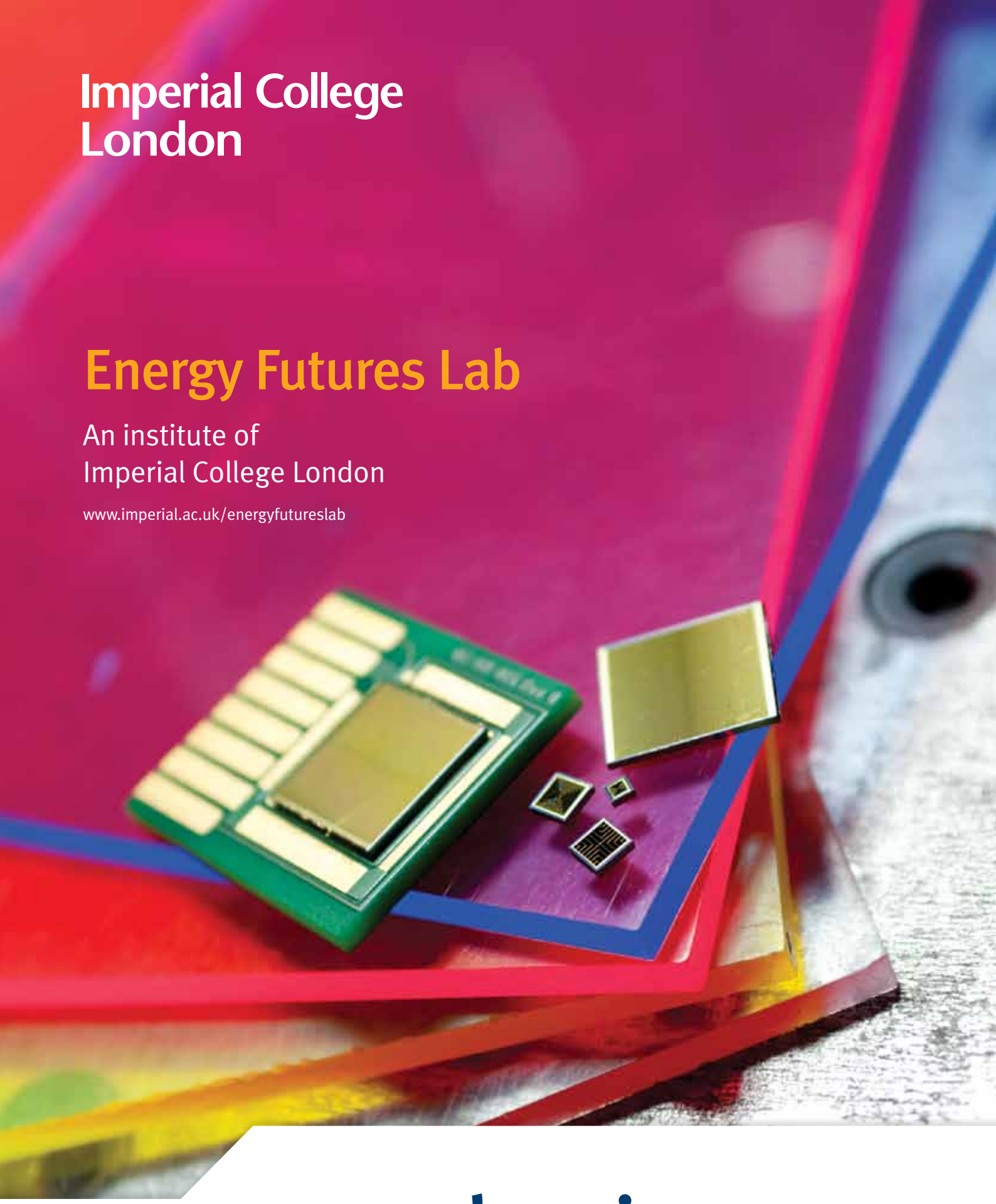
Imperial College London

Energy Futures Lab

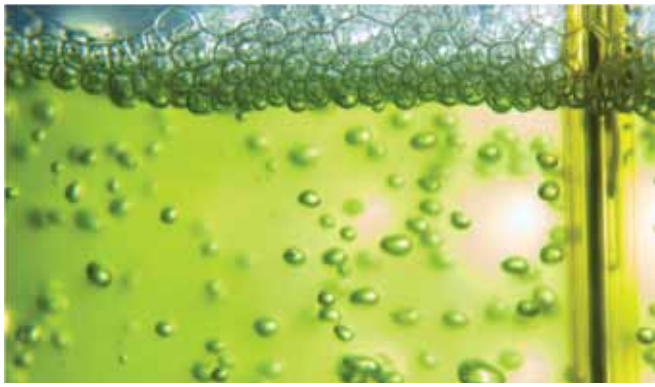
An institute of
Imperial College London

www.imperial.ac.uk/energyfutureslab



annual review 2010

securing our future energy supplies



Foreword

I am pleased to introduce the Energy Futures Lab Annual Review for 2010.

This was the first year of the Energy Futures Lab as a Global Challenge institute of Imperial College London, with a mission at the centre of Imperial's strategy. With its new status, and with new facilities to match, the Energy Futures Lab continues to represent the wide ranging expertise that the College has to contribute to the global challenge that is securing a sustainable energy future for all. This is seen in exciting new programmes that reflect the full spectrum of energy technologies that will be part of this shared future; from the 'artificial leaf' to the more immediate benefits of carbon capture and storage. I know the Lab is particularly proud of the achievements of its students, such as the Racing Green Endurance team whose tenacity is a lesson for us all and gives me great confidence in the next generation of energy professionals that will take these ideas forward.

The Energy Futures Lab has continued to build on its inclusive strategy engaging with a wide number of researchers and draws in industry and government working with them at all levels. I warmly welcome the prominence that teaching and outreach takes enabling a well-rounded, informed debate on energy issues.

Sir Roy Gardner, Chairman, Energy Futures Lab Advisory Board

Front page cover: High efficiency solar cells resting on coloured plastics which are used to ensure as much of the solar spectrum is utilised as possible when trying to convert sunlight to electricity. This research is undertaken by Dr NJ Ekins-Daukes, Department of Physics. **Above center:** Hydrogen bubbles created in the bioreactor developed by a team of Chemical Engineers as part of the New and Renewable Routes to Solar Hydrogen display.

Director's report

The Energy Futures Lab (EFL) at Imperial College London has just completed its fifth year of operation and I am delighted to be able to introduce a summary of our activities in this 2010 annual review.

Highlights during the past twelve months include: the continuing development of our Artificial Leaf programme to produce fuels using renewable energy, through the award of new funding worth £2.7M, coverage in the press, and well attended international workshops at the College; the launch of our Electric and Hybrid Vehicle network which has already generated new research programmes in this rapidly emerging area; the announcement of a major new research partnership with Scottish Power through Centre for Carbon Capture and Storage (IC4S) to investigate CCS and its role in reducing the CO_2 emissions of power stations; the housing of a bio-reactor from our Solar Hydrogen programme within an exciting display on contemporary issues in science in the Science Museum, where it stimulated over 640 people to engage in a debate about the role of hydrogen in a future energy system; the Racing Green Endurance team who have successfully completed a drive down the whole of the 26,000km Pan-America highway in their electric supercar; the highly successful student led energy conference put together by our Sustainable Energy Futures MSc students which attracted over 200 delegates from industry, Government and academia; and the appointment of EFLs first two visiting Professors: Alain Bucaille - Senior VP Research and Innovation Corporate Department AREVA, and Michael Liebreich – Chief Executive Bloomberg New Energy Finance.

A review of the energy research programme across Imperial shows that we have an energy research income of £53M per annum, around one third of which is from industry, supporting a team of over 600 faculty, research staff and PhD students. This provides a unique combination of depth and breadth to energy research at the College, with research themes including solar, nuclear fission and fusion, electric and hybrid vehicles, transport, fuel cells and batteries, hydrogen, carbon capture and storage, future fuels, oil and gas, green aviation, bio-energy, smart electrical networks, energy business, energy systems and energy policy.

The Energy Futures Lab has built on this capability by tackling a series of Grand Challenges in the energy sector. In addition to our existing grand challenge programmes such as those on cleaner fossil energy with Shell, and urban energy systems with BP, over the past year we have been developing a major new programmes in Planet 2050: Smart Energy Futures (in collaboration with the Grantham Institute for Climate Change at Imperial) to explore the role that smart systems can be play in the development of both the electricity and gas sectors, and our evolving Artificial Leaf programme, which seeks to use renewable energy to produce useful liquid fuels, with the ultimate aim of closing the carbon cycle such that carbon dioxide can become a useful feedstock for fuel production.

Our Masters and PhD programmes continue to go from strength to strength. For the three years our MSc in Sustainable Energy Futures has been in operation, well over half of the students have entered from industry, and this year 12 students won industry and international scholarships to allow them to undertake the course. We took our first 15 students into our new Centre for Doctoral Training in Energy Futures, which provides added value education and training for PhD students undertaking energy related research programmes at the College.

We continue to place great importance on disseminating our research throughout the energy sector and beyond. We have organised a number of popular workshops and symposia, including lectures by Will Cavendish, Director General, International Energy & Climate Change, Department of Energy and Climate Change, and Lord Nick Stern, London School of Economics.

Professor Nigel Brandon, Director, Energy Futures Lab

THE ENERGY FUTURES LAB (EFL), LAUNCHED IN 2005, was created to support and enhance the development and promotion of energy research, education and translation at Imperial College London. In 2009 the EFLs contribution was recognised when it became one of Imperial's four Global Challenge institutes, sitting alongside the Grantham Institute for Climate Change, the Institute of Security Science and Technology, and the Institute of Global Health Innovation.

Acting as a focal point for energy research with the College, the Energy Futures Lab coordinates 15 technology focussed or cross-cutting Research Networks, which integrate staff and students working in those fields across Imperial, and provides a recognised portal into these activities for those external to the College, in industry, academia and Government – both nationally and internationally.

The Energy Futures Lab initiates and leads the development of new Grand Challenge research programmes, working with researchers from across the College to bring together new teams to tackle some of the major energy challenges facing the world today – such as how we can continue to use fossil fuels whilst minimising their impact on our environment, and how we can effectively harness renewable energy to provide the services we need for transport, power and heating/cooling.

The Energy Futures Lab also has an award winning education and outreach programme. Our MSc in Sustainable Energy Futures, and our Energy Futures Centre for Doctoral Training, both aim to provide a holistic view of the energy system, training a new generation of energy professionals whose skills and knowledge will complement the diversity of energy technologies expected to be used in the future. Our outreach and events showcase our research to new audiences and encourage informed public participation in the energy debate.

THE ENERGY FUTURES LAB IS GUIDED BY 3 BOARDS. Day-to-day management is provided by the operations team located in the EFL headquarters at Imperial's South Kensington campus.

Technical Working Group

This group comprises Network leaders, Grand Challenge directors and the EFL operations team. It facilitates interaction at an academic level to identify research opportunities and to develop new Grand Challenge themes. The Group meets six times per year.

Strategy board

This group includes members of senior staff from Faculty, other institutes, relevant research groups and the EFL operations team. Meeting termly, this group is chaired by the Energy Futures Lab Chairman, Dr Raymond Orbach former Under Secretary of State for Science at the US Department of Energy and Director of the Energy Institute at University of Texas, Austin. It tackles operational and internal policy issues and provides advice on strategic direction.

Advisory board

This board convenes annually and comprises senior figures from the energy sector and Imperial. It provides external governance and provides advice on strategic targets. It is chaired by Sir Roy Gardner, Chairman, Compass Group. This year three new members have joined – Steve Holliday, CEO, National Grid; Ron Dennis, Executive Chairman, McLaren Group and Rob Gray, Chairman, UK Investment Banking, Deutsche Bank.

governance and advisory boards

CASE STUDIES

Solar

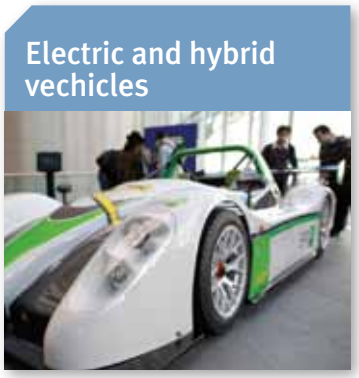
The Solar Network has been operational for the last 12 months. With the Solar Network, the Energy Futures Lab has built the Artificial Leaf programme and successfully bid for Strategy Investment Funding from the College to support the recruitment of two new academics within Departments of Chemistry and Life Sciences to strengthen the Artificial Leaf programme. In conjunction with this, and to build profile, the Solar Network has launched a website describing its work and led a number of events to share knowledge around the solar energy to fuels topic.

IC4s

Imperial College Centre for Carbon Capture and Storage was launched in June 2009 and brings together the largest community of researchers in this field at a single institution in the UK. The Centre provides a 'shop front' for external organisations to recognise the strength in depth of the skills and knowledge Imperial has in this area. Differing from other EFL Networks, IC4S operates an industrial club to fund PhD studentships in Carbon Capture and Storage with the results of all projects available to all members. Current members include BG Group, Shell and Qatar Petroleum.

Electric and hybrid vehicles

The Electric and Hybrid Vehicles Network was launched in October 2010 and brings together researchers from 7 departments working in areas including fuel cells, batteries, electric motors, power electronics, internal combustion engines and vehicle architecture, from micro to macroscale and from test beds to policy. As a new network, the Electric and Hybrid Vehicle Network has introduced an internal seminar series to share research to enable future collaboration and built a website to promote Imperial's activities in this area.

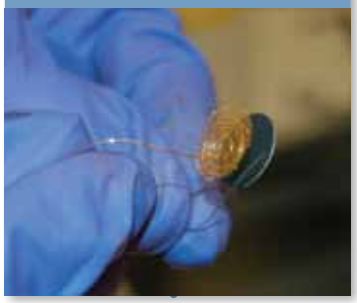


THE ENERGY FUTURES LAB COORDINATES a series of Research Networks around the subject of energy. The Networks range from technology specific Networks, such as solar or fuel cells to themes that cut across the spectrum of technological disciplines and feed into each one, such as systems, policy or business. The Networks act as focal points to encourage academic collaboration at a research level, transcending traditional departmental or faculty boundaries. Networks exist at a variety of maturities. Some are well established centres, such as the Centre for Transport Studies, while others have emergent Networks, such as Electric and Hybrid Vehicles, launched in October 2010.

Energy business

Energy policy

Fuel cells



Nuclear fission

Transport

Green aviation

Nuclear fusion

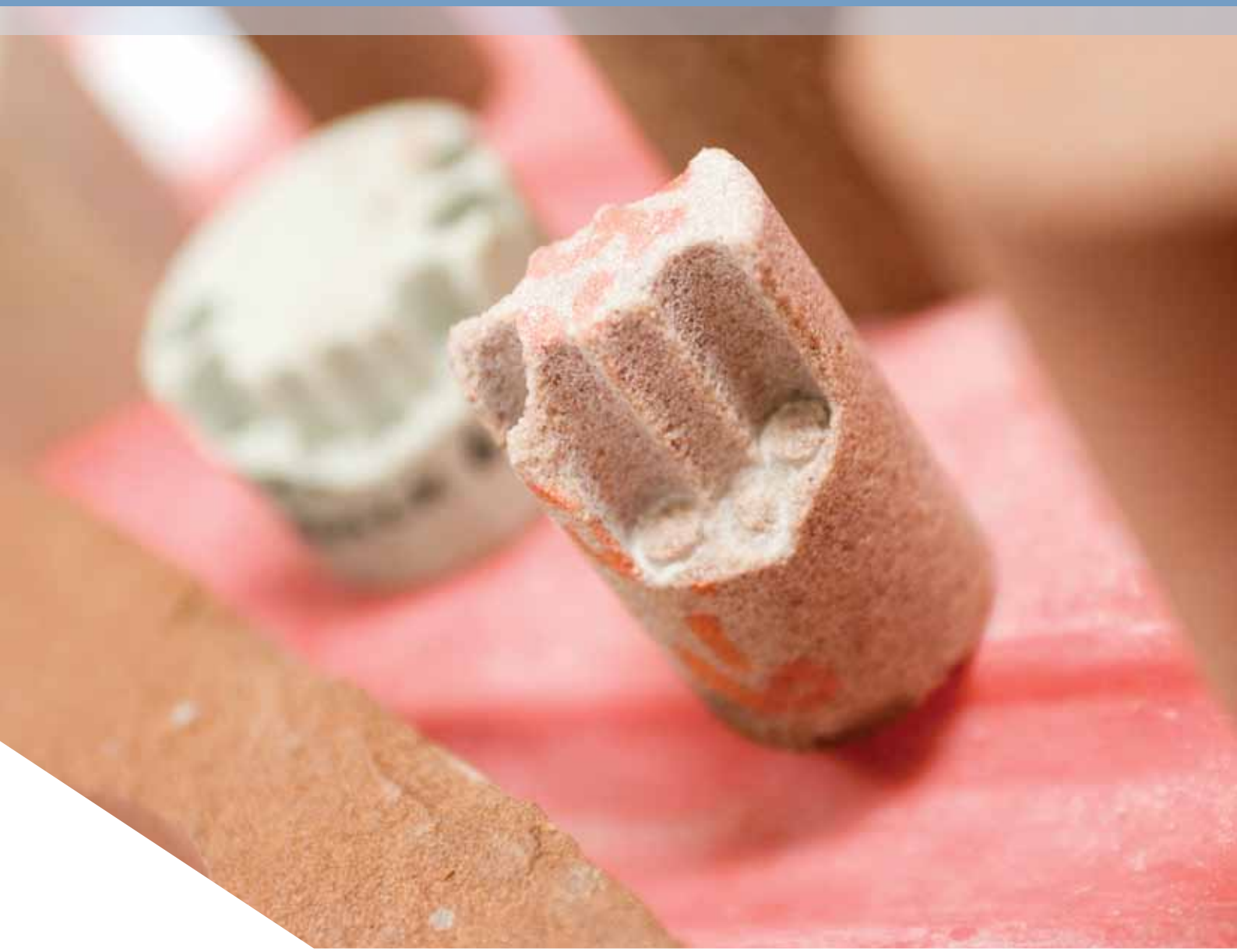
Oil and gas

Smart networks

Energy systems

Future fuels

Bio energy



Shell-Imperial Grand Challenge Programme in Clean Fossil Fuels (SGC)

THIS IS A £3 MILLION, 5 YEAR COLLABORATION between Imperial and Shell. It is now in its fourth year with 9 researchers (4 Post-doctoral and 5 PhD students) currently employed by Imperial. There are a further 11 academic staff that contribute to the overall technical guidance and governance of the programme. In the last 12 months, 10 papers and 1 book chapter have been published covering SGC research.

SGC currently has six active projects, some nearing completion and two relatively new. There have also been two successful secondments of SGC PhD students to Shell research offices (Amsterdam and Rijswijk) to extend work on modelling aqueous electrolytes and trapping mechanisms for CO_2 sequestration and a further two workshop meetings with Shell. A new Theme on reservoir recovery has also been initiated.

Theme A: CO_2 lifecycle management in the reservoir

CO_2 thermophysical properties. This project covers the phase behaviour of water, hydrocarbons and CO_2 and was expanded in 2010 to include brines. Experimental phase behaviour measurements at high temperature and pressure of CO_2 + n-decane + water are almost complete, providing benchmark data on a prototype model system that has also been successfully modelled using predictive molecular equations of state. Extension of the models to

« Sandstone cores used to measure how CO_2 is trapped.

more complex reservoir fluids is being pursued. Novel interfacial tension measurements from ambient conditions to high temperatures and pressures of various CO_2 + n-alkane + water mixtures were also published with supporting models which seem promising for prediction under reservoir conditions. Additional investigations into the phase behaviour of brine systems containing CO_2 have recently been initiated.

CO_2 multiphase reservoir flow properties. Recent experiments on sandstone cores have successfully delivered the first super-critical CO_2 capillary trapping results, a key mechanism for ensuring secure CO_2 storage in reservoirs or aquifers. On-going work is seeking to establish if there is a significant difference in wetting characteristics and capillary trapping between super-critical CO_2 and oil-brine systems. The work is supported by micro-CT rock imaging studies which track fluid displacement and trapping at the pore scale. The core CO_2 trapping data compare well with the predictions of pore network models derived from micro-CT images of the sandstone rock pore structure.

Thermal stimulation of enhanced coal-bed methane (ECBM). This project to investigate potential enhancements of methane production from coal through CO_2 injection (ECBM) concluded in June 2010. Research outcomes included details on the effects of thermal stimulation on coal bed permeability and CO_2 injectivity. Matrix swelling strain is a key parameter limiting our understanding of ECBM and this was significantly advanced. In addition, thermal cycling tests indicated that there may be a thermally stimulated zone around the well bore with altered elastic and swelling properties. Overall through thermal stimulation it has been shown that swelling is important to stress levels, shear stress is less of a concern and permeability is expected to increase. Detailed geomechanical models of the process have also been developed. Although this work has now stopped under the SGC, a grant from the European Union has allowed its continuation.

Hydrogen-carbon dioxide infrastructure design. In the latest phase of this project to provide tools to design future H_2-CO_2 distribution systems in a hydrogen-CCS economy, detailed information concerning Dutch requirements has been collated to enhance the spatial network modelling and address key questions concerning which storage sites are required first and comparing projected infrastructure requirements with existing facilities.

Theme B: Efficient and clean recovery of (non-conventional) hydrocarbon reservoirs

Thermodynamic models for asphaltene containing fluids. Using the expertise within the Molecular Systems Engineering Group, this new project involves an integrated approach to the molecular modelling of the thermodynamics and phase behaviour of heavy oils containing asphaltenes in the presence of CO_2 and brines. Extending this approach to these challenging systems will provide a powerful predictive tool for the design of improved, more efficient processes for recovery from non-conventional oil and gas reservoirs.

Pickering emulsification for enhanced oil recovery. This new three-year project is investigating the use of nanotechnology for improving reservoir recovery. It involves using emulsions stabilised by nanoparticles adsorbed at the oil/water interface as an alternative, more targeted, approach for stimulating recovery to the existing surfactant/polymer systems whose performance over the years has been inconsistent and difficult to control.

Qatar Carbonates and Carbon Storage Research Centre (QCCSRC)

This $70 million, 10 year collaboration between Imperial, Qatar Petroleum, Shell and Qatar Science and Technology Park, addresses the underpinning science and engineering of storing carbon dioxide in carbonate reservoirs. It is now fully functioning with 26 researchers (2 Lecturers, 11 Postdoctoral Fellows and 13 PhD students) and a dedicated Programme Manager. A further 14 academic staff contribute to the overall technical guidance and governance of the programme.

QCCSRC has three active projects with another two in development. The first two projects held technical workshops with the sponsors in the first half of 2010. This has enabled good alignment on individual projects and direct researcher-sponsor engagement within this large multidisciplinary programme. There has also been Imperial College London representation at several notable conferences and regional events in the Middle East featuring carbon capture and storage.

Project 1: Fundamental research applied to carbonate reservoirs. A field site reconnaissance trip was followed by a full fieldtrip to three locations in the region chosen for the relevance of their outcrop rocks to the Qatari subsurface. Several hundred samples were collected and brought back for laboratory investigation using a suite of state-of-the-art imaging and analytical equipment. Foremost amongst these has been the emerging technique of Clumped Isotope Mass Spectrometric Analysis. This novel geochemical analysis technique has enabled determination of the temperatures at which the rocks were precipitated, a key issue in understanding the development of the reservoir and its characteristics. This is the first such facility to be established in the UK.

QCCSRC researcher logs an outcrop which is very similar to the hydrocarbon-bearing rocks in the Qatari subsurface.

Project 2: Fundamental chemistry and physics of carbon dioxide injection into carbonate reservoirs. This project measures and develops prediction procedures for the thermophysical properties (viscosity, diffusion, phase behaviour) of CO_2 mixed with reservoir fluids, how these react with carbonate reservoir rocks and how CO_2 is transported through the complex rock pore/fracture network for enhancement of oil recovery and/or long-term trapping and storage. A wide suite of high temperature-high pressure equipment, costing over £1M to date, has been custom built to address these fundamental issues. The requirement for corrosion resistance to the concentrated brines found in these reservoirs is a serious complicating factor in the design and operation of the equipment. The experiments conducted include multiphase flow and imaging of rock cores to study fluid displacement processes, capillary trapping, relative permeability and contact angle/wettability changes. Key elements of the work are linking understanding at the pore/fracture scale to how CO_2 migrates and is trapped at large reservoir length/scales, and using limited experimental data to calibrate and validate molecular equations of state and transport models which can predict fluid behaviour over the whole range of reservoir conditions and fluid compositions.

Project 3: State-of-the-art reservoir simulator for carbonates. This is the newest project, started during 2010, which aims to apply advanced fluid modelling techniques, developed at Imperial for ocean modelling, to multiphase (CO_2-containing) fluid flow in structurally complicated carbonate reservoirs. This will improve both accuracy and speed compared with current models and already significant progress in this direction has been accomplished. Insights from the first two projects will enable the simulator to be not only technologically advanced but also incorporating the latest advances in our improved understanding of the geology, physics and chemistry of carbonate reservoirs.

PhD student Charles Dean preparing an experiment using a fluidised-bed reactor.

Scottish Power Academic Alliance

Launched in September 2010, the Scottish Power Academic Alliance brings together Imperial College London, through the Energy Futures Lab, and the University of Edinburgh to research all aspects of carbon capture and storage (CCS). It will focus on technical innovation around the capture and offshore storage of CO_2, policy and regulatory aspects of CCS and investigate what the UK needs to do to capitalise on the commercial opportunities the technology offers – especially in developing a national skills capacity.

Scottish Power is part of the Iberdrola group, one of the largest energy companies in the world, with global interests in coal and gas fired power stations. In the UK their assets include Longannet Power station in Fife, a 2.4GW coal fired power station on the shores of the Firth of Forth, the 3rd largest coal fired power station in Europe which Scottish Power would like to become part of the first generation of European power stations to be retrofitted for CCS, storing CO_2 in offshore geological formations under the North Sea with the first phase implemented by 2014.

Over its 5 year term this multi-million pound programme will utilise the expertise of staff from across Imperial and Edinburgh providing a framework for collaborative research. During the first year Imperial projects shall include the start of a whole systems analysis of the CCS value chain, drawing upon Imperial's world leading systems engineering knowledge whilst the Centre for Environmental Policy shall begin a PhD programme investigating the policy and institutional frameworks for investment in a CCS network in the United Kingdom.

Speaking at the public launch of the Alliance, Nick Horler, Scottish Power's Chief Executive, said: "This is a terrific step forward for Scottish Power and will help us in our ambitions to make CCS a reality in the UK by 2014. I am enormously proud to be associated with the work of some of the world's leading authorities on CCS. Their input will be vital to improve our understanding of this essential technology and help us to reduce CO_2 emissions and tackle climate change."

PhD student Bojan Tamburic and Dr Fessehaye Zemichael operating the projects' experimental bioreactor, extracting hydrogen from algae

New and renewable routes to solar hydrogen

THIS £4.2M PROJECT SPONSORED BY EPSRC is now in its third year. The aim of the project is to develop materials and technologies to utilise solar radiation for the direct conversion of water into hydrogen (and oxygen) gas for subsequent application in fuel cell and chemical systems. The multidisciplinary project is a collaboration between the Departments of Biochemistry, Chemistry, Chemical Engineering and Earth Science and Engineering. In the last academic year, almost 30 researchers ranging from undergraduates to senior academic staff were directly associated with the work, which has centred on three main areas.

Biological research has focussed on improving hydrogen yields from the green algae *Chlamydomonas reinhardtii* by looking for ways to increase oxygen uptake and manipulate metabolic pathways. This manipulation, called 'knock-down' has been achieved and certain metabolic pathways were successfully altered, leading to mutants with higher hydrogen yields. Researchers are also working on mining culture collections to identify other marine *Chlamydomonas* species that can produce hydrogen in sulphur-deprived conditions. Additionally more detailed analysis of the protein structure of Photosystem II has been undertaken as well as oxygen resistant hydrogenases (from cyanobacteria) supporting the fundamental understanding of how to manipulate the genome of algae to our advantage.

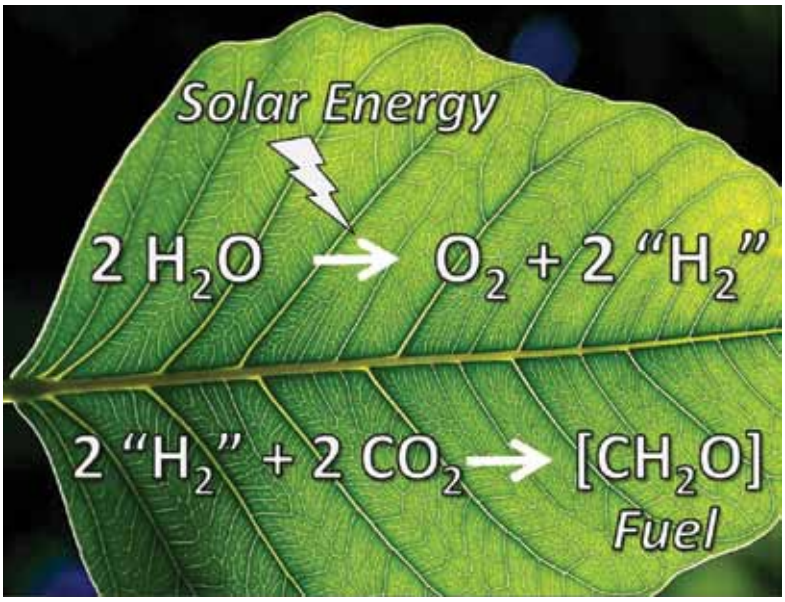
Chemical research aims to develop novel materials with high conversion efficiency by improving our understanding of the kinetics and lifetime of charge carriers as well as the generic interaction of photons with semiconductor interfaces. Research has focused on the sensitization of TiO_2 surfaces with various dyes for electron injection.

Bojan Tamburic talks to children at the Science Museum in London about the solar hydrogen bioreactor that was on display over the summer.

Researchers in Chemical Engineering are designing and developing devices for scaling-up systems to produce biological hydrogen and photo-electrochemical hydrogen. Advances include the operation of a number of novel photo-bioreactors (with one exhibited at the Antenna Exhibition, Science Museum, London) and the determination of growth, nutrient uptake as well as hydrogen production kinetics. In particular a new MIMS (membrane inlet mass spectroscopy) system is now operational to determine the amount of dissolved gases and thus the intrinsic early kinetics of hydrogen production. A test-bed reactor for photo-electrochemical hydrogen production has been operated and a number of models (including computational fluid dynamics) have been devised to help debottleneck the solar to hydrogen production process. A new computer controlled thin film pyrolysis system has been developed to reproducibly fabricate large area doped photoanode films on various substrates. Key dopants and film thickness have been identified using photocurrent spectroscopy.

Artificial Leaf

Imperial's Artificial Leaf programme is targeting the development of catalytic systems capable of efficiently harnessing renewable energy sources to achieve the reduction of carbon dioxide into chemical fuels. Such systems are the key technological challenge in strategies for carbon-neutral, renewable synthesis and utilization of liquid transportation fuels. Furthermore, such systems will enable the efficient storage of the renewable energy in chemical bonds, thereby addressing the intermittency limitations of most renewable energy sources. Articles describing how we are moving forwards to address these challenges have recently been published in the Guardian and Nature Materials.



This illustration shows how sunlight and water can be used to create carbon fuel.

The Artificial Leaf programme targets the solar driven reduction of CO_2 to energy rich carbon based fuels. Developing a technology which achieves this goal cheaply and efficiently will require overcoming significant scientific and engineering challenges. As part of the Artificial Leaf project, we are addressing parallel strategies for achieving this. These strategies build upon our established expertise in photovoltaics, fuel cells and photosynthesis. They range from direct photochemical reduction of CO_2 and photovoltaics plus electrochemical CO_2 reduction to solar water photolysis coupled to the dark reduction of CO_2 by molecular hydrogen. Further challenges include energy efficient CO_2 capture from the atmosphere, low cost solar to electricity conversion, efficient fuel utilisation and CO_2 recycling.

Our Artificial Leaf programme has been greatly strengthened this year by the award of £1.8M by EPSRC for a 3 year Nanotechnology Grand Challenge project targeting the development of nanostructured catalysts for thermochemical, electrochemical and photochemical reduction of CO_2 to molecular fuels. This is led by Dr Charlotte Williams, Department of Chemistry. This programme is now complimenting our established programmes targeting solar driven hydrogen generation from water and nanostructured functional materials. Further support is being provided through the Energy Futures Lab by the Alan Howard Scholarships for Energy Futures and by direct investment of College funds to the EFL to drive the recruitment of new academic posts in the areas of multi-electron catalysis and the molecular processes of biological photosynthesis.

L to R: Dr Celine Weber, Prof Nilay Shah and Dr Salvador Acha discuss ways to save energy in cities.

urban systems

THE BP URBAN ENERGY SYSTEMS PROJECT explores how energy, costs and environmental impacts could be reduced in the future if cities were to integrate their resource supply systems. The project's main activity is developing and applying a new modelling framework named SynCity to integrate different model types and facilitate a hierarchical approach to city and energy system design.

The SynCity framework provides tools to solve four inter-related problems:

- ***Layout model.*** This is an optimisation-based approach to organising the city layout.
- ***Agent-based land-use and transport model.*** This model combines the important features of agent-based modelling with transport demand models to establish patterns of movement and activity in the city.
- ***Energy interconversion and infrastructure model.*** This optimises: resources to import into the city; the resource interconversion technologies and their scale and location and energy vector networks.
- ***Service network design model.*** This is concerned with the design of smart, robust urban energy service networks.

Over the past year we have developed the toolkit to the point where it can be used in real design studies; examples include Melbourne and Lingang New Town.

PLANET 2050 IS A JOINT RESEARCH INITIATIVE between the Energy Futures Lab and the Grantham Institute for Climate Change, bringing together engineers and scientists to explore the technological barriers to reductions in CO_2 emissions, exemplified in the UK reduction target of 80% of 1990 levels by 2050.

Kick-starting the initiative, the Grantham Institute has backed a series of PhD research projects that contribute to our understanding of pathways to increased electrification, low grade heat in a fossil fuel free world and cooperative pervasive networked systems for large scale electric vehicle deployment.

The initiative is intended as a 'lighthouse' activity – demonstrating the pathways that will need to be adopted if these stringent targets are to be met in an optimal and integrated fashion and creating the foundations for a wide number of innovations from across the university and its partners. Turning theory into practise, Clemens Lorf, a student from the Department of Mechanical Engineering, working under the direction of Dr Ricardo Martinez-Botas is supporting the Racing Green Endurance project (see page 19) monitoring the performance of the prototype car throughout its 26,000 km journey, a unique data set on the efficacy of an electric vehicle in a range of road conditions and establishing a methodology benchmark against which the capability of commercial vehicles can be assessed.

MSc in Sustainable Energy Futures

THE MSc IN SUSTAINABLE ENERGY FUTURES (SEF) is a unique multidisciplinary master's programme, bringing together leading energy experts from Imperial and beyond to provide a wide-ranging education in energy engineering, science, policy and business. It enables our graduates to evaluate next generation energy technologies from technological, economic, environmental and policy perspectives to fully understand their place in the future energy landscape.

The course continues to go from strength to strength and in September 2010 the third cohort of 53 students completed another highly successful year. New features of the course in 2009/10 included the Energy Futures Debating Society, which conducted lively debates on topics such as the roles and responsibility of developed nations in tackling climate change and place of nuclear electricity in a future low carbon generation portfolio. At the invitation of International Power, the group went on an informative and enjoyable visit to Dinorwig pumped storage hydroelectric power station in North Wales. In a packed programme there was even time for an early morning ascent of Snowdon! The year was rounded off in great style with the inaugural Sustainable Energy Futures Conference. The event was organised by the students (with expert help from the EFL team) and funded by kind donations from International Power, BP, Davis Langdon, Vestas and the Bridgestone Group. Led off with a key-note speech from Jonathan Brearley, Director of Energy Strategy and Futures at Department of Energy and Climate Change (DECC), the event was a great success, with 210 registered delegates from around the College and the energy sector. Feedback from delegates was unanimously positive with an immediate tangible outcome being increased support for MSc projects from industry with at least five organisations, including DECC, proposing and some sponsoring projects in 2010/11.

In October the fourth cohort of students arrived. Selected from well over 300 applicants, they comprise graduates from a variety of engineering and scientific disciplines with the majority having industrial/professional experience. The international reputation of the course appears to be growing with more and more students supported by prestigious scholarships from the likes of Iberdrola and Chevening.

The course continues to grow and evolve and in 2010/11 we are delighted to be able to offer a new module in Energy Business led by Professor Gerard George, Director of the Rajiv Gandhi Centre in the Business School. We are looking forward to another successful and productive year!

PHOTO COURTESY OF ALED MOSES

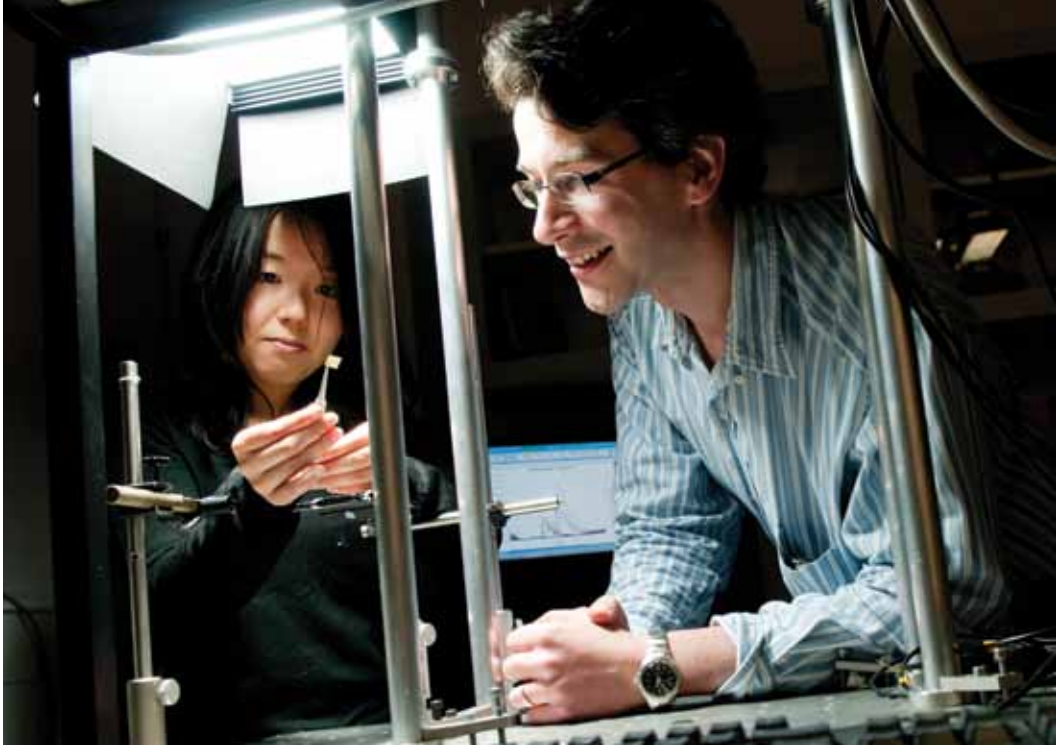
LEAVERS DESTINATIONS

In addition to those going to study for a PhD, graduates of the MSc in SEF have gone on to work for:

- Gazprom
- Bloomberg New Energy Finance
- JP Morgan
- Du Pont
- Energy Excel
- Carbon Descent
- Eni

Right: CDT students come from a wide range of departments.

Far right: Centre students are tackling energy issues from across the technology spectrum.



PhD student Megumi Yoshida is working with Dr Ned Ekins-Daukes on high efficiency solar cells.

Energy Futures Centre for Doctoral Training

The Energy Futures Centre for Doctoral Training, funded by EPSRC, enables the Energy Futures Lab to provide translational activities to PhD students in energy at Imperial. This year the Centre has recruited 15 students from across the College. Students in the Centre have had the opportunity to attend an Energy Summer School, specialist energy business course and meet students studying energy from around the UK. The students also take part in the Energy Futures Debating Society and share their research at monthly CDT seminars. To help develop PhD opportunities in multidisciplinary energy projects at Imperial, the Energy Futures Lab is offering small bursaries to support students or projects.

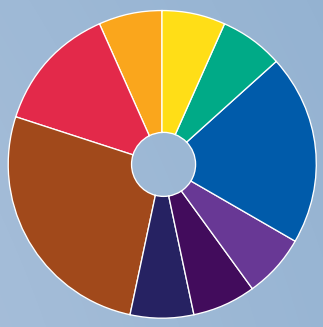
Alan Howard Scholarships for Energy Futures

The Alan Howard Scholarships for Energy Futures provide funding for Israeli PhD students and early career researchers to work at Imperial, building academic links and developing some of the next generation of energy engineers and scientists.

Following Mr Howard's generous renewal of the scholarships last year we were able to welcome proposals for MSc students and early career researchers. Two proposals were awarded this year, both feeding into the Artificial Leaf project. PhD project "The high temperature electro-catalytic reduction of carbon dioxide" supervised by Prof John Kilner (Materials), Prof Nigel Brandon (Energy Futures Lab) and Prof Jacob Karni (Weizmann Institute) and early career researcher project "Catalytic conversion of carbon dioxide to fuels" supervised by Dr George Britovsek (Chemistry) were awarded. These projects complement scholarships already awarded in Mechanical Engineering, Electrical Engineering, Earth Science and Engineering, Chemistry and the Centre for Environmental Policy.

Department

- Aeronautics
- Biology
- Centre for Environmental Policy
- Chemical Engineering
- Chemistry
- Civil Engineering
- Electrical Engineering
- Materials
- Mechanical Engineering



Theme

- Bioenergy
- Electric and hybrid vehicles
- Fuel cells
- Green aviation
- Oil and gas
- Smart Networks
- Solar
- Systems
- Transport

Industrial engagement

WORKING WITH CORPORATE PARTNERS has always been part of the Imperial way of thinking. Our 1907 Charter states the objectives of the University shall be "to provide the highest specialised instruction and the most advanced training, education, research and scholarship in science, technology and medicine, especially in their application to industry" and that philosophy lives on to this day.

At a time of unprecedented changes in public funding for all university research and higher education, combined with the growing demand for new and innovative technologies to meet the energy challenges of the future, our relationship with our corporate partners has never been more important. They provide support and direction for our research, inspiration and employment for our graduates.

Data from Longannet power station in Scotland, owned by Scottish Power, will be used as part of the Scottish Power Academic Alliance.

Against this backdrop we are therefore pleased to report that 2010 was another strong year of working with our established industrial partners. Early projects such as the BP Urban Energy Systems programme are now providing real world solutions to complex societal challenges whilst programmes such as the Shell-Qatar Petroleum funded Qatar Carbonates and Carbon Storage Research Centre is a leading example of how adopting a long term strategic approach to research, education and skills development affords the greatest opportunity for a step-change in energy technology. We are also pleased to introduce new companies to Imperial such as Scottish Power and old partners back such as General Motors as we work with these corporations to help them realise their own ambitions to lead within their business areas.

2011 will undoubtedly create new challenges. In anticipation, the Corporate Partnerships team is continuing to work with new and established partners to optimise the benefits of working with our world class institution and the many ways in which we help them address the new energy future.

Events 2010 »

The Energy Futures Lab coordinates and supports a series of public and professional lectures, talks and seminars. These include Imperial and external speakers, and take place inside and outside College. Events organised during the past year include:

FEBRUARY
U.S. Alternative Fuels/Vehicles: Federally–Funded R&D Status and Market Implications; *Dale Gardner, US National Renewable Energy Laboratory*

APRIL
Solar network symposium, led by *Prof James Durrant and Dr Ned Ekins-Daukes*

MAY
CCS Early Enablers Seminar: Health, Safety and Environmental Regulation; *Joint event with Health and Safety Executive, Environment Agency and Energy Institute*

JULY
Worshipful Company of Engineers visit

SEPTEMBER
Energy in 2050: What's desirable? What's possible?; *Gert Jan Kramer, Shell Projects & Technologies, University of Leiden*

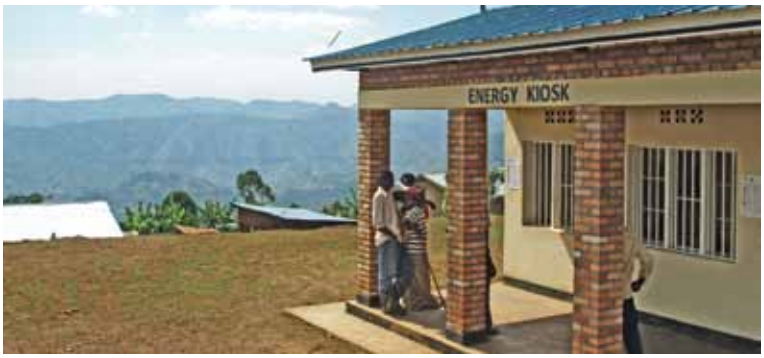
Schools outreach and undergraduate engagement

Building on our awarding winning Outreach programme, Energy Futures Lab has undertaken work with the College's Reach Out Lab, led by Lord Robert Winston. The Reach Out Lab is a new facility linking Imperial's schools outreach and public engagement activities science, technology, engineering and mathematics.

The Energy Futures Lab and Reach Out Lab have collaborated to allow school-aged children access to research labs and academics. Students from the Centre for Doctoral Training have also taken part in sessions run by the Reach Out Lab team.

Racing Green Endurance drove down the Pan-American highway in their electric supercar

The Energy Futures Lab supports extracurricular undergraduate activities in energy. This year has seen a number of undergraduate-led activities step out from their lecture theatres and labs and bring national and international recognition.



Energy Kiosk in Bugesera, Rwanda, constructed by E.quinox to bring electricity to the rural populus

Racing Green Endurance is a team of under- and recent graduates of Imperial who turned a Radical racing car into an electric supercar which they successfully drove down the 26,000km Pan-American Highway, starting in Fairbanks, Alaska, and ending in Ushuaia, Argentina at the tip of the South American continent. The students have raised funds through sponsorship and have had media coverage in the international press. The RGE team endeavour to show that electric vehicles are a viable sustainable transport solution, while inspiring young people to study maths and science.

E.quinox is a not-for-profit student led organisation that aims to bring electricity to more people in developing countries. The project, currently working in Rwanda, builds 'energy kiosks' that are roofed by solar panels. The solar energy collected is stored by mobile battery boxes which are hired by local residence for a small fee. The team have most recently constructed two new energy kiosks and upgraded the original kiosk.

MSc in Sustainable Energy Futures conference
Led by students of MSc programme

OCTOBER
Deutsche Bank prize school visit

Electric and Hybrid Vehicle Network Launch
Talks from Chris Walsh, Cenex and Miguel Fragoso, GM UK

Developing a "Clean First" Design of Market Incentives for the Power Sector; *Meg Gottstein, Regulatory Assistance Project*

NOVEMBER
Road transport technology and climate change mitigation – discussing the Grantham Institute briefing paper; *Dr Dave Howey, Imperial College London*

Artificial Photosynthesis workshop;
Joint event with British Embassy in Denmark and Swiss Embassy in UK

Real world emissions modelling;
Dr Robin North, Imperial College London

Solar fuels symposium, led by *Prof James Durrant and Dr Ned Ekins-Daukes, Imperial College London*

Smart, safe, and just: Goals for the global energy system; *Prof Rob Socolow, Princeton University*

DECEMBER
Celebrating Racing Green Endurance

Research from the Energy Futures Lab often features on the Imperial homepage and in the news.

If you are interested in working with us by carrying out research, funding us or collaborating with our outstanding researchers, please contact:

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Become a member of Energy Futures Lab to receive regular updates and invitations to events:

www.imperial.ac.uk/energyfutureslab/about/membership

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About Imperial College London

As the only UK university to focus entirely on science, technology, engineering, medicine and business, Imperial College London offers a critical mass of international research expertise and a vibrant home for innovation and enterprise.

Sustained support for Imperial's research at the EFL is a sound investment in the UK's economy and in developing the next generation of energy pioneers, researchers, innovators and entrepreneurs.