![UNSW logo] THE UNIVERSITY OF NEW SOUTH WALES

Engineering Research Report
Young Researchers Changing the World

Never Stand Still   Faculty of Engineering

CONTENTS

MESSAGE FROM THE DEAN

It continues to be my pleasure to lead such a dynamic group of internationally respected researchers. From the smallest nanoparticles to space programs and the biggest issues facing humankind, UNSW engineers are working to understand, model and solve issues in the areas of health, energy, water, future materials and the digital world. Much of their hard work can take years to reach the marketplace, but without the patient, tireless groundwork at the cutting edge of modern engineering thought and practice, progress would not be made at all. I hope you find this summary of some of our world-class research inspiring and energising.

PROFESSOR GRAHAM DAVIES
Dean, Faculty of Engineering

INTRODUCTION

Engineers are shaping the future in almost every aspect of modern-day life. Whether redesigning major infrastructure, solving water resource issues and other problems relating to climate change, creating a proactive health system that can predict health issues before they occur, or finding more efficient ways to search through the vast masses of information swirling around the internet, UNSW engineers are at the forefront of research.

UNSW Engineering is Australia largest engineering faculty, with more than 8500 students across 10 Schools covering everything from petroleum to biomedical engineering. Many leading research centres are based at the Faculty, some of the more recent additions being the Australian Centre for Sustainable Mining Practices, the Australian Centre for Space Engineering Research and the Australian Centre for NanoMedicine.

Increasingly much of our research is multi-disciplinary, with collaboration across other faculties and institutions throughout the world. Our researchers also work closely with industry partners to keep the research focused on real problems in the real world.

UNSW Engineering continues to add to its world-class research facilities, with the groundbreaking, sustainable Tyree Energy Technologies Building. This adds to other recent facilities, such as the new Bionic Eye Laboratories, the Solar Industrial Research Facility and the flexible Design Studio.

UNSW is truly an institution established so our engineers can change the world.

01 ENERGY

PRODUCING ENERGY IN SUSTAINABLE WAYS REMAINS ONE OF THE KEY PROBLEMS ENGINEERS GRAPPLE WITH DAILY. AT UNSW, WE COMBINE OUR EXPERTISE IN PHOTOVOLTAICS, MINING AND ELECTRICAL ENGINEERING TO ADDRESS GEOTHERMAL POWER, METHANE CAPTURE AND SAVING POWER AT EVERY JUNCTURE.

ELECTRICITY BLOWN AWAY

OPTIMISING ELECTRONICS TO PREVENT WASTED POWER FROM WIND FARMS

Photo:
Wind turbines

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Wind power is a growing energy source worldwide, but at the moment, large amounts of electricity are lost when power from wind turbines is converted into mains electricity grids. Professor Vassilios Agelidis, Director of the Australian Energy Research Institute, and his award-winning team from the School of Electrical Engineering and Telecommunications are redesigning the converter cells to reduce the switching frequency within the converters. By redesigning and optimising the electronics in this way, they are dramatically reducing the amount of wasted power. "We want as little energy lost inside the converter as possible," he says.

The Australian Government has set a target of 20% of our energy to come from renewable energy sources by 2020. Connecting large wind farms with the transmission grid requires novel voltage-sourced converter (VSC) based high-voltage-direct-current (HVDC) power transmission technologies to become commercially competitive. VSC-HVDC systems are project specific, so their cost is usually very high. Vassilios says it is therefore important to find modular solutions to reduce manufacturing costs.

As the power coming from a wind turbine is inconsistent, it needs to be converted to a continuous supply and frequency. "The current has to be synchronised with the electricity grid because the wind turbine doesn't run at the same speed all the time," Vassilios says. But the converters get very hot, losing large amounts of power and also requiring ionised water or oil systems to cool them down. "The cost of running the converters can be as high as 30% of the capital costs, and some of these projects cost hundreds of millions of dollars," he says. "You lose energy for the next 30 years, and you have to pay for the energy that you lose and then pay for managing the energy loss. So, if you bring the costs down it will be significant. The heat generated by the switching losses needs to be removed from the system to increase reliability and performance."

The research is focused on modular-multilevel VSCs that will be used as building blocks for the next generation of VSC-HVDC systems. These new systems are promising for the connection of large wind and solar farms, and for cost-effective transmission of bulk power.

The team has successfully built some low-power prototypes, and is looking to extrapolate these prototypes for the industry, through large turbine manufacturers such as Vestas, Siemens, Sinovel and Enercon. "Our role is to study and optimise the converters so when they are built commercially they will be much more efficient," Vassilios says. "There are companies in China, Sweden and Germany that are looking at building these commercially in the next year or so."
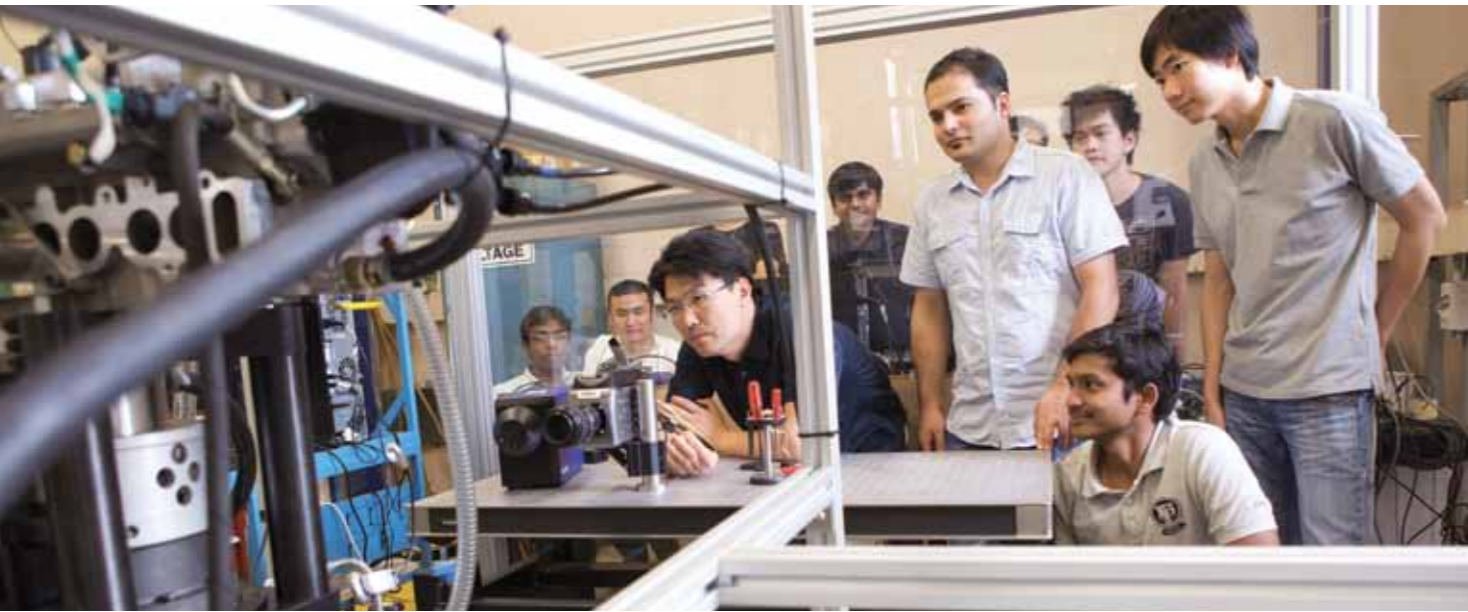
INSIDE THE ENGINE ROOM

A RARE LOOK INTO THE COMBUSTION CYLINDER

Photo:
Dr Shawn Kook and members of the Engine Research Group are working with an optically accessible diesel engine.

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Optically accessible engines hum and purr in the UNSW Engine Research Laboratory, providing researchers with a unique opportunity to study how changes in engine design affect what's going on inside. "The processes going on inside an engine are very complicated and surprisingly little understood," says Dr Shawn Kook, senior lecturer in the School of Mechanical and Manufacturing Engineering. "These include chaotic turbulent flow, complex spray atomisation and evaporation, and combustion chemistry involving hundreds of chemical species and thousands of chemical reactions."

In the lab, there are two types of optical engines: a spark-ignition direct-injection petrol engine and latest-generation common-rail diesel engine. Both engines are a single-cylinder version of production engines and their state-of-the-art design includes an extended piston with piston-crown window and windows replacing the original cylinder liner. Through the optical windows, advanced laser and imaging diagnostic techniques are used to observe and quantify combustion and emissions-formation processes.

"Prior engine development has occurred largely by trial and error over many decades, but to overcome barriers in efficiency improvement and to satisfy impending emissions regulations, the in-cylinder mechanisms responsible for the efficiency loss and pollutants formation must be clarified," Shawn says. "The advanced optical/laser-based diagnostics performed in the optical engine provides detailed information concerning the fuel spray, in-cylinder turbulent flow structure, mixture ignition and combustion."

The engines are very versatile and can be calibrated to be applicable for any engine, size or model. They not only improve fundamental understanding of in-cylinder phenomena, but also provide validation data for the development of advanced computational models for these phenomena.

A modelling team led by Dr Evatt Hawkes exploits multi-dimensional mesh of engine geometry where mixing and chemical reactions are solved in realistic conditions. Both the insight obtained and the quantitative data gathered for computational model validation accelerate the development of clean and efficient engines.

Through developing a better understanding of the in-cylinder workings of an engine, Shawn is hoping the team can dramatically improve the fuel efficiency of car engines, but says the trick is to also lower the amount of harmful emissions. "Furthermore, engines must be optimised to new alternative fuels such as gas-to-liquids, coal-to-liquids, biofuels, and hydrogen: existing engines are designed to burn conventional fossil fuels and do not make the best use of alternatives."

Wider interest in the engine research group and its work is demonstrated by the fact that it has received many grants, including six ARC grants in 2011.

"We have to combine all the information we have – in-cylinder flow, mixing process, pollutant formation ¬– to revolutionise future fuel use," Shawn says. "The Engine Research laboratory gives us the tools to create that kind of revolution."

PV WORLD RECORDS CONTINUE

WORLD'S MOST EFFICIENT LARGE AREA PRODUCTION CELL

Photos:
PhD student Brett Hallam
Industrial sized laser-doped solar cell fabricated on a commercial production line.

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If there was an Olympic Games for the production of photovoltaic cells, UNSW would rarely leave the winners' podium. In almost every race to make PV power cheaper and more efficient, UNSW is a world-leader, continually setting the bar higher.

In two of the latest world records set at UNSW, PhD student Brett Hallam in the School of Photovoltaics and Renewable Energy Engineering has made the most efficient large area production cell fabricated on standard commercial-grade silicon wafers. The results were achieved on a standard industrial production line for screen-printed solar cells, modified with laser-doping equipment.

The first record, at 19.3% efficiency, was substantially higher than the standard efficiency currently being produced in commercial production of 18%. The previous world record for a solar cell fabricated in a similar fashion was 18.8%. Subsequently, the record was broken by a 19.4% cell.

"This is an extra 10% improvement over conventional solar cells," Brett says. "You don't need as much roof space to generate the same amount of electricity."

The process involves laser-doping the solar cell, using a high-powered laser, and then plating a contact that is ¼ the width of a human hair. Previously, laser-induced defects have prevented good results from this method, but Brett says record efficiency has been achieved by the careful selection of laser parameters such as wavelength, pulse duration, pulse shape and power.

The technique provides many efficiency gains. Primarily it reduces the "shadow" caused by metal contacts on the surface, allowing more light to get into the cell. Also, it enables the cell to access a wider range of the light spectrum. "We've replaced the really heavy diffusion with light diffusion on the whole surface, so we can generate more electricity from blue light."

Brett says the process ingeniously uses the power of the cell to help make itself. The silicon wafer is put in a metallic solution and light is shone on it so the voltage across the solar cell drives a reaction that plates metal onto the front surface. As copper is the primary metal, rather than silver, it leads to cheaper production costs.

The technique moves away from a need for very high temperatures, so lower-quality substrates can be used.

"It ends up being slightly more expensive to convert from a silicon wafer to a solar cell… but we gain a lot in terms of the other components," Brett says. "So if you've got a 200-watt module with screen printing and a 200-watt module with laser doping, ours will be cheaper.

"We're only talking savings of 3–4% but some of the biggest companies in the world are producing two gigawatts a year, and if cost price is $1.40 a watt, 3–4% is quite substantial – its millions of dollars."

A patent has been filed for the process, and industry research partners across the world are now working with the UNSW team. The technique will also be put into a production line at the new Solar Industrial Research Facility (SIRF) at UNSW.
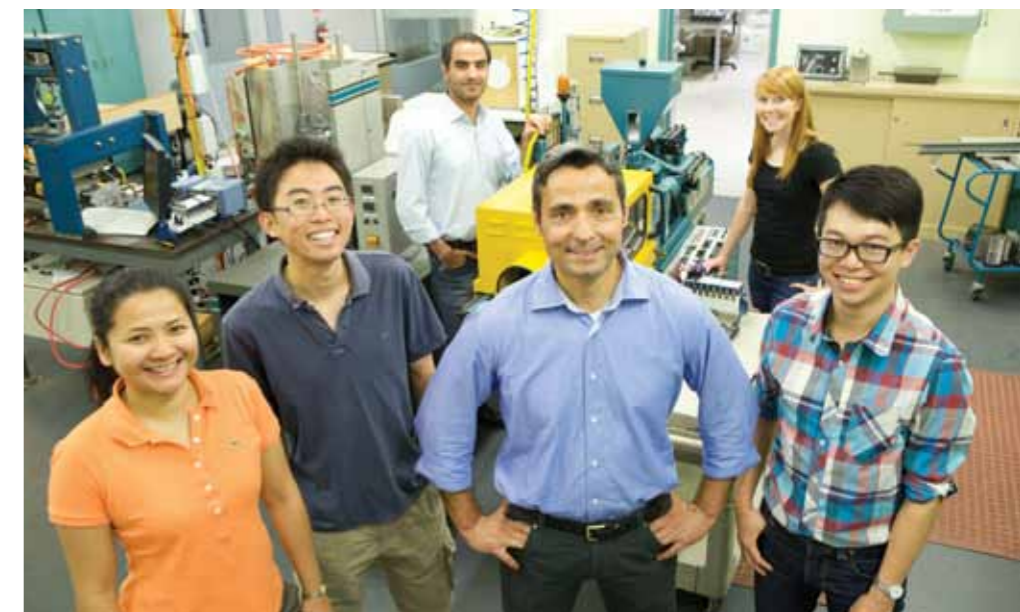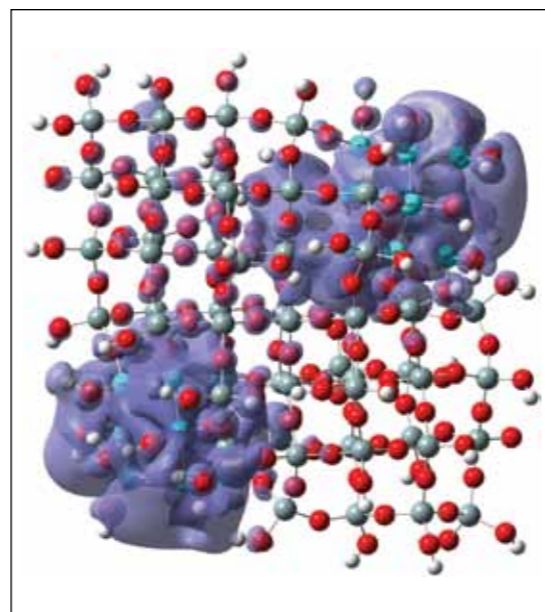
QUANTUM DOTS

DESIGNING THIRD-GENERATION SOLAR CELLS

Photos:

PhD student Binesh Puthen-Veettil

Density Functional Theory calculation of two silicon quantum dots consisting of ten atoms each (bright blue), embedded into silicon dioxide (red: oxygen atoms; grey: silicon atoms; white: hydrogen atoms terminating outermost bonds). The semi-transparent blue iso-surface shows a quantum-confined electron state located in both silicon quantum dots and on some adjacent atoms of the silicon dioxide. The simultaneous existence of one electron state in two adjacent, yet separate quantum dots is a pure quantum mechanical phenomenon known as electron tunneling.

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The world-leading photovoltaic work at UNSW continues on three main fronts: making silicon solar cells more efficient, thin-film or second-generation solar cells, and the solar cells of the future – the so-called "third-generation" solar cells. Much of this third-generation work is aimed at developing layered or "tandem" solar cells, where solar cells with different properties are placed on top of each other in order to extract energy from the full range of light wavelengths. In present tandem designs, different materials are used for each layer, making them very costly.

PhD research student Binesh Puthen-Veettil, in the School of Photovoltaics and Renewable Energy Engineering, is designing a solar cell with layers of different sized silicon quantum dots, each of which would extract the energy from a different light wavelength. "Each layer will act like a different material," he says. "The larger the quantum dots, the longer the wavelength. Red light would be absorbed by larger quantum dots and blue light by smaller ones."

A quantum dot, a type of nanostructure, is a cluster of material embedded in another material. "It's just a bunch of atoms in a shape, but the size is on the nano scale – less than 100 nanometres," Binesh says. "For photovoltaics, the size of the dots is 2–10nm."

Meanwhile, Dr Dirk Konig, Senior Research Fellow and Head of the Theory and Characterization Groups in the ARC Photovoltaics Centre of Excellence, is using density functional theory to very precisely study, place and modify individual atoms to create optimal solar cell designs.

"Density functional theory basically describes electrons in any solid matter on a per atom basis," Dirk says. "Most people look at a top-down picture of a structure, but I come from the other direction, bottom up – we start with the individual atoms."

Using the data-dense techniques with specialised software he developed, Dirk can uncover and predict with high accuracy the mechanisms shaping the optical and electronic behaviour of individual atoms and their properties, such as absorption gaps and doping. "It provides vital insight into material properties … we can look at things such as defects in nanocrystals – how they affect electronic behaviour."

He said two of the more challenging applications so far have been putting silicon nanodots in nitride, which has not been done before, because the interaction of nitrogen with other atoms is very difficult to simulate, and developing a novel method to provide positive charges to silicon nanocrystals, by doping the embedding oxide material.

"It's giving us more inside knowledge of different materials so we can develop better structures and starting points for processing technologies to come up with a better solar cell design."

MANUFACTURING POWER

SAVING MONEY AND IMPROVING ENVIRONMENTAL FOOTPRINTS

Photo:

Right: Associate Professor Sami Kara and his researchers investigating the energy and the eco-efficiency efficiency of injection moulding process.

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Manufacturers are lining up at UNSW's Life Cycle Engineering research group, in order to save money and improve their environmental footprint, according to Associate Professor Sami Kara, founder and head of the group, which is based in the School of Mechanical and Manufacturing Engineering.

Sami says most existing factories in Australia are highly inefficient in their use of water and energy. "More and more companies are coming to us saying 'We want to cut down our energy use'. As well as saving them money, this can easily translate to reduced environmental impact, so unlike many environmental solutions, it's a win-win situation for manufacturers – cost and environmental footprint reduction at the same time."

Sami says work at large manufacturers has shown that there is usually very little understanding of electricity and water usage. "The electricity gauge at the factory door is often their understanding of electricity consumption," he says. "Once we understand the flow, we can look at technological solutions."

For example, at one factory, Sami's team discovered that auxiliaries, such as air-conditioning and heating, had a greater impact on power consumption than the production line itself. Like many Australian factories, the building was designed in the 1960s, without much regard for the conditions or the manufacturing process. A great amount of heat generated by large ovens was getting caught under the ceiling, and air-conditioning was then used to cool the building. "We've proven that the heat loss is more than enough to generate power," Sami says. The group has proposed installing a generator that will produce power for the factory and export power to the grid at times, using this "waste" heat and heat from the steam boiler. "Their power bill is in the millions, and so if you have a $250,000 investment, it will pay off in less than a year's time," Sami says.

The group is also working on intelligent monitoring systems that can assess changing energy use in a factory and modify auxiliary systems as necessary. For example, the same manufacturer has clean-room facilities that need heating, ventilation and stabilisation of particles, but the facilities aren't used on the weekends. "The question we are asking is can we turn the systems off on a Friday afternoon, and if we do, how early should we turn it on again before the people start working again on Monday morning? It would require a huge kick of energy to clean up the air, so would it be better to run it all weekend at a low rate, or run it shorter and more intensely? We will develop some sort of monitoring and control system which gives you the best possible energy consumption."
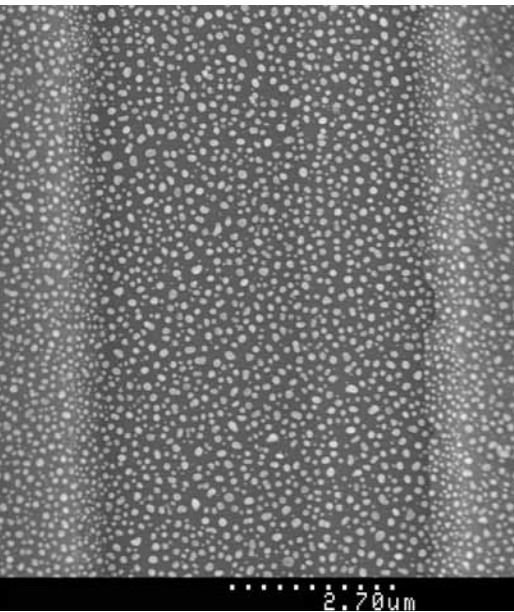
TRAPPING THE LIGHT FANTASTIC

AT THE CUTTING EDGE OF THIN-FILM PHOTOVOLTAICS

Photos:
Silver metal nanoparticles deposited on Si
Dr Supriya Pillai

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New research at UNSW is increasing the amount of light that can be trapped in thin-film photovoltaics.

Thin-film PV is seen to be one of the major ways to reduce the cost of PV production, as it is about 100 times thinner than traditional silicon wafers. Thin film semiconductor materials, such as silicon, is usually deposited on a substrate such as glass, and is just 2–3 microns thick, as opposed to traditional silicon cells, which are about 300 microns thick.

But as Dr Supriya Pillai, of the ARC Photovoltaic Centre of Excellence in the School of Photovoltaics and Renewable Energy Engineering, notes, thin-film technology has difficulties to overcome. "The light that is actually being absorbed is being dramatically reduced because the thickness is so low," she says. "It's 100 times less thick than a usual cell, so you reduce the amount of light absorbed significantly."

One of her challenges has been to increase the amount of light entering the thin film, so that as much of the available light can be caught and used. One of the ways to do that is by texturing the cells, but that can lead to reduced performance and is difficult to achieve in thin films. Supriya is therefore adding a layer of carefully constructed silver nanoparticles to a finished cell in an emerging field called plasmonics. "The metal nanoparticles act like antennas absorbing

the incident radiation and scattering it into the underlying semiconductor," she says. "When you texture a cell, you are increasing the surface area. When you use plasmonics, it's a totally different layer put on once the device is fabricated. It's not increasing the surface area of the silicon in any way, and it doesn't negatively affect the electrical properties."

Supriya says the nanoparticles are designed to not only maximise the scattering of light, but to do it at large angles, "so they are basically scattering beyond the escape cone, so it has a chance to be caught again because it keeps bouncing within the cell. Larger particles tend to scatter more than smaller particles – something in the 100–300 nanometre range seems to be ideal. The main challenge of the work at the moment is to incorporate it with other layers in the cell with minimal losses."

When nanoparticles form on the rear of the cell, significant light is still lost. "We have to minimise the loss," she says. "This means we have to use the nanoparticles with additional layers without affecting the scattering properties."

The next step will be to see whether the nanoparticle layer can be incorporated into conventional reflective layers that are currently used at the back of PV cells, such as white paint or a reflective metal. Promising results have been achieved so far.

COAL + CO$_2$ = METHANE?

DEVELOPING "CLEAN COAL" TECHNOLOGY THAT COULD STORE CARBON DIOXIDE UNDERGROUND

Photos:
A methane gas collection facility of the China CBM Co. Ltd. Dr Yildiray Cinar (third from left) with the company engineers.
A sucker rod pump on a CBM well producing water to make way for methane gas.

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Imagine if we could not just help solve our carbon emissions problems by storing CO$_2$ underground, but by doing so, gain access to otherwise inaccessible methane deposits trapped in coal.

This is the goal of research being undertaken by Dr Yildiray Cinar, Fengde Zhou, Wanwan Hou and Guy Allinson from the School of Petroleum Engineering.

Funded by the Australian Department of Resources, Energy and Tourism's "clean coal technology" program and the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC), Yildiray and his team are exploring how to maximise the extraction of methane from coal beds by injecting CO$_2$. Nitrogen can also be used for this purpose, but – if the coal bed is deep and not going to be mined for coal – CO$_2$ can be used, providing potentially important carbon sequestration.

Methane is often stored naturally in coal under pressure and, although traditionally it was simply pre-drained by coal miners to prevent explosions, it is increasingly being used as a power source in its own right, cleaner than burning the coal itself.

Usually it is almost impossible to recover all of the methane adsorbed on coal by natural depletion, so something more is needed to increase recovery – hence the method of injecting other gases.

"In this project we're determining the optimum injection schemes of CO$_2$ and nitrogen gases," Yildiray says. "Whether or

not a system can eventually be implemented isn't yet known, but it has major potential."

Yildiray says the main characteristic that makes coal beds attractive for CO$_2$ storage is that CO$_2$ is adsorbed onto the coal surface in preference to methane. "When you inject CO$_2$, it sticks to the coal and this process releases additional methane. However, over time the coal matrix swells, which reduces permeability of the coal in the longer term, an engineering problem to be solved" he says. Guy adds there are still many other obstacles to be overcome before the method could be used, and there is a whole interplay of economic factors.

Although the technique could potentially be used in the reservoir in China's Qinshui Basin, where Yildiray and Guy have been analysing the permeability and other properties of the deposit, the situation in Australia could be quite different.

"Often in Australia we have large volumes of CO$_2$ being produced by power stations but the coal seam methane reservoirs might be some distance away," Guy says. "In the end it will come down to economics. How costly is it to do all of this in the locality that has the coal seams? We've got to work out the conditions under which it will work and be economically viable – that's our job."

Guy says that determining how to keep the CO$_2$ locked in the coal is one key. "It might break through later and we have to determine the optimal conditions that prevent that, so it stays in a stored condition."
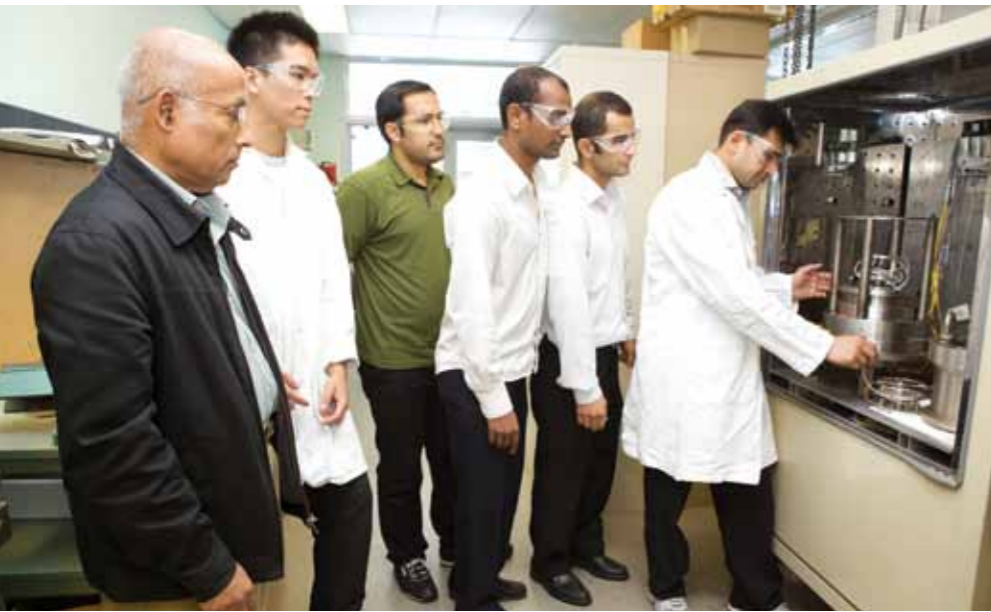
HEATED ISSUES

FRACTURING ROCKS TO ACCESS OUR GEOTHERMAL POWER

Photos:
Professor Sheik Rahman and students looking at the rock properties apparatus.
Close up of the rock properties apparatus.

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Australia's geothermal reserves – hot rocks deep underground – have the potential to provide far more renewable power than every other form of renewable power in existence in Australia. Yet the fledgling industry has been frustrated by very high capital costs, political inaction and some unexpected geological complexities.

Professor Sheik Rahman, at the School of Petroleum Engineering, is one of several UNSW researchers who have been at the forefront of research into geothermal power since the early 1990s when they developed an initial "heat map" of Australia that showed we potentially had in the order of 190 million petajoules stored as geothermal energy. Optimists said that within a decade we would be producing vast amounts of power using these resources. "At that time we were speaking about the experiences overseas," Sheik says. "And if geological conditions were favourable, we could have developed the geothermal sector then."

However, the Australian resources do not have the well-connected fracture systems that many hot rock resources have in other parts of the world. "If you want to produce commercial quantities of hot water to generate power through a binary system, you need in the order of 40,000 barrels a day," he says. "We don't have sufficient porosity in the granitic basement to take that volume and get it out the other end."

Sheik has been studying how to inflate and extend underground fracture systems so that large volumes of water can be pushed through. He has discovered it takes about 1–6 weeks of pumping high-volume water to expand the fracture systems in this way.

"My research, luckily enough, has applications in the oil industry," he says. For example, India and Vietnam have similar granitic basements, but they contain oil. "Here, the content is water. In essence, there is no big difference in the technology. How you apply the technology is different."

Sheik says that incorporating this procedure in the initial drilling and testing, to make the resource usable, is not a big investment in the life of the reservoir. "A fully developed stimulated reservoir can sustain uninterrupted supply of economic thermal energy over 20 years," he says. After that the temperature of the reservoir is likely to slip below 140°C, making it much harder to generate electricity. "But, because heat is produced by the decaying of radioactive elements, the reservoir can regain its initial temperature over the following 10 to 20 years."

He remains optimistic that our geothermal resources will start supplying energy to the grid from mid 2015. "In Australia at the moment we have more than 10 companies actively operating and the level of investment would be more than a billion dollars. And with the carbon tax or a carbon economy coming, it makes more sense for people to get this together to go after it.

"By 2020, we should be able to produce 200 MW and if the government is prepared to put money in it, we can take that further."

TAMING WAVES

ACCURATE MODELLING OF DEFORMATION WAVES

Photos:
Road damaged by earthquake (Christchurch 2010).
Seismic waves travel in the soil over long distances.
Dr Carolin Birk

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The problem with studying complex wave behaviour is that most computer models have to work with finite boundaries, and the waves reflect at these hypothetical boundaries, adversely affecting the calculations. This makes usual computer models unsuitable for seemingly "boundless" media, such as soil, air, large bodies of water or long pipes.

Carolin Birk, Lecturer in the School of Civil and Environmental Engineering, has been working to resolve this problem by developing a new numerical method that can take into account deformation waves propagating in large areas.

"A lot of commercial software uses the classical finite element method that is typically used for systems that are bounded, such as bridges and buildings," she says. "It's very good for some problems, but it has its weaknesses."

Carolin says the finite element method can't properly take into account effects such as radiation damping. "Say you have a power plant with a time-dependent load acting on it," she says. "Waves will travel through the soil away from the structure towards infinity, transporting energy away from the structure. This effect is called radiation damping. We always have damping in reality, but in mathematical models we sometimes neglect this aspect of damping because it's very difficult to quantify."

In the new numerical method being developed, hypothetical boundaries aren't used, the damping effect the soil is modelled accurately.

"Another limitation of the standard method is that if you want to model something where you have a crack in a plate, we create a mesh around it, and the mesh has to be very, very fine at the crack tip," she says. "It takes a huge amount of calculating power. The new numerical method overcomes this drawback by not using a mesh around the crack at all."

She hopes one of the key ways in which the new methods will be used is for non-destructive testing of gas pipes, particularly after a pipe ruptured on Varanus Island, WA, in 2008, leading to the loss of 35% of WA's gas supply. Conventionally, pipe testing is done by putting a transducer on the top of the pipe, highlighting defects very close to the transducer. However, it would be far more efficient to send guided waves along the pipe, reflecting the signal when they came across cracks or other disturbances. "At the moment it's very difficult to interpret these signals," she says. "All the theory to fully interpret this is not there yet."

There are other potential uses down the track too, including modelling the diffusion of water or air pollution over large areas.

Carolin says teams have been working on the new numerical model for 15 years. "I'm fine-tuning it all the time, but nothing is complete, ever."

02 HEALTH

UNSW ENGINEERS ARE AT THE FOREFRONT OF RESEARCH IN SO MANY ASPECTS OF HEALTH. AS WELL AS FLAGSHIP PROGRAMS LIKE THE BIONIC EYE, THE WORK IN NANOMEDICINE, CONTAMINANT DETECTION AND PROACTIVE PERSONAL HEALTH CARE IS BRINGING ABOUT A HEALTHIER WORLD.

FOOD SAFETY

DETECTING NASTIES QUICKLY AND EASILY

Photos:
Food pathogen and peanut allergen

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A tool that will quickly provide the ability to detect contaminants, toxins, pathogens and allergens in food – days earlier than current methods – is being developed by a multi-disciplinary team from the schools of Chemical Engineering, Biotechnology and Biomolecular Sciences and Chemistry.

"Food is a complex mixture of carbohydrate, protein, fat and other edible components," says Dr Alice Lee, a Senior Lecturer of Food Science and Technology at the School of Chemical Engineering. "If there are pathogens, contaminants, toxins or food allergens present in that complex matrix, they can be very difficult to separate from the food components."

Traditionally, detection would involve collecting and then growing cultures in a specialised laboratory. "That process can take days," says Dr May Lim, Research Fellow at the ARC Centre of Excellence for Functional Nanomaterials in the School of Chemical Engineering. "At least one day, and usually 4–5 days if food pathogens are concerned, and that may be too late – by then you may already have an outbreak. By developing better technology for capturing and sensing food allergens and pathogens, we could improve the response time and accuracy of food allergen and pathogen analysis, particularly at trace levels that are of biological significance."

May and Alice, in collaboration with Professor Justin Gooding from the School of Chemistry and Dr Christopher Marquis from the School of Biotechnology and Biomolecular Sciences have been attaching

bio-recognition agents to magnetic nanoparticles. These biomolecules are designed to bind specifically to the pathogen or allergen of interest. "Usually you know what pathogen you're after," May says. "For example, looking for the source of an E. coli outbreak."

Because the nanoparticles to which the bio-recognition agents are attached are magnetic, they can easily be pulled out from the food matrices and concentrated. "And the more E. coli you have, the more accurate your detection," May says. "The bottleneck is not usually in the final detection, the bottleneck is in the separation and concentration steps."

Using the newly developed nanoparticle methods, the process can take just a few minutes.

"We have proven the concept in detecting metal ions, e.g, copper ions, in water supply," she says. In just five minutes, the group successfully detected copper ions in water at the equivalent level of one drop of copper solution in an Olympic-sized swimming pool. "With other techniques, even after 20 minutes we still haven't got the full detection signal."

The group is now focusing on developing more robust molecular or biological recognition agents, and detection platforms.

May says although the technique will have many uses, such as the detection of cancer biomarkers or doping in competitive sport, the group has a particular focus on increasing food safety.
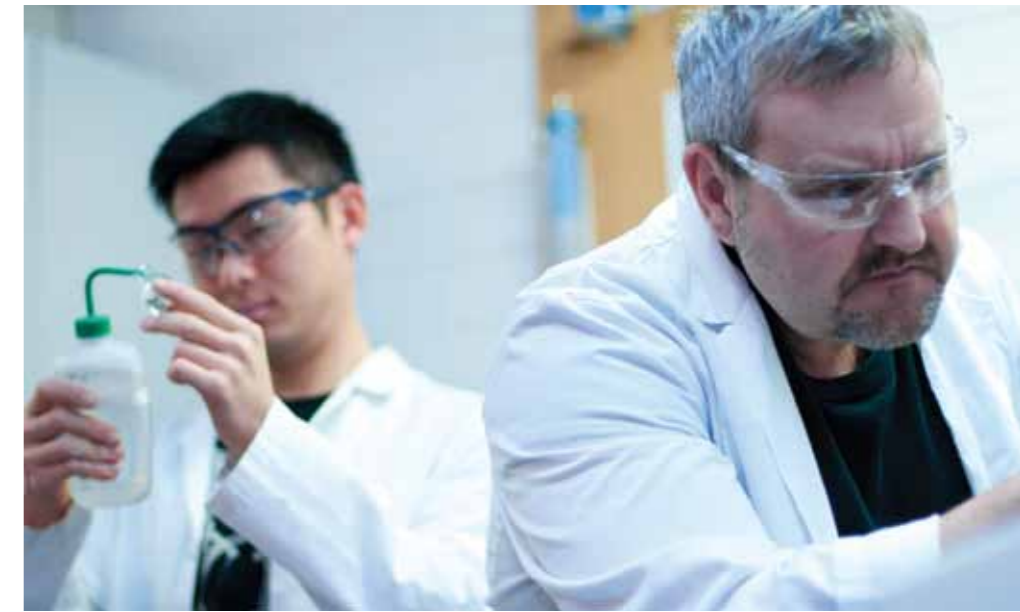
BIONIC EYE

VISUAL PROSTHESIS TO BE PLACED IN HUMANS

Photo:
Left: Associate Professor Gregg Suaning (left) and Scientia Professor Nigel Lovell.

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One of the cornerstone and most talked about projects at UNSW is the bionic eye, with UNSW part of the Bionic Vision Australia consortium that received $42 million in Federal Government Funding in 2010 to implant a bionic eye in a person in four years.

In 2011 the project ramped up, and now some 50 people work in the new research facilities in the basement of the Samuels Building at the Kensington campus.

"It's progressing well," says Professor Nigel Lovell, a UNSW Scientia Professor of the Graduate School of Biomedical Engineering. "Proof of principle has been established, and all parts of the technology are well in-hand. We will put it in several individuals in 2013 and by then we'll have a next-generation device as well."

Nigel has been involved since 1997, when he and Associate Professor Gregg Suaning set out to develop a visual prosthesis for the treatment of disorders causing blindness, such as retinitis pigmentosa. He says that international competition to create a bionic eye is stiff and a US company has already begun human trials. "But theirs takes six hours of surgery to put it in front of the retina. Our device will be placed behind the retina, which is a much easier surgical procedure."

Nigel acknowledges the eventual vision won't be the same as a sighted person. "You won't be able to perceive colour, as you're just stimulating a whole lot of nerve cells irrespective of how these cells encode colour," he says. Initially, the vision will be split into about 100 moving elements, or phosphenes, each one providing an intensity of light on a grey scale. "We will probably also have an eye-tracking system so the camera will move with your eyes, and the implantable device will be powered wirelessly by radio waves," he says.

The next steps include refinement of surgical approaches, and some fine-tuning of the implant design. But research continues into all aspects of the project, including image processing, neurophysiology and biocompatible high-density electrode arrays. "The whole thing has to be made out of biologically safe things, such as titanium, platinum and silicone rubber," Nigel says. "We have to make the bionic eye in a way that will last inside the body for a lifetime – not something that would last for a couple of months."

Nigel emphasises that one of the most important aspects of the bionic eye research program is the spin-off technologies that could have a positive effect in other areas of health care. For example, the state-of-the-art electronics and electrode manufacture techniques could be used in other implantable devices. Research on what happens when you stimulate a whole lot of neural tissues at once could have an impact on paralysis treatment.

CHANGING THE FUTURE OF MEDICINE

HARD TO TREAT DISEASES PINPOINT FOR NANOMEDICINE

Photos:
NanoMed research in the Lab
PhD candidate Alex Soeriyadi and ACN Research Manager Dr Michael Whittaker

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What would it mean for human health if scientists could develop drug carriers that take toxic drugs to a specific diseased site in the body, drop the drug cargo into the disease with particles so small that they quickly release from the body without side effects for the patient.

This is no longer a dream with scientists and biologists working together at UNSW's Australian Centre for NanoMedicine (ACN) in the School of Chemical Engineering, where research is being undertaken that will eventually mean cures for some of the hardest to treat diseases including neuroblastoma, lung cancer and liver fibrosis.

Faculty of Engineering experts, Professor Tom Davis and Dr Cyrille Boyer are world recognised for their work in polymer chemistry. "Our research is to use polymers to deliver drug or toxin cargo with the ability to fight disease. However as scientists we aren't experts on cell biology, especially diseased cells, so through ACN we work in disease focused teams with each team made up of experts from UNSWs faculties of engineering, medicine and science", says Tom.

For one such ACN team Tom and Cyrille are involved with the Storr Liver Unit at Westmead Millennium Institute. Liver fibrosis is a major health issue becoming more prevalent in line with growing alcohol consumption, obesity and hepatitis B or C.

"We needed to look for a new approach", says Tom. "We knew we had to target the liver's hepatic stellate cells (HSC) which are responsible for liver fibrosis, however targeting these cells is challenging due to the lack of specific receptors or motifs on the cells. Our research led to the design of nanoparticles that specifically target HSC, and deliver therapeutic agents to them.

Using polymers for drug delivery is also proving promising in treating neuroblastoma in Tom and Cyrille's work with Professor Maria Kavallaris of the Children's Cancer Institute Australia. "Neuroblastoma is a difficult to treat cancer diagnosed in children under one year of age and accounts for six to 10% of all childhood cancers. Despite intensive therapy, including chemotherapy and bone marrow transplant, neuroblastoma has the lowest survival rates of all common childhood cancers (40-50%)." says Tom.

"At the advanced stage neuroblastoma is highly metastatic – that means it spreads to different organs in the body. ACN is examining a method to simultaneously deliver a gene silencing technology called short interfering RNA (siRNA) where we block the expression of proteins thus stop the cancer's growth while also stopping the resistance to chemotherapy and metastatic spread of the cancer". A key has been ACN's development of magnetic nanoparticles used for imaging the tumour while simultaneously delivering siRNA or chemotherapy. "We have a long way to go", says Tom, "but by bringing together expert polymer chemists and biologists, we recently developed novel antifouling iron oxide nanoparticles complexed to siRNA that efficiently transfected into neuroblastoma cells."
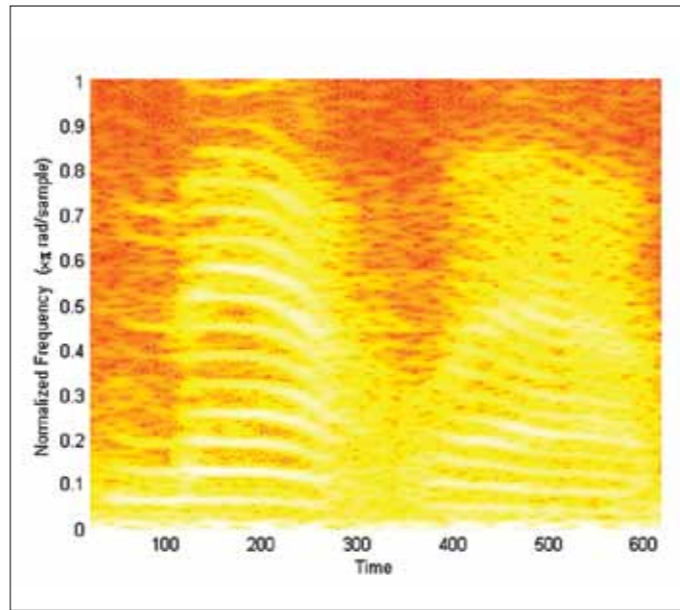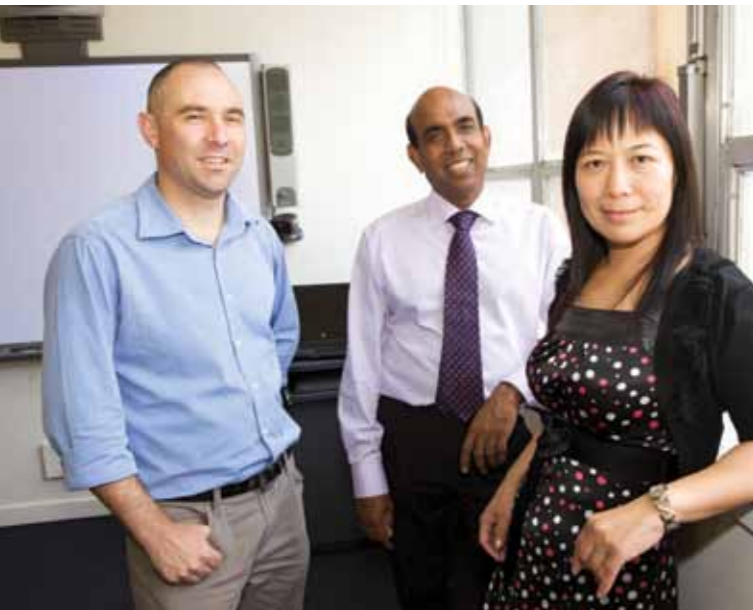
SOUNDING AN ALARM

RECOGNISING MENTAL LOAD THROUGH SPEECH ANALYSIS

Photos:
Investigating new frontiers in non-invasive measurement of mental state: Dr Julien Epps, Professor Eliathamby Ambikairajah and Conjoint Professor Fang Chen (left to right);

Short-term fluctuations buried in the signal spectrum can reveal clues about the speaker's mental state and mental load

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The team gratefully acknowledges the ongoing support of all collaborators

The ability to automatically recognise mental illness or even the cognitive load of a person by the way they are speaking is being developed by a team of UNSW researchers.

Dr Julien Epps, Senior Lecturer in signal processing in the School of Electrical Engineering and Telecommunications, is determining signs of mental illness from voice patterns to enable earlier intervention and monitor the progress of treatment. In one project, in collaboration with the Black Dog Institute and the UNSW School of Psychiatry, Julien is working on finding objective measures of depression. "If you carefully select 20–30 millisecond segments of speech and model the spectral envelope, that seems to be the richest source of information," he says.

Another project, with the Ambulance Research Institute, is trying to recognise pre-suicidal speech from telephone speech – which would be a useful additional tool for ambulance and emergency services. "They have huge logs of telephone calls that are grouped into categories – usually into physical risk, rather than mental state," Julien says. "One trend in health care is the trend towards automation – lots of ambulance-call services are moving towards telephone triage systems. It's a little bit 'blue sky' … but years down the track this could become part of real systems. We know it's possible."

In related research, Julien and Professor Eliathamby (Ambi) Ambikairajah have been working with a NICTA team headed by Conjoint Professor Fang Chen on algorithms

to determine cognitive workload, based on speech. This could be useful in call centres or air traffic control, where it would be beneficial to know the ongoing mental workload experienced by staff.

"When there are many telephone operators working with many calls, from their speech we can tell which operator has a high cognitive load, so the call that's coming through can go to the person with the low cognitive load," Ambi says. Normalisation techniques take out individual variation, in the same way that speech-recognition software accounts for differences in speech and accents between different people.

Other ways to measure cognitive workload currently under investigation include electroencephalography, but using voice is unobtrusive, continuous and automatic while a task is in process.

Ambi says distinguishing between high and low cognitive load levels is relatively easy using voice patterns. "If it is a low load, they will speak smoothly, the pitch will vary smoothly, as will the spectral energy levels." Trying to add a third, "intermediate" level is considerably more complex but results show that three levels of mental load can be distinguished with accuracies of up to 95% for controlled laboratory tasks.

The work has already been commercialised by NICTA through start-up company BrainGauge, which recommends applications in recruitment services, call centres, emergency response, financial services, road traffic management, air traffic control, defence, gaming and in-car safety.

PINPOINT THERAPY

DELIVERING DRUGS TO THE PRECISE PARTS OF THE BODY THAT NEED THEM

Photo:
Dr Hien Duong and Dr Cyrille Boyer are preparing a new generation of iron oxide nanoparticles for gene therapy.

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By wrapping drugs in nanoparticles we can now not only deliver drugs directly into the precise parts of the body that need them, but we can also accurately monitor them with magnetic resonance imaging scans.

This work has applications in treating such diseases as the fatal childhood cancer neuroblastoma, potentially allowing much smaller doses of chemotherapy to be precisely targeted to the area of the body where it can be most effective, such as a tumour.

Dr Cyrille Boyer and others at the newly formed Australian Centre of NanoMedicine (ACN) in the School of Chemical Engineering, in collaboration with Professor Maria Kavallaris (Children Cancer Institute), have been designing a new generation of stable nanocomposite materials with cell-targeting properties able to deliver therapeutic agents and to monitor the response of the tumour. With specific receptors on the outside, the nanocomposites are designed to be recognised and absorbed into specific cells, such as cancer cells, where they release their drug under controllable stimuli. As the nanoparticles are constituted of iron oxides, they can be accurately tracked in the body using magnetic resonance imaging. The polymer-inorganic nanocomposites are stimuli-responsive (pH or temperature) to help the control of the release of therapeutic agents.

Cyrille says that as well as delivering drugs, the nanoparticles can be joined to small interfering ribonucleotide acid (RNA). RNA cannot survive in the body on its own. "It is very sensitive," Cyrille says. "If you introduce it in the body it will degrade in few minutes. But if you inject it conjugate to the nanoparticles it is stable for several days."

The ACN was launched in July 2011 and is one of the newest multidisciplinary centres at UNSW. It aims to build research teams to create an improved future through better drug delivery technologies, diagnostics, imaging agents and therapies.

ACN combines researchers from the UNSW Faculties of Engineering, Medicine and Science in conjunction with The Children's Cancer Institute Australia, the Lowy Cancer Research Centre and the Centre for Advanced Macromolecular Design, to deliver therapeutic solutions to research problems in medicine. Already, 20 researchers are working together on diverse topics, including the eye disease uveitis, liver fibrosis and liver cancer.

As with any area of medicine, it will take years for advances in nanomedicine to be used in humans, and although early results look promising, Cyrille says there would need to be a host of trials in increasingly complex animals before there could be any human trials. "It's a growing field and you can't start today and tomorrow you get something," he says. "It's a very new field."

BSD-500
Hyperthermia
System
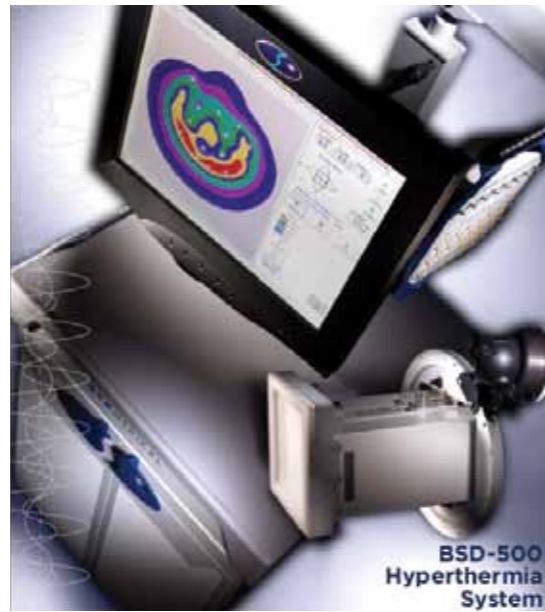
HOT TREATMENT

HEATING NANOPARTICLES IN THE BODY TO FIGHT TUMOURS

Photos:
Dr Victoria Timchenko
The BSD-500 hyperthermia system for the treatment of surface and subsurface tumors

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New ways to treat cancers are being explored by Dr Victoria Timchenko of the School of Mechanical and Manufacturing Engineering. The exciting new method involves heating nanoparticles in the body with near-infrared light to aid hyperthermia treatments.

"The use of heat (hyperthermia) is an effective treatment for some cancers when combined with chemotherapy, radiotherapy, or both," Victoria says. "In it, the temperature of the tumour is raised for a limited period of time. The amount of temperature elevation is a few degrees above normal temperature, usually in the range of 41–45 °C, like a fever. This temperature is not sufficient to kill cells directly, but research has revealed that it enhances the treatment of certain cancers by increasing the effect of radiotherapy or chemotherapy. It also appears to have beneficial effects on the immune response to cancer."

Laser light is used to heat the tumour, and research has shown that embedding gold or silver nanoparticles in the tumour increases the absorption of the laser light. However, this process needs to be fully understood so that the effect of heating the tumour can be maximised, while minimising normal tissue damage and patient stress during such a procedure.

Victoria has studied heat transfer for years and has recently been collaborating with

Michael Jackson, Director of Radiation Oncology at Prince of Wales Hospital, and others in order to develop computational models of thermal processes in the human body. These can be used by clinicians for hyperthermia treatment planning, to provide feedback control during a treatment and during post-treatment evaluation. One of the world's leading experts in the area of radiative heat transfer in dispersed systems, Leonid Dombrovsky from the Joint Institute for High Temperatures, Moscow, Russia, accepted a visiting professor appointment in the School of Mechanical and Manufacturing Engineering, and as a result of his collaboration with Victoria, a combined thermal model was developed for laser hyperthermia of tumours with embedded gold nanoparticles.

The next step, to account for the complex processes in the human body, is to expand the model to include metabolic heat generation, blood perfusion through capillaries, heat transfer between arterial blood and ambient tissue, and thermal conversions in venous blood and tumour tissue.

Victoria says that using nanoparticles in hyperthermia could potentially be used in other clinical treatments. "For example, nanoparticles, separately or in combination with liposomes, can be used for drug delivery and also for the combination of hyperthermia treatment and drug delivery."

PREVENTING FALLS IN THE ELDERLY

PERSONAL WEARABLE DEVICES CALCULATE HEALTH RISKS

Photo:
Left: A new ambulatory monitoring device developed at the Graduate School of Biomedical Engineering. Worn on the waist or around the neck, the device measures acceleration, gyroscopy and altitude, quantifying human movement.

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Falls in the elderly are estimated to cost society more than $850 million a year, a cost that is set to rise as the average age rises. One in three people over the age of 65 will have a fall at least once a year, and each fall can seriously affect quality of life or cause death in severe cases.

Over several years a team of researchers in the Graduate School of Biomedical Engineering and the School of Electrical Engineering and Telecommunications have been developing compact wearable devices that could not only warn health services that a patient has fallen, but can predict – through assessing body movement, such as the way they are walking – who is at risk of falling. The devices analyse the movement of wearers as they sit, stand and get out of bed, estimating activity and energy expenditure, then calculate if they are becoming more susceptible to falls.

"It includes a number of sensors – barometric pressure, accelerometer and gyroscope," says UNSW Scientia Professor Nigel Lovell in the Graduate School of Biomedical Engineering. "With all those things we can eliminate false alarms," Nigel says. In a trial involving an early model of the device, 68 elderly patients were assessed, and the device showed 99% agreement with a clinical falls-risk estimate.

Nigel says that the devices will help people manage their own health care in their home, reducing health care costs. If an individual is identified to be at risk of

falling, preventative treatments could be initiated, such as physiotherapy and muscle strengthening, or the provision of walking aids.

In order to improve the functionality of these and other devices, Dr Vijay Sivaraman and others in the School of Electrical Engineering and Telecommunications, have been developing both power-saving techniques and security to protect patient privacy. The innovative security method uses the person's own body movements to generate secret keys between the body-worn device and the base station.

"Wearable wireless sensors can provide intelligent, non-intrusive, continuous monitoring at dramatically reduced cost, with round-the-clock diagnostic and intervention capability," Vijay says. "Our work in this area is developing the highly energy-efficient, lightweight, flexible and robust communication protocols that are an integral part of such a system."

The substantial power saving comes through dynamically assessing the transmission channel between the device and the base station, so that energy is not wasted unnecessarily when the channel is good, and loss is contained when the channel is bad. "We have shown that in typical body-worn scenarios, as much as 20% of communication energy can be saved with intelligent power control," he says.

03 FUTURE MATERIALS & INFRASTRUCTURE

WHETHER IT'S FINDING BETTER WAYS TO INTEGRATE IMPLANTABLE DEVICES INTO THE HUMAN BODY, SOLVING HYDROGEN STORAGE ISSUES, OR SHORING UP MINING TUNNELS, OUR NEED FOR NEW MATERIALS IS INSATIABLE.

BOLTING AHEAD

PREVENTING CATASTROPHIC FAILURE OF MINING EQUIPMENT

Photo:
Associate Professor Serkan Saydam collecting the rockbolts to be tested.

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Research on the failure of large bolts used in mining to support rock walls will result in safer conditions for mine workers, and less likelihood of mines having to shut down because of bolt failure.

Rock bolts, typically 2.4 m long by 22 mm diameter, were pioneered in Australia and first used in the Snowy Mountains Hydroelectric Scheme. They are now widely used in underground excavations the world over in mining and tunnelling. Anchor bolts, or rock bolts as they are known, are bonded into the rock using polyester resin. Rock bolting methods currently in use in Australian coal mines are designed to minimise the resin annulus to maximise the load transfer between the deforming rock mass and the steel rock bolt.

Increasingly higher strength grades of steel have been used to meet the increasingly demanding requirements placed on the bolts. An unfortunate consequence of this is that catastrophic rock bolt failures have started to be reported – leading to serious safety issues and impacts on mine production – and the potential exists for this to become an industry-wide problem. "Unfortunately, the move to higher strength steels has led to catastrophic rock bolt failure in several of the 30-odd long-wall mines operating in Australia, resulting in broken rock bolts falling from the roof," says leading chief investigator of the project, Associate Professor Serkan Saydam from the School of Mining Engineering. "In these mines the incidence of rock bolt failure has been substantial."

It is possible that the increase in extraction width from 250 to 400m in Australian long-wall mines has led to an increase in the loading on the rock bolt, leading to more premature failures through stress corrosion cracking.

"We're trying to identify the environmental factors responsible for stress corrosion cracking of the rock bolts – what is really causing failure, and how do we develop strategies to stop it?" Serkan says.

Serkan and a team of researchers have been examining groundwater and rock samples from four mines, looking at microbiological and geochemical analyses, as well as differences in temperature and humidity in the mines. In particular, the team is considering the microbacterial impact, which hasn't been studied closely before, and studying the metallurgical factors responsible for stress corrosion cracking of the bolts by examining alloy chemistry and the structure of different steels.

The research is funded by an ARC Linkage grant and supported by partners Anglo Coal Australia, Beltana Highwall Mining Pty Ltd, Jennmar Australia Pty Ltd, Narrabri Coal Operations Pty Ltd and Springvale Pty Ltd. Part of the money from the grant was used to fund a new bolt-testing laboratory that will cost more than $100,000, and will replicate the temperature, humidity and lighting in underground mines.

Because Australian rock bolting technology is now used internationally, the work will be of substantial significance and will help maintain Australia's international prominence in this field.

BIONIC POLYMERS

DESIGNING IMPLANT MATERIALS THAT WILL WORK WITH THE BODY

Photo:
Dr Rylie Green in the laboratory at the Graduate School of Biomedical Engineering

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"I believe that within the next decade the bionic man will make the leap from science fiction to reality," says Dr Rylie Green from the Graduate School of Biomedical Engineering. "The most important factor is the interface where a synthetic device meets the biological environment. To this end, my research aims to understand cell-material interactions and design appropriate material interfaces with bioactive components that will promote integration between tissue and device."

Rylie is designing hydrogels that conduct electricity. They could be used in a range of implantable devices, such as pacemakers, Cochlear devices, robotic limbs and bionic eyes, making the devices safer and more integrated with the body.

Traditionally, implants have incorporated metals for electrode coatings, such as platinum, gold and alloys. For some years, Rylie and others at UNSW have been developing conductive polymers that have several advantages over the metals: they can pass charges in the form of electrons and ions, and they are much more easily incorporated into the body. Polymers can be doped with specific proteins, or parts of proteins called peptides, for the part of the body in which they are going, increasing the likelihood that the body will accept and incorporate the implant. The plastics can be designed with rough nodular surfaces at the nano scale, rather than the smooth metal surfaces, which means that the body tissues can easily interact with them. Often, with smooth-surfaced implants, the body detects the device as "foreign" and tries to protect itself by growing scar tissue around the implant. Over time, larger electrical currents must be used to stimulate the nerves through the scar tissue.

Rylie says that the new hydrogels are a step up from conductive polymers. "The main difference is that their stiffness is a lot closer to tissue than the conducting polymers," she says. "You still get all the benefits of the conducting polymers but they are more flexible and because they are softer your body can interact with them better." Conductive polymers can be brittle and friable, but the gels are a consistency more like a disposable contact lens, which have been shown to be stable for up to two years.

She says the conductive properties of hydrogels are similar to polymers. "They are orders of magnitude better than platinum." But a hydrogel is also an excellent vehicle for targeted, controlled-release drug delivery. "You can put a greater volume of active agents in the hydrogels, – you can load them up with anti-inflammatories and growth factors," she says."

NATURE'S ENGINEERING

ARE THE SOLUTIONS TO OUR BIG PROBLEMS STARING US IN THE FACE?

Photo:
Dr Zora Vrcelj

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Botany, geology, zoology: if engineers really understood nature's systems, we could dramatically reduce waste, reduce power consumption and operate more sustainably. Yet most engineers don't know nearly enough about biological systems and how they could benefit structural engineering, according to Dr Zora Vrcelj, of the School of Civil and Environmental Engineering.

She has been designing a biomimetics keyword finder that can search through biology databases for ideas that may help engineers, whether in construction, materials science or biomedical engineering. "With the increasing pressure to develop new environmentally friendly materials and better structures, sources outside of traditional engineering methods must be seriously considered," Zora says. "Use of a biomimetics database could provide information or inspire engineers looking for alternative solutions to existing problems."

For example, engineers designing non-stick surfaces may find solutions in the leaves of certain plants if they knew how to mine the knowledge database. Fibres such as spider web – which is light and flexible and roughly three times stronger than steel – could be exploited.

"In engineering we are presented with a problem and search for a solution, whereas in nature we see a solution and wonder what the problem is," she says. "Millions of years of evolution have created a perfect system, a compendium of best practice. It's a source that we should analyse more – we should be learning from nature rather than conquering it, which is what we've been doing ever since the industrial revolution."

Zora says the key to searching through biological databases is finding a set of 10–15 synonyms for engineering words. For example, "tension" may appear in the biological database as "pull", "drag", "draw" or "heave". "Rough surfaces" could be found under "uneven", "coarseness", or "irregularity".

"Nature organises things in the best possible way, and there is no such thing as waste in nature." She says that in nature, everything is recyclable, but the general rule in most industrial production is that 96% of the input of a product is wasted and only 4% becomes the final product.

"Our industry contributes to 39% of total waste," Zora says. "We use high temperatures, aggressive chemicals, a lot of power and a lot of force to create materials that are heavy, inflexible and have a single use. In nature, most materials are light, flexible and adaptive. It's recyclable, it's reusable. Biomimetics really questions everything we do. There's a lot of research to be done – it's really baby steps, but it is helping us look at engineering in a different light."

HYDROGEN STOREHOUSE

USING NANOPARTICLES TO HOLD AND RELEASE THIS CRITICAL GAS

Photos:
Dr Francois Aguey-Zinsou in the state-of-the-art hydrogen research lab established at UNSW.

H₂ is widely abundant in the form of water and a clean energy vector that could solve the energy needs of future generations.

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As our world's energy needs change dramatically in the coming decades, we will need to be able to store and release hydrogen in a compact and safe manner. Because hydrogen is a low-density gas, most existing hydrogen storage is incredibly bulky and unwieldy.

"For a car to go about 400km, you need to store about 5kg of hydrogen, which would require a barrel about 5m in diameter," says Dr Kondo-Francois Aguey-Zinsou, Senior Lecturer in the School of Chemical Engineering.

As a result of this problem, Francois, in partnership with Dr Cyrille Boyer from the Centre for Advanced Macromolecular Design in the School of Chemical Engineering, has been developing a range of new hybrid materials able to store hydrogen and release it again at a range of temperatures.

"The idea is to move out of the old gas tank technology and have materials that store hydrogen at a much higher density," he says. "What we are trying to do is find materials that can readily store hydrogen."

Francois and Cyrille are developing nanomaterials that are a hybrid of a polymer and a light metal, such as magnesium or lithium, able to form covalent bonds with hydrogen. Usually with covalent bonding, a lot of heat is needed to break the bonds to release the hydrogen. "The trick is to make the bond weak enough so you don't need excessive high temperatures, but strong enough to keep it there for storage," he says.

The polymer increases hydrogen storage and provides a "backbone" for the assembly of the nanomaterial, while also preventing adverse reactions with oxygen or moisture. "We are trying to build a hybrid system that can release hydrogen at different temperatures – the polymer would release hydrogen at or close to room temperature, and the metal at higher temperatures," Francois says. "The reason we are doing this is because we are thinking of a cold start in a car. You need enough hydrogen to be released during a cold start to start the fuel cell, then once the fuel cell is running, reuse the heat, of about 100°C, to release more hydrogen."

The group is aiming to develop stable materials that have a 3% mass storage capacity of hydrogen at ambient temperatures. Francois admits this may not sound like much, but existing materials have a storage capacity of less than 1% at room temperature. "So we are aiming to increase it by a factor of three," he says. As hydrogen has three times more stored energy per kilogram than normal petrol, these sort of incremental gains could have major benefits.

Francois says that in this early phase of research it is exciting discovering more about the potential of nanocomposites to store hydrogen. "Obviously we don't know how everything is working at this stage, but it's like flying: they first started flying aircraft 2m above the ground, and now aircraft go all around the world. We have to start somewhere."

ENGINEERING OF GEOMATERIALS

CRACKING THE MYSTERIES OF LARGE MOISTURE VARIATIONS IN SOIL

Photo:
Dr Adrian Russell at the beach where he first studied the interaction between soil strength and water.

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New research will change the way geotechnical engineers design civil infrastructure which interacts with unsaturated soils. Currently used design tools are only applicable when the interaction takes place with soils that are fully saturated or completely dry. However, often the soils are above the ground water table where they are variably saturated and may experience changes to their moisture content. Therefore, true margins of safety in retaining wall design, shallow foundation design or pavement design, for example, cannot be known using existing tools.

"When you are at the beach building a sand castle, the sand is strongest when a small amount of moisture is added to it. When the sand suddenly gets very wet, a lot of that strength is lost" says Dr Adrian Russell, Senior Lecturer in the Centre for Infrastructure Engineering and Safety in the School of Civil and Environmental Engineering. "We're looking at particularly complicated aspects of soil behaviour – what happens when the soil is unsaturated and when the amount of moisture changes a lot, for example through drought or flooding."

When reflecting on widely used design tools based on Rankine earth pressure theory (1857) and Terzaghi bearing capacity theory (1943), Adrian says "the need is to update these so they are relevant to soils which vary in their moisture content". "We have to seriously question established design procedures and possibly redo them all."

For the past 15–20 years UNSW geotechnical engineers have been developing the mechanics of soil behaviour under different moisture conditions, but they are now modelling and developing practical applications that will feed into design codes.

"We're building in our labs pieces of equipment to replicate how large structures operate and interact with soils while they are unsaturated and as they change from being very wet to very dry, and vice versa," Adrian says. "We're employing the latest mechanics of soil behaviour to solve real problems. Soil behaviour involving large moisture variations, and how unsaturated soils interact with infrastructure, is something the civil engineering industry doesn't know a lot about yet."

The work will be useful in everything from house construction to much larger projects, including embankment dams, airport runways and slope stability.

Adrian says that in the past, engineers basically just applied very large safety factors in design to deal with the uncertainties of soil behaviour. "In an extreme case you'd conduct a design, based on your knowledge and expertise, and increase its capacity by a factor of three for safety."

This inaccurate method is unable to account for additional soil strength that may be present when the soil is unsaturated, resulting in unnecessarily conservative designs and expensive infrastructure. It also fails to account for soil strength losses that may occur due to sudden saturation of the soil, for example due to heavy rain or burst water pipes.

"At the very least we need to identify the risks and the likelihood of certain things happening as moisture conditions change, and if they do happen, how severe the impacts on our infrastructure will be," Adrian says.

04 WATER

CLIMATE CHANGE WILL CONTINUE TO STRETCH OUR WATER RESOURCES, SO EVERY EFFORT TO UNDERSTAND AND MODEL THE WAY WATER IS MOVING AND CHANGING OUR WORLD IS VITAL – FROM COASTLINE EROSION TO THE INCIDENCE AND SEVERITY OF LOW-FREQUENCY DROUGHTS.

A DIAMOND FINISH

EFFICIENT POLISHING OF THE WORLD'S HARDEST AND MOST INERT MATERIAL

Photo:
Left: Dr Yiqing Annie Chen in the Laboratory for Precision and Nano Processing Technologies (LPNPT)

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New methods to polish diamonds and diamond composites are being developed that take less than a tenth of the time of traditional methods, and use considerably less energy.

As well as its obvious uses in jewellery, diamond has mechanical, chemical, optical, thermal and electrical industrial applications, such as in computers or cutting tools. For most of these uses, a highly polished finish is necessary. The production of synthetic diamond has doubled in the past decade, and is now estimated to be more than 8 billion carats a year, but many of these can only be used for imprecise application because the surfaces are so rough.

Annie Chen, the Vice-Chancellor's Post-Doctoral Research Fellow in the School of Mechanical and Manufacturing Engineering, has been developing new polishing techniques and says that in one example, polishing time was reduced from 240 minutes using traditional mechanical abrasive methods to 18 minutes using the new method. "The beauty of this is its simplicity," she says. "The old methods are very time-consuming and costly when using diamond powder as an abrasive to polish diamond or require a special atmosphere to prevent oxidisation, and a heated chamber to about 700–950°C. They heat the whole chamber with a hot metal plate. We have also needed a high temperature, but it's generally created by the friction – the rubbing of the diamond on the metal disk."

In the new abrasive-free dynamic friction polishing method, a diamond or diamond composite surface is polished by simply pressing it on to a rotating catalytic metal disk in a dry atmosphere. Therefore, much of the special equipment that is needed in other methods – to heat the metal disk or to maintain a special atmosphere – isn't needed. "We use the frictional heat from the rotation between the diamond surface and the metal polishing disk to generate the elevated temperature for the chemical reactions between the diamond and catalyst metals," Annie says. The chemical reactions at the polishing interface convert diamond carbon to softer non-diamond carbon, which is removed by continuing mechanical rubbing, or be oxidised to CO or CO_2 gas.

"Diamond is the hardest and the most chemically inert material in nature," Annie says. "Using dynamic friction polishing, a fine surface finish with roughness less than 50 nm can be obtained in 3 minutes for single crystalline diamond."

A patent for the method and apparatus has been registered and industry has been showing interest in the technique.

One of the ways in which Annie believes the work can be used in the future is for human implants. Diamond is not only ultra resistant to wear and tear, it is bio-compatible, so easy methods for its shaping would potentially aid the implant industry. Current research is also testing diamond polishing using metal powders.
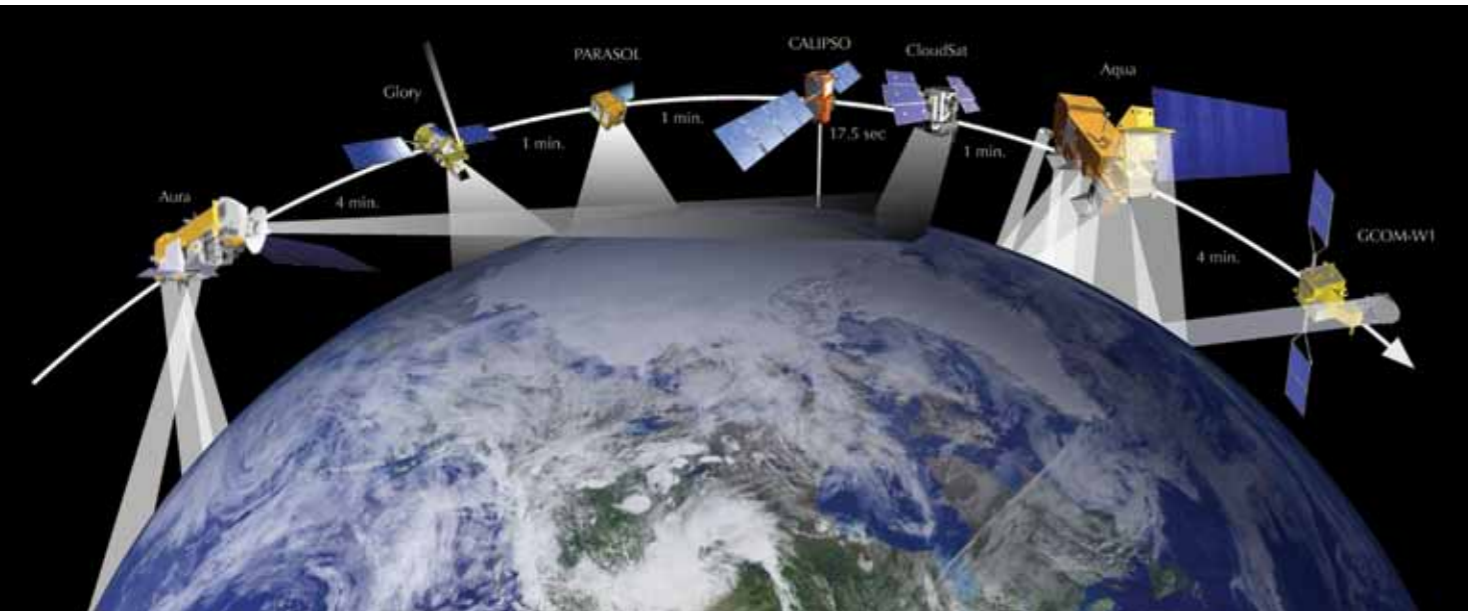
EVERY DROP COUNTED

PIECING TOGETHER THE EARTH'S HYDROLOGICAL CYCLE

Photo:

NASA and its international partners operate several Earth observing satellites that closely follow one another along the same orbital track. This coordinated group of satellites is called the Afternoon Constellation, or the A-Train, for short. Four satellites currently fly in the A-Train: Aqua, CloudSat, CALIPSO, and Aura. GCOM-W1 and OCO-2 are scheduled to join the configuration in 2012 and 2013, respectively.

Photo courtesy of nasa.gov

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Once rain falls, where does it go? How much is absorbed into plants or the soil, and how much of that is evaporated again? How much flows into rivers, or forms clouds and then becomes rain again?

These are some of the key questions Dr Matt McCabe and his team of researchers are answering at the UNSW Water Research Centre, in the School of Civil and Environmental Engineering, in Australia's largest hydrological research program. Using satellites and a vast array of ground equipment, they are gradually piecing together a picture of how water travels through the earth's hydrological cycle, and then developing models to simulate the cycle and explore how changes in the system will affect it. "Improving our capacity to observe and model these systems is not just a research question," he says. "Australia's water security is of major national importance and enhancing our ability to simulate system behavior and response has many practical implications. Water resource management and supply, irrigation scheduling, drought monitoring, and flood forecasting and prediction all require an accurate quantification of the state of the hydrological system. None of this can be achieved without first being able to measure and model these interlinked processes."

Satellites collect data about large movements of water (such as rainfall, soil moisture and cloud development), which can then be used to evaluate model predictions. At the UNSW Baldry Hydrological Observatory in central-west

NSW, Matt and the team use radar to track rainfall, infrared scintillometers for measuring heat exchange between the surface and atmosphere, cosmic ray soil moisture systems and laser-based isotope instruments that can be used to track the origin and fate of atmospheric and liquid waters. Below-ground depth profiles show soil moisture, temperatures and ground heat flux, as well as monitoring the water table. "The site and equipment will ultimately be used to address one of the grand challenges in hydrology: observationally based closure of the hydrological cycle," Matt says.

In multi-disciplinary research with the Australian Nuclear Science and Technology Organisation, the UNSW researchers are using stable water isotopes to understand how much water is evaporated from the soil and how much is transpired by the plant itself. The experiment involves cutting-edge application of a range of instrumentation: radon detectors for measuring flux concentrations, LIDAR units for measuring the height of the boundary layer and eddy covariance systems for surface heat fluxes.

Matt is also deeply involved with an international multi-institution effort supported by the World Climate Research Programme to produce a global climatology of evapotranspiration. "It is the hydrological consequences of climate change that will most directly impact society," he says. "If we are to appreciate these impacts and subsequently adapt to potential changes, a firm understanding of how the water cycle will be affected is paramount."

PREDICTING THE UNEXPECTED

FORECASTING EXTREME DROUGHTS AND FLOODS

Photos:

Professor Ashish Sharma
Is flood risk increasing?

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As climate change is expected to change the incidence, length and severity of droughts and storms, we need new models to be able to accurately forecast low-frequency anomalies, such as extreme droughts or floods.

Professor Ashish Sharma, in the School of Civil and Environmental Engineering, was recently made an Australian Research Council Future Fellow in order to coordinate research into this vital field.

"The processes that lead to low-frequency variability are very subtle – things like extra heat storage in the ocean," he says. "The existing models work at a relatively coarse resolution. They are much better than what they were 10 years ago, but they are still not capable of simulating these subtle aspects of our climate."

Ashish says that predicting what will happen in terms of rainfall in the next 50–100 years is the biggest issue facing humanity, as we can't live without water. He has been amassing evidence that shows climate change is causing increasing variability of rainfall, with longer, wetter spells of rainfall as well as longer dry spells. "In one part of the country you might have a situation where rainfall seems much more variable, so you need bigger dams and storage areas," he says. "But because of increased temperatures you're having changes in evaporation as well."

Ashish's work is designing better models to determine how much rainfall will be available, rather than just expecting history

to repeat itself. For example, whereas predicting a 100-year flood event would previously have involved calculating the largest previous flood in a century, we should be able to determine – based on predictors such as greenhouse gas concentrations in the atmosphere – how large a new 100-year flood event would be. "The chance of such freak or extreme events will increase, but that doesn't necessarily mean more rain overall," he says.

"What we're doing is an engineering correction. We're seeing what's missing in the model simulations and then developing a model to try to simulate that." For example, attributes that might need to be incorporated could include a site's elevation and aspect. "Suppose you have an existing dam – that dam might need to be expanded or you might not need that dam at all," Ashish says. "The biggest challenges we have are trying to integrate information from three different fields – hydrology, climate science and statistics – to come up with a system to predict the low-frequency variations. It's very interesting and messy at the same time."

Ashish is also studying the impact of long periods of reduced rainfall and how that may affect design principles. For example, the extreme rainfall in an area may stay the same, but the conditions preceding an extreme storm may be significantly different, which could affect water flow and the impact on infrastructure.
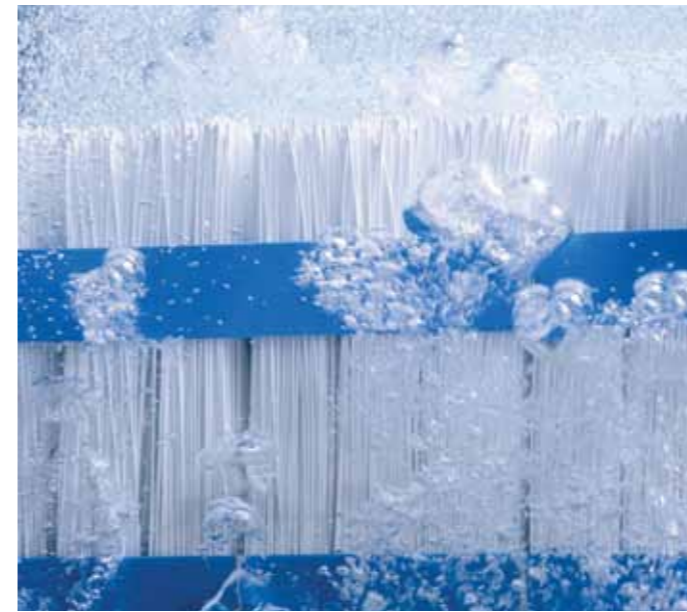
BEACH EROSION

HOW RISING SEA LEVELS AND CHANGING WAVE PATTERNS WILL AFFECT OUR COASTLINE

Photos:
Narrabeen-Collaroy beaches located on Sydney's northern beaches is typical of developed coastlines around the world, where the potential for changing storm wave patterns and rising sea levels will likely threaten homes and infrastructure in coming decades.

Dawn rising over an experimental rig installed on the SW Coast of Cornwall, a collaboration between researchers of the University of Plymouth (UK), University of Deleware (USA) and UNSW, to measure and model detailed physical processes that cause the onshore-offshore movement by individual waves of sand on beaches.

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UNSW researchers have begun an international project to create the first tool to forecast how changes in wave patterns and rising sea levels will affect beach erosion.

"At present engineers and scientists are unable to accurately predict how the combination of changing wave patterns and rising sea levels will affect beach erosion," says Associate Professor Ian Turner from the Water Research Laboratory in the School of Civil and Environmental Engineering.

Intensive monitoring of sand movement, wave action and water levels has now been established at 10 open beaches in NSW and other beaches in the UK and the US. Using cameras, lasers, sonar and on-the-ground measurements, Ian and a large team of researchers are quantifying the changes to beaches over time and under different conditions. The three-year ARC Linkage project – in which UNSW is partnering with Macquarie University, the University of Plymouth in the UK, NSW DECCW, two councils and a commercial venture, CoastalCOMS – should help establish a computer model that will help predict the impact of rising sea levels and changing storm patterns that are expected as a result of climate change.

At the beaches in NSW, cameras record all sand movement and researchers take regular measurements. "On a stormy day from a typical beach in Sydney we could see in the order of a hundred thousand cubic metres of sand being moved from the top of the beach to offshore," Ian says. "The width of the beach can change by 80m over a decade. But at what point are we going to see our coastlines behave outside these highly variable behaviours that we've seen?"

He says that currently there is no indication that the sea level rise attributed to climate change has increased erosion risk. "At Collaroy [which has been studied for 35 years] we've seen no net erosion… no signal at all that the sea level rise has had a direct impact on eroding the coast. Is that peculiar to that location, or is that the case up and down the coast?... We are starting to gain an understanding."

However, changes in storm waves are likely to have an impact. "Wave activity may become a bigger factor in erosion at many beaches than sea level rise," he says. "We are getting an understanding of how storms behave now, so when the next major storm arrives, we will know the likelihood of damage to property."

In parallel with this research, Ian has been involved in a large international field experiment on the north coast of Cornwall in the UK, working alongside researchers from the USA and UK, to undertake detailed measurements of sand movements caused by individual waves as they arrive at the shore. This work will help create a generic tool for forecasting the response of sandy coastlines to changing wave patterns and sea levels.

CLEANER MEMBRANES

NOVEL NEW LOW-HEAT ANTI-FOULING APPROACH

Photos:
Membrane filters
Dr Jaleh Mansouri and Dr May Lim

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A new way of keeping polymeric membranes clean has been developed by a multi-skilled team of researchers in the School of Chemical Engineering.

Over time, polymeric membranes that are used in desalination and other liquid processes become fouled with an accumulation of organic matter and microorganisms. Cleaning the membranes, especially with chemicals, is a costly exercise: it requires a lot of energy and stopping the industrial process, and usually degrades the membranes. "In the dairy industry common practice is to clean the membranes quite often because of fouling, and so you may have to change the membrane every 2–3 years," says Senior Research Fellow Dr Jaleh Mansouri. "In other applications, after 2–3 years you might lose 20–50% of the membrane's efficiency because of the fouling."

The team has developed a low-heat process that coats the surface of the membrane with a thin film of titanium dioxide. Dr May Lim, Research Fellow in the Particles and Catalysis Research Group, says titanium dioxide does two things: it acts as a photocatalyst and also acts as a non-stick anti-fouling surface.

"Titanium dioxide has been used since the 1970s," she says. "The main use has been as a photocatalyst – when you shine ultraviolet light on it, it creates chemical species that degrade organics, turning them into carbon dioxide and water. In the last 10 years, people have found titanium dioxide also has anti-fouling properties. The main difference is that we are using a low-temperature process to prepare the coating on the surface of the membrane."

Usually, to put a coat of titanium dioxide on any substrate requires temperatures of more than 350°C, but such temperatures would destroy the polymeric membrane itself. The new process is done at 90°C, which doesn't negatively affect the membrane. "We heat treat the coated membrane in hot water at 90 degrees Celsius. to give us a nice coating that is stable and won't peel off," Jaleh says. "We had to fine-tune the treatment, to not have any detrimental effects on the membranes. Compared with controls, we're getting 20–30% better performance, which is quite significant in commercial applications."

Specific polymers are added to the coating solution, creating multiple channels at the nano scale, which improves the anti-fouling properties of the membrane. The group is also experimenting with light-assisted deposition of silver on the membrane, to increase its anti-microbial properties.

May says breakthroughs in this area have come through multi-skilled teams working together: using their separate, existing expertise on titanium nanoparticles and membranes. "Where the breakthroughs are is when different teams work together and combine their knowledge," she says. "We have a very big membrane group and big nanoparticle research group and by working together, we got this result".

05 DIGITAL WORLD

THE DIGITAL REVOLUTION HAS CREATED CHALLENGES PREVIOUS GENERATIONS COULDN'T EVEN ENVISAGE, AND THE PACE OF THE DIGITAL WORLD MEANS THE ISSUES IN THIS AREA ARE INCREASING IN NUMBER: EVERYTHING FROM MORE ACCURATE AND EFFICIENT DIGITAL SEARCHING TECHNIQUES, THROUGH TO ELASTIC COMPUTING, VIRTUAL REALITY TRAINING SYSTEMS AND METHODS TO SAVE POWER.
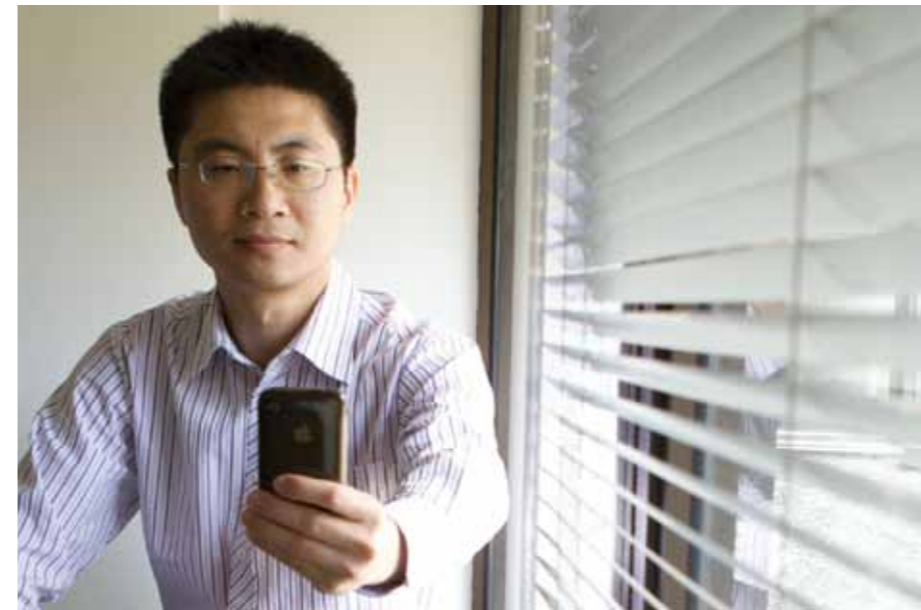
LINKING PEOPLE WITH PEOPLE

THE SCIENCE BEHIND SOCIAL NETWORKING

Photo:

Left: Dr Xiongcai (Peter) Cai believes the progress in people to people recommendation will enable people to find other people easily in online social networks.

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Despite the growing dominance of social networking sites, the methods used to search for "links" between people in databases are inefficient and based on simplistic formulas.

Dr Xiongcai (Peter) Cai, Research Fellow in the School of Computer Science and Engineering, has been working with a team of researchers to develop more appropriate ways to search for links between people. He says that traditionally, these searches are done through the more familiar "item-to-people" recommenders. For example, Amazon would keep a track of the products its customers have ordered in the past, and therefore recommend other books to them based on these choices. But in this process, the new books don't get a choice about who they are recommended to. With systems involving people, the receiver has to "choose" as well as the initiator.

"Previously we didn't really have any suitable existing techniques to apply to people-to-people recommendations," Peter says. "The recommendations are based on one side of the equation: if someone likes someone. Most on-line social systems have different kinds of approaches and different kinds of directions, but we decided to focus on that links prediction – to really predict whether there is a link from one to the other, not just 'is Alice interested in Bob?', but 'is Bob also interested in Alice?'."

Peter's group has developed prototypes that search for two-way or reciprocal matches on a database of about 2 million names and 20 million "links". "We have developed several methods and have some trials using those methods, so currently we are trying to prepare something to make it into the real world. Surprising findings derived from our results show that user behaviours are often different from users' explicit preferences in terms of relationship development."

He gives an example of how current systems, such as LinkedIn or some internet dating sites would recommend people. "Let's say 'Alice' likes 'Bob' and 'Charlie'. If 'Denise' links with Bob, then the system currently recommends she also link with Charlie, based on what was determined by Alice. But our techniques look at both taste and attractiveness of Alice, Bob, Charlie and Denise. If Alice and Denise are interested in Bob and Charlie, that's not enough. Denise is really interested in Charlie, but Charlie may not be interested in Denise, so it's not really a match."

Peter says the research will hopefully enable people and organisations to find other people or organisations easily. "This kind of research is getting popular at the moment and getting more significant. We've taken this to industry partners and they're quite interested in this as well, and they want to get involved."
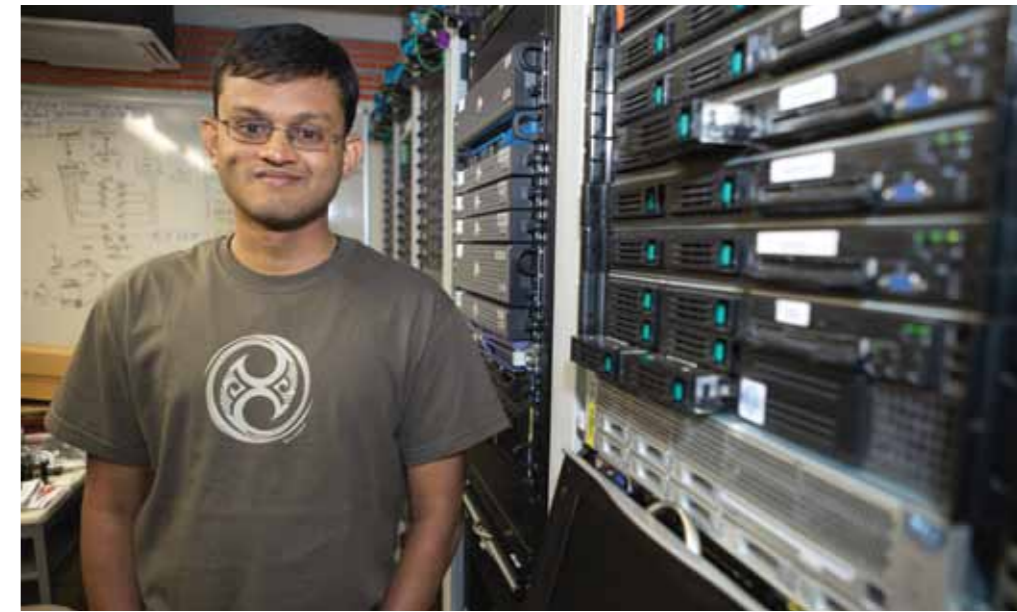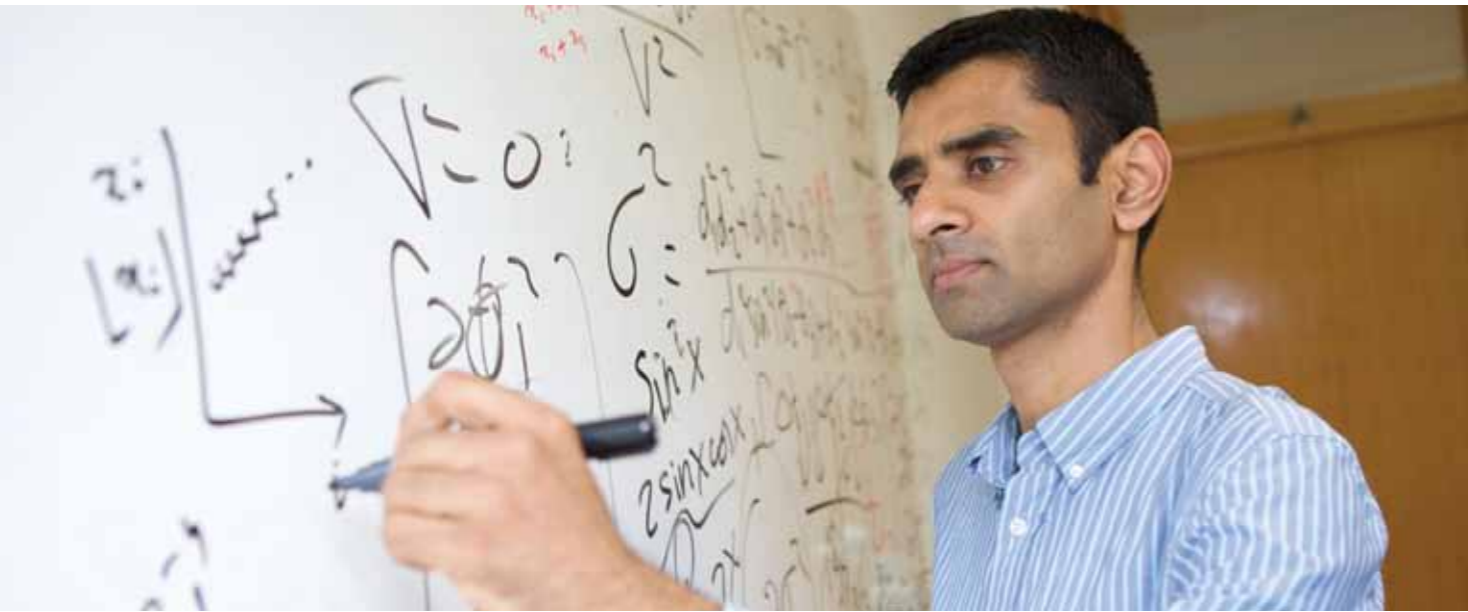
A GREENER INTERNET

REDUCING DIGITAL POWER CONSUMPTION BY A FACTOR OF 100

Photo:
Associate Professor Vijay Sivaraman is developing models for profiling energy consumption of communication networks, and prototyping novel schemes for improving energy efficiency of Internet equipment.

Further Information:
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Computers – and the internet in particular – are using way too much power, so Dr Vijay Sivaraman in the School of Electrical Engineering and Telecommunications is working on reducing their power consumption by a factor of 100 in the next 5–10 years.

"Energy consumption of the world is a concern and at the moment the ICT [Information and Communications Technology] sector is about 3% of the total energy consumption, which is about the same as airlines, but growing rapidly," Vijay says. "Traffic is doubling every two years on the internet and power consumption is doubling every five years or so. It is believed that ICT will be a main driver behind the doubling of world energy consumption by 2030. Network equipment accounts for 14% of ICT energy consumption, and the increasing amount of power consumed by internet routers is becoming a serious concern for router manufacturers and Internet Service Providers (ISPs) alike."

This has two major implications: firstly, the actual energy consumption of the equipment, and secondly, the heat generated means large computer facilities need vast cool rooms to store computer technology. "Some of this equipment you could cook a pizza on top of it, it's so hot," Vijay says. "Cooling costs can be high."

Vijay's research has two broad directions: retrofitting existing internet equipment with power-savings modes, such as intelligently putting internal components to sleep; and redesigning internet architecture to optimise the energy footprint of high-bandwidth (e.g. HD video) services.

"We have made significant progress in the first aspect, demonstrating with real internet traffic traces that over 80% of energy associated with memory in routers can be saved with negligible impact on performance," he says. "Our method for intelligently putting memory components to sleep is being patented.

"If you want to save power in your house, you switch off lights you are not using," Vijay says. "In core networks, very often the load is quite low: 10–20%. But there are spikes, so you need to wake up your system quickly when you need it."

He says another area of research is based on the principle that equipment is more energy efficient when operated at full load. "If you could somehow force your traffic to go through a smaller set of routers and just switch the rest of it off, that would make it more energy efficient," he says.

This research project is part of the GreenTouch consortium, a group of 50 organisations dedicated to creating a sustainable internet, and involves working closely with Alcatel-Lucent, one of the largest manufacturers of telecommunications equipment.

ELASTIC COMPUTING

THE ABILITY TO QUICKLY RAMP UP COMPUTER RESOURCES

Photo:
Right: Dr Srikumar Venugopal with the servers hosting his experimental cloud infrastructure in the School of Computer Science and Engineering.

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To take full advantage of cloud computing's power, we need computer hardware and software that are "elastic" – that is, they need to be able to quickly ramp up to use the vast resources available. Currently, most software is unable to do this effectively.

Cloud computing is the ability to outsource computing power at times of need, using resources of external providers such as Amazon, Microsoft and Google. It is seen as a way of "democratising" the internet, as everyone prepared to pay a fee has the ability to use vast computer resources with little to no up-front costs. The elastic capability (the ability to quickly add or remove resources) could be important for anyone who has a sudden need for extra computing power – such as an emergency service dealing with a crisis.

Lecturer in the School of Computer Science and Engineering, Dr Srikumar Venugopal, has been researching cloud computing and ways to make it more effective and efficient. At the moment someone who uses cloud computing to access – say – 100 computers at once, doesn't usually get a 100-fold increase in performance. "The software that is written is not very easily elastically scaled," he says. "There is an inherent assumption that all that software is running on one computer, so the performance doesn't improve by the number of machines."

In particular, Srikumar has been researching how to make applications benefit from elasticity. Often when one part of a system is scaled up, it just creates a bottleneck in another part. "Which part of the application should be scaled up? All points, or just part of it? We need something that works outside the software but allows it to take advantage of all the elasticity options."

Srikumar is also determining how to make cloud computing more economical for small users, so they are not wasting money on resources they don't need. "You are paying for these services by the hour, so you really don't want to exceed the amount you need," he says. "How do we find the minimum amount of power we need in order to maintain a service?"

He says one of the problems with current elasticity in cloud computing is that it is not automatic, which is something he is hoping to develop. "Right now, most of the cloud computing scalability, they have to say 'this part of the system I'll make elastic'. There always has to be a human in the loop to say 'let's add resources here'. The main aim is to make all of this automatic. You don't want to wait for a human to respond."

VIRTUAL MINING

IMPROVED SAFETY AND ENVIRONMENTAL TRAINING

Photo:
Inside the virtual reality facility

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A groundbreaking virtual reality facility in the School of Mining Engineering is not just giving today's engineers the ability to see things in mines they would never usually get the chance to experience, but it is improving safety. "There are a lot of things underground that you really can't see," says Dr Rudrajit Mitra. "On top of the roof for example. Or things that no one has lived to see because it causes a fatality. For example, we can show what happens when an outburst occurs along with the indicators that lead to an outburst. In a real mine the students wouldn't be able to see these events."

The Virtual Reality Laboratory consists of a 360-degree screen with 12 projectors on top. Users stand in the space wearing 3D glasses.

Rudra says the existing modules that run in the facility are being improved, and new modules are being developed. In the sustainability module, one of the assignments asks students to place all parts of a mine in a landscape, while taking into account other "interest factors" in the area, such as tourism. "It gives the students a way of thinking outside the box about where to put these infrastructures," Rudra says. "What are the cost implications of that – that is one of the new additions we have planned to put into the module."

In one of the modules being planned, the laboratory will be able to show how coal was formed, taking people through the millennia-long process above ground and under ground.

Rudra says the virtual reality laboratory is widely respected for its practical applications, because training, research and simulation can be undertaken in a safe and forgiving environment. The virtual environments replicate real mine sites and risk-taking behaviour can be identified without putting personnel at risk. "Industry has been concerned that several new rules and regulations have been implemented to improve safety and work procedures resulting in a significant improvement in safety in recent decades, but accidents and injuries continue to occur – sometimes with serious consequences. Interactive computer-based visualisation of mine environments has the potential to improve safety through improved understanding of mine environment hazards, procedures and processes relating to day-to-day operations."

Mining companies are showing interest. "One leading mining company plans to develop a similar set-up at their own site," Rudra says.

Part of the innovative computer research facilities that have been developed at the School of Mining Engineering includes an interactive learning system (ViMine) that provides an authentic experience working with industry software, while developing an understanding of the broader and longer-term impact of technical decisions.

SMART SEARCHING

SCOURING DATABASES FOR KEY INFORMATION

Photo:
Associate Professor Wei Wang (far right) and his team members Yifei Lu and Jianbin Qin.

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One of the problems when searching through a vast database, or the World Wide Web, is that you almost need to be an expert in the area to know what words to put in the "search" box. For example, if you wanted to find out about a movie, and all you remembered about it was the approximate year it came out and a word or two from the tag line, you would be unlikely to locate it quickly and easily, even on a dedicated movie site such as IMDb.

Funded by an ARC Discovery Project, Dr Wei Wang and a team of PhD researchers in the School of Computer Science and Engineering have developed a prototype database searcher that focuses on links rather than formal language. "About 80% of database queries are very, very simple, but there are always 20% of queries that are complex and unexpected," he says. "This research will help casual users to obtain valuable information easily from databases, and this ultimately leads to a wider and easier use of database technologies and an increase in productivity.

"It's also possible that no single page supplies your need for information, so this method can combine that information – we search beyond the page boundary to describe what you are looking for."

Wei has also been developing several methods that can quickly and easily search through large databases for similar objects, such as plagiarised paragraphs in university essays. Previously it was very time-consuming to do such searches. "Many systems that had to deal with the problem for large datasets resort to approximate or heuristic solutions, because fast and scalable exact solutions were not available," he says. "Our research enables us to apply exact solutions to these problems, hence guarantees that there is no sacrifice of result quality. For example, in plagiarism detection, this means all suspicious cases will be found out and referred to the experts."

The system designates each object or article with a mathematical signature "and if two objects are very similar, their signatures are likely to be very similar as well," he says. "The prototype we put on the web has been used by other universities in the US and Germany."

The system could be used for governments or institutions such as large banks searching for similarities in merged databases to find multiple records that might apply to the same person. It will also have the capability to search through images and videos.
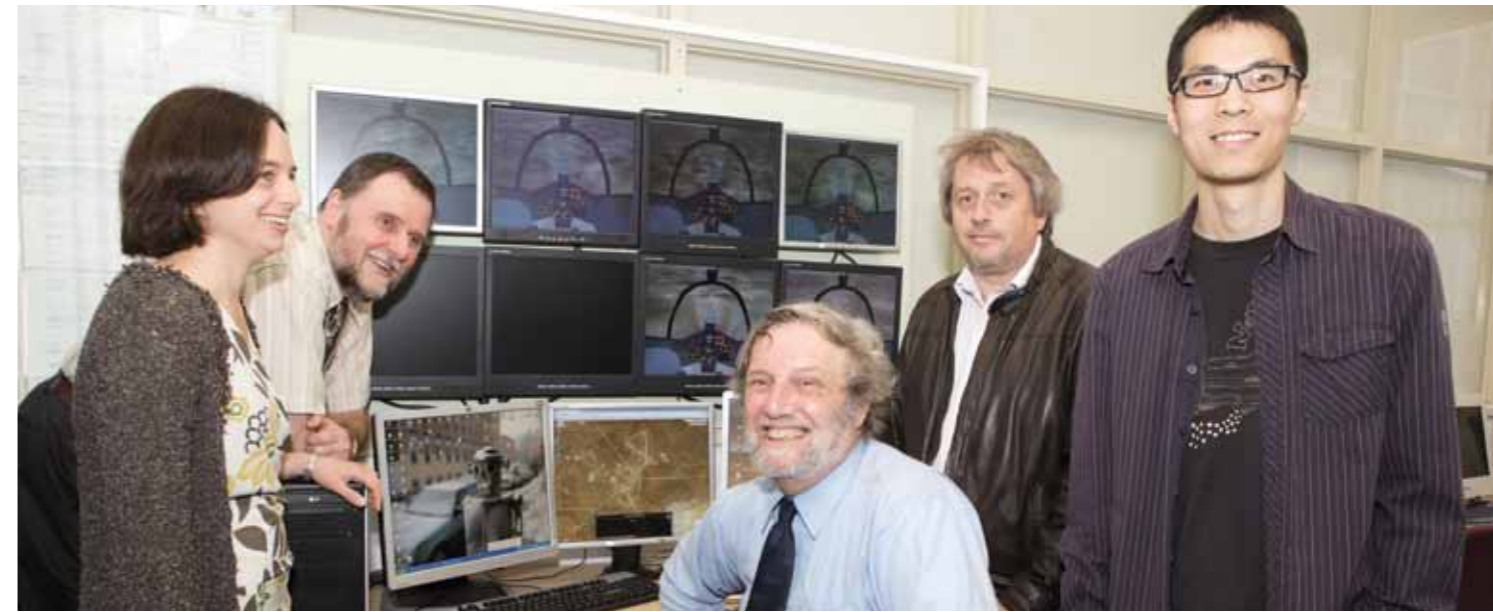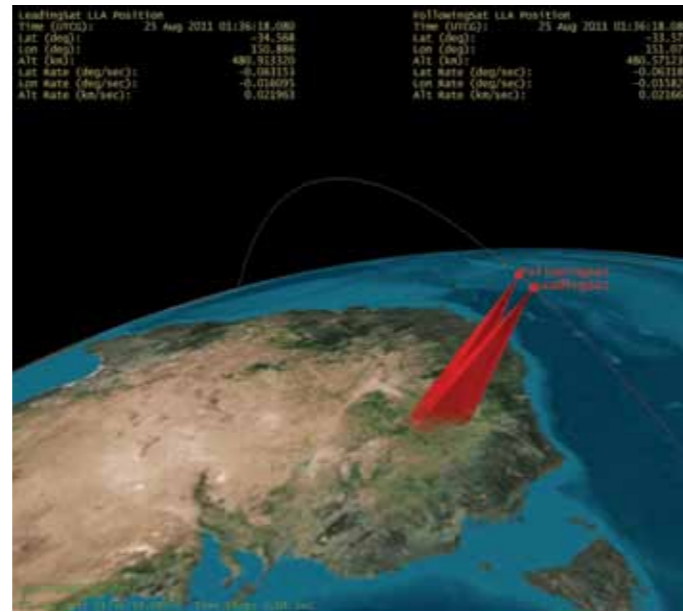
LOW COST SPACECRAFT

SPACE ENGINEERING AT UNSW – TEAMWORK AND WORKING TO REQUIREMENTS

Photos:
Dr Steven Tsitas

Two Synthetic Aperture Radar Spacecraft in along track formation imaging the Murray Darling Basin.

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A spacecraft optimised for monitoring soil moisture in the Murray Darling Basin is being designed by UNSW researchers as part of the GARADA Australian Space Research Program (ASRP) grant to the Australian Centre for Space Engineering Research (ACSER). Working in a different frequency band to current radar satellites, and with an orbit closer to the equator to maximise revisit frequency over Australia, the new radar satellite will support research into mapping soil moisture at high spatial resolution in this region vitally important to Australia's economy. "One of the toughest parts of spacecraft design is actually the requirements analysis, so identifying a compelling application to design to is extremely important" says Dr Steven Tsitas, from the School of Surveying and Spatial Information Systems, and Senior Research Associate at the Australian Centre for Space Engineering Research (ACSER). The spacecraft will also be able to detect deforestation in tropical rain forests in support of global efforts to reduce carbon emissions due to forest degradation and deforestation. Two of these spacecraft flying in formation, one behind the other, will allow flood waters to be accurately mapped, as well as providing redundancy. "Space engineering is based on teamwork, and one of the pleasures of working on GARADA has been the chance to work with a team of talented people to develop this design" says Steven.

To improve the ability to measure soil moisture, a long wavelength is required to minimise the effects surface roughness and overlying vegetation has on the returned radar signal. This requirement leads to the selection of L-band (1.2 GHz), which is fortuitously the frequency mobile phones operate at. This allows Commercially Available Off the Shelf – COTS – microchips from the mobile phone industry to be used as microamplifiers instead of much larger solid state power amplifiers to amplify the radar signal on the satellite for transmission to the ground. Research is underway to combine these COTS components to allow this innovative fully active radar design. While this spacecraft is necessarily big – requirements lead to an antenna size of 11.5 x 2.8 m – researchers are considering a folded design that would allow a Falcon 9 launch, reducing costs considerably.

Aside from big spacecraft, Steven is also researching spacecraft the size of a shoebox – 6U CubeSats – capable of imaging the Earth in multiple optical bands of light for agricultural monitoring.

SWARM MENTALITY

THE EMERGING BEHAVIOUR OF UNMANNED MACHINES

Photo:

John Page, team convenor, surrounded by some swarm research participants (from left) Naomi Tsafnat, Zoran Vulovic, John Olsen and Haoyang Cheng.

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Surprise, surprise: bees, ants and other animals that work as groups have plenty to teach us Homo sapiens, according to John Page, of the School of Mechanical and Manufacturing Engineering. He is researching swarms, which involves agent programming and emergent behaviour, an exciting new field that will potentially be used in many areas, including marine search and rescue, or military operations with unmanned machines. The use of unmanned aerial machines has expanded rapidly in the past decade, but there have been problems with communication between vehicles and external controllers and their vulnerability was demonstrated by a recent virus attack on the USA's Predators.

The research is gaining an understanding of how swarms move collectively, as well as how individuals make choices and communicate in the swarm. "This stuff is very, very new," John says, though it has roots in the animal kingdom. "For example, the grey wolf hunts caribou, and the caribou run faster than wolves. They can't sit around and have a conference to discuss how they are going to ambush the caribou. So instead, each wolf is "programmed" or has training – they learn it as pups – to stay a fixed distance from its mates, depending on the strength of smell. As the smell gets stronger, they get closer together." By operating in this way, the wolves eventually surround the caribou, although their individual movements will be different each time. "If you were to try to program that behaviour on a machine it would be extremely difficult. The problem is you don't know how they are going to behave. It's deterministic, but the answer's not predictable – the

equation has a series of different, equally valid, answers to it."

John gives another example of a flock of birds. To simulate how a flock relates, you can put an agent in the centre of a flock and tell it to avoid contact with other birds, but to fly in the same direction as its near neighbours. The flock would fly a different pattern every time, but the same possible flocking would result.

In developing simulators to analyse such swarm behaviour, John's team has expanded to include a philosopher to help answer questions about the nature of group intelligence and reality itself.

They have also been studying the effect of mutation by designing swarms with slightly different characteristics and giving them a task to do. "Then we take our swarms and choose the best two swarms and amalgamate randomly some of the characteristics of these swarms. We're not mutating individuals in the swarm, we're mutating the entire swarm. The differences are so small between them that it takes many generations to start seeing a difference, but the more rules you apply, the more mutations you have and fewer generations are required."

Another part of the work is to understand the caribou's side of the equation – answering the question 'how do other entities, which may also be swarms, respond to a swarm's behaviour?' This could be helpful in order to drive entities towards a targeted area, such as an enemy into a military zone, or traffic into the most appropriate part of a city grid.
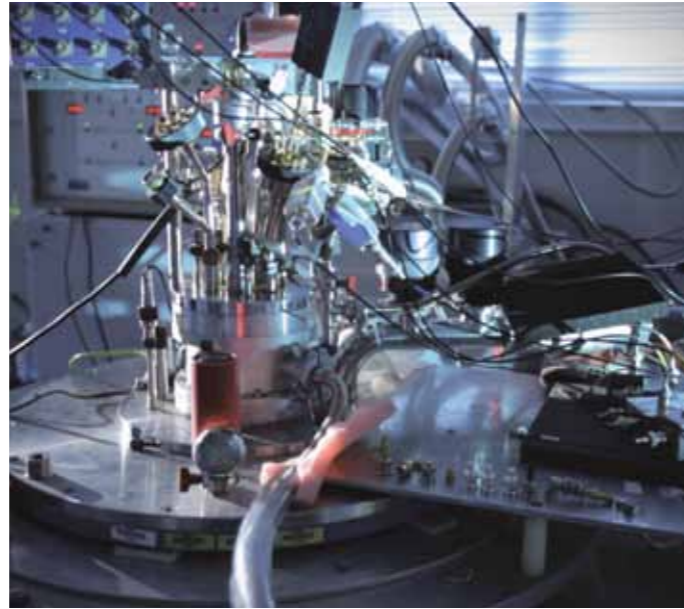
QUANTUM SPIN

BUILDING THE SUPER COMPUTER

Photos:

Dr. Andrea Morello in his quantum measurement laboratory

Part of the measurement setup to observe a single electron spin in silicon. The sample is cooled to a temperature of 0.04 degrees above absolute zero, and connected to an electronic setup capable of measuring extremely small currents and delivering high-frequency microwaves, while minimizing the disturbance to the delicate quantum state of the spin. These experiments have demonstrated the ability to encode quantum information in a single atom placed in a silicon chip.

Further Information:

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Building a quantum computer may still be 10 years away, but Dr Andrea Morello is completing some of the breakthroughs that will make it possible.

Andrea is a Senior Lecturer in Quantum Nanosystems with the School of Electrical Engineering and Telecommunications, and a Program Manager in the ARC Centre of Excellence for Quantum Computation and Communication Technology. Andrea says that because of their potential to factor very large numbers, quantum computers will be particularly useful for encryption and data security.

"Despite what some people say, quantum computers are not going to replace classical computers," Andrea says. "They are not universally better. They are different and in certain cases will be much faster than a classical computer – not because the clock speed is faster, but because the algorithm is completely different."

Due to the different 'laws' of quantum physics, quantum numbers can have two different values at the same time, which changes the way calculations can be made. "As a simple example, let's say you have an unsorted database of a million entries – say the Sydney telephone book where someone shuffled the names. If you have to look for a number in that random database, it will take you an average of 500,000 searches to find the one you want using a classical approach. A quantum computer will do it in the square root of the total – about 1000 – because of the algorithms. It will not scroll through the list. It's like looking at all the names at the same time."

Two years ago, as one of the first steps in building a quantum computer, Andrea and his team became the first in the world to read the magnetic state of a single electron bound to an impurity atom in silicon. "What we did is basically shake it to see how long it takes to get back to its normal state. It takes six seconds 'relaxation time'. That sets a limit to the time you have to do all the rest of your quantum calculations."

Now, at temperatures close to absolute zero, they are writing information onto the spinning electron using short bursts of high-powered microwaves. "Combining microwave engineering with ultra-low temperatures is a pretty tricky field – you really need to know what you are doing," he says. "Technically it's very hard to do. It's like trying to stroke the wings of a butterfly with a jackhammer."

The team is facing several challenges as they research how to best write quantum bits of information, including learning how to shield the information from interference – some of which comes from inside the nuclei of the silicon atom itself.

The next step is to design quantum logic gates and then to transport the information to another place. "In classical computers you use a wire. In quantum computing it is much more difficult, because you need to do it without losing coherence," Andrea says. "Once we can show we can read, write, calculate and move information around, then we expect we'll be able to convince industry to make the computer."

CREDITS