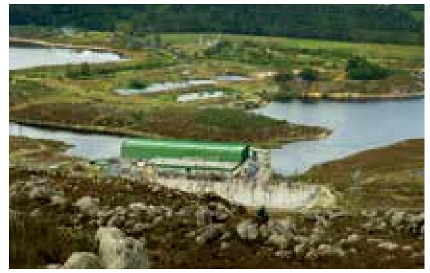
A number of open-cycle gas turbines (OCGTs) were added to the existing Ankerlig and Gourikwa sites in the Western Cape to meet peak load demands. The additional capacity of the Gas I project is 1 040 MW, which increases the total open-cycle gas turbine installed capacity to 2 442 MW.

Return-to-service Projects

A total of 23 previously mothballed coal-fired units at Camden, Grootvlei, and Komati Power Stations are close to being fully recommissioned and returned to service (RTS). Further modifications are needed to improve plant availability, reliability, and efficiency as well as compliance with new environmental regulations.

Ingula Pumped-storage Scheme (1332 MW)

Ingula is currently under construction along the escarpment of the Little Drakensberg, South Africa. The plant is a 4 x 333 MW reversible pump-turbine powerhouse that consists of the upper Bedford Dam and the lower Braamhoek Dam, which are 4.6 km apart and connected by underground tunnels.



Medupi Coal-Fired Power Station (4800 MW)

Medupi is a greenfield power plant project situated in Lephalale, consisting of six units, with gross nominal capacity of 800 MW each. This power station will be the fourth-largest coal-fired power plant and the biggest dry-cooled power station in the world.

Kusile Coal-Fired Power Station (4800 MW)

Kusile is the second-most-advanced coal-fired power plant project in Eskom after Medupi. Similarly to Medupi, the station consists of six units, each rated at approximately 800 MW. It will be the first power station in South Africa to utilise flue gas desulphurisation (FGD).

Sere Wind Farm (100 MW)

Sere, a key renewable energy project, located near Vredendal in the Western Cape, is near completion. This project will have a capacity of 100 MW, consisting of approximately 50 wind turbines spread over an area of 16 square kilometres.

Solar 1 (100 MW)

This concentrated solar power (CSP) project, located near Upington in the Northern Cape, benefits from the highest solar irradiation in the country. The plant is comprised of a heliostat field and power tower, circulating a binary salt mixture. Heat is transferred to a conventional water-steam Rankine cycle plant. Plant performance and efficiency will be determined on completion of the engineering studies.

Life extension of numerous plants

These on-going engineering studies need highly skilled reverse engineering and plant operation status to be conducted to ensure sound investment decisions. A large number of the existing 87 units that make up the present coal generation fleet require retrofits to adapt to new environmental legislation to reduce dust, sulphur dioxide, and nitrogen oxides emissions by 2015 and 2020.

Transmission and distribution grid improvements

Both the transmission and distribution grids throughout South Africa are currently being upgraded and developed. These improvements are crucial to meet the requirements of the increased power production. These improvements towards a smart grid will help reduce costs and improve efficiency.

Projections estimate power production to increase from the existing 44 GW to 75 GW of installed capacity by 2025, for which all available technologies can be applied, using wind, solar, coal, and nuclear generation methods.

The major driver for power generation from renewable energy resources worldwide is to reduce climate-change-causing carbon emissions. However, two other drivers are even more important in the current South African context: implementation time and funding access. Building large coal-fired or nuclear power stations can take a decade from the pre-feasibility study to commissioning, while wind farms and CSP plants can be planned, built, and commissioned in a much shorter time. Financing renewable energy power plants, as opposed to coal-fired and nuclear plants, seems less cumbersome, and funders will frequently accept lower returns on investment. The cost of electricity from renewable energy resources has decreased significantly over the last five years due to an increase in the roll-out of renewables over the last decade (economies of scale) and the general international economic downturn.

In order to comply with future demand, the large deposits of coal found in the northern regions of the country present an opportunity to develop clean coal technologies for baseload applications. Development of renewable energy technologies has already started in South Africa. Wind and, especially, solar resources will certainly play a larger role in the future generation mix, but the intermittent nature of these renewable energies will have to be thoroughly addressed. The cooling capabilities along the southern and western coasts, as well as the relatively long distance from the northern coal power stations, suggest further nuclear developments. All of these options form part of the future sustainable energy mix of South Africa.

Consideration of the power generation locations relative to the demand areas also needs thorough investigation to adapt and develop the transmission and distribution grids to fully master the power system dynamic behaviour under all conditions. A more distributed power system, as well as smart grids, will certainly play a major role in reducing the full system costs.

3 Bridging the skills gap

Eskom management has identified the skills required to effectively grow the power system as key challenges that need to be addressed urgently. The last large power generation unit was commissioned by Eskom two decades ago. The experts who were part of that build scheme have either left or are approaching retirement.

The current new build projects will last for the next couple of decades and will create real opportunities for skills development of new engineers. These projects reduce the dependency of the South African economy on foreign technologies and expertise, which presently are largely provided by foreign equipment manufacturers. The numerous graduate engineers recently employed by Eskom and its partner companies in South Africa need to be skilled to design, manufacture, erect, commission, operate, and maintain the new fleet of Eskom power plants and the transmission network.

For a power utility that deals with complex systems, it is essential that its engineers have a global overview of the systems and processes on which they work. It is also crucial that they fully understand and master the design criteria, quality of manufacturing, modes of operation, and quality of maintenance. These factors all impact the cost of electricity through capital expenditures, primary energy consumption, other operational and maintenance costs, and environmental impact.

The current EPPEI programme concentrates on improving the understanding of the global power chain over the complete lifetime of power projects, some of which last for more than a century, depending on the technology used. This requires a high level of postgraduate education at master's and doctoral levels. In order to achieve these goals, EPPEI is building a strong long-term partnership with academic institutions at the six lead South African universities to align their curricula to service the needs in the power industry.

On the one hand, the course curriculum of undergraduate students at university is being adapted to address the power generation and transmission systems to raise early interest in students in the energy field and encourage them to pursue postgraduate studies. On the other hand, the engineering research specialisation centres (SCs) funded by Eskom at the lead universities and their partner universities already constitute a strong body of knowledge and research for power activities at postgraduate level.

The annual target is for 60 Eskom engineers at bachelor degree level who have between two and four years' experience in the company to join the EPPEI programme full time for a two- or five-year period to obtain a masters or doctoral degree, respectively. Prior to registering at a university, they attend courses at the Eskom Academy of Learning (EAL) for four blocks of four weeks each during the course of one year. Once they have passed the exams, the students are allocated a research topic devoted to an Eskom problem and directed to one of the SCs at the lead or partner universities, where they carry out research under the auspices of an industrial mentor and an academic supervisor.

This research conducted by Eskom engineers is aimed at fostering the relationship between Eskom and university specialists. EPPEI management intends to establish cooperation between these SCs, the power system original equipment manufacturers (OEMs), foreign power utilities, and foreign universities (as seen in the table to follow).

Area of specialisation	Lead university	Partner university
Energy Efficiency	University of Cape Town (UCT)	Nelson Mandela Metropolitan University (NMMU)
Combustion Engineering	University of the Witwatersrand (Wits)	University of Johannesburg (UJ)
Emissions Control	North-West University (NWU)	Vaal University of Technology (VUT) & University of Venda (UVen)
Material Science	UCT	NMMU
Asset Management	University of Pretoria (UP)	Tshwane University of Technology (TUT)
High Voltage Engineering (AC)	Wits	VUT
High Voltage Engineering (DC)	University of KwaZulu-Natal (UKZN)	Durban University of Technology (DUT)
Renewable Energy	Stellenbosch University (SUN)	Cape Peninsula University of Technology (CPUT)

It is envisaged that the EPPEI structures will provide a skills development service to other Eskom partnering companies in South Africa and, later, to the rest of Africa.

It is worth keeping in mind that the power currently generated by Eskom makes up 40% of all power generated on the African continent. It is expected that this example of skills development in South Africa could become beneficial to the rest of Africa's 900 million inhabitants, a figure that should reach 1.8 billion three decades from now.

The EPPEI **structure**

4

EPPEI offers a compelling value proposition to three key stakeholders:

- Eskom employees

  EPPEI offers practical and professional postgraduate engineering education that provides the opportunity to deepen knowledge in a key specialisation area and, thus, create a clear career path for individuals.

- Local universities

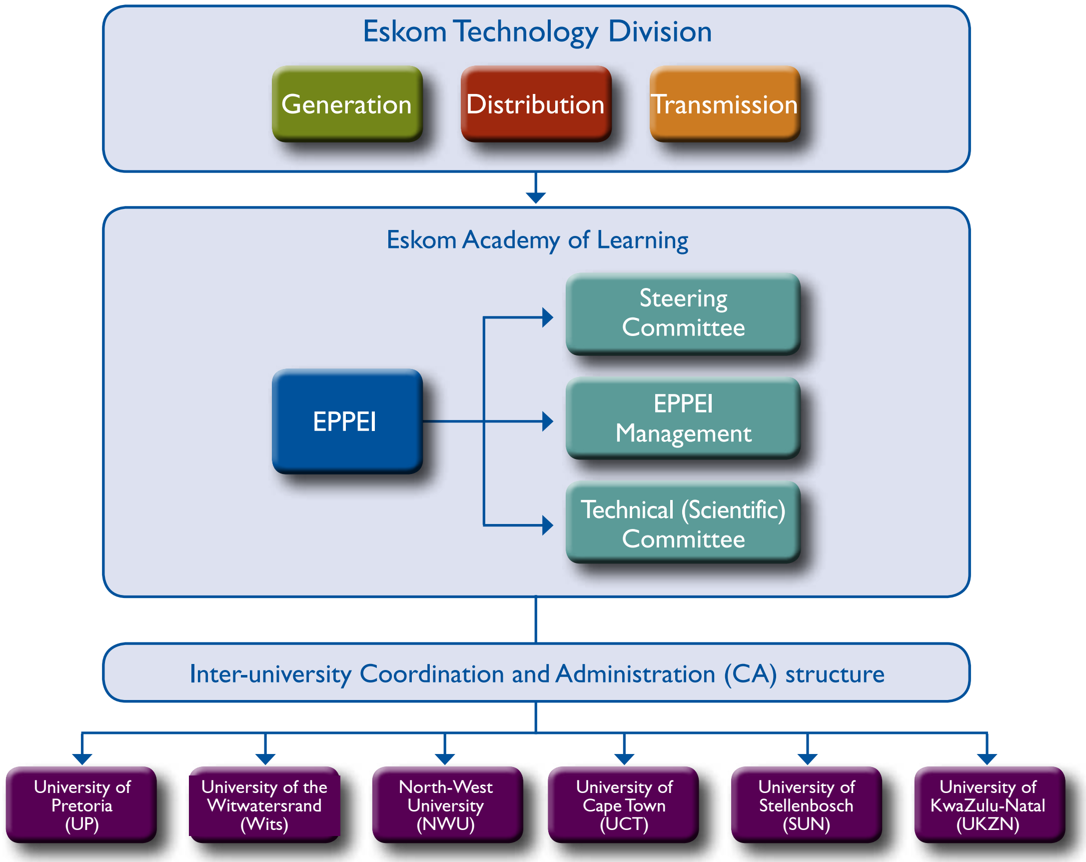
  EPPEI provides access to research funding and increased collaboration between different universities as well as between universities and industry.

- South Africa

  EPPEI can greatly increase South Africa's expertise base in selected technologies. This is in line with government's National Development Plan goal to gradually transform the economy into a knowledge-based economy, while simultaneously spawning a service industry around the power industry, thereby increasing earnings from technology exports.

4.1 EPPEI governance

The governance of the EPPEI programme is structured using a three-tiered approach, namely, a Steering Committee, a Technical Committee (these meet regularly), and a permanent Management Team. The Management Team is supported by the inter-university coordination and administration structure.



The six Deans of the lead universities serve on the Steering Committee. This committee is chaired by the Eskom Divisional Executive in Technology and meets annually to review its progress and give the general strategic orientation to the EPPEI programme.

The academic and industrial coordinators of the eight specialisation centres (SCs), Eskom RT&D management, EPPEI management, and the EPPEI Junior Enterprise serve on the Technical Committee. It meets twice a year and is chaired by the EPPEI Programme Manager. This committee addresses the course curriculum and the research programmes conducted at the Eskom Academy of Learning (EAL) in Midrand and at the EPPEI SCs, respectively.

The Management Team is an internal EPPEI body that organises and manages the EPPEI operation according to decisions made by the Steering and Technical Committees in agreement with EAL rules.

The members of the EPPEI Management Team

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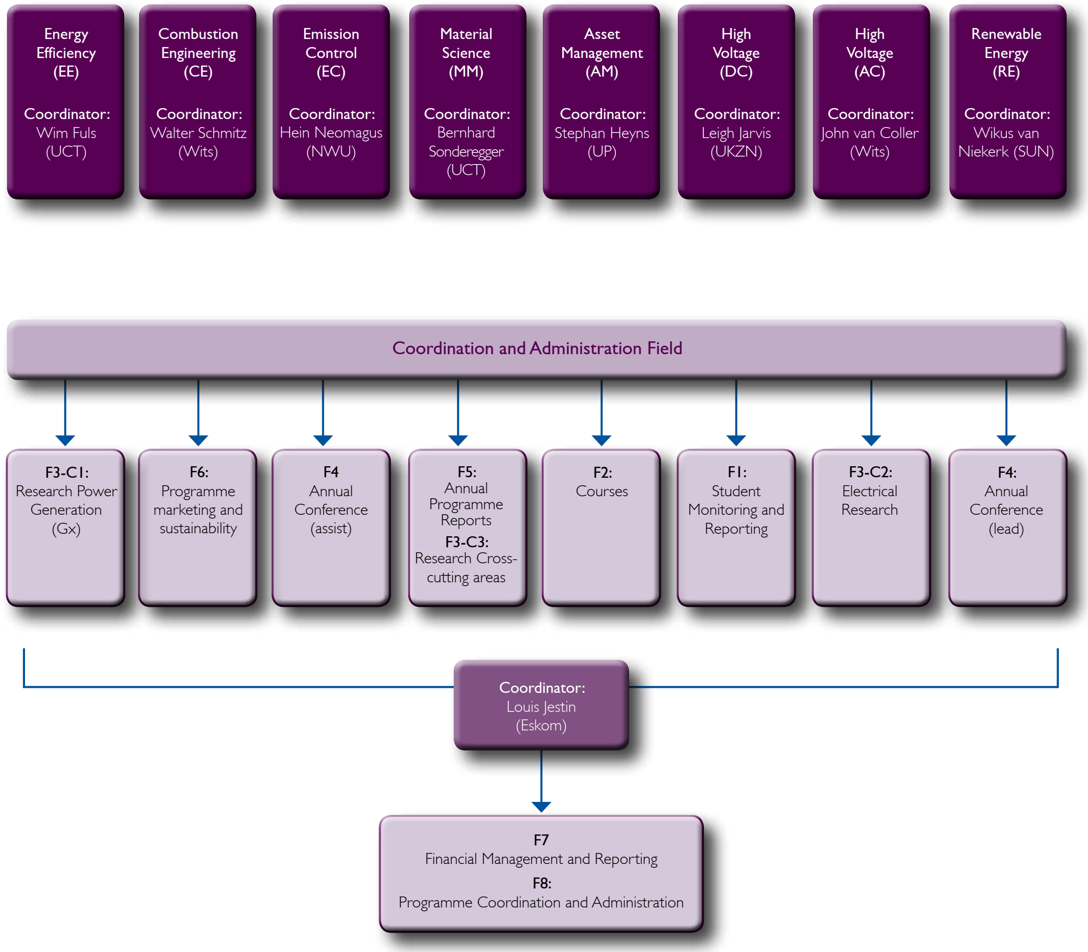
An inter-university structure has been created to support the EPPEI Management Team with the coordination and administration of the EPPEI programme. This structure was put in place to ensure that the EPPEI programme is sustainable in the long run as well as fully beneficial to all stakeholders. The eight university SCs will share the management and operation of the administration and coordination tasks as illustrated in the following schematic.



As the programme grows and relationships develop with foreign universities, OEMs, utilities, and related organisations, these will be included in the governing committees. It is envisaged that more structured and organisational work will be directly conducted at university level to make the structure self-sufficient and sustainable in the long run.

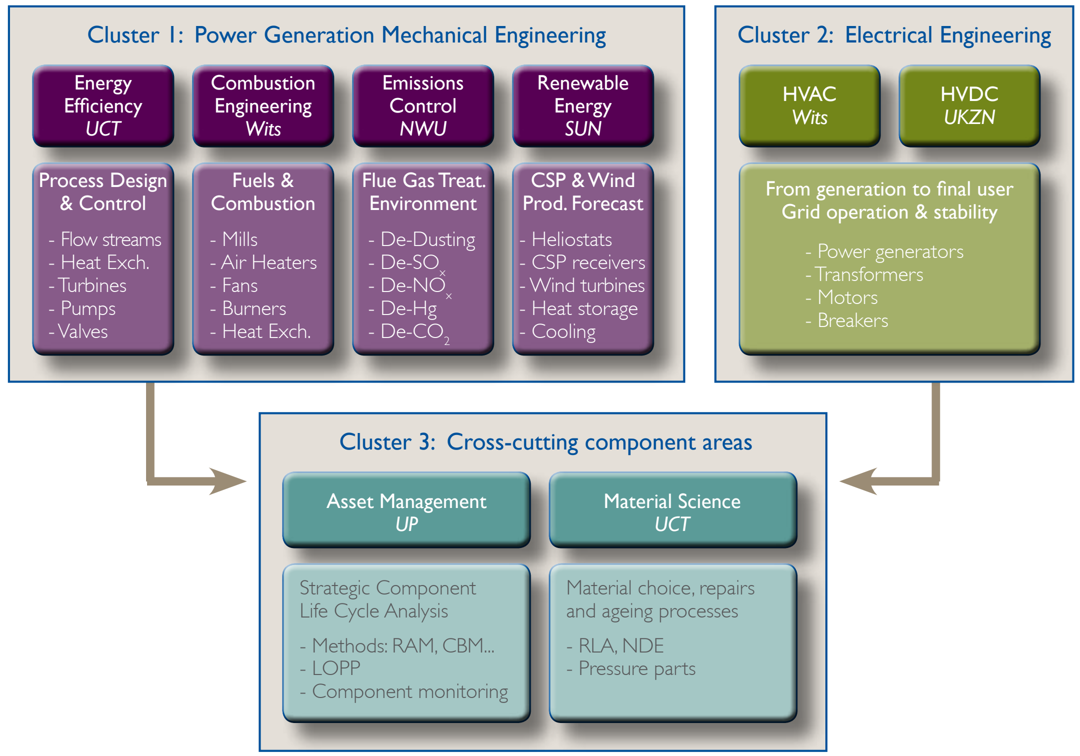
4.2 EPPEI research governance

It is essential that the research carried out at the SCs aligns with Eskom's engineering needs and also complements existing research carried out at Eskom RT&D as well as other academic institutions. To accurately identify these needs and report back on research conducted during previous years, an EPPEI workshop is held at the beginning of each academic year among the academic and industrial specialists, current EPPEI students, and representatives of previous student intakes. Eskom researchers and representatives from Eskom Centres of Expertise (CoEs) are key stakeholders at this workshop to ensure accurate definitions of Eskom problems and to structure resulting research to solve them. To facilitate organisation and reporting, this workshop is grouped and organised in three clusters:

Cluster 1: Power Generation (Energy Efficiency at UCT, Combustion Engineering at Wits, Emission Control at NWU and Renewable Energy at SUN)

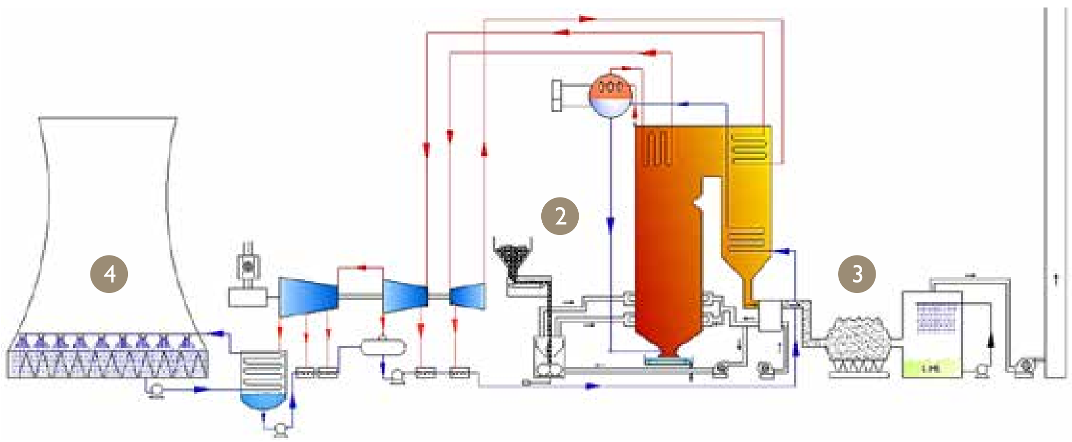
Cluster 2: Electrical Engineering (High Voltage AC Engineering at Wits and High Voltage DC Engineering at UKZN);

Cluster 3: Cross-cutting Engineering (Material Science at UCT and Asset Management at UP)



SO_x	–	Sulphur Oxides	RAM	–	Reliability Availability Maintainability
NO_x	–	Nitrogen Oxides	CBM	–	Condition Based Maintenance
Hg	–	Mercury	LOPP	–	Life of Plant Plan
CO_2	–	Carbon Dioxide	RLA	–	Remnant Life Assessment
CSP	–	Concentrated Solar Plant	NDE	–	Non-destructive Evaluation

The following schematic illustrates a power plant using a pulverised fuel (PF) Rankine cycle, which presently produces more than 90% of South Africa's electricity. The legend indicates the complementary nature of the SCs towards research for this type of power plant. The Rankine cycle power plant type, which is used for nuclear, gas combined cycles, and even CSP, produces more than 70% of electricity worldwide and constitutes the core part of the research for power generation in EPPEI at this stage.



1 **Energy Efficiency at the University of Cape Town** for the global water-steam and air flue-gas process design and operation monitoring in steady state and transient regimes.

2 **Combustion Engineering at Wits University** for the pulverised fuel combustion in the furnace and the heat transfer between the flue gas and water-steam circuit along the flue gas path.

3 **Post combustion flue gas treatment at North-West University** for removal of dust, sulphur and nitrous oxides.

4 **Plant cooling at Stellenbosch University** either by air dry or wet technologies.

5 & 6 **Electrical engineering at Wits and KwaZulu-Natal Universities** for the electrical component design, operation monitoring and maintenance.

7 **Material and Mechanical Engineering at the University of Cape Town** to take part in the proposal of most appropriate high temperature materials and to investigate the failure mechanisms and to propose repair strategies.

8 **Asset management at Pretoria University** to optimise the long term maintenance strategies of the strategic components of the plant.

Note: Numbers 1, 5, 6, 7 & 8 relate to the entire system.

Based on the Rankine cycle example of inter-university cooperation to achieve common objectives, that is, increased plant reliability, availability, and efficiency, further similar collaborative projects are being identified to reinforce this integration. The following topics are proposed:

Numerical tools development

This project will consider all numerical tools used and developed by students in the EPPEI programme at different universities. The students conducting research need to ensure that the software used in their projects is aligned with the software policy within Eskom. This project will ensure that tools in the following areas of research are centrally coordinated: computer-assisted design (CAD) tools, process flow modelling tools in steady-state and transient regimes, computational fluid dynamics (CFD), finite element analysis (FEA), engineering calculation tools, electrical component modelling, and electrical network modelling tools.

Plant performance and testing (P&T)

This group will ensure that measurements taken to evaluate plant performance are executed correctly. The group will ensure that any testing conducted during the EPPEI programme is in line with the processes used within Eskom. This project will form a central source of information on testing and will enable Eskom to standardise its protocols and develop skills in this critical field.

This project should also investigate improving the online monitoring of plants using the EtaPRO tool that Eskom is rolling out on all its pulverised fuel power stations. The new measurement techniques and monitoring tools should enable better condition monitoring of the plant for all main components.

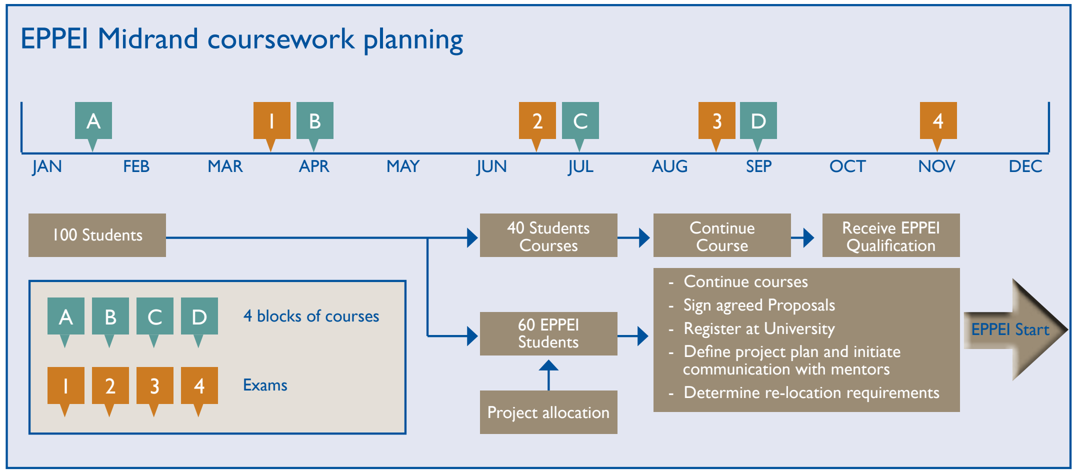
Generation-transmission coordination

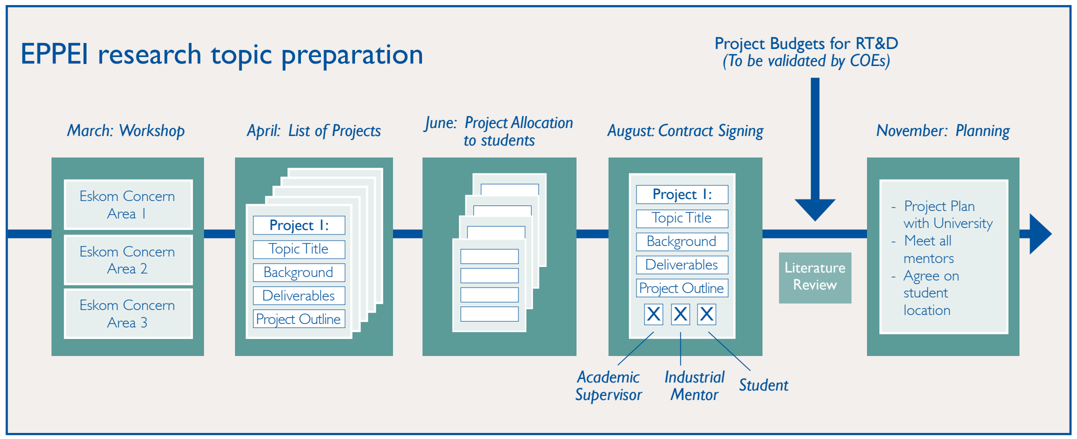
Eskom's vast electrical network is a constantly evolving system. The complexity of the network and its management should become another inter-university project, especially when more dispersed and remote renewable energy production is developed. This project will ensure that grid-related research is relevant to the needs of Eskom for improved dynamic stability behaviour and also provides detailed information for plant design and operation.

4.3 EPPEI course and research coordination

To fulfil its objectives, the EPPEI programme ensures that students are given academically challenging problems and courses that ensure that participants become well-rounded engineers. The course curriculum and research topic preparation were developed to ensure that the programme could be completed within two years for a master's degree and within three years for a doctorate degree. Programme recruitment begins one year prior to registering at university. During this recruitment period, Eskom employees complete four blocks of required coursework on a part-time basis that are required to start the programme.

As illustrated below, parallel to the course curriculum, the academic and industrial specialists develop research topics relevant to technical problems experienced by Eskom. These problems are identified through research completed by previous students and relevant operational problems that need to be resolved. Once Eskom's problems have been identified and the results of the previous years' research have been shared among the industrial and academic specialists during an early-year workshop, the academic specialists are responsible for the formulation of new research topics for the next intake of master's and doctoral (PhD or DTech) degree students.





The illustration on the previous page also shows the interaction between the course curriculum and project preparation. The research topics are proposed by mid-year to candidates who have successfully completed the first two blocks of EPPEI courses offered at the EAL. The research topics are allocated in close collaboration bewteen the Eskom and academic specialists and the relevant business line managers of the candidates. The specific engineering backgrounds of the candidates, such as electrical, mechatronics, mechanical, chemical, material, civil, etc., are taken into account.

Once in agreement, a three-party contract is signed between the candidate, the industrial mentor (a specialist in the research area), and the academic supervisor, who is also a specialist in the area, preferably from the university where the student will register. This agreement should be signed by September of the year prior to registration at the university where the research is going to be carried out.

4.4 EPPEI coursework

Courses must ensure that students understand topics at an academic level and build on this expertise through advanced courses in selected fields before starting their research. The courses need to ensure that students from all engineering disciplines have the opportunity to, firstly, further their understanding in the overall engineering subject matter and, secondly, further their understanding in their specific engineering discipline. Therefore the courses, offered by EPPEI at the EAL, serve the following objectives:

- refresh fundamental knowledge in physics and mathematics;
- establish basic development drivers, operation, and maintenance of power projects;
- understand basic design and operation criteria of power generation and transmission processes and components;
- familiarise engineers with everyday numerical tools processes and procedures used at Eskom.

The fundamental courses are mainly delivered by lecturers from the six lead universities, while the advanced courses can be delivered by industrial specialists from Eskom or EPPEI partner companies. These courses, which are listed in the next section, can be attended by individuals who are not directly enrolled in the EPPEI programme.

In order to address the weaknesses identified during the first intake of EPPEI students in 2012, the coursework has been restructured in four blocks of four weeks each, which are all delivered in the year before registration at university. The exam results from the first two blocks of courses form part of the selection criteria to screen prospective candidates for final acceptance into the EPPEI programme. These blocks are all delivered before candidates start their research at the various SCs. As illustrated previously, students who successfully complete the first two blocks of coursework are given a research topic mid-year prior to joining the relevant SCs. After completion of the EPPEI courses, students who will join Pretoria and Stellenbosch University are still required to successfully complete further courses before starting their research projects.

This gives students the opportunity to start a literature review, prepare a project plan, and gather the resources required for their research project. However, the successful completion of four blocks of courses is required before students can undertake their research degrees by full dissertation.

4.4.1 Coursework offered at EAL

Overview of the Power Industry (3 days)

The purpose of this course is to give learners an understanding of the Power Industry. The economics and efficiencies of the different generation technologies, including both traditional (such as coal-fired and nuclear) and renewables (such as wind and solar) will be taught. They will also be introduced to the planning and economics of the transmission and distribution segments of the electrical utility industry including the different national plans. This training aims to equip learners with a more holistic view of the power industry and how it has evolved.

Fundamentals of Engineering Mathematics (3 days)

The purpose of the course is to highlight and reinforce some of the common areas in engineering mathematics typically covered in an undergraduate engineering curriculum. Highlighted areas include: linear algebra, functions, calculus, differentiation, integration and ordinary differential equations. The course is structured around the electronic textbook: "Essential Engineering Mathematics" by M Batty. All students must have access to the textbook. The course serves as a refresher and is intended to provide a common mathematics basis for other courses in the EPPEI programme.

Life Cycle Management (2 days)

This course introduces the basic principles of the physical asset management process in a life cycle context. This includes an introduction of maintenance management fundamentals, management of equipment reliability, and optimising maintenance decisions. It focuses on condition based maintenance as a part of the maintenance decision process. The course is broadly structured around the textbook: "Asset Management Excellence" second edition, by Cambell J.D., Jardine A.K.S. and McGlynn J. The Eskom library is expected to have a number of copies of this book available for students to consult during their preparations.

Electric and Magnetic Systems (3 days)

This course gives a basic technical understanding of the operation of typical power system apparatus including transformers, rotating machines, and transmission lines. The course aims to provide learners with the fundamental knowledge of the apparatus and equivalent circuit representations, an essential tool in the engineers' toolbox. The course also aims to provide learners with the practical aspects and uses of the apparatus.

Material Science (3 days)

The course provides an overview of the factors which govern the mechanical behaviour of engineering materials, with particular emphasis on alloys for components in power plants. These factors include material composition, microstructure and service environmental parameters. The lectures include:

- overview of the classification of engineering materials;
- tensile testing and the stress-strain curve, elastic and plastic behavior;
- strain hardening, annealing, recovery and recrystallization of metals;
- classification of ferrous alloys, phase transformations in the Fe-C (steel) system;
- heat treatment of steels;
- strengthening mechanisms: work hardening, solid solution strengthening and precipitate hardening;
- materials under stress: failure and fracture toughness, leak before break;
- materials under stress: fatigue and environmental effects, creep behaviour.

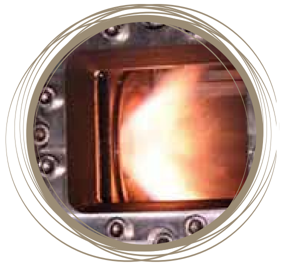
Microsoft Excel VB Programming (1 day)

The purpose of the course is to introduce learners to the use of functions in Microsoft Excel and the creation of user-defined functions and sub-routines in the Visual Basic for Applications (VBA) environment. This training aims to allow engineers to use Microsoft Excel to build numerical models of plant and equipment.

Statistical Science in Electrical Energy (2 days)

The intention of this course is to provide an overview of statistical sciences as applied to the Electrical Energy industry. The attendees will learn some descriptive methodologies in order to extract information from data. The emphasis, for this part of the course, is the ability to describe the behaviour of data by some statistical model(s). Some emphasis is also placed on the relationships between variables (e.g. how does the water consumption relate to the energy sent out by a thermal Power Station).

Thermo Physics (2 days):



The purpose of this course is to apply key thermodynamic concepts from the basic thermodynamics course. The main focus will be on the water/steam Rankine cycle. A step by step approach will be taken throughout this course, starting from a basic open loop to a more efficient closed loop Rankine cycle as used by the power generation industry. Thermal performance of cycle components such as pumps, turbines, steam generators, condensers, contact and non-contact feed water heaters, etc. are evaluated and integrated into the Rankine cycle. The (T-S) diagram will be introduced onto which the Rankine cycle can be plotted. It will give a better perspective into abnormal conditions as well as the ability to predict the impact of modifications. The purpose of this course is not an in-depth investigation into the field of thermodynamics, but simply to use its basic principles as a starting point for more detailed investigations.

Power Plant Chemistry (2 days)

The course teaches a basic understanding on water treatment and basic chemistry. The learner will understand water treatment as the production of demineralised water, control of water and steam cycle chemistry, oxygenated treatment, flow accelerated corrosion, air in-leakage, condenser tube leaks, boiler deposits and chemical cleaning, steam deposits, turbine preservation. In basic chemistry, learners will learn the fundamentals of phase diagrams, states, element classification, chemical mass and electrical balances, chemical reactions and kinetics, homogeneous and heterogeneous combustion, pollutant emission reactions (CO, CO_2, SO_x, NO_x, VOC, PAH, heavy metals), water treatment basic chemistry and corrosion mechanisms.

Eskom specialisation centre (SC) **Strategies**

5

- Eskom specialisation centre in **Energy Efficiency** at the University of Cape Town — www.uct.ac.za
- Eskom specialisation centre in **Combustion Engineering** at the University of the Witwatersrand — www.wits.ac.za
- Eskom specialisation centre in **Emission Control** at North-West University — www.nwu.ac.za
- Eskom specialisation centre in **Material Science** at the University of Cape Town — www.uct.ac.za
- Eskom specialisation centre in **Asset Management** at the University of Pretoria — www.up.ac.za
- Eskom specialisation centre in **High Voltage Engineering (AC)** at the University of the Witwatersrand — www.wits.ac.za
- Eskom specialisation centre in **High Voltage Engineering (DC)** at the University of KwaZulu-Natal — www.ukzn.ac.za
- Eskom specialisation centre in **Renewable Energy** at Stellenbosch University — www.sun.ac.za

EPPEI specialisation centre in Energy Efficiency at the University of Cape Town

"Spes Bona" – *"Good Hope"*

Strategic Plan

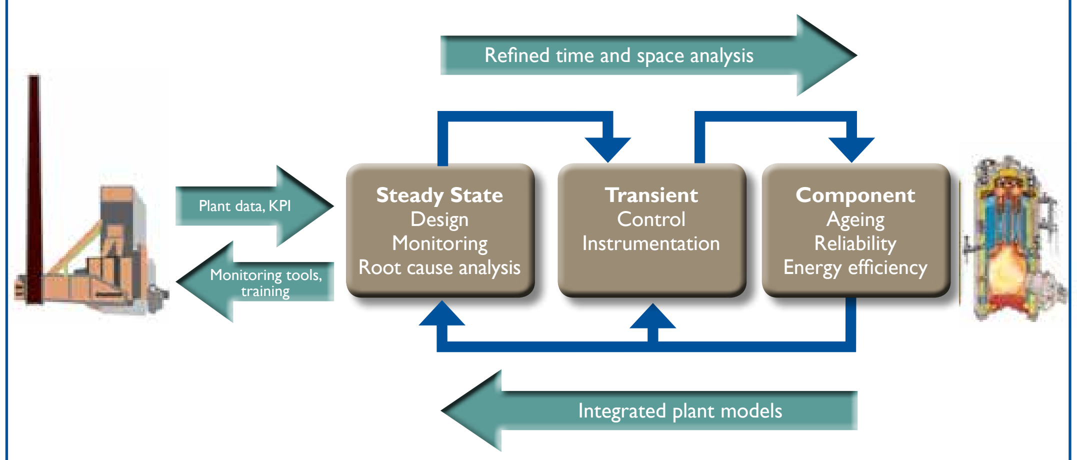
It is the aim of the SC in Energy Efficiency to develop skills and tools to improve the availability, reliability and environmental impact of Eskom power plants by increasing the efficiency of energy production. This will be achieved by focusing on complete plant process flow modelling and analysis.

Modelling will focus on the Rankine water-steam cycle, which is the main process common to more than 90% of all power plants in South Africa as well over 70% worldwide. The models will include all necessary control and instrumentation logic to enable steady-state and transient design analysis as well as normal and incidental operation analysis. The models will be physics-based rather than empirically based, using fundamental thermodynamic principles.

The modelling will be done in three different regimes, namely, steady state, transient state and component level. The steady-state models will mainly focus on plant design and normal operation, while the transient models will focus on transitions from one steady condition to the next as well as various control schemes. Refined component models of the fluid-structure interaction of some specific components will be developed and integrated in the steady-state or transient-state models, where needed.

It is envisaged that the developed plant models will serve as the integrator/federator for work done by other SCs within the EPPEI programme. Plant model outputs will serve as inputs to SCs requiring thermohydraulic process conditions. Further integration can be done with grid models developed at the two High Voltage Engineering SCs to eventually have a complete macrosystem model that could predict any scenario response on the national grid and its local influence on plants in terms of participation, availability and remaining life.

Finally, key plant performance indicators identified by this SC could be fed back to the online monitoring systems to better operate and maintain the current plants. The plant model will serve as a high-fidelity simulator to train operators, technicians and engineers in efficient use and design of power plants. This will improve the root cause analysis capability and the ability to conduct cost-effective trade-off studies of plant modifications or improvement.



Interaction between various levels of modelling and the plant

Research expertise and development areas

Steady-state process flow modelling

The SC will develop and validate detailed steady-state models of key power plant components and processes such as the water-steam circuit, fuel feeding, air-flue gas flows, etc. The steady-state models will serve as references for more complex transient models. The SC will also act as integrator for specific components currently under development in other EPPEI SCs, such as combustion models, flue gas treatment and cooling towers.

The developments will use commercial software that complies with the Eskom engineering tool policy and, in particular, that is utilised at existing power plants such as EtaPRO/VirtualPlant. Alternative and/or supplemental tools may be identified to enable more advanced steady-state analyses to be included in Eskom's toolset.

The development will assist in:

Engineering

- Front-end engineering design
- Conceptual and basic plant design
- Cost of electricity forecasting
- User requirement specification

Operation

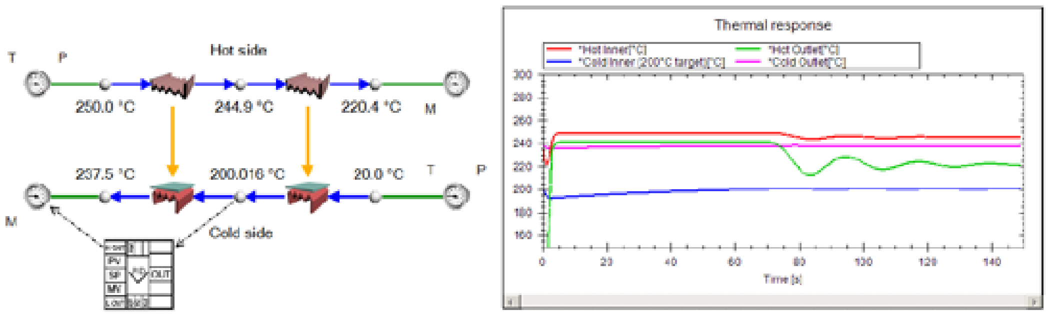
- Troubleshooting and root cause analysis
- Condition monitoring
- Energy efficiency monitoring
- Life cycle management

Transient process flow simulation

Dynamic plant models will be developed using the Flownex Simulation Environment, which is already included in the Eskom tools policy. It has sufficient capability to simulate complex transient process flow phenomena, including control loop characteristics, and allows for easy development and integration of custom-developed models.

These models will facilitate:

- analysis of the transient response of components under different scenarios;
- study of the philosophies of different control loops and PLC settings/tuning;
- evaluation of costs and benefits of increased plant operation flexibility;
- defining parameters to be implemented into the online plant monitoring;
- generation of thermal inputs to the materials and asset management SCs for damage analysis.



Example of a transient result of a heat exchanger containing a controller to achieve a certain set point temperature, implemented in Flownex

Component behaviour

More in-depth component refined modelling is, when required, devoted to explaining either the steady-state or transient suite of models. Reduced order models will be developed from detailed CFD analyses and checked against either real plant components or scale test facilities.

Component analysis may include:

- steam turbine performance characteristics;
- valve, pump, and fan performance
- boiler auxiliary components: mills, burners, and soot blowers;
- heat exchangers (condensers, cooling towers, air heaters, etc.);
- specific components derived from studies conducted in other EPPEI SCs, such as combustion system behaviour of coal power stations at Wits, the plant cooling system at SUN, flue gas treatment at NWU, and electrical machines at UKZN and Wits.

Academic-industrial relationship development

Universities

- Wits – combustion (boiler heat transfer parameters)
- SUN – process modelling of cooling systems
- UP – asset management (life cycle input data from steady-state and transient models)
- UCT – materials science (provision of component operational data for material analysis)
- Foreign universities could be contacted for relevant exchanges, such as the University de Toulouse (France) for poly-phase solid-gas CFD analysis.

Original equipment manufacturers (OEMs) and utilities

The OEMs of power plant components – Hitachi Power Europe, Alstom, Steinmüller Engineering, Howden, Siemens, Babcock, etc. – will be contacted in the early stage of development of the SC in order to not reinvent the wheel, but to collect know-how and to foster it through IP development. Utilities suppliers such as EDF (Électricité de France) and STEAG will also be contacted to collect information and capture their experience in operating in a European environment.

Industry partners

Collaboration with companies that master information and tools required for development. ESTEQ/M-Tech/Samanshi will train EPPEI students and participate in new implementations using the Flownex modelling tool. General Physics, developer of EtaPRO, is to participate in expanding the online monitoring of plants.

Hardware

A mini steam plant (9 kWth) will be designed and constructed using commercial components to verify the transient modelling capabilities. It will also serve as a training platform for engineers in the design, construction, and operation of the Rankine cycle.

Developing university partner

As part of a collaborative agreement, Nelson Mandela Metropolitan University is working on a research project entitled "Modelling and Simulation of the Control of Power Generation Plant Processes and Systems". The research project is focused on investigating power plant energy improvements attainable through advances in the field of control and instrumentation within power generation plants. Particular emphasis is initially being placed on the main control loops in coal-fired power plants, with the aim of generating a model in SysML of a plant controller for research and educational purposes.

EPPEI specialisation centre in Combustion Engineering at the University of the Witwatersrand

"Scientia et Labore" – *"Through knowledge and work"*

Strategic Plan

Measurement and instrumentation equipment installed on key components in the full combustion systems is quite limited and sometimes inaccurate in existing plants. Additionally, control devices have drawbacks and inaccuracies, which complicate control of the operation set points of components and sometimes control of total boiler behaviour. It is, therefore, difficult to monitor the combustion system online for early detection and diagnosis of abnormal situations that cause unreliable and inefficient operation.

Local environmental standards require implementation of NO_x reduction technology in all existing and new-build plants. The low-NO_x burner operation requires accurate coal and air flow measurements for optimal control due to its operational limits and the variations in coal quality and the need for load shifting of Eskom plant.

An urgent need exists to improve measurement and online monitoring of:

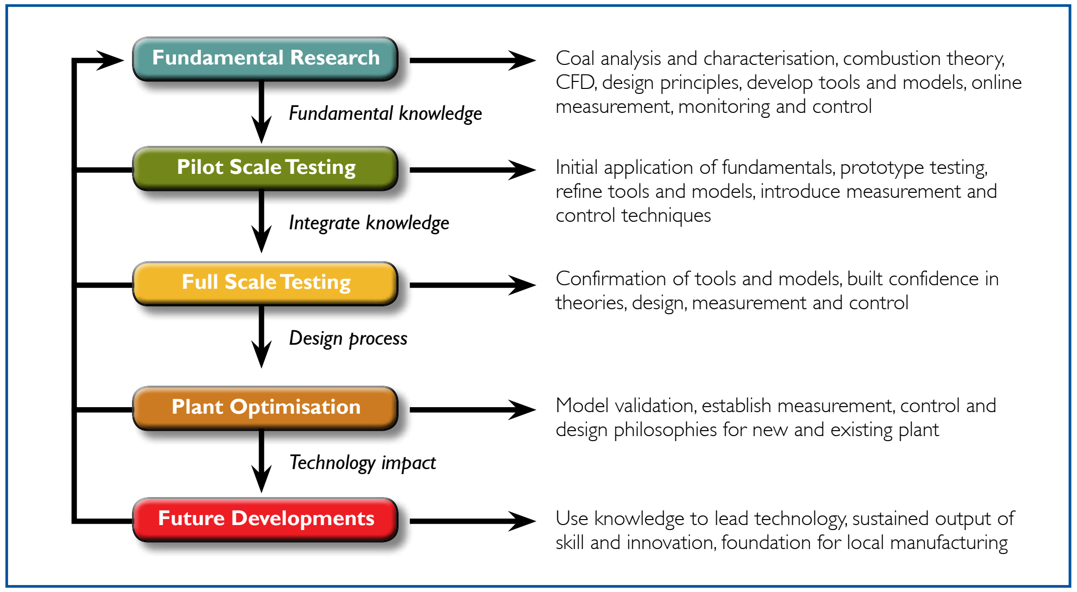
- coal mass flow and coal quality, especially ash and moisture content;
- milling plant performance to control fuel/air ratios, particle size, and mass flows;
- air streams to wind boxes, burners, and air heaters;
- heat transfer from flue gases to the air and water-steam circuit.

Pulverised fuel (PF) boiler showing four burners in operation during plant start-up

The SC strives to improve understanding of local coal impact and predicting of the effects on coal-fired power plant. Research is focused on current Eskom requirements to:

- improve and grow a repository of skills and knowledge of existing plant;
- create skills and tools to design, operate, and maintain plants;
- ensure that future plants are cleaner, available, reliable, efficient, and safe (CARES);
- achieve world-class output in combustion engineering-related technologies;
- retain a highly skilled engineer base in Eskom to create a healthy fleet for current and future power generation using state-of-the-art technology;
- host the combustion system design intellectual property purchased by Eskom;
- attract local manufacturers to build and supply burners for the local market;
- provide a continuously improved bouquet of experimental facilities in heat transfer, combustion technology, and thermodynamics.

To achieve its goals, the SC embarks on an applied research method ranging from fundamental research to pilot-scale and full-scale testing, which is then taken to implementation and further development, as outlined in the research flow chart.



Research expertise and development areas

Coal quality has a marked effect on boiler plant operation, from entering the system to the final disposal of ash. The envelope of research is characterised by plant components such as:

- milling plant and PF piping;
- air heaters, fans, and ducting;
- pulverised fuel and oil burners; and
- boiler internal heat exchangers.

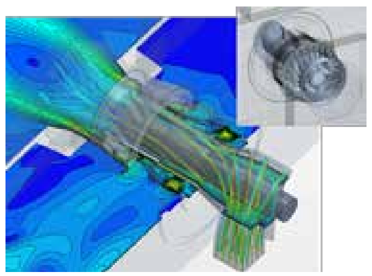
Milling plant and pulverised fuel (PF) piping

Coal combustion requires a steady stream of known quality and quantity of pulverised coal. To ensure consistent combustion performance, measurements and process controls need to be in place. The plant is subjected to high wear rates due to the use of high-ash coal, which causes a steady decline in mill performance. The goal is to establish a methodology for a mill health monitoring system (MHMS) to identify mill conditions for improved operation and required maintenance prediction. Pneumatic transport of coal particles is an important aspect in coal delivery to burners and often causes maldistribution and mass flow fluctuations in the piping system. To fully understand the mechanisms influencing flow behaviour, it is necessary to model the PF transport system. This can be achieved by means of a two-phase flow CFD analysis. In addition, measurement systems need to be identified, tested, and implemented to measure the mass flow of air and particles and, possibly, the size distribution of particles flowing through the PF pipes.

Air heaters, fans and ducting

Eskom's air heaters suffer from excessive air leakages, corrosion, erosion, and blockages. Accurate measurement of flow rates, velocity, ash, and temperature distribution, as well as gas species distribution in the ducting and air heater itself, is necessary. Empirical performance and CFD models need to be developed to study the impact of air leakage, acid dew point, thermal performance, as well as gas and ash distribution. Measurements are often difficult due to large duct sizes and complex duct configurations. Better on-site measurement techniques will be developed and implemented for improved accuracy in performance testing concerning the boiler plant, in general. Improved monitoring of draught groups and induced and primary air fans is needed to avoid catastrophic failures and develop maintenance schedules based on real conditions for improved efficiency.

PF and oil burners



Low-NOx burner simulation results

South African power stations are currently implementing low-NO_x burner technologies to meet more stringent emission limits enforced by government legislation. Design and operation of burners have to be well understood. The influence of mass flow fluctuations and changes in coal quality on flame stability, pollutant formation, and combustion efficiency needs to be studied for suitable burner design, manufacturing, tuning, monitoring, and operating philosophies. The combination of poor coal ignition characteristics, lack of measurement, poor plant condition, and insufficient control leads to excessive and undesirable use of oil burner support. Once the relative influences of key parameters have been understood, the research focus will be to determine the required level of measurement accuracy on coal and industrial burners. The SC will facilitate development of an online combustion health monitoring system (CHMS) using EtaPRO, which is implemented in all Eskom's coal power stations

Boiler internal heat exchangers

Energy released from combustion is transferred from combustion products to various heat exchangers to heat water, steam, and air along the gas path. Heat transfer surfaces are exposed to high-temperature corrosion, fly ash erosion, tube external slagging and fouling, scaling, as well as oxidation and flow-accelerated corrosion within tubes. This can lead to tube leaks and consequent unavailability, reduction in efficiency, and load losses. In order to better monitor and operate the boilers to limit these degradation mechanisms or detect them early, the condition and performance of heat exchangers, temperature, and flow measurements on the gas and steam side are required. The research will validate and use tools such as DIMBO and CFD to allow quick and reliable investigation into the current performance of the boiler internals and propose measurement and monitoring techniques to be applied.

Academic-Industrial relationship development

Eskom's RT&D unit in the Eskom Sustainability Division plays an important role in combustion research.

South African universities

- UCT and Wits – both universities will carry out projects in system efficiency and control implementation; Wits will provide CFD solutions to compare to UCT's two-phase flow test loop results using PF instrumentation
- NWU – coal quality assessment and supply rate specifications for devolatilisation and coal combustion
- Wits School of Chemical Engineering – conducting of coal analysis and classification
- UP – development and installation of measurement techniques to monitor the erosion and vibration of fans

Foreign universities

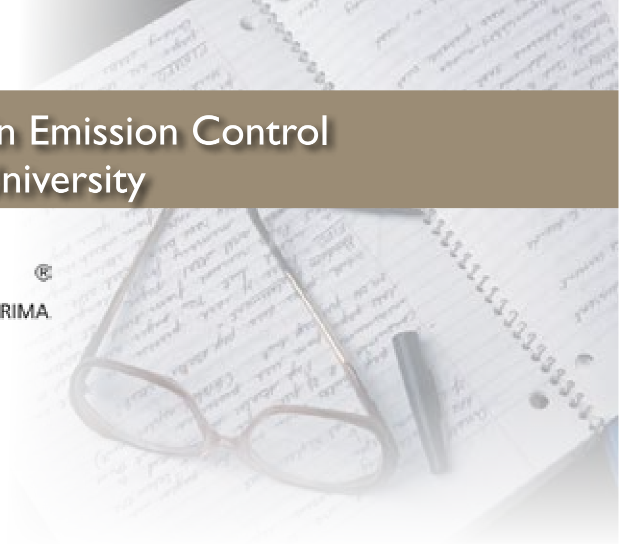
- INP Toulouse – dense two-phase flow simulations using the NEPTUNE code developed at IMFT

OEMs and industrial collaboration

- Laboratory coal testing – Eskom RT&D (DTF and PSCTF), Hitachi (Japan), IFRF (Italy), and CRIEPI (Japan)
- Full-scale tests, applied research, and technology implementation – Eskom Generation, EDF (integration of the SATURNE code)
- Low-NO_x burner designs - Steinmüller, Doosan Babcock, Hitachi, Alstom etc.
- Full-scale industrial laboratory burner tests - Doosan-Babcock (UK), XCC (China), etc.
- Full scale tests, applied research and technology implementation – Eskom Generation, EDF (integration of the SATURNE code)
- Low-NO_x burner designs – Steinmüller, Doosan Babcock, Hitachi, Alstom etc.
- Full-scale industrial laboratory burner tests – Doosan-Babcock (UK), XCC (China), etc.

Developing university partner

A partnership between Wits and the University of Johannesburg (UJ) is being formed. It is envisaged that UJ will focus on industrial flow measurement and performance testing. The collaboration aims to improve measurement accuracy to evaluate the current state and performance of the plant and implementation of online process flow measurement. Course material will be prepared to teach fundamental knowledge on industrial flow measurement. A framework for a comprehensive training program to train Eskom staff will be established, with the intention of integrating with the greater EPPEI training program. Research into new or alternative measurement systems will be conducted. The aim is to improve the online measurement methods during routine performance testing and propose procedures and guidelines that will enhance the relevance and accuracy of these measurements.



EPPEI specialisation centre in Emission Control at North-West University

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

"Innovation through diversity"

Strategic Plan

Eskom operates coal-fired power stations, which emit approximately 230 million tons of CO_2 and more than one million ton of SO_2 into the atmosphere annually. International pressure and local legislation controlling pollutant emissions such as SO_2, particulates, and NO_x have become more stringent over the past decade.

Emissions control must be considered to optimise and, if necessary, modify old technology to perform beyond design capabilities for the existing fleet and ensure that plant emissions meet increasingly strict standards that have been set by government for new power stations currently under construction. The primary focus of this SC is (i) to understand existing emissions of SO_2, NO_x, CO_2, Hg, and particulates into the local atmosphere from power stations and (ii) to research and develop effective pollution mitigation technologies for the retrofitting of current processes.

In addition, the SC will work closely with Eskom and OEM technology providers to ensure that new power plants meet future emission requirements. The main objectives are, therefore, to ensure that Eskom is at the forefront of understanding emission mitigation technologies to limit the total emissions into the atmosphere from its processes without making electricity unaffordable within the South African context.

Stack emission monitoring

Research expertise and development areas

The SC focuses on monitoring and quantifying emissions and evaluating the impacts of emissions related to power generation by coal-fired power stations in South Africa. Furthermore, existing emission control technologies are analysed and modelled and solutions brought forward for improved operation, guaranteeing sustainable power generation in the short term and the future, with minimum impact on the environment.

Emission quantification and emission impacts assessment

The implementation of emissions standards have to be coupled with accurate particulate and gaseous emissions measurement. Eskom has, over the past five years, continuously monitored the emissions from many of its stacks using various technologies, collectively called continuous emissions measurements (CEMs). CEM technologies are well established in developed economies such as the USA and Europe. The challenge with CEMs, however, is ensuring that measurement results accurately reflect emissions. This requires a well-structured calibration programme and existing measurement verification. The SC will work with Eskom to achieve the highest standards of CEMs to ensure that all emissions are quantified and understood.

Modelling the impacts of emissions from Eskom

Eskom is the single largest emitter of criteria pollutants such as SO_2, NO_x, CO_2, and greenhouse gases. Emissions must, therefore, be quantified and their impact on human health and the environment evaluated. Ongoing evaluation of Eskom's emission contribution and the impact on air quality, especially around the new coal-fired power stations, is vital to potential non-compliance scenarios and to determine emissions standards on stacks. In this regard, dispersion modelling is an important tool to assess the contribution of all pollutants to the prevailing air quality. The validity of results is highly dependent on monitoring quality of emissions and meteorological input data. The relative contribution of Eskom to air quality degradation can only be accurately assessed if emissions are well quantified and the ambient air pollution apportioned to all contributing sources.

Emissions offsets

Currently, particulate matter (PM) emissions from domestic burning are the most serious health risk to the South African population, especially in townships where coal and wood are burnt for cooking and space heating. Implementing high-cost emissions abatement measures on Eskom stacks is not likely to improve air quality in South Africa for the majority of high-risk individuals over the next decade. As a result, emissions offsets could be an option, where low-emissions technologies are introduced in the domestic setting to dramatically decrease PM emissions. As such, all aspects of emissions offsets will be considered over the next five years as part of the emissions control activities.

Process emission control

The ultimate aim of this SC is to limit coal-fired power-station-related emissions according to legislation and to minimise effects on humans and the total biosphere. Emission of particulate matter currently has the largest impact on the health conditions of South African citizens, and particulate control is, therefore, most important, followed by (in order of priority) SO_2 removal, NO_x removal, CO_2 removal, and Hg removal, as discussed in more detail in sections 1 to 4 on the following pages.

Measurements and monitoring for process evaluation and control

Effective operation and evaluation of unit process performance for emission control can only be achieved through accurate measurement of relevant variables: temperature, pressure, flow rate, gas/coal/ash composition, particle size, and particulate content. The measurements require accuracy, reliability, and robustness and should preferably involve advanced online instrument technologies. The strategy of the SC is to (i) evaluate the status of the current instrumentation for particulate control and de-SO_x processes and (ii) investigate the implementation of modern monitoring systems.

Coal and ash characterisation

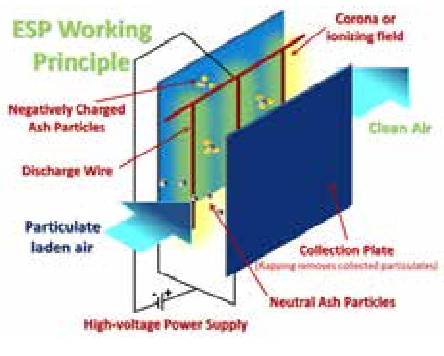
Since the vast majority of the electricity in South Africa is generated from coal, the characterisation of coal and coal ash is an important tool in understanding and reducing emissions. The coal used for power production varies from most northern hemisphere coal in that most coal is inertinite-rich and has relatively high ash content up to 40%. The combination of these two factors is thought to cause a different ignition and combustion pattern, which, in turn, could result in increased NO_x emissions. The relatively large ash content is an additional contributor to increased particulate emissions, and the composition and forms of the ash influence downstream particulate collection. Ash analysis techniques are, therefore, also used as tools for process emission control.

1. Desulphurisation

Research will consist of developing advanced CFD models (two-phase flow) for relevant desulphurisation processes based on accurate laboratory evaluation of associated adsorptive, absorption, and reaction rate properties of the sorbents and solvents used. The laboratory evaluation of the dissolution and reaction kinetics of limestones and other calcium (Ca)-containing minerals for the wet flue gas desulphurisation (FGD) process involves detailed characterisation of typical South African limestones and coal ash and the determination of reaction and diffusional rates under plant conditions. For the development of dry FGD processes, laboratory experiments consisting of minerals characterisation and resulting transformation, coupled with reaction kinetics, will be elucidated. Advanced process models are being developed for both wet and dry desulphurisation processes.

2. Particulate control

The majority of Eskom's coal-fired power stations make use of electrostatic precipitators (ESPs) as a control system to capture particulate emissions. With the use of low-grade coal, large quantities of ash are produced that require effective removal to limit fine particle release into the atmosphere. To improve the efficiency of ESPs in controlling particulate emissions, knowledge of (i) ash resistivity, which depends mainly on the chemical composition, (ii) flue gas flow patterns within the ESP units, and (iii) electrical field strength required for effective precipitation will be required. The various aspects affecting ESP performance will be combined in a suitable process model, the development of which will be aided by the use of CFD modelling. In addition, fabric filter plant (FFP) units will be studied, in which coal and ash fundamentals are combined in fundamental and applied process models.



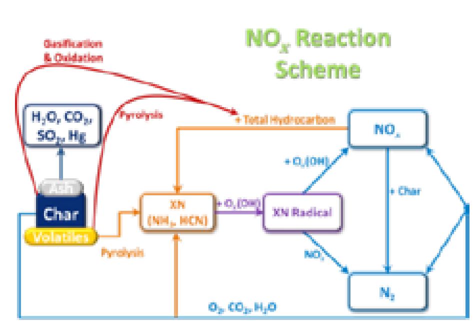
Principle of ESP

3. Carbon dioxide capture and mercury control

The SC will follow the latest technological trends in CO_2 capture and Hg control by actively participating in specialised conferences and forming key associations with world leaders in these fields in order to incorporate existing technology in a very short time when required by legislation or strong impact.

4. Denitrification

Laboratory results will be generated for low-NO_x burner modelling and will involve evaluation of a complex kinetic model using a drop tube furnace and thermogravimetric analysers. Detailed equations with relevant kinetic parameters will be evaluated that are suitable for incorporation in the CFD models developed by the combustion engineering SC at Wits. Coupled with this investigation is the advanced molecular study of NO_x generation, involving the tracking of nitrogen compound liberation during coal devolatilisation using advanced analytical techniques.



Reaction scheme for nitrogen oxides

Academic-industrial relationship development

In the SC, fundamental and applied research is combined to understand and reduce emissions to the environment. Emissions and processes are monitored with advanced analysis equipment and modelled using state-of-the-art software packages. Process emission control is implemented by a combination of i) a thorough characterisation of the solid materials and ii) using computational modelling techniques to describe emission controlling process units to ultimately validate and optimise the current processes. Evaluating the impacts of the emissions on the atmosphere and biosphere will also form a core activity of the centre. This will be achieved through in situ and remote sensing monitoring and modelling activities. This broad approach requires strong networks, and the following academic and industrial partners have been identified for collaboration:

- **South African research partners:** Vaal University of Technology, University of Venda, Wits, UKZN, Eskom RT&D, and UCT.
- **International research collaborations:** International Energy Agency, National Center for Atmospheric Research - USA, NASA, Naval Research Laboratory, - USA, and Pennsylvania State University.
- **OEM and industrial collaborations:** Alstom, Hitachi, Steinmueller Engineering, and Électricité de France.

Developing university partners

A laboratory has been developed at the Vaal University of Technology (VUT) for the determination of the properties of sorbents for both wet and dry flue gas desulphurisation, relevant to elucidation of the chemistry and reaction kinetics involved. The CFD modelling of a dry FGD/CFB process is also being investigated. Collaboration has been established with the University of Venda for joint research projects to investigate the indoor and outdoor exposure of rural and township residents to particulate matter emitted from domestic burning.

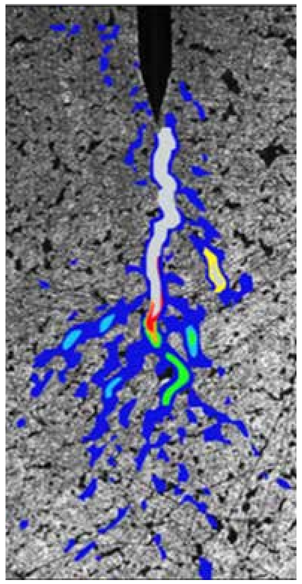
EPPEI specialisation centre in Material Science at the University of Cape Town

"Spes Bona" – *"Good Hope"*

Strategic Plan

Power generating plants operate under highly demanding conditions that include high temperature, high stress, oxidation and corrosion, and complex tribological environments. In its most basic form, plant reliability is critically dependent on the integrity of a broad range of engineering materials (mostly metals) that make up structures, machines and systems within the plant.

Given the anticipated plant life-time, material integrity is expected to remain within the design performance for periods often in excess of 300 000 hours. Consequently, accurate characterisation of the material condition with regards to the damage level, and prediction of the damage that occurs during exposure to operating conditions, and concomitant loss in design properties, is necessary. The situation is further complicated by repair activities, particularly those involving welding, that alter existing materials and could disadvantage integrity.



Damage and cracking indicated with Digital Image Correlation.

New material developments are required to handle these challenges and an industry must be developed to manage the use of new materials during design, construction and maintenance while existing plants continue to produce the most energy at the lowest cost.

The SC activities are directed towards the most urgent challenges in this field. The focus is on high temperature behaviour, fatigue and corrosion, with emphasis on materials utilised in power generation. Research will explore the influence of service operating environments on performance in order to:

- better predict life of engineering materials and components in power generating plant;
- optimise material selection for plant construction, improve manufacturing technologies including welding;
- improve the reliability of material and component integrity monitoring.

Research expertise and development areas

Seven focus areas have been identified by Eskom:

- physical metallurgy and metallography;
- structural integrity;
- high temperature behaviour (including creep and fatigue);
- environmental degradation (including corrosion);
- welding metallurgy and processes;
- materials modelling;
- non-destructive evaluation (NDE).

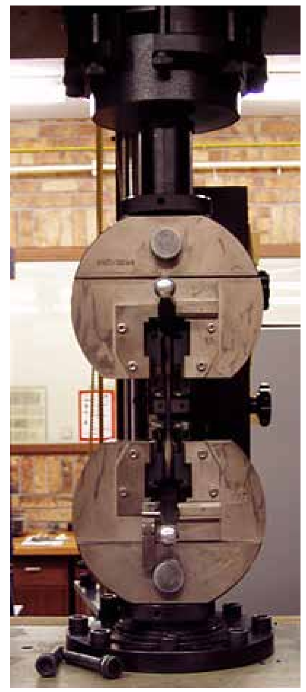
The principle research objective lies in integrity management of a range of materials within Eskom's fleet. As such, the key aspects are monitoring and understanding, modelling and predicting of prevalent material damage mechanisms. Detailed research questions include creep life assessment of metal alloys and welded joints, fracture and fatigue measurement and modelling of boiler tubes and other high temperature components, stress corrosion cracking (SCC), creep rupture properties of advanced materials, the welding thermal cycle effect on service properties and the use of NDE to assess and monitor material integrity and remnant life. The research is categorised in three major parts: (i) sample allocation and materials testing, (ii) investigation and understanding of microstructural processes, and (iii) modelling of material behaviour.

Sample allocation and material testing

Prior to microstructural investigations, sample material allocation is essential. Specimens are either extracted directly from damaged power plant components or prepared in test facilities that mimic component temperature, stress or environment. Weldments and heat affected zones of base material are produced by actual welding or thermo-mechanical simulator experiments.

The specimens form the basis for a wide range of mechanical testing; yield strength, hot strength, micro- and macro-hardness, embrittlement and fatigue. These analyses can link microstructural features with actual mechanical properties and contribute to understanding material property degradation.

This knowledge is essential in the application of NDE and online monitoring of power plant components.



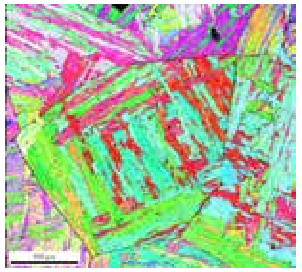
Universal testing rig

Investigating and understanding microstructural processes

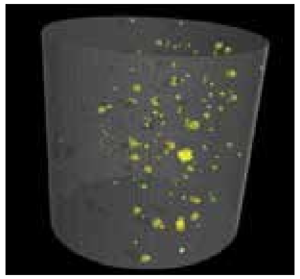
The SC is investigating the microstructural evolution, damage and degradation processes. Research topics relevant to the long-term material behaviour include elements ranging from the micro- to the macro-scale:

- **micro-scale:** dislocation densities, (sub)grain boundaries, precipitates and pores;
- **meso-scale:** pores, grains, micro-cracks and local depletion of alloying elements;
- **macro-scale:** inhomogeneous microstructures (weldments), cracks and oxide layers.

It is vital to understand the fundamental mechanisms of damage accumulation using novel materials characterisation techniques. Since damage can be in the form of voids, cracks, inclusions, etc., the focus is on the development of quantitative characterisation. A variety of microscopy techniques is necessary for a comprehensive investigation of the degradation process including electron microscopy which can either be conducted directly at UCT's Centre for Materials Engineering or in collaboration with industrial partners and university facilities, such as Eskom Research and Innovation Centre (ERIC) or the Nelson Mandela Metropolitan University (NMMU).



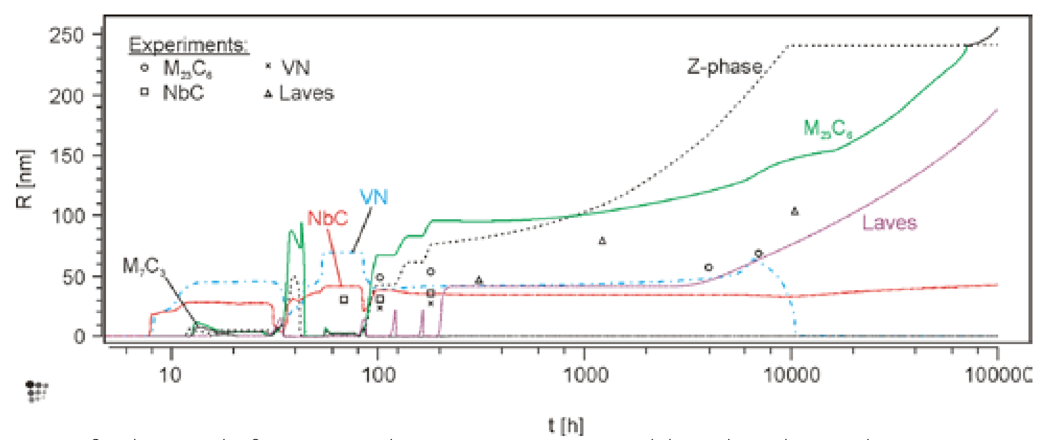
Grain structure measurement using electron diffraction



Porosity measurements using X-ray tomography

Modelling material behaviour

Integrity assessments can only be achieved by modelling damage mechanisms and failure processes. Accurate prediction of both local material degradation and global damage and macroscopic mechanical properties based on real-life material defects within a complete process of damage evolution, is vital. The SC will also model creep, fatigue (thermal, corrosion and mechanical) and stress corrosion cracking.



Simulation result of precipitate evolution in a creep resistant steel during thermal power plant service

One strategy is to improve phenomenological models for material degradation to provide fast and straightforward prediction of remaining component life. To increase model accuracy and flexibility with regard to material compositional changes or varying heat treatments, microstructural modelling has to be done first. Appropriate models for precipitate evolution already exist and can act as the core for the development of more complex models, including dislocation movement, pore formation or nucleation of micro-cracks. Effects such as oxidation or corrosion can be included by local diffusion. Simulation results in mechanical property prediction of components based on initial microstructure, thermal and mechanical load, environment or heat input due to welding, and ultimately remaining component life.

Academic-industrial relationship development

The SC will benefit substantially from input from other materials research centres and related activities within SA and abroad. The following entities have been identified to play a key role in research collaboration:

South African universities

- SUN – Department Mechanical and Mechatronic Engineering
- UP – Department Material Science and Metallurgical Engineering
- Wits – School of Process and Materials Engineering
- NMMU – Centre for High Resolution Transmission Electron Microscopy.

Foreign universities

- Loughborough University (UK) – Department of Materials.
- University of Manchester (UK) – School of Materials.
- Cambridge University (UK) – Department of Materials Science and Metallurgy.
- Graz University of Technology (AT) – Institute for Materials Science and Welding
- Vienna University of Technology (AT) – Department of Materials Science and Technology
- Denmark University of Technology (DK) – Department of Mechanical Engineering

OEMs, Material developers and Industry partners

- Alstom, Siemens, Hitachi, Babcock, Steinmuller, Howden, Sulzer, etc.
- Mannesmann & Vallourec, Nippon Steel, Voestalpine, Bohler etc.
- Industrial collaborations will be established through Eskom (including EPRI, VGB, EDF/MAI and ETD).

Developing university partner

The SC has partnered with the Centre for High Resolution Transmission Electron Microscopy at NMMU. The intention is to foster growth in materials science and engineering at NMMU while deriving substantial support from advanced characterisation of materials using high resolution electron microscopy and related techniques for the research projects within the SC. This partnership will overlap with the Department of Mechanical Engineering at NMMU.

EPPEI specialisation centre in Asset Management at the University of Pretoria

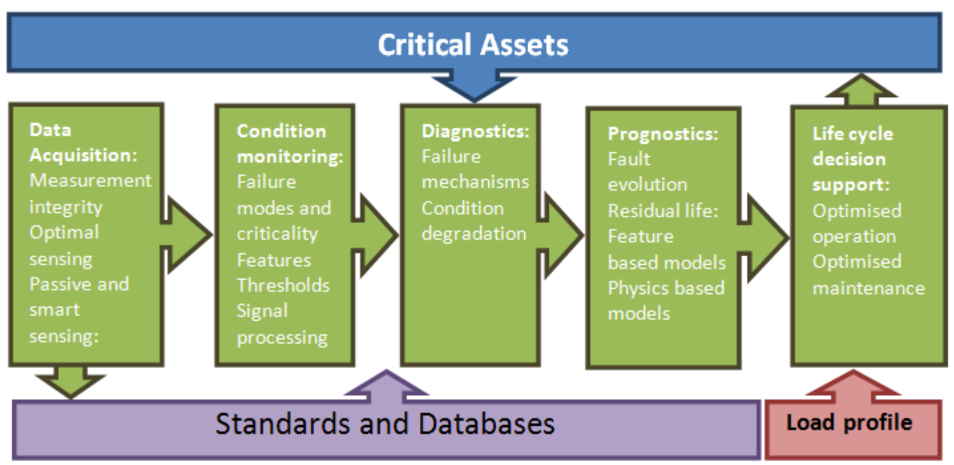
UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

"Ad destinatum persequor" – *"Pursuing towards destiny"*

Strategic Plan

This SC is developing skills and techniques to monitor and manage key components affecting the availability of Eskom plant assets such as turbines, fans, generators, boilers (piping and tubes), transformers, mills, and bulk solids plant. Management of such complex assets requires a deep understanding of asset management principles enhanced by highly specialised asset integrity analysis and evaluation capabilities. This is a multidisciplinary challenge which draws expertise from diverse fields such as machine condition monitoring, signal processing, artificial intelligence, statistics, structural dynamics, finite element analysis and fatigue as well as integration of these principles into life cycle management and the decision environment.

Once critical assets have been identified, carefully selected operational data are acquired. The data feeds into the condition monitoring process, which forms the basis for diagnostics processes to identify the nature and extent of incipient faults. There is an increasing need to interpret this information from a forecasting strategy point of view, for example, to estimate the remaining useful life of assets. This information, coupled with an understanding of the asset's load profile, provides input for life cycle decisions and interventions. All of this happens in an environment where immense amounts of data need to be stored and be accessible in standardised formats of high integrity. This process is summarised in the following schematic.



Schematic of main research thrusts

Research expertise and development areas

Critical assets

Eskom operates a huge variety of assets with very diverse attributes and limited resources. It is, therefore, imperative to focus on assets with the most significant impact on key performance indicators such as unplanned capability loss factor. While a range of assets are considered, the main focus currently includes turbines, with fatigue of low-pressure blades, boiler tubes with associated water leakages, life cycle management of electrical transformers, and condition monitoring of complex generator systems.

Data acquisitioning and integrity

Asset integrity and performance management increasingly require a system parameter measurements such as solids, liquid and gas flow rates, pressure, temperature, oil condition or vibration, and detailed operating condition logs. Measurement faults could result in incorrect conclusions regarding system condition and incorrect maintenance decisions and could, ultimately, have a very significant effect on plant performance. Measurement integrity verification methods are therefore critically important in the asset integrity management process. With data volumes growing exponentially, it is becoming crucial to ensure optimal selection of measurement parameters. Powerful microprocessing capabilities are increasingly allowing a large part of the processing to be done at the sensor, while communicating only appropriate parameters in accordance with applicable information standards.

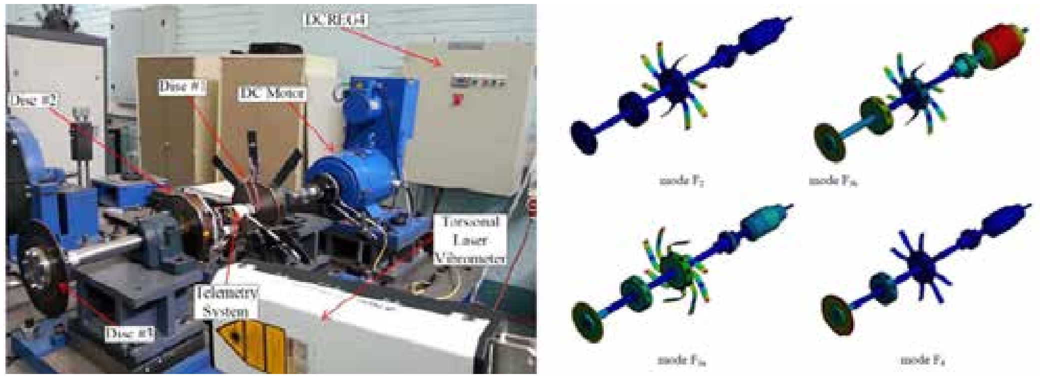
Condition monitoring

While significant progress has been made in diagnostic analysis of complex industrial assets and imminent failures can often be identified, significant research challenges still exist. Examples include dealing with fluctuating operating and process conditions in systems. Fluctuations make it difficult, on the one hand, to distinguish between changes induced by operational conditions and faults or damage or, on the other hand, situations where operational fluctuations are so small that it becomes difficult to identify gradual structural or performance degradation. Specialised signal processing techniques are often required to extract robust features sensitive to the system degradation.

Diagnostics

Understanding failure modes and criticality is crucial in identifying optimal condition monitoring approaches. Detailed models to link features extracted from system response and performance measurements are indispensible in the diagnosis of system faults. As an example of research in diagnostics, the SC focuses on the development of computational models, for turbo-generator rotor (see figure) and journal bearing dynamic behaviour. These models are used to establish diagnostic procedures to link anomalies in the measured rotor response to developing faults, which may not be observed with existing standard instrumentation or sophisticated signal processing techniques.

Related to this, the SC has developed significant expertise in condition monitoring techniques that separate deterministic and stochastic machine behaviour under widely fluctuating conditions that are simultaneously robust enough for in-field implementation. Large emphasis is placed on the application of specialised statistical techniques that have not found their way into the condition monitoring field. Such approaches may well be followed in the analysis of combustion processes or damage in mills.



Development of modelling techniques for understanding the torsional response of turbines

Prognostics

Condition monitoring and non-destructive evaluation (NDE) are often done to prevent unexpected (sometimes catastrophic) failures in critical assets and provide an indication of time-to-failure. Time-to-failure is, however, affected by random parameters, which can only be approximated with statistical models. Maintenance decisions based on the outcomes of condition-based time-to-failure estimates, therefore, contain a strong element of uncertainty, suggesting a need to integrate traditional condition assessment and statistical reliability models. The focus is on developing a range of models to predict remaining useful life of power generation assets. These models range from simple knowledge-based models to life expectancy models, artificial intelligence models and physical models.

Boiler tube failure is a major cause of unavailability of fossil fuel generating units. Fatigue and corrosion fatigue areas are some of the dominant failure mechanisms. Countless small indications exist all over a boiler, and removing them all for repair is impossible. Reliable and qualified NDE methods are needed to identify the critical defects. The NDE technique capabilities must be assessed by utilising proper qualification for each geometry and NDE technique. Realistic finite element models are currently under development for engineering life cycle decision support and calibrated with online measurements to identify failure risks. The SC is further developing response reconstruction techniques for plant asset durability testing for experimental validation of structural integrity against shock, vibration and usage loads.

Life cycle decision support

When considering life cycle management decisions, the focus starts to extend beyond immediate failure towards understanding the long-term operational and maintenance implications. The current research, therefore, encompasses integration of condition information with improved understanding of the degradation mechanisms in order to manage maintenance interventions, risk, inventory, and end-of-life decisions. Current research investigates optimal outage planning based on risk in the context of low-pressure steam turbines as well as optimised maintenance of mill plant using reliability and availability principles.

Standards and databases

The importance of optimal utilisation and life cycle management of physical assets is rapidly growing in our competitive society, resulting in the emergence of new asset management specifications and standards such as PAS55 and ISO 55000. At the same time, the complexity and extent of the enterprise asset management process, supported by software such as SAP, with performance and condition monitoring systems such as EtaPRO, are becoming increasingly important and form a framework for implementation of the asset management research programme described above.

Academic-industrial relationship development

Asset integrity management spans a broad range of disciplines, and optimal implementation of it requires collaboration among various entities with a broad range of interests and skills. The table summarises the collaborative arrangements that have been achieved.

Stakeholder Group	Entities involved	Aim of collaboration
Academia (UP)	• Graduate School of Technology Management	Make a broad skills base in the physical asset management field, distributed over various departments in UP, available to industry
Academia (Non UP)	• University of South Africa • Tshwane University of Technology • Technical University of Luleå (Sweden)	Formal and informal collaboration agreements with entities that have, or are developing expertise in asset integrity management, to advance this aspect of asset management in South Africa
Industry (Non Eskom)	• Anglo American • Exxaro • Sasol • Rand Water • Weir Minerals	Various chairs jointly sponsored by Anglo America, Exxaro, Rand Water, Sasol and Weir Minerals; these activities are highly complementary to the Eskom focus on plant asset management

Development of specific collaborative projects is critical and is sought with the SCs in combustion engineering, material science, and high-voltage engineering. Similarly, the monitoring, analysis and management techniques will be closely integrated with the Energy Efficiency SC.

Developing university partner

UP partnered with Tshwane University of Technology (TUT) and, subsequently, entered into a collaborative agreement in plant asset management and related disciplines. TUT will focus final-year projects on plant asset management specialisation and will solicit, sponsor, and host masters and doctorate students in the field of plant asset management, who will be supervised by both TUT and UP.

EPPEI specialisation centre in High Voltage Alternating Current (AC) at the University of the Witwatersrand

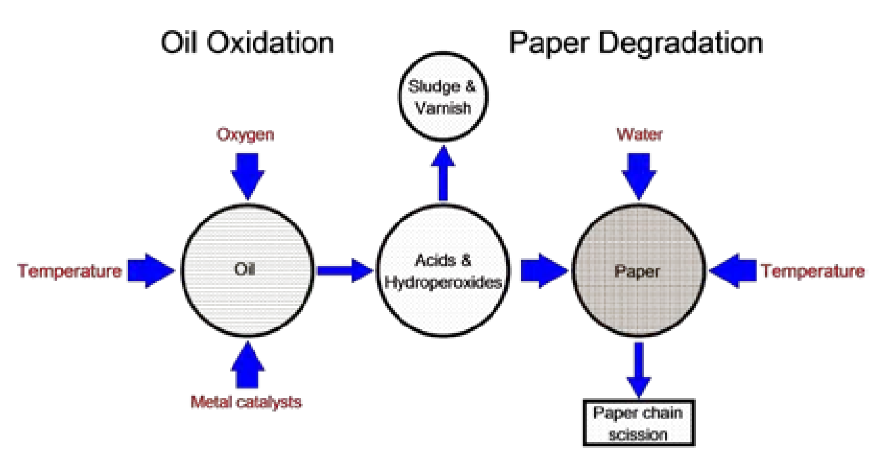
"Scientia et Labore" – *"Through knowledge and work"*

Strategic Plan

This SC aims to build up the Eskom skills base in electrical engineering by presenting courses and conducting research in the area of high voltage (AC), which includes generation, transmission and distribution.

Generator stator insulation and generator rotor insulation integrity is crucial for reliable generator operation. Due to high temperatures, mechanical stresses, and vibration present in an operating generator, there is an inevitable steady degradation of the insulation condition. Partial discharge testing is one of the most important diagnostic tests conducted on generator insulation, but test result interpretation and estimation of remaining life is still a challenge. Generator transformers also operate in demanding environments, and their failure accounts for a large portion of the current Eskom unplanned capability loss factor (UCLF).

The transmission research focuses on the performance of transmission lines in environments that include lightning strikes, switching surges, power frequency overvoltages and pollution. Once again, the objective is to maintain reliable operation of Eskom's large transmission network. Expertise in lightning performance of transmission lines is crucial for line designs that have acceptable lightning performance (a limited number of flashovers due to lightning). Switching surge performance is particularly important for live-line work where human safety must be ensured. Good pollution performance requires insulator selection that considers the pollution performance of various types of insulators (ceramic or polymeric). In addition to a reliable transmission network, reliable operation of large electrical networks involves maintaining acceptable transient stability, small-signal stability, voltage stability and frequency stability.



Factors contributing to oil-paper insulation degradation

In the area of distribution, research focuses on improved monitoring and protection of equipment such as transformers, which have historically had limited monitoring. Stresses on transformers have increased due to electricity theft, non-linear loads, and unbalanced sharing of single-phase loads among the three phases. With increased penetration of renewable generation in distribution, better monitoring and control of transformers will be essential. The presence of non-linear loads increases the importance of power quality and electromagnetic compatibility studies.

Research expertise and development areas

The activities of the EPPEI High Voltage (AC) SC, established within the Wits High Voltage/Lightning/EMC Research Group, will be directed, in particular, at the following broad areas that Eskom has identified as particularly important to its business sustainability:

- electromagnetics and electric field modelling;
- electromagnetic compatibility (EMC) and power quality;
- power system protection (generation, transmission, and distribution);
- AC equipment, including generators, motors, switchgear, transformers and surge arresters;
- insulation and insulation coordination;
- physics of electrical breakdown in liquid, solid and gaseous insulation.

Insulation degradation

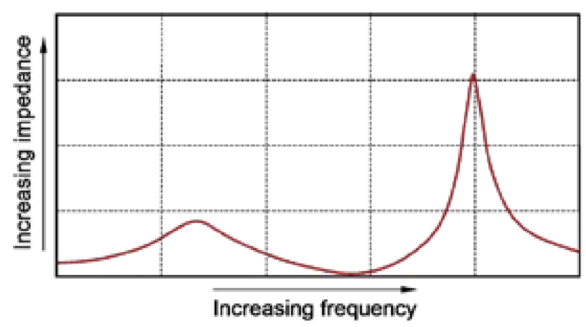
The remaining life of a transformer depends mainly on the condition of its insulation. The windings are usually insulated using an oil-paper combination, where the paper performs a mechanical separation function, and therefore, the mechanical strength of the paper determines the remaining life of the insulation. The factors contributing to oil-paper insulation degradation are shown in the figure above.

There are existing theoretical models of insulation degradation, such as the Arrhenius equation, but the challenge is in adjusting its constants to match the actual degradation of insulation. The SC will also focus on new methods of monitoring insulation degradation (within motors, generators and transformers), including time domain spectroscopy and frequency domain spectroscopy, thereby helping to better estimate remaining life and allowing for better utilisation of assets and a much more realistic reliability index.

Network EMC phenomena

Network EMC phenomena can be in the form of power quality issues (harmonics, unbalance, voltage dips and flicker) or electromagnetic interference issues (corona-related interference). Power quality issues will become an important area of research, as more power electronic devices are introduced into the network. This will include more high voltage direct current.

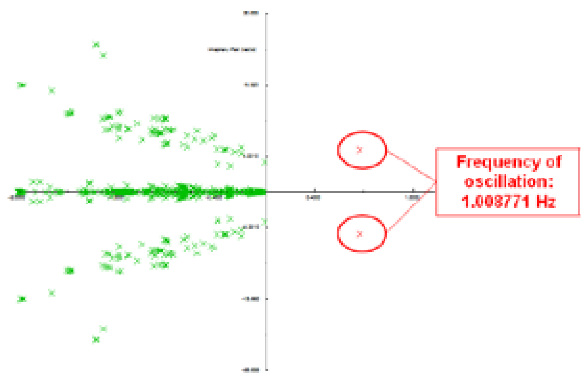
With the increased usage of power electronic devices to improve operating efficiency of various plants (for example, electrostatic precipitators and large motors), it becomes more important to understand the full impact on the operating plant. Instrumentation has been purchased that will allow more comprehensive power quality investigations than can currently be performed using conventional power quality meters. Interference by corona on PLC operation will also be a future research focus.



Supply impedance variation with increasing frequency as seen by the harmonic currents injected into the supply by power electronic converters

Power system stability

In the recent past, there have been network incidents where the stability (specifically small-signal stability) of the Eskom network has been compromised due to particular operating conditions.



Eigenvalue analysis showing unacceptable negative damping of network power oscillations (shown in red)

The SC will conduct research in the area of small-signal stability, with specific emphasis on observability (perhaps assisted by the phasor measurement units (PMUs) currently being installed around the Eskom network) and controllability (effectiveness of power system stabilisers (PSSs) installed on individual generators and used to provide damping of any small-signal oscillations).

Academic-industrial relationship development

The high voltage university research community in South Africa revolves around four universities: Wits, UKZN, UCT, and SUN. Each university has strengths in different areas, and collaboration will be very beneficial and will be actively pursued.

South African universities

- UKZN – power system studies, FACTS devices, insulation studies
- UCT – power system studies
- SUN – insulator studies, renewable energy sources

Foreign universities

- Technical University of Delft (the Netherlands)

Original equipment manufacturers (OEMs)

- Wits has an excellent relationship with many original equipment manufacturers, including Alstom, Actom, Siemens, ABB and CBI-electric.

Industry partners

- Industrial collaborations will be established through Eskom agreements (including EPRI and EDF).

Developing University partner

The partner university of this SC is the Vaal University of Technology (VUT). VUT has built up a reputation in cable research under the leadership of Professor Jerry Walker. VUT also has close links with cable manufacturing companies such as CBI Electric African Cables. VUT is in the process of building and equipping a high voltage laboratory that will complement the high voltage laboratory at the University of the Witwatersrand. Professor Walker acts as an external examiner for many of the undergraduate and postgraduate high voltage projects at Wits.

EPPEI specialisation centre in High Voltage Direct Current (DC) at the University of KwaZulu-Natal

UNIVERSITY OF KWAZULU-NATAL

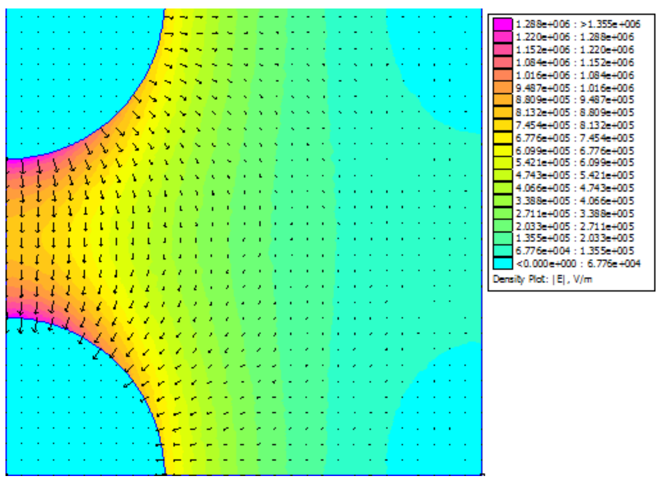
"To be the Premier University for African Scholarship"

Strategic Plan

This SC has two operational high voltage laboratories, one focused on direct current (DC) and the other on alternating current (AC). The combination of the two laboratories at sea level, along with a powerful real-time digital simulator (RTDS), is well situated to support Eskom with its expanding grid.

The impact of new resources, including renewable electricity sources and possibly nuclear energy, on the existing grid is important and will naturally result not only in growth, but also in a more complex grid. This will put increased pressure on South Africa to develop and consider different technologies in order to deliver electrical power efficiently and reliably.

Eskom views high voltage direct current (HVDC) systems as an enabler for future expansion of the existing grid. There are a number of potential HVDC systems, a bipole connecting the Limpopo province to Gauteng province, a separate bipole through KwaZulu-Natal, and an increase in capacity of the existing system from the Cahora Bassa Dam in Mozambique.



Modelled sphere-sphere gap

The strategic plan is to develop laboratories, the intellectual competence, and the design ability of Eskom and UKZN in line with the grid capacity upgrade.

HVDC systems research will focus on:

- circuit-breaker technology;
- conversion technology;
- system configurations;
- implementation of new components and technologies;
- condition monitoring;
- line configurations;
- clearances;
- insulation materials for transformers, overhead lines, and cables;
- communication.

Research expertise and development areas

HV laboratories

Due to the wide variety of high voltage testing equipment, the HV laboratories can conduct testing and measurement of voltages up to 400 kV AC, 500 kV DC, and 800 kV impulse. The availability of a corona cage, test line set-ups, multiple indoor facilities, and an outdoor facility facilitates (among others) outdoor insulator testing, materials testing, line configuration testing, corona testing and cable testing.

The ability to configure these voltages and conduct comparative tests is crucial to increase the capacity of transmission line designs, including conversion of HVAC to HVDC, as well as analysis of outdoor insulators, breakdown of air gaps with and without floating objects, and corona studies, including audio and radio interference.

The laboratories also facilitate analysis of dielectric insulation materials under both AC and DC conditions, including partial discharge and material breakdown strength. In addition to the experimental work, there is a strong computational modelling base for investigation of the electric field, ionisation, breakdown, and corona, using tools such as finite element methods and Boltzmann equation solvers.

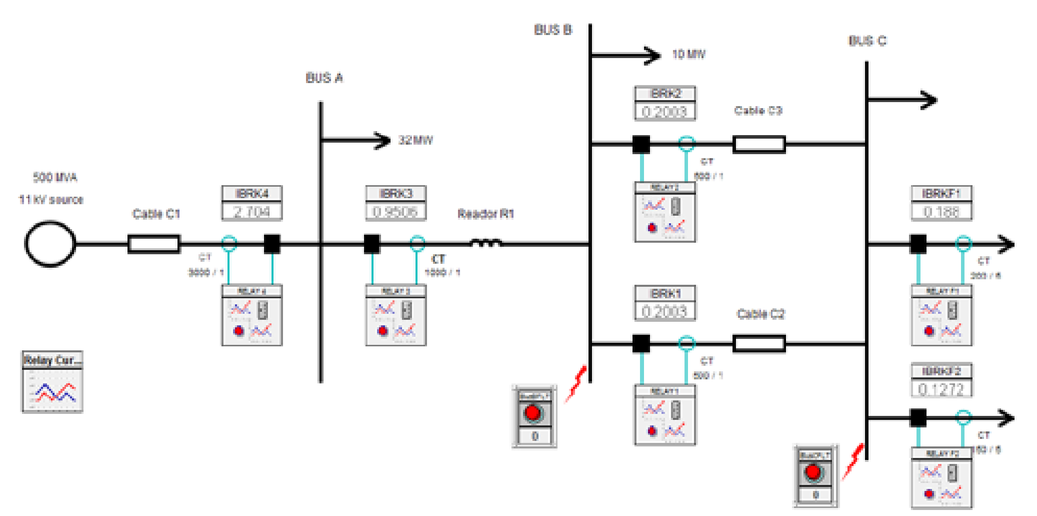
The collaboration with a high-altitude laboratory at Wits is also crucial, as the voltages for corona and breakdown will differ between the laboratories.

Power systems

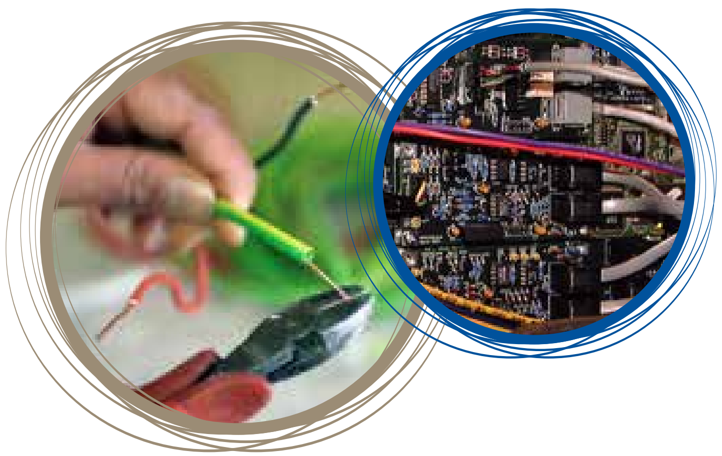
The RTDS is equipped with cutting-edge RISC processor cards (PB5), thus enabling real-time simulation studies of power systems dynamics. The RTDS can simulate a power system with hardware in-loop, without having to place the power system at any risk, for example, a study of ABB Mach 2 controllers used at Apollo.

The power system studies include:

- stability studies using FACTS devices and controllers;
- protections and fault studies using hardware in-loop protective relays and testing;
- substation automation and protection studies, such as the inclusion of superconducting fault current limiters;
- Geomagnetically induced currents (GICs) and the effects on power systems and associated equipment;
- real-time simulation studies for existing generators and controllers;
- renewable and distributed energy resources connected to the power grid;
- the impact of a changing generation pattern;
- simulation and understanding of power swings and subsynchronous resonance effects from LV to HV grids.



Power system for protection studies



Academic-industrial relationship development

South African universities

- Wits – School of Electrical Engineering
- DUT – Department of Electrical Engineering

Foreign universities

- University of Strathclyde (Energy Systems Research Unit)
- STRI (Sweden)
- EPRI (USA)
- University of Southampton (Energy Technology Research Group)

Industry partners

- etalumiSe (Pty) Ltd is an international authority on real-time digital simulators (RTDSs) for the study of electromagnetic transients in real time. Dr Rigby has run a number of RTDS training workshops, which EPPEI students and staff have attended. He has been instrumental in helping one of UKZN's EPPEI students on GIC simulations and helps supervise postgraduate students at UKZN.

Contact: Dr Bruce Rigby
etalumiSe (Pty) Ltd.
Postal Address: P.O.Box 95, Umhlanga Rocks 4320, South Africa
Tel: +27 (31) 561 5813; Fax: +27 (86) 579 1409

Developing university partner

UKZN and Durban University of Technology (DUT) have, for a number of years, collaborated on Eskom power system stability projects. With the help of EPPEI funding, this collaboration has now deepened. Currently, DUT's Electrical Power Engineering Department does not have permanent staff qualified with doctoral degrees in electrical engineering. There is a national drive to encourage academics at higher educational institutes to enrol in doctoral degrees, and this has been encouraged at DUT. UKZN has offered it supervision capacity to supervise DUT electrical engineering staff towards getting their doctoral degrees. There are currently two DUT academics, Mr Reddy and Mr Akindeji, being supported.

EPPEI specialisation centre in Renewable Energy at Stellenbosch University

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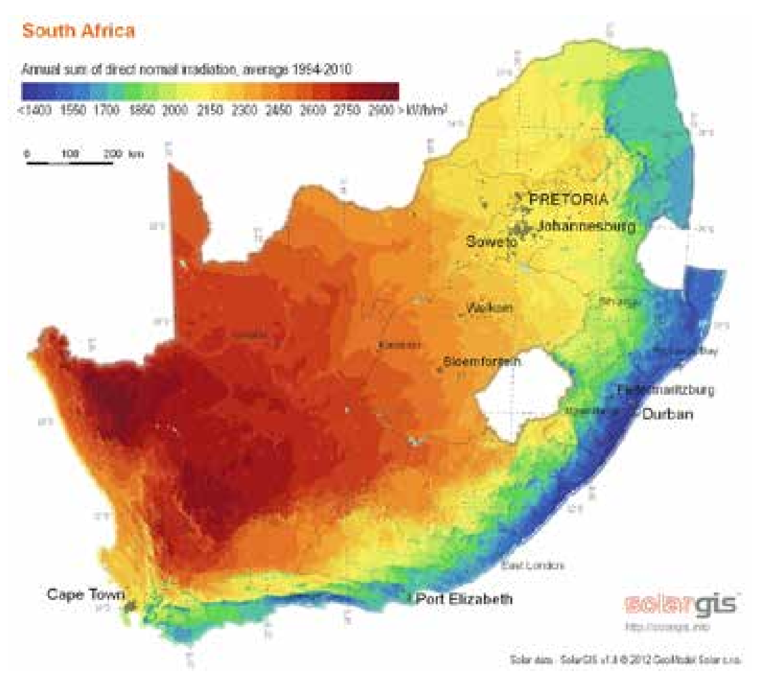
Strategic Plan

In the framework of the upcoming renewable energy development in South Africa in wind and concentrated solar power (CSP), some of the key technical challenges that need to be addressed by Eskom engineers in the short to medium term include::

- integrating renewable energy power stations with variable output into the national grid;
- forecasting electricity production from these power stations;
- operating and maintaining the Eskom renewable energy power stations to optimise electricity production and to reduce costs; and
- addressing some unique South African challenges such as dry-air cooling for CSP plants and cleaning of mirrors and panels in dusty, arid conditions.



High concentration of direct normal solar irradiance over the Northern Cape

The key research focus areas for this SC are:

- support design, operation, and maintenance of wind farms and CSP plants, including the optimisation of electricity production;
- feasibility studies for renewable energy power stations;
- tender specifications and procurement processes;
- overseeing construction, commissioning and grid integration; and
- research and development to facilitate technology transfer to South African operations.

Background Information

Eskom has been developing two new-generation renewable energy projects over the last decade. One is a CSP plant at Upington in the Northern Cape and the other a 100 MW wind farm on the West Coast, now called Sere. During planning, the 100 MWe CSP plant would have been one of the largest solar power stations in the world, with a thermal storage facility to sustain up to 14 hours of electricity generation after sunset. The funding for both these power stations is included in the tranche of funding Eskom received from the World Bank for the Medupi power plant, and both projects should be implemented in the next five years. Recently, Siemens AG was appointed as the engineering procurement construction (EPC) contractor for the Sere wind farm, which will come online in 2014.

South Africa has an abundance of renewable energy resources that can be utilised for electricity generation:

- **Solar energy** – with 50% more solar irradiance than Spain and 20% more than North America, South Africa arguably has the best solar energy resource in the world. Although the direct normal solar irradiance is highest in the Northern Cape, making that area most suitable for CSP, concentrator photovoltaic (CPV), and tracking photovoltaic (PV) stations, the global horizontal irradiance in the rest of the country is also attractive for generating electricity from photovoltaic panels.
- **Wind energy** – the best wind farm areas are concentrated in the Eastern, Western and Northern Cape. Measured wind energy resources predict capacity factors of wind farms in the 30% up to low 40% range, sufficient to make wind farms economically viable.
- **Hydro** – South Africa is a water-scarce country, with most of the large-scale viable hydro sites already exploited. The best large-scale hydro option is imported hydro from neighbouring countries. Small hydro is limited to the river areas of KwaZulu-Natal and the Eastern Cape.
- **Ocean energy** – two exploitable forms of energy from the sea exist in South Africa. The average wave energy resource is around 40 kW/m crest length along the South-West coast. The Agulhas ocean current, with an averaged measured velocity of 1.5 m/s, is attractive because of its energy density and consistency, reducing the variability of the electricity supplied to the grid.
- **Bio-energy** – South Africa has limited water and arable land for biomass production and therefore the biomass available for power generation will always be limited. Studies have shown that the most promising biomass available for co-firing in coal-fired power stations is residues from forestry and agricultural activities and invasive species. Bush encroachment and woodlands in our neighbouring countries are also possible resources for electricity generation.
- **Other renewable energy resources** – South Africa has very limited geothermal resources that can be easily exploited. It is possible to extract geothermal energy from greater depths (more than 3 000 m) using fracking technology, which is rather contentious. Energy from waste streams such as municipal solid waste and landfill gas is available in South Africa and could be exploited at small scale.

The major driver for electricity generation from renewable energy resources in the world is to reduce carbon emissions that cause climate change. Although this is significant, two other drivers are more important in the current South African context: implementation time and access to funding. Building large coal-fired or nuclear power stations takes many years from pre-feasibility studies to commissioning, usually at least a decade, while wind farms can be planned, built and commissioned in as little as three years and CSP plants in five. Eskom faced many hurdles financing Medupi and Kusile, but obtaining financing for renewable energy power plants seems to take less effort, and these funders will frequently accept lower returns. The cost of electricity from renewable energy resources has decreased significantly over the last five years due to an increase in the roll-out of renewables over the last decade (economies of scale) and the general economic downturn internationally.

Research expertise and development areas

The following research areas are under way in the field of renewable energy technologies:

1. Concentrating Solar Power (CSP)

- System modelling and optimisation,, including thermal storage systems
- Development and optimisation of heliostats, receivers and heliostat field layouts
- Dry-air cooling for CSP plants
- Solar augmentation of existing coal-fired power plants
- Resource measurement, assessment and yield prediction (also for PV systems)

Solar thermal roof laboratory at Stellenbosch University

2. Wind Energy

- Operation and maintenance of wind farms, including specialist topics such as conditioned-based maintenance, embedded lidar systems to measure wind speed and direction for real-time turbine control
- Grid integration of wind turbines
- Wind and energy-yield forecasting
- Cohabitation of wind and radar systems, developing solutions applicable to both radar systems and/or wind turbines
- Blade health monitoring. Very large blades need to be monitored by more sophisticated means than visual inspection. Embedded transducers and structural dynamic response measurement technologies should be investigated.

3. Photovoltaics (PV)

- Site identification, optimal layout and yield prediction (also see previous point)
- PV field performance testing in dry, dusty, hot environments to reach guaranteed production levels; massifying performance testing of PV panels to plants with thousands of panels
- Modelling cloud cover and its impact on grid stability combined with short-term storage systems to manage power drops.
- Modelling performance of silicon and thin-film PV modules under operational conditions

4. General Topics

- Modelling the South African electricity supply and demand system to determine the impact renewable energy power stations may have
- Investigating the biomass resources available for co-firing in coal-fired power stations
- Wave energy technology studies, including sea-water pumped-storage schemes
- Developing ocean current energy systems suitable to generate electricity in the Agulhas ocean current

Academic-industrial relationship development

The list of research organisations and companies with whom cooperation is in place or actively pursued is as follows:

- On CSP technology development, collaboration exists between Stellenbosch University, UP, UKZN, and the CSIR. International collaboration with the DLR, the Fraunhofer Institute for Solar Energy in Germany and the Institute for Solar Energy in Freiburg has been established. The next step will be to incorporate an industry partner such as Abengoa (who will build the first CSP independant power project (IPP) plants in South Africa) or the successful bidder on the CSP plant at Upington. At present, a national solar energy test and development facility is being discussed by various role players in South Africa.

- On wind energy technology, Stellenbosch University cooperates with UCT and CPUT (host of the new South African Renewable Energy Technology Centre). Cooperation with OEMs in this area needs to be developed. Companies such as Vestas, Suzlon, Gamesa and Siemens will all have wind turbines installed in South Africa in the next five years. Currently, Vestas has the largest market share and has been represented in the country the longest, and could therefore, be the most interested in setting up a partnership. Siemens supplies the wind turbines and is the EPC contractor for the Sere wind farm and is the most likely company to support the EPPEI SC in Renewable Energy Technology.

Developing university partner

The Cape Peninsula University of Technology (CPUT) has been identified as the primary partner of the EPPEI SC in Renewable Energy Technology. The Department of Higher Education and Training (DHET) has awarded R105 million to CPUT to set up the South African Renewable Energy Technology Centre (SARETEC). The centre will focus on training technicians for the wind and solar PV industries. Stellenbosch University is in the process of signing a memorandum of agreement with CPUT to facilitate the access of EPPEI and other students at SUN to have access to the facilities at SARETEC.

6

Local skills development

The eight Eskom specialisation centres (SCs) at the six South African universities have two principal objectives. The first of these is to successfully train local engineers and scientists to be in a position to address operational and strategic challenges for the foreseeable future in the power generation industry. The second of these is to address existing challenges that are faced on a daily basis by the Eskom power utility through research programs.

Training of highly competent engineers with a relevant array of skills in the power generation industry is likely to have several national benefits that transcend the immediate needs of Eskom. It is expected that from the ongoing EPPEI research in the respective SCs, local expertise will reach a critical mass in the future. This critical mass will facilitate and establish local development and manufacturing.

Each of the eight SCs will offer courses at EAL as part of the EPPEI programme. These courses are open to be attended by individuals who work in the power industry, but are not EPPEI students. This will increase the pool of individuals in South Africa who are further up-skilled in the industry.

Local industry will have direct access to research through coursework and publications that result from the EPPEI research projects. As these research projects are carefully selected to solve problems directly experienced by Eskom they will be highly relevant to industries and companies that partner with Eskom. The employees of these entities would also have direct access to the most up-to-date research in the field. This will ensure that not only Eskom but the South African industry as a whole would grow concomitantly.

A primary objective will be to ensure that research outputs address current and future challenges for Eskom as well as being published in leading international peer reviewed journals to ensure excellence of the results. This increase in skills, published research and knowledge will raise South Africa's international standing in power generation related topics. This will also enable South Africa in the long run to not depend wholly on international material and service suppliers as well as current OEMs.

In summary, the focus of the development push is to develop highly competent engineers with a relevant array of skills, to actively solve Eskom technical issues. This will in turn foster greater confidence in local ability and will encourage growth in the research and development of power industry related technologies.

7

Appendix 1 How to join EPPEI

Are you interested in advancing your engineering career in Eskom through EPPEI? Here's how to apply...

The minimum requirements to apply for admission into the EPPEI programme for 2015 are:

- A BTech or Engineering degree (BSc. or BEng.)
- Eskom engineer in training or experienced engineer
- Interested to obtain a MSc. degree in the specialisation areas listed in this document

The process for the intake of students for 2015 will start during June 2013. Keep an eye out for the advertisements!

Be sure to have at least the following information available:

- Your qualifications
- Certified copies of ID, degree, academic record
- Short description of your responsibilities and main outputs over the last six months
- Short resume, and motivation for admittance in the programme
- A photograph of yourself
- Current position held
- Specialisation areas you are interested in

For further information please contact:

Malcolm Fawkes
Email: FawkesMG@eskom.co.za
Office: +27 11 655 2552

8 Appendix 2
Directions and Maps

Directions to Megawatt Park (Eskom Head Office) in Sunninghill

From Pretoria:

1. Take the Ben Schoeman (M1) highway to Johannesburg
2. Stay on the Johannesburg highway, and exit at the Woodmead offramp
3. At the top of the offramp, turn right at traffic lights onto R55 to Woodmead.
4. Straight over first traffic lights (Woodlands Drive Dunwoody Centre on the left)
5. At next traffic lights, turn left into Maxwell Drive (R564)
6. At next robot turn right into Eskom Head Office entrance (security boom at the gate)

From Roodepoort:

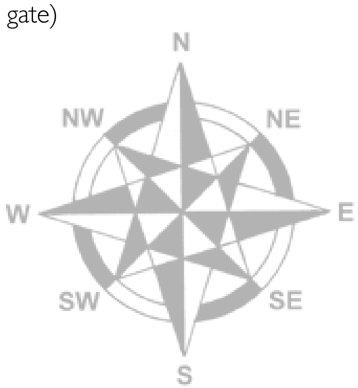
1. Take Western Bypass (N1), and exit at the Rivonia offramp
2. At traffic lights at bottom of offramp, turn left and immediately move to the right before the next traffic lights
3. At these traffic lights, turn right into Witkoppen Road, travelling parallel to the freeway
4. Straight over first traffic lights (Bowling Road, Sunninghill Hospital on left)
5. Continue to next traffic lights, and cross straight over into Eskom Head Office entrance (security boom at the gate)

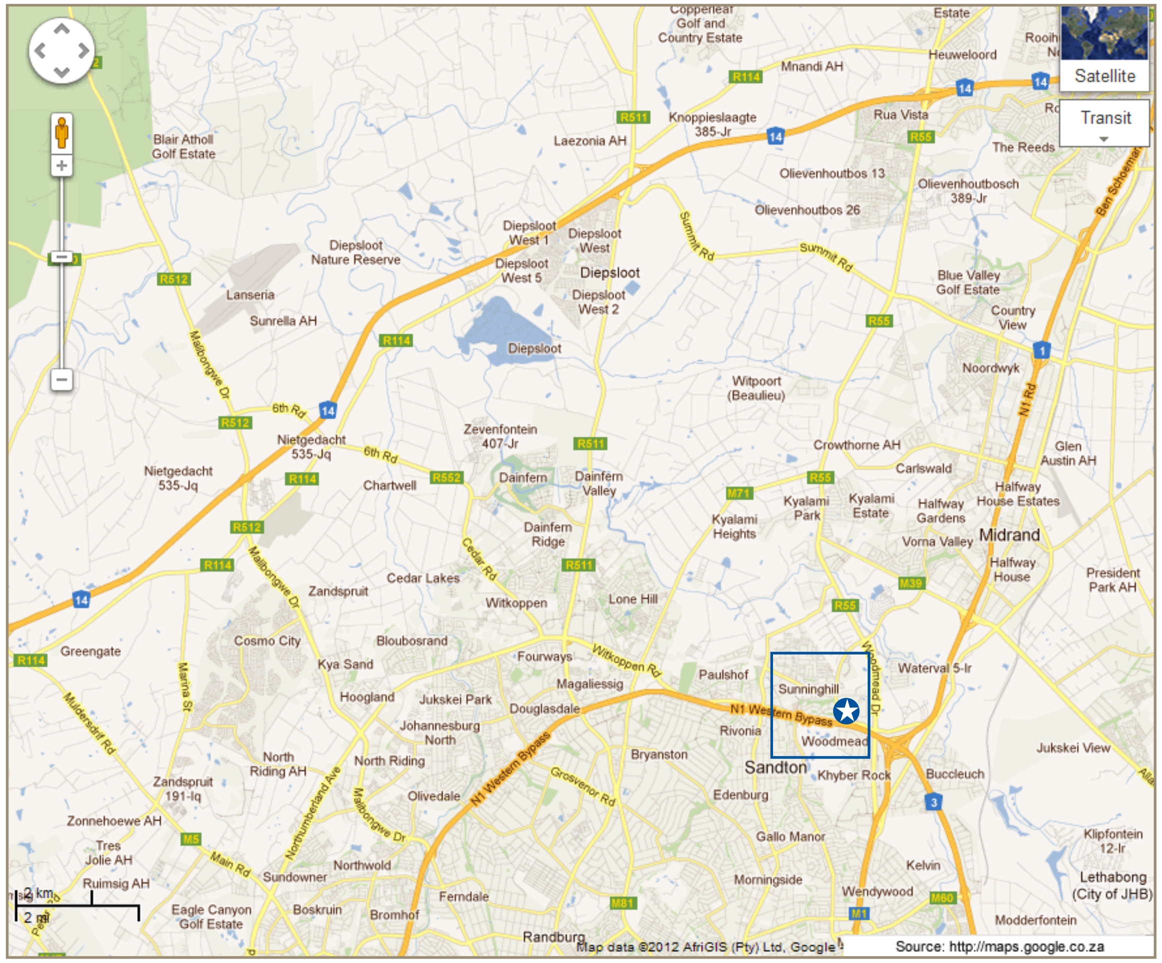
From Johannesburg:

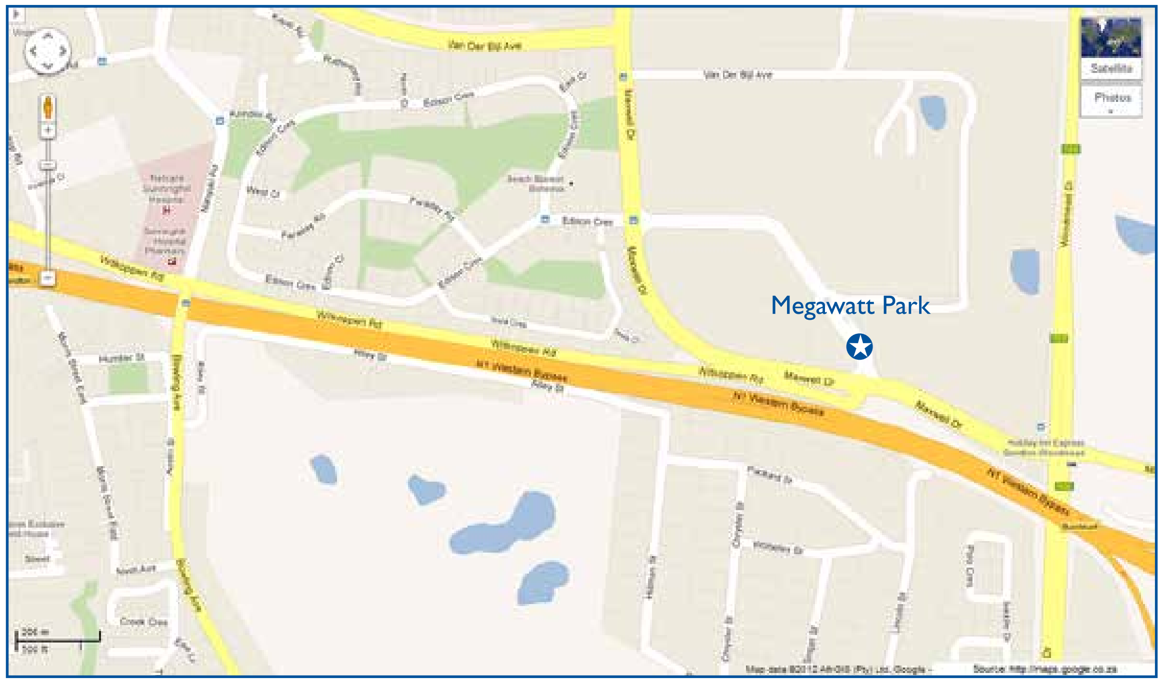
1. Take M1 North to Pretoria, and exit at Woodmead offramp
2. Follow road left through yield sign onto Kyalami Road
3. Straight over first traffic lights (Woodlands Drive Dunwoody Centre on the left)
4. At next traffic lights, turn left into Maxwell Drive (R564)
5. Turn right into Eskom Head Office entrance (security boom at the gate)

Once through the Eskom gates:

* Ahead is a traffic circle, turn right at the circle
* Visitors' parking is on your left

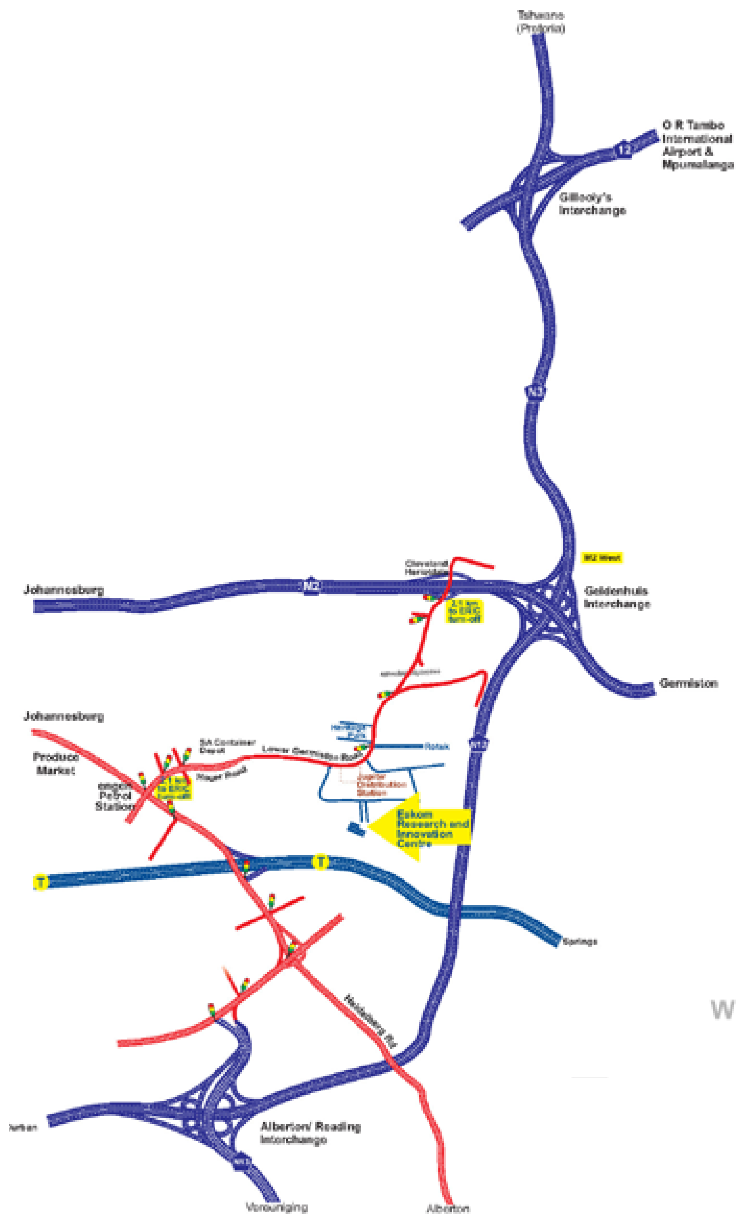


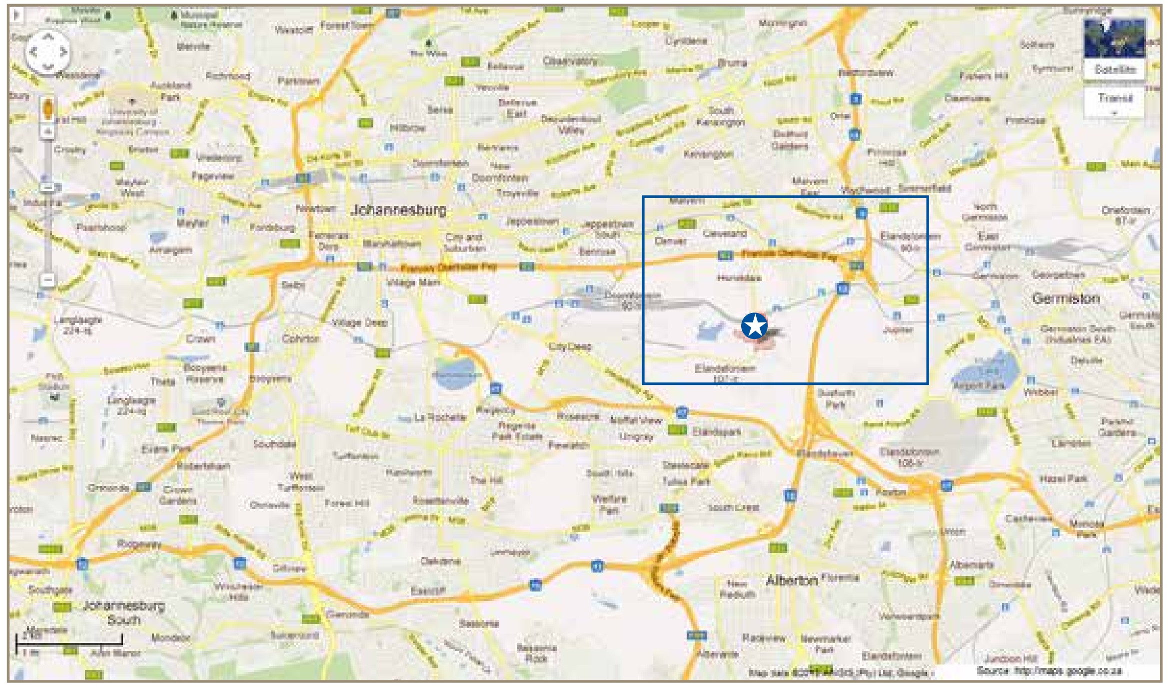


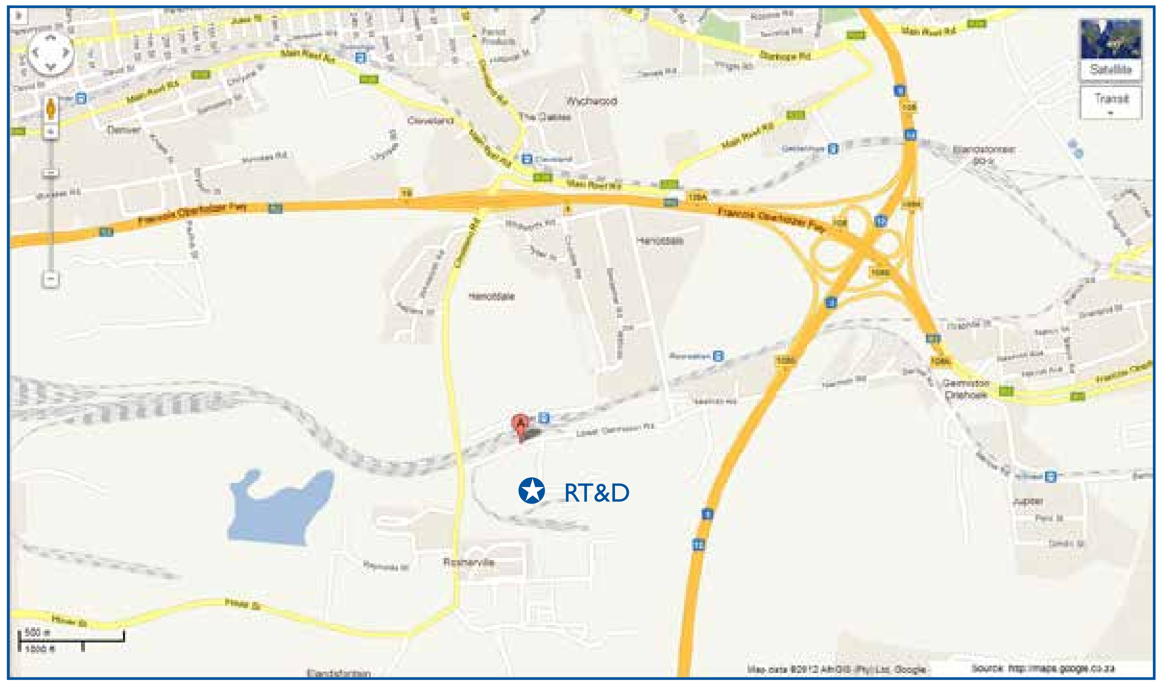


Directions to Eskom Research, Testing and Development (RT&D) in Rosherville

1. Travelling south on the N3 from Pretoria towards Johannesburg
2. At the Geldenhuys interchange take exit 108, M2 west towards Germiston
3. Keep right at the fork towards M2/Johannesburg onto the Francois Oberholzer highway
4. Take exit 4, Cleveland Road
5. At the traffic light turn left onto Cleveland road
6. Continue straight onto Lower Germiston Road
7. Approximately 300m after the first sharp right hand bend turn left at the ERIC sign board
8. Follow the road to the ERIC entrance on the right hand side







Directions to Eskom Academy of Learning (EAL) in Dale Road, Midrand (S25° 59'11,2" E28° 9'29,1")

From Sandton/Roodepoort:

1. Take the Ben Schoeman Highway to Pretoria (N1)
2. Take the Allandale Road off-ramp
3. Turn right at the traffic lights at the top of the off-ramp (you will be crossing the highway)
4. Continue over two sets of traffic lights and turn left at the third set of traffic lights into K101 Road
5. Continue over three sets of traffic lights and turn right at the fourth set of traffic lights into Dale Road
6. Cross the traffic lights and continue straight for 0.6 km. The entrance to EAL is on your right

From Pretoria:

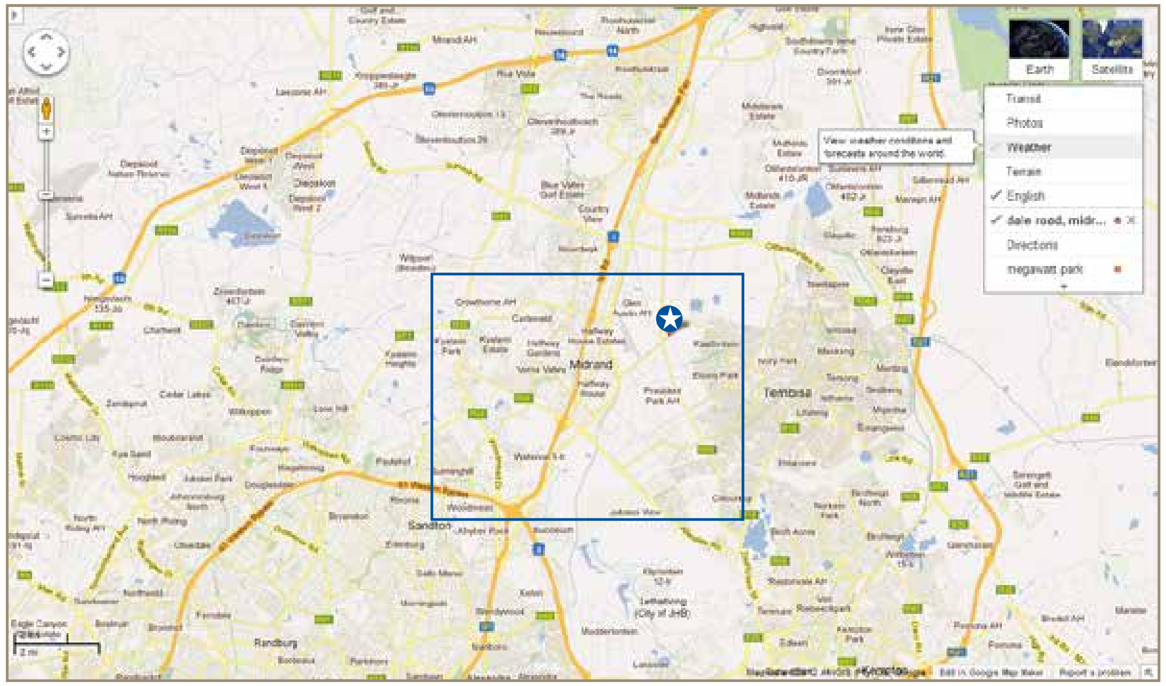
1. Take the Ben Schoeman Highway to Johannesburg (N1)
2. Take the Olifantsfontein Road off-ramp
3. Turn right at the traffic lights at the end of the off-ramp and continue straight
4. Cross the traffic lights and continue straight
5. At the four-way stop turn right into Allan Road and continue for approx. 3.7 km
6. At the traffic lights turn left into Dale Road
7. EAL is 0.6km down the road, on your right

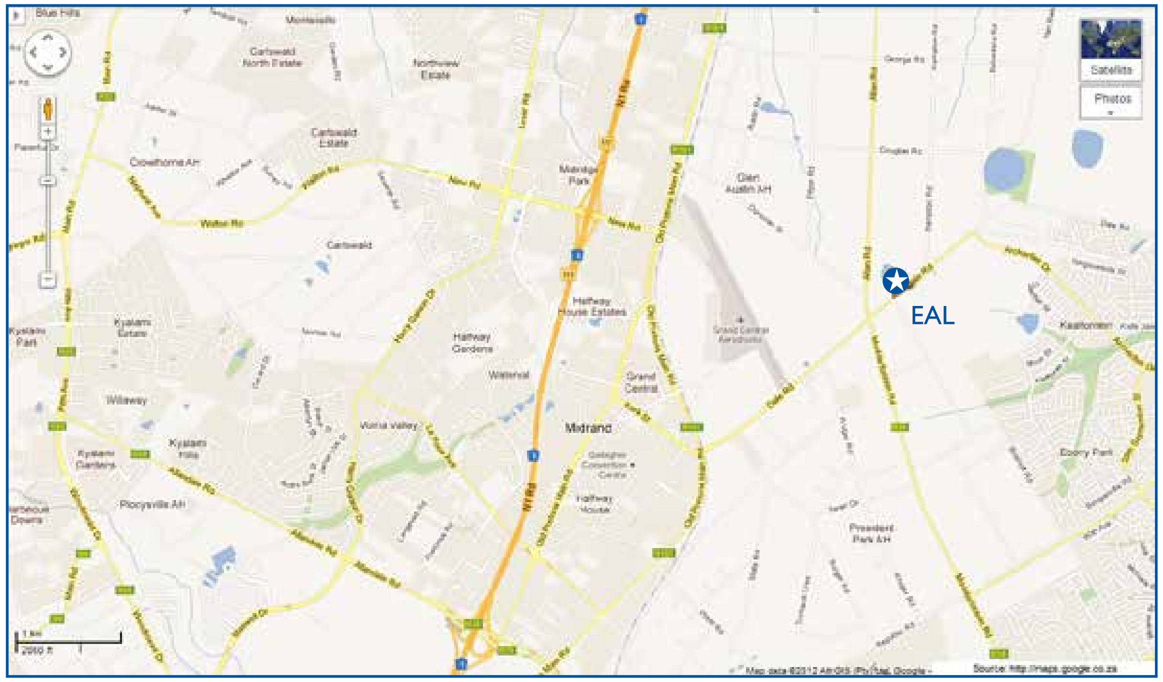
From Kempton Park:

1. From the Civic Centre continue along CR Swart Road in a westerly direction, following the Chloorkop sign and later the R561 sign
2. Turn left into Allandale Road at the R561 Halfway House sign and continue straight for 8.2 km (crossing Setter Road)
3. Turn right into K101 Road. Continue over three sets of traffic lights and turn right at the fourth set of traffic lights into Dale Road
4. Cross the traffic lights and continue straight for 0.6km. The entrance to EAL is on your right

From East Rand:

1. From the N3 (N1) Pretoria highway take the N1 North Pretoria off-ramp and continue straight
2. Take the Allandale Road off-ramp
3. Turn right at the traffic lights at the top of the off-ramp (you will be crossing the highway)
4. Continue over two sets of traffic lights and turn left at the third set of traffic lights into K101 Road
5. Continue over three sets of traffic lights and turn right at the fourth set of traffic lights into Dale Road
6. Cross the traffic lights and continue straight for 0.6 km. The entrance to EAL is on your right.





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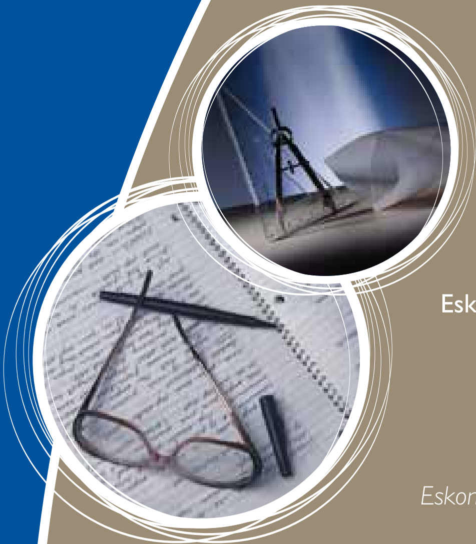

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