Imperial College London

Energy Futures Lab

An institute of
Imperial College London

www.imperial.ac.uk/energyfutureslab

annual report 2009

securing our future energy supplies

Front cover photo: Low cost, dye-sensitized solar cells power the blue electric fan on the right of the picture. The solar cells come from research led by EFL's Deputy Director, Professor James Durrant. **Above:** The Racing Green Endurance car: Imperial students are transforming one of the world's fastest petrol-powered racing cars into a high performance electric vehicle. They aim to be the first to drive an electric vehicle the full length of the Pan American Highway—the longest road in the world—and hope to dispel negative perceptions of the limited range of electric cars.

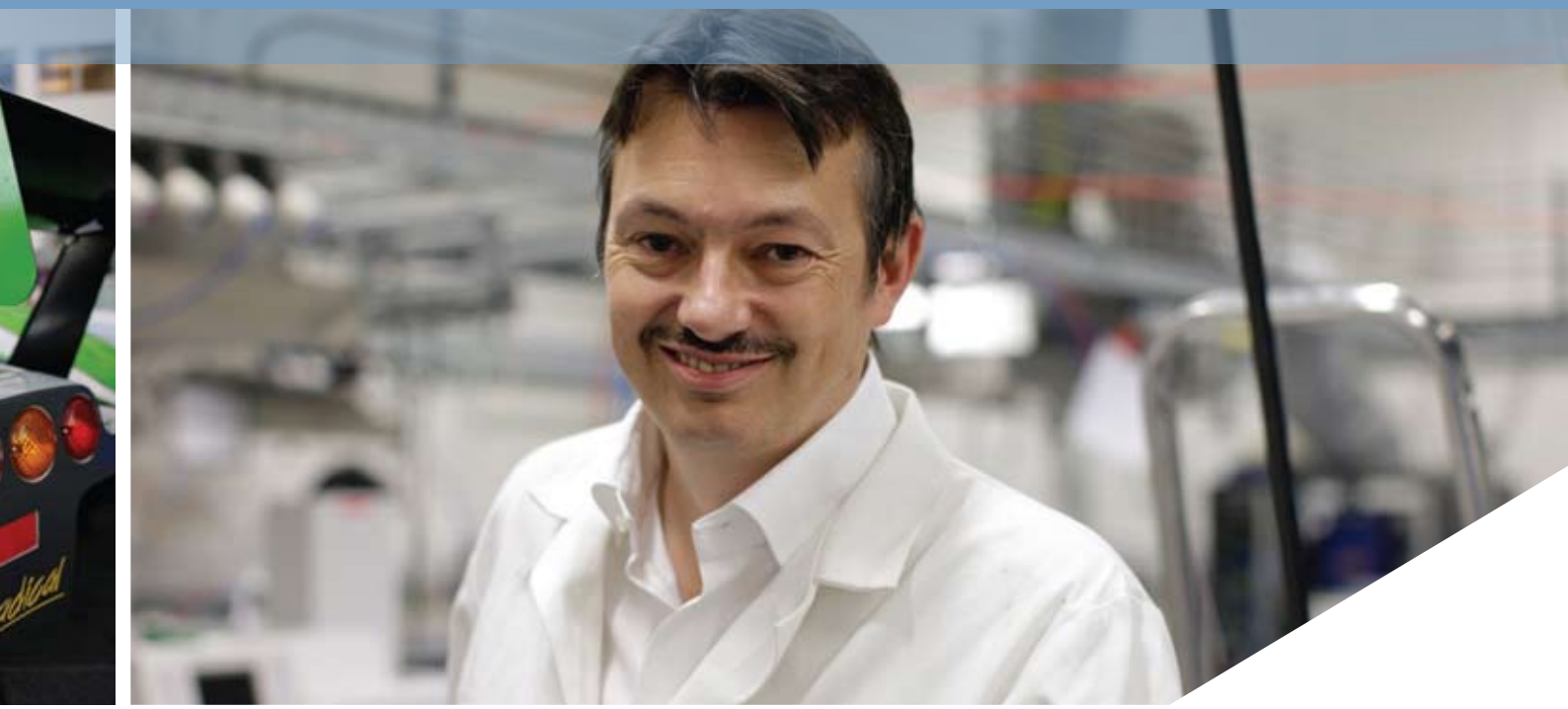
Foreword

I am pleased to introduce the Energy Future Lab Annual Report for 2009 – the year we became an institute of Imperial College London, and secured strategic investment from the College and industrial partners.

The need for sustainable and secure energy has taken high priority on national and international agendas, despite a backdrop of the worst recession in over 70 years. This prominence has been reflected by the United Nations Climate Change Conference in Copenhagen and the UK Government's pledge to fund new power stations with carbon capture and storage technology.

I am pleased to endorse the progress and contribution made by the Energy Futures Lab of Imperial College London. It has established itself in a way that enables it to engage with researchers, government and industry at all levels and stages of the research process, from fundamental research to industrial troubleshooting. I warmly welcome the emphasis it also puts on training the next generation of energy professionals and engaging with the general public in the wider energy debate.

Sir Roy Gardner, Chairman, Energy Futures Lab Advisory Board



Director's Report

The Energy Futures Lab at Imperial College London has just completed its fourth year of operation, and I am delighted to be able to introduce a summary of our activities in this report. Energy remains a critical global challenge, and one that Imperial is uniquely placed to address.

Highlights during the past twelve months include: becoming an institute of Imperial College London; opening our new dedicated headquarters in Dalby Court by the UK Government's Chief Scientific Advisor Professor John Beddington; establishing fifteen research networks to bring our energy research community together; launching the Imperial College Centre for Carbon Capture and Storage (IC^4S); extending our Grand Challenge programme in cleaner fossil fuels with Shell; being awarded the IChemE award for Innovation and Excellence in Education for our Masters programme in Sustainable Energy Futures, coupled with our prize winning students who fought off tough competition to win the Npower energy challenge; and receiving an EPSRC award for a Centre for Doctoral Training in Energy Futures, which will help at least 50 PhD students specialise in a range of energy issues over the next seven years.

A review of the energy research programme across Imperial shows that we have an energy research income of £30M per annum, around one third of which is from industry, supporting a team of some 600 faculty, research staff and PhD students. This enables a unique combination of depth and breadth in 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. Over the past year we have been involved with major new programmes in Electric Futures (in collaboration with the Grantham Institute for Climate Change at Imperial) to explore the role that low carbon electricity can play in the built environment and the transport sector, and Artificial Leaf, which seeks to use renewable energy to convert carbon dioxide back into useful liquid fuels.

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 an international workshop on "Solar to fuels and back again", and our 2009 Annual Lecture given by Steve Holliday, CEO of National Grid.

Professor Nigel Brandon, Director, Energy Futures Lab

THE ENERGY FUTURES LAB IS ONE OF FOUR IMPERIAL MULTIDISCIPLINARY INSTITUTES set up to respond to the global challenges of developing sustainable energy sources, tackling climate change, improving global health and addressing safety and security. In early 2009, the EFL was recognised as an institute of Imperial College London, which is providing core funding to support activities and create new headquarters and student work space.

The EFL acts as the focal point for energy research across Imperial by working across faculties and departments, bringing people together to deliver world-class research programmes, educational activities, entrepreneurship and advice for key decision makers.

The EFL co-ordinates 15 research networks to bring academics together in areas of Imperial's energy expertise. These networks integrate energy research across College and raise external visibility and accessibility.

The EFL is also taking the lead in developing new Grand Challenge research programmes, where we are identifying opportunities to address major, long-term energy issues facing the world today. In addition, the EFL works to educate the next generation of energy professionals at MSc and PhD levels and to encourage participation in public debate through its prize winning outreach programme.

The Energy Futures Lab has restructured its management system to reflect its new status as an institute of Imperial College London.

Technical Working Group

This comprises academics from across Imperial, bringing together the research network leaders, Grand Challenge directors and the EFL operations team. The group aims to identify current research and funding opportunities, and to build new Grand Challenges from them. They meet around six times per year.

Institute Director: Professor Nigel Brandon

Institute Deputy Director: Professor James Durrant

Institute Director for Education: Dr Andy Heyes

Programme Manager: Victoria Harding

Business Development Manager: Dr Peter Evans

Clean fossil fuels: Professor Geoff Maitland

Urban energy systems: Professor Nilay Shah

Biological hydrogen advisor: Professor Peter Nixon

Next generation biofuel advisor: Dr Richard Murphy

Bioenergy network: Professor Richard Templer

Carbon capture and storage network: Professor Martin Trusler

Electric and hybrid vehicles network: Dr Ricardo Martinez-Botas

Energy business network: Professor Erkko Autio

Energy policy network: Dr Tim Cockerill

Energy systems network: Professor Sandro Macchietto

Fuel cells network: Professor Anthony Kucernak

Futures fuels network: Professor Peter Lindstedt

Green aviation network: Professor Ferri Aliabadi and Dr Paul Robinson

Nuclear fission network: Professor Robin Grimes

Nuclear fusion network: Professor Steve Rose and Professor Roger Evans

Oil and gas network: Dr Velisa Vesovic

Solar network: Professor James Durrant and Dr NJ Ekins-Daukes

Smart networks network: Professor Goran Strbac

Transport network: Professor John Polak

Strategy Board

The Strategy Board includes senior staff from Faculty, other Imperial Institutes, relevant research groups and the EFL. Meeting three times per year, it supports EFL operations and provides internal governance. The Board provides advice on funding strategies and direction for the research agenda. It is chaired by the Energy Futures Lab Chairman, Professor Ray Orbach, former Under Secretary of State for Science at the US Department of Energy.

Institute Chairman: Professor Ray Orbach

Institute Director: Professor Nigel Brandon

Institute Deputy Director: Professor James Durrant

Institute Director for Education: Dr Andy Heyes

Faculty of Natural Sciences: Professor Donal Bradley

Faculty of Engineering: Professor Jeff Magee

Business School: Professor Gerry George

Grantham Institute for Climate Change Director: Professor Sir Brian Hoskins

Energy policy: Professor Jim Skea

Pro-Rector Commercial Development: Mr Edward Astle

Research Strategy: Dr Chris Thompson

International Relations: Professor John Wood

Research Communications: Natasha Martineau

Advisory Board

The Energy Futures Lab Advisory Board comprises senior figures from the energy sector and Imperial. It meets annually and provides external guidance and advice on the strategic targets of the Energy Futures Lab and comment on its output. It is lead by a senior external figure from industry—Sir Roy Gardner.

Chairman: Sir Roy Gardner, Chairman, Compass Group plc; President, Energy Institute

Dr Paul Golby, CEO, Eon UK

Mr Syamal Gupta, Special Advisor, Tata Group

Professor Sir Peter Knight, Deputy Rector (Research), Imperial College London

Mr Sam Laidlaw, CEO, Centrica

Dr Eddie O'Conner, Chief Executive, Mainstream Renewable Power

Professor Stephen Richardson, Deputy Rector and Principal, Faculty of Engineering, Imperial College London

Sir John Rose, Chief Executive, Rolls Royce

Sir Neville Simms, Chairman, International Power

Mr James Smith, Chairman, Shell UK

Mr Philip Yea, Chairman, British Heart Foundation

Energy business

Imperial's Energy Business Research Laboratory develops theoretical, managerial and policy insight into how environmentally sustainable energy technologies can be economically created, implemented and adopted.

Carbon capture and storage (CCS)

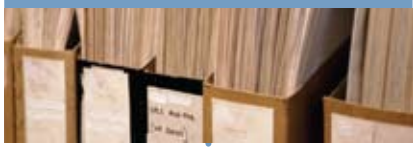
Imperial has the largest CCS research programme in the UK, which focuses on capturing, transporting and storing carbon in geological formations, as well as legal and regulatory issues, environmental impact analysis and systems research.

Bio energy

Managed by the Porter Institute, this network aims to produce renewable energy from materials derived from biological sources. Imperial research includes investigating whether sugars from plant cell walls can be used to make biofuels such as ethanol to burn in car engines.

Energy policy

The Imperial Centre for Energy Policy and Technology (ICEPT) focuses on the policy behind the science and technology of producing energy, to analyse the impact of energy systems on climate, ecosystems and human health, and to explore the economic, legal and institutional aspects of related energy and environmental policies.



Electric and hybrid vehicles

Combining Imperial's technological, engineering, scientific and policy expertise, this network aims to reduce vehicle lifecycle emissions, raise the profile of research in this area, and strengthen collaborations with industry and government.

Energy systems

This network brings together Imperial's multidisciplinary expertise in systems modelling to make biological processes more efficient, to understand how energy, people and materials flow through different systems, and to apply existing novel technologies in new ways.

Research portfolio

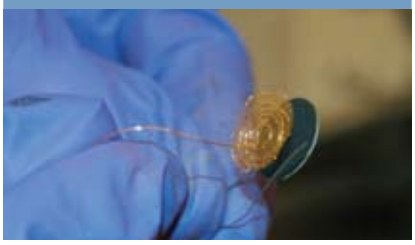
Project	Sponsor	Start date	Duration
Energy Futures Lab	Imperial College London	Feb. 2009	5 years
Clean fossil fuels	Shell	Feb. 2007	5 years
Qatar Carbon Capture and Storage Research Centre	Qatar Foundation, Shell & Qatar Science and Technology Park	Jan. 2009	10 years
Carbon capture, transport and storage infrastructure in the United Arab Emirates (Masdar)	Abu Dhabi Future Energy Company & Shell Abu Dhabi	Oct. 2008	3 years
New and renewable routes to solar hydrogen	EPSRC	Oct. 2007	5 years
Urban energy systems	BP	Nov. 2005	5 years
Alan Howard Scholarships for Energy Futures phases 1 &2	Donations	Oct. 2007 (phase 1), Oct. 2010 (phase 2)	5 years each
Centre for Doctoral Training in Energy Futures	EPSRC	Jan. 2010	5 years

EFL research networks

The Energy Futures Lab has established 15 networks to encourage researchers to communicate within and between disciplines and technologies, and to help establish Grand Challenge programmes. Each network pulls together researchers across departments and faculties, providing a conduit for interdisciplinary research, teaching and communications.

Fuel cells

Multidisciplinary research includes development of solid oxide, polymer electrolyte and alkaline fuel cells coupled with the analysis of the economic and environmental effects of fuel cell technology.



Future fuels

Emerging fuels, such as next generation biofuels and hydrogen, will have a major impact on both static and mobile applications. Researchers are combining knowledge from engineering and science disciplines such as combustion modelling and biochemistry understand the impact of future fuels.

Green aviation

The emerging demand to reduce the role of aviation on climate change brings together research interests including aircraft design, advanced materials, combustion and policy.

Nuclear fission

Research includes increasing the understanding of materials used in nuclear reactors, improving fuel performance, and developing better modelling techniques for simulating thermal and fluid flow processes in reactors. Other research focuses on the sustainable, safe and secure disposal of nuclear waste.

Nuclear fusion

This network combines Imperial's strengths in plasma physics and engineering to address the technical issues associated with the first generation of nuclear fusion power plants.

Oil and gas

Research at Imperial focuses on improved location and production of oil and gas, integrating them with emerging technologies such as carbon capture.

Smart networks

Research into developing a smarter electricity supply system includes new ways of controlling, operating and investing in networks, a better understanding of how new technologies affect grid operation, and better ways of balancing supply and demand by integrating energy systems, including offshore grids.

Solar

Imperial has the largest UK academic research programme on solar energy conversion, focussed primarily on developing new solar energy conversion technologies, such as organic and nano- photovoltaic cells, and ways of harnessing sunlight to synthesise chemical fuels.

Transport

Imperial's Centre for Transport Studies—one of Europe's leading inter-disciplinary transport research and teaching centres—specialises in new transport technologies, operations, environmental effects and policy and regulatory issues.

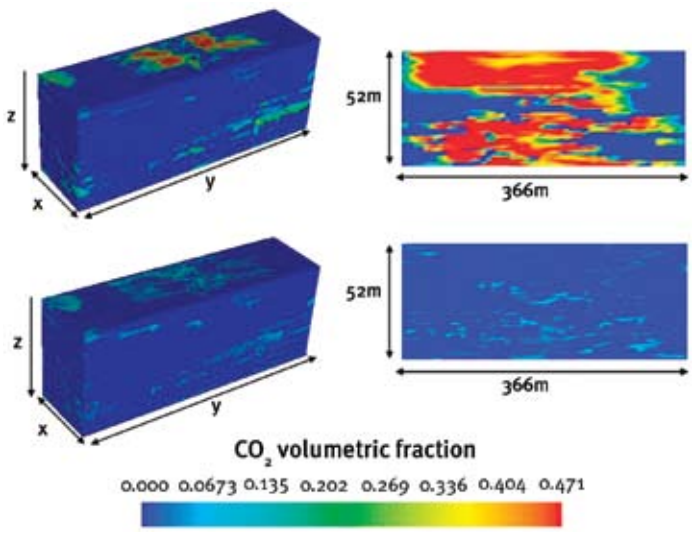
PhD student Christopher Pentland (L) and Professor Martin Blunt discuss carbon capture technologies.

Shell-Imperial Grand Challenge Programme in Clean Fossil Fuels

THIS MULTI-MILLION POUND PROGRAMME FOCUSES ON IMPROVING THE EXTRACTION of difficult hydrocarbons with minimal greenhouse gas release, and enhancing downstream delivery of energy and chemicals to the consumer. It is coordinated by Director Professor Geoff Maitland, and managed by a Joint Steering Committee comprising the Director, the Shell Sponsor Dr Claus Otto, the Energy Futures Lab Director Professor Nigel Brandon, and Dr Rick Wentinck (representing Shell Exploratory Research). Strong interaction through scientific exchange and exploitation of expertise and equipment in Shell and Imperial are key components of the collaboration.

Theme A: CO_2 lifecycle management in the reservoir

CO_2 thermophysical properties. This research is critical for understanding and predicting how CO_2 will behave when injected into an aquifer for long-term storage. High pressure-high temperature phase equilibrium equipment is fully operational and delivering new data on CO_2-hydrocarbon-water phase diagrams under reservoir conditions. Equations to model components of different molecular size, and association and dissolution effects have been developed and used to predict with good accuracy the phase behaviour of a wide range of CO_2-hydrocarbon-water mixtures over the entire range of



Modelling the effectiveness of capillary trapping in aquifers: 3D profile (L) and 2D cross-section (R) of trapped (top) and mobile (bottom) CO_2, after injection of CO_2 followed by brine.

pressure and temperature compositions encountered in oil and gas reservoirs during enhanced oil recovery (EOR) and carbon capture and storage (CCS) operations.

CO_2 multiphase reservoir flow properties. Capillary trapping is a rapid and effective mechanism to render injected CO_2 immobile when storing it in aquifers or depleted oil and gas reservoirs. To further our understanding of this process, the fraction of the trapped non-wetting phase (supercritical or liquid CO_2 in the CCS process) has been measured as a function of the initial saturation in sand packs representing the reservoir rock.

We have designed injection strategies for storage in both aquifers and oil fields that render up to 95% of the injected CO_2 immobile through capillary trapping. Experimental flow studies are being extended to consolidated sandstone rocks and supercritical CO_2 under reservoir conditions. Complementary X-ray imaging techniques have been explored as a means of providing fluid spatial distributions within rocks at the pore scale.

Thermal stimulation of coal. Understanding the impact of injecting CO_2 into coal beds on pore structure and the swelling characteristics of the coal is important. Swelling experiments on water-saturated coal samples subjected to cyclic freezing and thawing have been carried out where CO_2 is injected at different temperatures, from 40°C down to 0°C. Further tests were accompanied by simultaneous swelling strain and permeability measurements of a coal sample. Theoretical work has helped to assess and validate wellbore thermomechanics and swelling models using experimental data obtained to date.

Hydrogen-carbon dioxide infrastructure design. We are developing models for designing and optimising the infrastructure needed in the Netherlands to link the manufacture/generation of hydrogen (both liquid and gas) and carbon dioxide to local and regional distribution, sales or storage sites. The project has shown that for any conceivable scenario, economically competitive hydrogen supply networks can be designed. The deciding factors to make the Dutch hydrogen economy a reality are the cost of fuel cell vehicles, and supporting policies. CO_2 network design will be strongly influenced by CO_2 point sources and sinks. Recent model enhancements include being able to decide when to shutdown any given plant, and if an existing or old plant needs to be expanded or new plant built, inclusive of entire gasoline supply chain emissions (i.e. CO_2 from extraction, transport, refining, distribution).

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

A workshop held in January 2009 brought together expertise across Imperial to explore how further investment in Theme A topics might build on the current projects to ensure more comprehensive coverage of CO_2 reservoir flow and storage issues, and to identify new ideas for optimising reservoir recovery under Theme B. As a result, Shell agreed to fund four further projects in the Grand Challenge to run from Autumn 2009 until the end of 2011:

Theme A extensions:

- Thermophysical properties: extension to include brines: CO_2-brine-hydrocarbons phase behaviour (Principal Investigator: Professor Martin Trusler)
- Core floods and X-ray imaging for CO_2: direct measurement of wettability (Principal Investigator: Professor Martin Blunt)

Theme B extensions:

- Clean, efficient production of non-conventional hydrocarbons - thermodynamic models for asphaltene containing fluids (Principal Investigator: Professor George Jackson)
- Pickering emulsification for EOR (Principal Investigators: Professor Alexander Bismarck, Dr Milo Shaffer)

These projects will employ four Postdoctoral Research Associates and two PhD students. Recruitment of staff is well advanced and the projects will be active before year end.

Qatar Carbonates and Carbon Storage Research Centre (QCCSRC)

This $70M, 10 year research programme is jointly funded by Qatar Petroleum and Shell. The programme aims to strengthen Qatar's engineering talent and expertise and expand Imperial's capacity in CCS/advanced fossil fuels through five research projects:

1. Fundamental research applied to carbonate reservoirs
2. Characterising CO_2/reservoir fluids and their interaction with carbonate rocks
3. State-of-the-art reservoir simulator for carbonates
4. Pilot-scale validation
5. Field-scale demonstration project

Chemical Engineering PhD student Egwono Okpoko assembles a lab-scale pressurised fixed-bed reactor to remove CO_2 from power station exhaust.

An overall framework agreement was signed in July 2008 and individual work plans have been agreed for the projects. Work plans have already been implemented for Project 1 and Project 2, and Project 3 is agreed and will be signed soon. The remaining two projects, involving scale-up to pilot and field scales, will be finalised by the end of 2009.

The first half of 2009 was mainly occupied with intense recruitment of staff for Projects 1 and 2 and the QCCSRC programme manager, Dr Iain Macdonald, who brings a wealth of knowledge and experience of Qatar oil and gas to this critical coordination role from his previous work for Qatargas. Following this period of recruitment, Projects 1 and 2 are now active. Equipment design/purchase and 'gap analyses' based on extensive literature reviews to identify major issues and opportunities are now underway.

Project 1: Fundamental research applied to carbonate reservoirs. Dr Cedric John was the first QCCSRC Lecturer to be appointed and is the Theme Principal Investigator for this project. Professor John Cosgrove is also actively involved in expanding the project, with two post-doctoral research assistants and two PhD students now in place. The first major activities involve two field trips to Oman to collect outcrop materials from carbonate reservoirs. These will be used for developing methodologies for understanding the evolution and structural characteristics of carbonate reservoirs.

Project 2: Characterising CO_2/reservoir fluids and their interaction with carbonate rocks. Professors Martin Blunt and Martin Trusler are the Theme co-Principal Investigators for this project with involvement from academics from the Departments of Earth Science and Engineering and Chemical Engineering and Chemical Technology. Dr Edo Boek was appointed as the second QCCSRC Lecturer and will play a major role in developing this project. This project has three sub-projects, the recruitment status of which is:

2.1: Pore-scale reservoir physics: two Postdoctoral research assistants (PDRAs) and two PhD students appointed.

2.2: New underpinning science and engineering required for hydrocarbon gas or CO_2 in carbonates at reservoir conditions: two PDRAs and three PhD students appointed; one PDRA and one PhD yet to be appointed.

2.3: Molecular equations of state and transport models for Qatar fluids: 2 PDRAs and 2 PhDs appointed

QCCSRC profile in Qatar

Professors Geoff Maitland and Martin Blunt attended the opening of the Qatar Science and Technology Park on March 16th in Doha, and took part in the Qatar Petroleum exhibition stand to explain the aims and planned research of QCCSRC and the close interaction of Qatar Petroleum, Shell, QSTP and Imperial that underpins it.

One focus of the programme is to build up the technical infrastructure in Qatar for carbon management. Opportunities for Qatari students to become involved have been publicised through advertisements in Qatar and by building links with the local universities in Qatar. Several potential PhD students have been identified and it is planned to integrate them into the programme through initial MSc studies from 2010 onwards.

John Cosgrove, Professor of Structural Geology, on a field investigation site in Oman to collect outcrop materials, as part of research to characterise carbonate reservoirs.

Masdar

Masdar is an initiative launched by the government of Abu Dhabi in low carbon energy to help position the state as a world-class research and development hub for new energy technologies, while ensuring that they maintain a strong position in world energy markets. Masdar is seeking to help achieve this goal through partnership with leading universities.

Limestone sorbents for removing CO_2 from natural gas and refinery gas streams: these could could also be used to capture CO_2 from large-scale power plants.

In October 2008 Masdar entered into a collaborative research programme with Imperial and Shell Abu Dhabi to develop a state-of-the-art capability to analyse CO_2 capture from flue gas in the United Arab Emirates. The objective of the three-year project is to develop a system of analysis of CO_2 capture, transport and storage technologies and the ability to use them effectively within a carbon management framework. It will provide Shell and Masdar with the opportunity to model and plan for carbon management projects in the UAE. It will also provide the capability to assess new technologies, allowing better investment decisions.

Students from the UAE will be completing PhD projects as part of the initiative, helping to develop local skills and sustainable regional development. One student has entered the programme after successfully completing the Energy Futures Lab MSc in Sustainable Energy Futures to work on developing systems-based models for CO_2 and CO_2-enriched flue gas management infrastructures. Two further students are joining the programme this academic year. They will be developing accurate and robust molecular-based models for predicting fluid viscosity and geochemistry and performing measurements of relative permeability on carbonate core samples.

PhD student Bojan Tamburic and Dr Fessehaye Zemichael work on a prototype reactor for harnessing solar power to extract clean hydrogen energy from algae.

New and renewable routes to solar hydrogen

THIS £4.2M PROJECT SPONSORED BY EPSRC AIMS TO DEVELOP MATERIALS AND technologies to utilise solar radiation for directly converting water into hydrogen (and oxygen) gas for subsequent application in fuel cell systems. The multi-disciplinary project is a collaboration between the Departments of Biochemistry, Chemistry, Chemical Engineering and Earth Science and Engineering. In the last academic year, 27 researchers ranging from undergraduates to senior academic staff were directly associated with the work, which has centred on three main areas in the past year.

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. Researchers are also mining culture collections to identify other marine *Chlamydomonas* species that can produce hydrogen in sulphur-deprived conditions.

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 so far has focused on water photo-oxidation parameters such as electron diffusion length, charge separation efficiency and collection efficiency. It appears that water photooxidation requires the generation of long-lived holes with significantly longer lifetimes than previously reported (>100ms).

Researchers in Chemical Engineering are designing and developing devices for scaling-up systems to produce biological hydrogen and photo-electrochemical hydrogen. Advances include the design, build and commissioning of a novel dual compartment photo-bioreactor and a new model that accurately describes algal growth. A test-bed reactor for photo-electrochemical hydrogen production has also been devised; this enables larger scale investigation and optimisation of key anode materials such as doped iron oxide and tungsten oxide.

Artificial Leaf

Current methodologies to utilize solar energy to synthesise chemical fuels are inefficient, expensive, and are complicated by complex, multistage chemical pathways. To date, there has been little motivation to overcome these limitations because of the availability and low cost of fossil fuels. However, environmental, security and fossil fuel supply imperatives now provide clear and urgent motivations to bring together research scientists and engineers to develop low-cost, efficient strategies for renewable fuel synthesis.

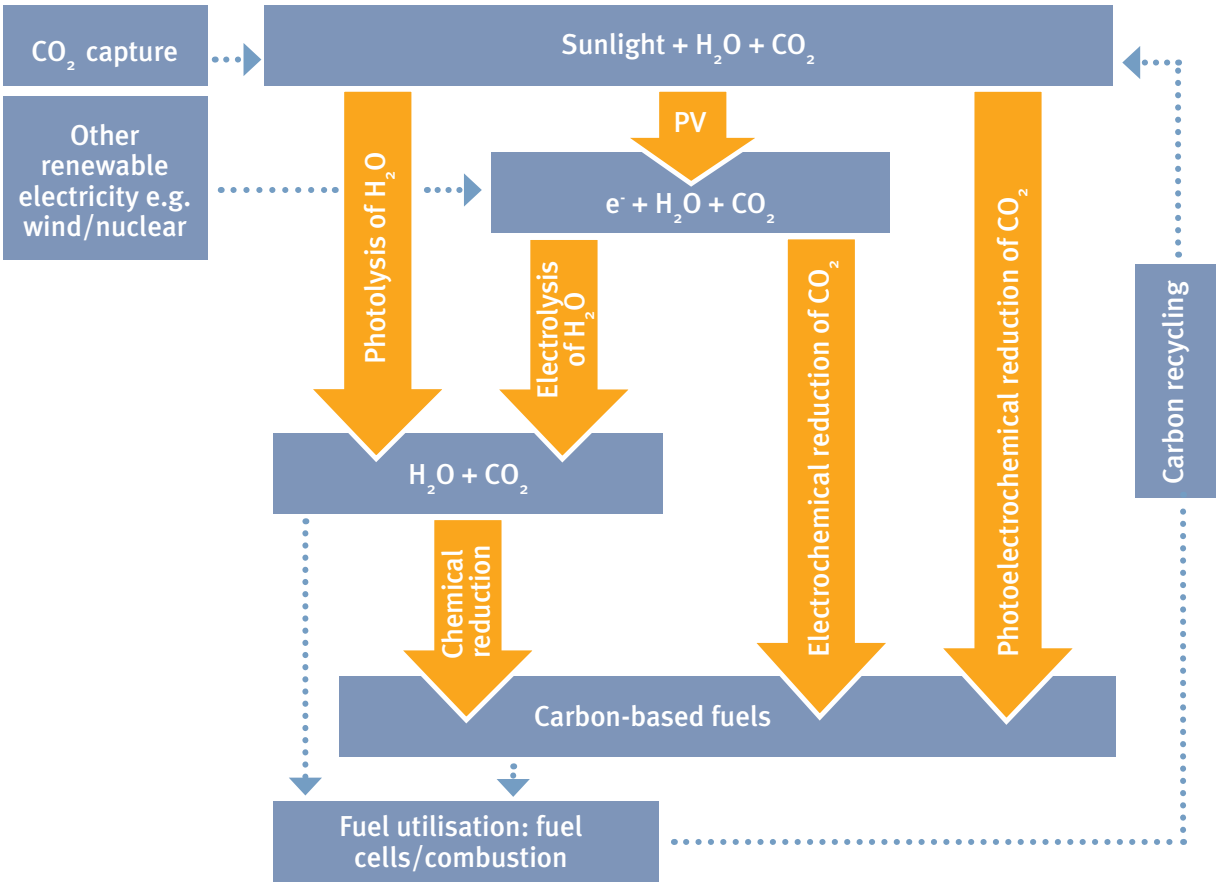
Plant photosynthesis demonstrates the viability of the direct conversion of sunlight to chemical fuels, storing the solar energy in the form of chemical bonds. While solar to biomass energy conversion efficiencies of natural photosynthesis are significant, they are relatively inefficient compared with other solar energy conversion technologies (e.g. photovoltaics). Additionally, the availability of suitable land that can be cultivated without competing with food production is limited on a global scale. These factors restrict the global potential of direct bioenergy conversion, which means that bioinspired artificial photosynthetic strategies are attracting extensive interest. The development of chemical reactors that can use sunlight to synthesise molecular fuels is a priority.

Imperial's Artificial Leaf project aims to develop catalytic systems that can efficiently harness renewable energy sources to reduce carbon dioxide into chemical fuels, to respond to the dual challenges of synthesising renewable transportation fuel and to provide scaleable energy storage to address the intermittent nature of most renewable energy sources.

The Artificial Leaf project builds upon our research into new and renewable routes to solar hydrogen, and will utilise Imperial's established expertise in photovoltaics, fuel cells and photosynthesis. It will focus upon what we believe to be the key challenge for renewable fuel synthesis: the reduction of CO_2 to energy-rich carbon based fuels. Further challenges include energy-efficient CO_2 capture from the atmosphere, low-cost solar to electric conversion, efficient fuel utilisation and CO_2 recycling.

Artificial Leaf harnesses expertise in:

Nanostructured materials
Catalysis
Biomimetic systems
Modelling
Photochemistry
Electrochemistry
Reactor engineering



L to R: Dr Celine Weber, PhD student Salvador Acha, Professor Nilay Shah and Dr Nouri Samsatli discuss ways of saving energy in cities.

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:

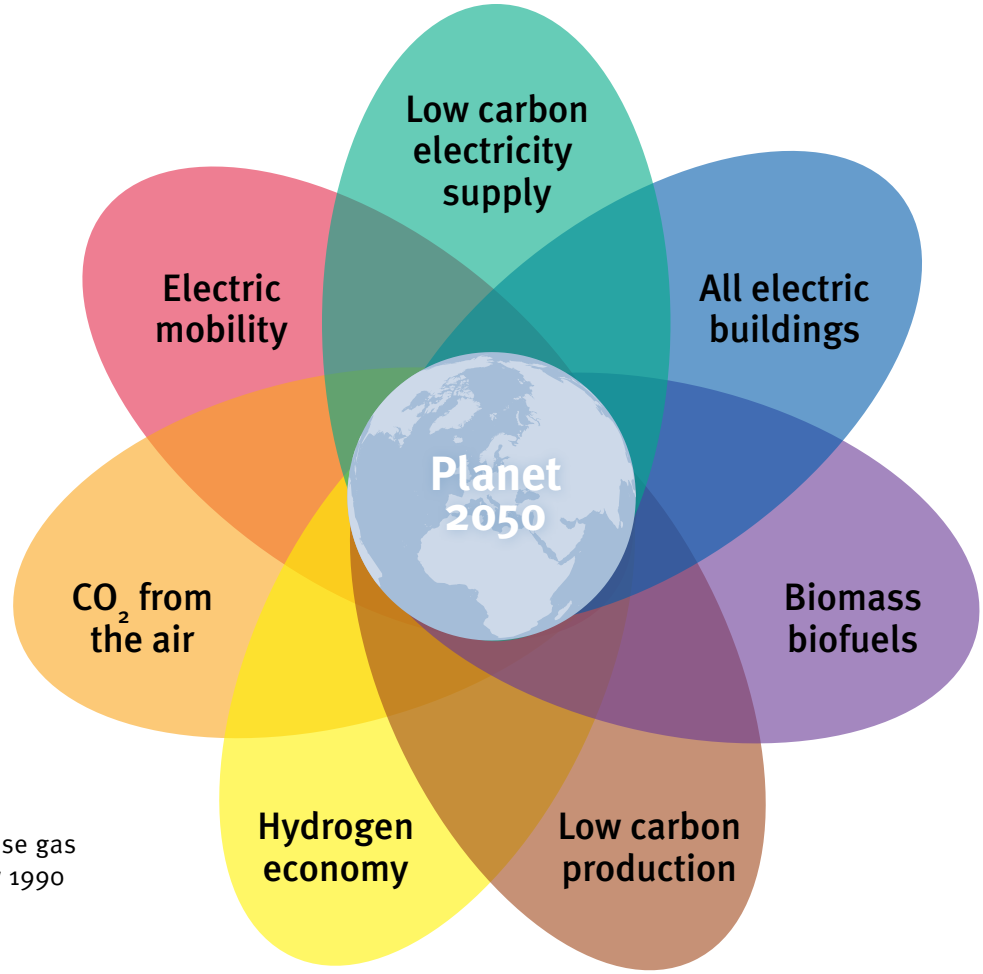
Layout model. This is an optimisation-based approach to organising the city layout. Inputting basic information about the city, its residents, boundary conditions and desired activities, it uses a combinatorial optimisation technique to develop alternative city layouts.

Agent-based land-use and transport model. This model combines the important features of agent-based modelling (the use of individual agents, e.g. people, with heterogeneous properties) with established four-step transport demand models. It takes the city layout and identifies where the agents are at any given time, what activities they are involved in, and the mode choices that they make when they move between places. This can then be used to infer time-dependent resource demands associated with the built environment (which can vary depending on building designs and standards) and the transport system.

Energy interconversion and infrastructure model. This optimises: the choice of resources to import into the city; the choice of resource interconversion technologies and their scale to incorporate in the city; the design of any networks for resource flow through the city; and the destination of wastes (including waste heat).

Service network design model. This is concerned with the design of robust urban power networks that embrace heterogeneity of generation and conversion and incorporate the state of the art in the particular network type (power, gas, heat, etc.).

Over the past year, SynCity has been applied to the case of a UK eco-town, to look at alternative energy provision strategies that utilise district heating and biomass technologies. Early results indicate the potential for large scale improvements in energy efficiency (25-50%) through better design and resource integration. Additionally, each component model has been analysed in detail to develop a more general understanding of the influences on urban energy systems (e.g. the effect of development density). Further studies in the coming year will extend this work to real-world developments in the UK, China, the USA and elsewhere.



PLANET 2050 WAS LAUNCHED in November 2008 to develop the radical approaches required to achieve the Government's new target for greenhouse gas emissions. This Grand Challenge research programme is run jointly with the Grantham Institute for Climate Change. It was set up in response to the Government's commitment to reduce greenhouse gas emissions by at least 80% below 1990 levels by 2050.

Electric Futures

The first phase of Planet 2050, Electric Futures, will explore a major option for meeting the 2050 target: decarbonising the electricity system and developing all-electric buildings and transport systems. Electric Futures will harness Imperial's multi-disciplinary strengths across engineering, science, economics and policy development.

The five-year programme will create a technology strategy for a low-carbon electricity society as well as methods for getting there. It will assess how this strategy could contribute to UK and international efforts to mitigate climate change by evaluating the technical and economic impact of alternative technology options.

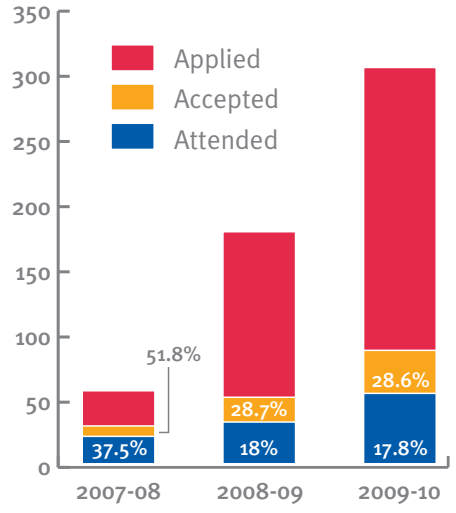
Electric Futures will:

- Identify and assess the technical and economic impacts of alternative technology options
- Evaluate the entire system from electricity generation through network technologies to all-electric buildings and transport systems as well as the individual components
- Develop the technology and policy strategies to reach a low-carbon system, including analysing the strategies in different economic and political contexts
- Inform the investment decision making process in order to support the formulation of commercial and policy frameworks.

Whilst funding discussions with industrial partners progress, the first generation of PhD students has started, funded by the Grantham Institute for Climate Change and the Energy Futures Lab. Projects include Cooperative pervasive networked systems for large-scale electric vehicle deployments, Low-grade heat in a fossil fuel free world, Impact evaluation and readiness of low carbon vehicles and Flexible CCS power plants.

MSc in Sustainable Energy Futures

THE MSc IN SUSTAINABLE ENERGY FUTURES IS A UNIQUE MULTIDISCIPLINARY MASTER'S programme, which brings together leading energy experts from across Imperial to provide a wide ranging education in energy engineering, science, policy and business. This will enable our graduates to evaluate the next generation of technology quantitatively, and to understand the place of this technology in the future energy landscape.

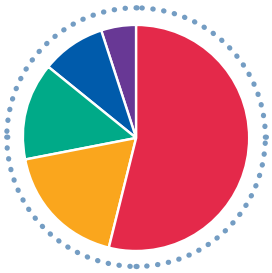


Student application data

The growth in the MSc in Sustainable Energy Futures enables the EFL to help meet the skills gap in energy engineering and science.

The MSc course is going from strength to strength. The second cohort of 33 students successfully completed the course and we welcomed 53 new students in October, selected from over 300 applicants. In addition to this rising demand for multidisciplinary energy education, the course and its students have also won a number of awards, including the Institution of Chemical Engineers Innovation and Excellence Award in Education, which recognises the team that best demonstrates innovation in training, development of staff or education of a wider community that changes public perception, develops young people, or addresses a chemical engineering skills gap. Our MSc students also won first prize in the Npower energy challenge, which is a national student competition for teams to present clean energy business ideas to Npower senior management. The EFL entry showed how Npower could enter into new energy efficiency agreements with their customers, whilst making a profit.

With the course moving into its third cohort of students, the role of course director has been taken over by Dr Andy Heyes, an award winning lecturer in the Department of Mechanical Engineering. Since taking on the role, Dr Heyes has developed an MSc debating society to explore more contentious energy issues. These include: the role of industrialised nations in leading the march on climate change; the construction of new nuclear power stations and their role in the UK energy landscape; and whether an individual can influence the use of one technology through their investment in it.



Leaver destinations 2008-09

- 54% Private industry
- 18% Job searching
- 14% Further education
- 9% Other employment
- 5% Public sector

EFL MSc students secure good jobs with a wide variety of employers.

Industry experience

- 34% 0 years
- 32% 0 to 1 years
- 23% 2 to 5 years
- 11% 6+ years

The MSc in Sustainable Energy Futures attracts recent graduates and experienced professionals wishing to change career or deepen their knowledge of energy technologies.

Student nationalities

- 49% Europe
- 22% UK
- 15% Americas
- 6% Asia
- 4% Middle East
- 2% Africa
- 2% Australasia

The MSc in Sustainable Energy Futures attracts the best and brightest from around the world.

PhD student Danlu Tong (L) is working on improving the efficiency of solvents for carbon capture.

Centre for Doctoral Training in Energy Futures

The Engineering and Physical Sciences Research Council has awarded the Energy Futures Lab funding for translational activities for PhD students as part of the Centre for Doctoral Training in Energy Futures.

The Centre will enable a cohort of 10 students a year for five years to take part in specialised transferable skills courses, attend an Energy Summer School, and organise and run a National Energy Conference for all the energy-related Centres for Doctoral Training in the UK. The funding also will provide a dedicated administrator to manage the student recruitment and co-ordinate the running of the Centre.

The cohort will be made up of incoming PhD students who are studying multidisciplinary energy research at Imperial.

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 College London, building academic links and developing some of the next generation of energy engineers and scientists.

This year marked the final call for proposals for the current phase of funding. In addition to PhD projects in Mechanical Engineering, Electrical Engineering, Earth Science and Engineering and Chemistry, the EFL has initiated a project on Conceiving a systemic energy approach to implement solar technology in small to medium size urban areas - The case of Israel. This is supervised by Dr Judith Cherni (Centre for Environmental Policy), Professor Berc Rustem (Dept. of Computing) and Professor Stratos Pistikopoulos (Dept. of Chemical Engineering).

Yaroslav Tencer is part-funded by the Alan Howard scholarships for his PhD in Mechanical Engineering.

In August 2009, Mr Howard pledged a further £750,000, bringing his total donation to £1.5M. To develop the scheme further, the Energy Futures Lab plans to incorporate scholarships for the MSc in Sustainable Energy Futures and a one-year placement programme for early career researchers into the projects supported by Mr Howard.

The opening of the Energy Future Lab as an Imperial institute, November 2009: Shell Chairman James Smith and student Alex Schay admire the electric 'supercar' (see inside front cover) being developed as part of the Racing Green Endurance project for Imperial students.

Industrial engagement

INDUSTRIAL PARTNERSHIPS TO ADDRESS the technological needs of society have always been central to Imperial's founding charter. Achieving a sustainable energy future lies at the core of global business in the 21st Century. The Energy Futures Lab works closely with a wide number of business partners to help fulfil this vision.

Industrial partnerships such has the BP Urban Energy Systems project and Shell Grand Challenge provide the essential long-term financial backing to support the research needed to develop the necessary step changes in energy technologies. Equally important is the role that business partners play in shaping our research agenda, supporting projects to address real-world issues, and sharing the ideas and information needed to bring concepts to fruition. These include both near-term technology improvements, such as enhanced oil recovery and exploitation of natural resources, through to long-term modelling for shaping cities of the future. Industrially funded facilities such as the Maurice Hancock Smart Energy Laboratory, supported by EDF and EON, also provide essential teaching and research tools.

Industrial partners of the Energy Futures Lab play a key part in delivering our education initiatives. The world is short of energy professionals ready to define and develop a sustainable energy future. Our industrial partners play an important role in providing our students with opportunities to apply their learning to real world problems through projects and internships.

Through these partnerships the Energy Futures Lab helps to shape industrial strategy providing academic insight into the most pressing technological challenges and opportunities. Its expertise is also available through Imperial Consultants to support operational imperatives, and through Imperial College's spin-out and licensing company, Imperial Innovations, to take emergent technologies to market.

Events 2009

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
Non-fossil based methods for hydrogen production: *Professor Marc Rosen, Engineering Institute of Canada*

MARCH
Clean power from deserts: *Dr Gerry Wolff, DESERTEC-UK*

Carbon capture and storage workshop for government and industry professionals: *Chaired by Dr Denis Peach, British Geological Survey*

Carbide-derived carbons for energy applications: *Professor Yury Gogotsi, Drexel University, USA*

MSc in Sustainable Energy Futures Industry Day

The zero race: Around the world in 80 days: *Louis Palmer, Solar Taxi*

APRIL
The energy aware home *Pilgrim Beart, Alert Me*

MAY
Carbon capture and storage: helping to deliver a 50% global emissions reduction by 2050: *Chaired by Dr Paul Fennell, Imperial College London*

Imperial College Centre for Carbon Capture and Storage: Launch: Keynote speech: *Neil Hurst, International Energy Agency*

Sustainability in the built environment: *Rob Buckley, Aecom*

Inspiring energy professionals of the future

Following the previous successes of the EFL's outreach work, recognised last year by the Rector's Award for Public Engagement, we have continued to communicate with future energy professionals through the Future Generations energy challenge. This is for Key Stage 3 pupils to explore the changing roles of different energy technologies and discuss how these can be deployed in the future to ensure we have affordable, secure and environmentally friendly energy to 'keep the lights on'. We are currently seeking funding to help us to develop this further and take it to a wider audience.

In addition to this, we welcome 15 and 16 year olds to work with the EFL as part of their work experience. This year they helped develop the Future Generations programme and also helped in data mining and writing for the website on our news and events pages.

For the first time, the Energy Futures Lab recruited undergraduate students for summer placements through the Undergraduate Research Opportunities Programme (UROP). These students helped to deliver aspects of our communications and outreach strategy by developing our website, providing referenced data to the Futures Generations game, and supporting the creation of the public display in our new headquarters.

Chemical engineering PhD student Francesco Coletti discussing future energy options with Year 9 students as part of the EFL outreach programme.

JUNE
UK-Japanese collaboration in next generation energy and environmental technologies: *Chaired by Professor Sandro Macchietto, Imperial College London*

Royal Institution family fun day: *Fuelling the future, Dr Peter Evans*

Science Technician CPD Conference 2009 Guest lecture: Future Generations: *Dr Peter Evans*

Sustainable Future: *Robert Sansom, EDF Energy*

JULY
Light energy for a brighter future: Joint Weizmann UK-Imperial symposium: *Chaired by David Cahen, Weizmann Institute of Science, Israel & Professor Jim Barber, Imperial College London*

Oil and gas and the future of the world energy mix: *Bernard Montaron, Schlumberger*

Developing a sustainable living lab in Abu Dhabi: *Khaled Awad, Masdar*

OCTOBER
Solar to fuels and back again Artificial leaf focused symposium: *co-ordinated by Professors Jim Barber and James Durrant*

NOVEMBER
Energy Futures Lab, an institute of Imperial College London *Opened by Professor John Beddington, Government Chief Scientific Advisor*

DECEMBER
Impact of intermittency: how viable wind generation will affect GB and Irish electricity markets: *James Cox, Poyry*

Energy Futures Lab Annual Lecture 2009: UK energy future—the road map to 2050. *Steve Holliday, National Grid*

Our web story about EFL's opening attracted over 1,000 unique visitors in just two days, as a result of featuring on the Imperial home page.

Research from the Energy Futures Lab often features in the news, including (L to R) The Guardian, Cronica and BBSRC Business.

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

www.imperial.ac.uk/energyfutureslab

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.