University launches new energy research initiative

by Dr Jörg Lalk

The University of Pretoria recently established a number of institutional research themes (IRTs) that are aimed at multidisciplinary and transdisciplinary research. These research themes cut across faculty boundaries and will further strengthen the University's reputation as one of South Africa's leading research universities.

The idea behind the IRTs is to focus the University's research efforts on a number of carefully selected themes that are relevant to South Africa's economic and social growth and development.

With the closing of the pebble bed modular reactor (PBMR) project by government, an opportunity presented itself to expand the University's participation in nuclear energy research to include the wider energy field. Since the dark load-shedding days of 2008, the South African government has also been hard at work to ensure South Africa's energy security. This has resulted in a number of relevant national strategies and policies, most notably the Integrated Resource Plan (IRP) of 2010. This plan represents a road map to electricity security for the next 20 years.

A recent study by Prof Anastassios Pouris, Director of the University's Institute for Technological Innovation, found that the University of Pretoria was the most prolific publisher of core energy research in South Africa between 1997 and 2007, sharing the top position with the University of Cape Town. In this respect, the University outperformed even Sasol.

National energy security

Until about 2006, South Africa was seen as a country with abundant and cheap energy resources. Coal was seen as an infinite resource for the generation of electricity and, although the country had a few hydroelectrical power stations and the only nuclear power station on the African continent, there was little motivation to move away from coal as the dominant source of electricity.

This changed in late 2007, when Eskom suffered a number of unplanned plant outages. Together with a higher than expected economic growth rate, this created what one could argue was the "perfect energy storm". During 2008, the country suffered rolling blackouts (somewhat diplomatically referred to as "load-shedding") that saw even the key mining industry being cut off from electricity supply for a while. The effect on the economy was huge, and in some cases industries have still not fully recovered from the subsequent economic fallout. These events, together with increased pressure to substantially reduce greenhouse gas emissions, led to a fresh look at South Africa's energy future.

During and after the blackouts of 2007 and 2008, a number of government policy and strategy documents were released that were aimed at taking the country towards a more secure energy future. The most notable of these were the Nuclear Energy Policy (approved by Cabinet in 2008) and the Integrated Resource Plan of 2010. Others included the Industrial Policy Action Plan, which has been in force since April 2008, the Energy Efficiency and Demand Side Management (EEDSM) Policy, published in May 2010, and the draft Nuclear Research, Development and Innovation Strategy

International nuclear energy trends

Currently operating reactors	440
New reactors proposed	344
New reactors planned (order placement imminent) or on order	149
New reactors under construction	59

(Source: www.world-nuclear.org, 1 August 2010)

→ *Table 1: International nuclear energy trends.*

→ *Energy distribution forms part of the University's institutional research theme.*

(NERDIS), which is being reviewed by the Department of Science and Technology. These policy documents all have in common the issue of energy security and its contribution to job creation, economic growth, research and human capacity/skills growth. These are underpinned by the Department of Economic Development's draft New Growth Plan, released in November 2010.

Against this background, an opportunity exists for focused research, as well as the training of scientists and engineers in the field. Over the last few years, the University has been involved in a number of energy-related activities, notably research relating to energy efficiency, demand-side management, fluoro-materials, carbon materials, nuclear energy, advanced materials, thermoflow, and engineering and technology management.

This, coupled with the fact that the University houses the largest school of engineering in South Africa and the only graduate school of technology management in South Africa, places it in a unique position to leverage its well-developed and highly rated scientific, engineering and management capabilities in support of government's energy objectives.

Research focus of the new energy theme

A careful analysis of existing research activities at the University revealed a correlation with known areas of interest in the wider energy sector, as well as a number of recent government policy papers, strategies and plans. Of importance are the typical national priorities that the Department of Energy evaluated while developing the new Integrated Resource Plan of 2010, namely future energy demand, required energy supply, the national economy, climate change and regional development. It stands to reason that the new initiative's research focus areas should be selected to support these national priorities. The University's new energy institutional research theme will initially focus on electrical energy, but will, over time, evolve towards the inclusion of other energy technologies such as biofuels.

The core focus areas are as follows:

Energy production

Nuclear energy

It is evident that South Africa cannot achieve its declared reduction in greenhouse gases and base-load requirements without expanding the contribution of nuclear power to the national power mix. The draft IRP made provision for at least six new nuclear power stations. At the same time, the Koeberg facility was to initiate a major project to extend the lifetime of the nuclear power plant. Despite ongoing problems in Japan, a number of countries – including China, Finland, the United Kingdom and the United Arab Emirates – are also engaged in major nuclear projects, which provide for research collaboration opportunities.

Nuclear energy is of particular importance to the University due to

→ **(Right)** *Coal-fired power stations provide for nearly 90% of the country's energy needs.*

the institution's participation in some research projects for the PBMR project. These projects benefited the University in a number of areas, including laboratory upgrades, new state-of-the-art equipment, new research skills and know-how in the nuclear field.

Coal

South Africa currently sources nearly 90% of its energy needs from coal, which in turn is responsible for the bulk of the country's greenhouse gas emissions. The University, through its South African Research Chair Initiative (SARChI) Chair in Carbon Technology and Materials in the Institute of Applied Materials, is already addressing this problem, notably with a focus on research into so-called "clean coal". In addition, the two new coal-fired power stations (Medupi and Kusile) that are currently being constructed by Eskom provide exciting research opportunities during their planned 40-year life cycles. Important areas of research would be the underground gasification of coal, CO_2 capturing and storage, as well as clean coal.

Renewable energy

It is the declared intent of government to drastically increase the contribution of wind and solar resources, in particular, to the national energy mix, with the anticipated contribution of these energy sources to approach 50% within the next 20 years. As these technologies are relatively new and in some cases rather novel, much scope for research exists. Examples include the planned new 5 000 MW solar park at Upington and the soon-to-commence 100 MW concentrated solar plant and 100 MW wind farm projects of Eskom.

Energy distribution

Smart grids

With the inclusion of non-traditional energy resources, such as renewables, with their inherently random availability, it becomes substantially more important to move towards so-called intelligent (or smart) distribution networks. As South Africa has barely touched this exciting field, opportunities for advanced research abound. In fact, once many of the anticipated new solar and wind plants are online, the country will have little choice but to invest in the upgrade of its current distribution network and move to a smart grid in the long term. This field includes research opportunities in areas as diverse as software engineering, control engineering, systems modelling and simulation, advanced sensing and measurement, secure communications and protection systems, all of which the University is well positioned to address. An interesting impact on the existing network would be a growing fleet of electric motor vehicles, especially with the pending release of such vehicles on the South African market by manufacturers such as Nissan, Toyota and General Motors, and possibly the locally developed Joule vehicle.

Energy storage

Renewable energy sources are generally viewed as not exhibiting base-load capabilities. They rely on the sun and the wind to generate energy. When the sun shines or there is a strong wind, it is quite plausible that there is no consumer need for the energy generated by these plants. A solution to this would be the ability to efficiently store energy when it is not needed and to release it later when it is needed, regardless of whether the sun shines or the wind blows. Further collaborative opportunities exist in this field, with both Eskom and the Council for Scientific and Industrial Research (CSIR), who already collaborate on finding a solution.

Energy optimisation

Energy efficiency and demand-side management

The University currently hosts the National Hub for Energy Efficiency and Demand Side Management (EEDSM) in the Centre of New Energy Systems. It continues to attract many postgraduates from across the country, as well as an increasingly strong contingent of international students to its programmes in energy efficiency. With its strong research track record, the hub has been recognised as a leader in EEDSM research, contributing to the alleviation of South Africa's energy problems.

Plant lifetime extension

Most power stations are designed to have a specific lifetime, typically 40 years, after which they are decommissioned and dismantled. Due to financial pressure and other reasons, many older plants are being upgraded to extend their lifetime expectancy, sometimes by 20 years or more. This poses particular problems with regard to engineering management, safety issues, materials longevity and maintenance. Examples include the pending Koeberg life extension programme. The University has excellent capabilities in these fields.

Thermal optimisation

Thermal efficiency is the key to optimised power plants. This is relevant to all coal, nuclear and solar power plants (wind being the exception). The University is already well positioned in this field and is known for its expert thermoflow know-how.

Advanced materials

Carbon and graphite

The SARChI Chair in Carbon Technology and Materials in the Institute of Applied Materials

Solar energy is a renewable resource.

(a joint effort between the Department of Chemistry in the Faculty of Natural and Agricultural Sciences and the departments of Chemical Engineering, and Materials Science and Metallurgical Engineering in the Faculty of Engineering, Built Environment and Information Technology) and the SARChI Chair in Fluoro-materials Science and Process Integration in the Department of Chemical Engineering are at the leading edge of specialist materials research in South Africa. Further research is also being done by the departments of Chemistry and Physics, including cutting-edge materials and computational modelling using the University's state-of-the-art cluster computing facility.

Ceramics

Silicon carbide (SiC) plays a critical role in high temperature nuclear reactors. This particular material is also being viewed with increasing interest by more traditional nuclear reactor designers, particularly as a cladding material in fuel elements is to replace existing zircalloy (this material reacted with steam in the Fukushima event, creating hydrogen, which then exploded). Other applications, such as high temperature heat exchangers, are also possible. The University is already regarded as an expert in the use and characteristics of SiC.

Composites

Although composite materials are traditionally viewed as important in automotive and aerospace applications, recent developments also demonstrated their applicability in the energy field. One example would be the use of such materials for nuclear reactor control rods. Other possibilities that exist include turbine blades for wind energy systems.

Heat-resistant materials

The issue of materials that are resistant to high temperatures enjoys substantial research interest. Applications of these materials range from nuclear applications to solar energy systems.

Material characterisation

The University has a world-class capability to do advanced and novel characterisation of materials. No research in advanced materials would be possible without the ability to determine the composition, structure, defects and behaviour of materials under specific conditions. Opportunities exist to collaborate with other such capabilities at both the Nuclear Energy Corporation of South Africa (NECSA) and the CSIR.

Materials modelling

Modelling of the properties of materials has reached such an advanced stage that it is more productive to first calculate the desired properties of advanced and exotic materials rather than to embark on expensive and time-consuming experimental investigations. The University of Pretoria is already recognised as a leader in this field, with excellent computational hardware and the most modern software in the field.

Policy, economics and society

Manufacturing localisation

It is quite clear that the rollout of new energy capacity will be hugely challenging for the South African manufacturing industry. The doubling of current generation capacity from about 40 GW to 80 GW will require the large upscaling of the local manufacturing industry, not only from a skills perspective, but also from a design, engineering management, manufacturing process and capacity perspective.

Legal and regulatory matters

Past experience illustrated the catastrophic effects on projects in the energy domain when specific legal and regulatory aspects are not properly addressed. What makes this so challenging is the fact that many energy technologies have surged ahead of the existing legal and regulatory frameworks. Areas of particular importance include carbon trading, compliance to environmental undertakings, such as the Copen-hagen Accord, legal frameworks for energy regulators, etc.

Health and safety

It is generally understood that health and safety are important in nuclear energy plants. Clean energy sources, such as solar and wind, also have health and safety challenges, notably with regard to heavy and other exotic materials that are used extensively in these plants.

Dynamic system modelling

The scope of the modelling of energy systems and their building blocks can range from the development of detailed mathematical models that can be used to predict particular physical phenomena, to high-fidelity complete dynamic system models (for example, a complete power station) used for the study of accident and operational behaviour, as well as operator training, to atomic-level computational models. Also included would be economic models that are typically used by governmental and utility organisations to do financial predictions and help determine policy. This field is vast and complex and truly multidisciplinary, requiring expertise from the mathematical, physical and materials sciences, as well as engineering and business management.

Design life cycle

It is widely accepted that all successful solutions exhibit some, if not all, of the characteristics of a total life cycle approach. Not only are the basic design processes part of the system's creation, but so are all the elements required to support, maintain, expand and eventually discard the equipment in a safe and environmentally friendly manner. The University is fortunate in that the Graduate School of Technology Management's senior academic and research personnel all have vast practical and industrial experience in this field. In addition, the school hosts the Chair in Life Cycle Engineering, putting it in a unique position in South Africa.

Risk management and mitigation

As South Africa embarks on the difficult path towards energy security, it has come to realise that this path is not only fraught with engineering, scientific and economic problems, but also many risks. Many large capital-intensive undertakings fail in some way or other because of a poor understanding of the inherent risks. The very fact that South Africa has serious problems with reliable and sufficient energy sources can be attributed to poor risk management. There is a clear need for practical risk management models that can be used to mitigate the energy supply risks South Africa currently faces, especially as this must be seen within the contradictory requirements of both an increased energy supply capacity and reduced greenhouse gas emissions.

Techno-economic analysis

With the focus on sustainable energy solutions also comes a question on future trends. As technologies tend to cross traditional borders and energy plants become a complex multidisciplinary "consortium" of technologies, it also becomes important to analyse technology trends and their economic impact. This would be a critical enabler for national energy policy-makers.

Sustainability

Of primary concern is the sustainability of energy sources (and by default the resulting systems), not only from a social and economic perspective, but also from a scientific and engineering viewpoint. The long-term limited coal reserves are well known, as is the case with uranium (although thorium – as a future nuclear fuel resource – is relatively abundant in South Africa). On the other hand, the belief that renewable sources, such as wind and solar energy, are unlimited is a fallacy, as the wind and solar electricity-generating plants also use other limited sources (for example, rare earth materials). The subject of energy system sustainability seems to be mainly focused on renewable resources. This is a severely limited outlook of a much richer and larger research field.

Environment

Waste management

The University is currently engaged in a novel nuclear waste research project that makes use of bacteria to remove certain radio isotopes from high-level radioactive graphite waste. The results of this research project form part of a European Commission Framework 7 Project, Carbowaste. One of the most contentious issues in nuclear energy remains the long-term storage of radioactive waste. At the University of Pretoria, glassy carbon is being investigated as an alternative for glass.

Pollution

It is clear that despite the South African government's ambitious promises to reduce the country's greenhouse gas emissions by 42% within the next 15 years, this goal will in all likelihood not be achieved. Almost all the current energy sources pollute the environment in some way or other, which provides vast scope for research. This is underlined by the fact that South Africa only ranked 115th out of 163 countries in the 2010 Environmental Sustainability Index published by the Yale University Centre for Environmental Law and Policy.

The way forward

Initially, the Energy IRT will establish a number of kick-off projects that will allow multidisciplinary research that cuts across the faculties of Engineering, Built Environment and Information Technology, and Natural and Agricultural Sciences. These projects were carefully selected to fit in well with the institutional research focus areas. They also comply with national energy priorities in that they address aspects of advanced materials, nuclear fuel, environment and renewable energy, while simultaneously leveraging existing skills of the University. It is anticipated that these initial projects will act as a catalyst for the establishment of further energy research at the University with the eventual aim of ending the initial three-year period of the IRT's University funding with at least 24 active projects, all of which are expected to attract substantial industry support and funding. Towards the end of 2011, a formal request for research proposals will be issued to ensure continued growth in new research projects.

The initial kick-off projects include the following:

Technology assessments and scenarios for energy systems
This aims to develop a detailed relational database and model to help energy decision-makers derive at realistic energy policies. In addition, the project aims to conduct a large and complete energy technology trend analysis, accompanied by a related gap analysis, focused on the South African industry. Discussions are already underway with a number of international and local organisations and universities as possible collaboration partners.

Contact Dr Jörg Lalk of the Graduate School of Technology Management (jorg.lalk@up.ac.za).

Energy optimisation
This project will be a continuation of the work being done in the National Hub for EEDSM, thermal optimisation and process optimisation fields.

Contact Prof Xiahua Xia of the Department of Electrical, Electronic and Computer Engineering (xxia@postino.up.ac.za), Prof Josua Meyer of the Department of Mechanical and Aeronautical Engineering (josua.meyer@up.ac.za) or Prof Thokozani Majozi of the Department of Chemical Engineering (thoko.majozi@up.ac.za).

Nuclear waste minimisation
This project will continue the work that has already been done by the departments of Chemical Engineering and Physics, where promising results were obtained. The project will – in all likelihood – continue its collaboration with the European Commission Framework 7 Programme.

Contact Prof Walter Focke of the Department of Chemical Engineering (walter.focke@up.ac.za) or Prof Johan Malherbe of the Department of Physics (johan.malherbe@up.ac.za).

Silicon carbide tubes for water-cooled reactor fuel elements
Ironically, this project was proposed about a month before the Fukushima event and aims to replace zircalloy nuclear cladding with silicon carbide. The project is undertaken in collaboration with a major international partner in the nuclear energy field.

Contact Prof Johan Malherbe of the Department of Physics (johan.malherbe@up.ac.za) or Prof Johan Slabber of the Department of Mechanical and Aeronautical Engineering (johan.slabber@up.ac.za).

Multi-product low carbon footprint power generation
This is a novel project that will make use of a variety of biofuels and bagasse to generate electricity in collaboration with a number of international partners.

Contact Dr Jannie Pretorius of the Department of Chemistry (jannie.pretorius@up.ac.za).

Smart grids for renewable energy integration
This project will attempt to understand the systems level impacts of renewable energy sources on the stability and sustainability of large distribution grids, with the eventual aim to develop decision models towards smart grids.

Contact Dr Louwrence Erasmus of the Graduate School of Technology Management (louwrence.erasmus@up.ac.za).

Of course, none of these projects, or those that will follow, will be possible without excellent postgraduate research.

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→ *A wind turbine.*