Imperial College London

Energy Futures Lab

Sustainable Power

Research Overview

Forging ahead

This Research Overview highlights the diverse range of approaches and technologies developed by scientists and engineers at Imperial that will be needed to generate power without releasing greenhouse gases that warm the Earth. Research includes devising ever safer ways to generate nuclear power and to dispose of nuclear waste, developing solar cells that can convert the most abundant source of power on the planet—sunlight—into electricity and tapping power from the waves and tides that churn the waters surrounding the British Isles, as well as the Artificial Leaf programme to mimic the way that green plants extract energy from sunshine.

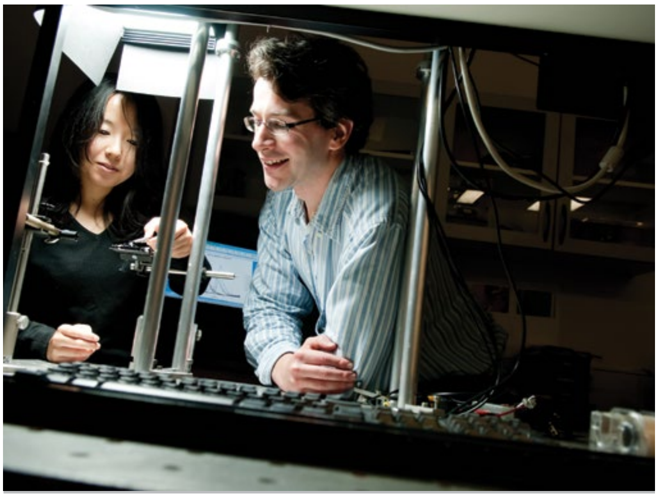
Generating a transformation

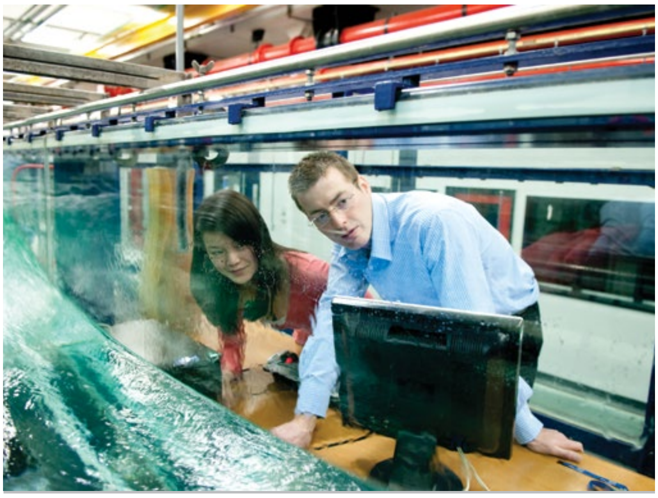
If the nation is to limit climate change, it must develop new ways to generate power without releasing greenhouse gases. Professor Tim Green, Director of the Energy Futures Lab, says, “The UK has set itself very ambitious targets to deliver an 80% cut in carbon emissions by 2050. It is quite clear that we are not going to do that without really transformational changes in how we use and how we deliver energy services. The work of the Energy Futures Lab is a really important part of that picture: without fundamental research and fundamental shifts in how we generate, distribute and use energy, we are not going to meet those targets.”

Power to the people

The UK government has pledged to obtain 15% of the country’s energy from renewable sources by 2020 as part of its efforts to cut greenhouse-gas emissions by 80% between 1990 and 2050, while ensuring that its energy supply is both secure and affordable.

Electricity is vital to everyday life: it is used to power railways, manufacture fashions, run computers, light homes and boil kettles. However electrical power generation accounts for 40% of carbon-dioxide emissions in the UK, which makes it the biggest single contributor to climate change. Almost half of the nation’s electricity is currently generated from gas with a further 28% coming from coal, the most polluting fuel in the country’s energy mix. Nuclear accounts for just 16% of the current supplies and solar, wind and wave power contribute a mere 7%. Some 20% of the current generating capacity in the UK is so old that it is due to close within a decade. Replacing it with greener technologies will be crucial if the UK is to keep its promises.





(Top) Professor James Durrant and Dr Brian O'Regan study dye-sensitized, nanocrystalline solar cells.

(Mid) PhD student Megumi Yoshida and Dr Ned Ekins-Daukes use a solar simulator to measure the electrical power delivered by a solar cell.

(Bottom) Dr Johannes Spinneken operates the multi-dimensional wave basin with a student in the Hydrodynamics Laboratory.

Running on

There are nine functioning nuclear power plants in the UK, most of which are between 30 and 40 years old. Because no new capacity to replace the power they generate has yet been built, it is likely that their operating lifetimes will be extended. To operate such plants safely beyond their expected lifetimes, scientists must understand the processes that cause pipelines to corrode and components to degrade so that they can better predict the point at which they might fail. Scientists at the Energy Futures Lab are working on computer models to identify potential failures and highlight instances where there is insufficient information about a component, so that experimental studies can be conducted.

Professor Robin Grimes, Professor of Materials Physics at the Centre for Nuclear Engineering, says, "Experiments are extremely challenging and expensive because of all the security, safety and safeguarding issues. If we can use computer models to discover the underlying principles, then we can make predictions about what will happen and identify potential cliff edges. The relationship between modelling and experiment is crucial: we can use models to identify the issues and to ensure we gain the right experimental data more quickly and effectively."

His colleagues are also concerned about the safe disposal of the wastes from nuclear power plants. If new power plants are commissioned, the UK will end up with about 500,000 cubic metres of high-level waste, which is about the volume of St Paul's Cathedral. Because it will remain radioactive for thousands of years, it must be stored safely. High-level liquid waste produced during the reprocessing of spent nuclear fuel is heated to produce a powder that is then mixed with crushed glass in a furnace to lock the radioactive elements into the glass structure, while intermediate-level waste is immobilised in cement. Researchers at Imperial study these structures to identify their durability. This work includes research into locking up waste by trapping radioactive substances within molecular structures and crystalline ceramics. In the long term radioactive nuclear waste will be placed in underground repositories located in the countries where it was created. To help identify suitable sites researchers are studying hydrology in underground environments, as well as waste-water interactions and the development of suitable barrier systems around the wastes.

The solar deluge

More energy from the sun falls on the Earth in one hour than is used by human civilisation in a year. Yet the combined output of existing solar energy systems supplies just 0.1% of the power that world currently uses.

Solar energy can be used to generate electricity using photovoltaic panels. These were first used in remote places such as telecommunication relay stations and satellites. Nowadays they are far more ubiquitous and are typically installed on roofs. Most panels are now connected to the electricity grid, which enables them to provide electricity locally when needed and remotely at other times. Indeed the International Energy Agency predicts that the solar energy could generate 11% of the worldwide electricity supply by 2050.

Researchers working at Imperial are developing lightweight plastic solar cells that can be printed directly onto flexible foils in a process similar to that used to make photographic film. Relatively cheap solar cells could thus be integrated into roof tiles and other construction materials. However only 20% of the solar energy that falls onto an existing photovoltaic panel is converted to electricity. Dr Ned Ekins-Daukes, a Senior Lecturer in Physics, is working on materials that could approach the thermodynamic limit of 87%. Achieving such conversion rates is challenging because sunlight is composed of light of many wavelengths but, by building solar cells from layers of different semiconductors, it is possible to absorb specific parts of the spectrum more efficiently. Devices that use such materials can currently reach conversion rates of up to 44% and are already being used in modern satellites. They could also be used in solar concentrator systems to generate power in sunny desert regions.

Making waves

During the windy winter months, the waters surrounding the British Isles become choppy. Generating power from the waves could help meet the increase in demand that comes during the cold weather.

Dr Johannes Spinneken, a Lecturer in Civil and Environmental Engineering, and Dr Matthew Piggott, a Reader in Ocean Modelling, use computer models to simulate the ocean environment. Because water waves are complex and disordered, devising numerical models to describe them is difficult. Moreover when a wave encounters an underwater structure, the fluid and the structure interact in various ways, which further complicates matters. The pair use their models to help identify the effects that placing, say, 100 marine-power generators on the sea bed would have on coastal erosion or deposition.

The researchers also create small-scale versions of ocean waves and currents using wave tanks. They use these to study the stresses and strains that waves and currents place on marine structures including the blades of tidal turbines. Results from experiments also feed back into the computer models, ensuring simulations are accurately based on real world data.

Artificial leaf

Sunshine is plentiful but, alas, it cannot yet be bottled and used as a liquid fuel. Because transport accounts for around a quarter of carbon-dioxide emissions in the UK and it also produces noxious gases and particulates that damage human health, running vehicles on liquid sunshine would cut this pollution. Green plants store solar energy when they use photosynthesis to convert it to chemical energy within their leaves. Professor James Durrant, Professor of Photochemistry, is working on artificial photosynthesis to create a series of mechanisms that enables the energy from sunlight to be stored in the chemical bonds of a liquid fuel.

When the sun shines on a green plant, it initiates a process that combines the sunlight with water and carbon dioxide to produce carbohydrates and oxygen, which the plant breathes out into the atmosphere. However, under certain conditions, green plants such as algae can be made to produce hydrogen as well as oxygen. Researchers at Imperial are using a biohydrogen reactor to force green algae to generate hydrogen which, once separated from the oxygen, can be stored for use as a fuel. Hydrogen-powered vehicles have fuel cells that combine the hydrogen with oxygen from the air to produce electricity and water vapour. If the hydrogen were produced using artificial photosynthesis, rather than from natural gas as it is at present, then the process would reduce carbon emissions.

Professor Durrant and Dr Klaus Hellgardt are also investigating a second technique to directly split water into molecular hydrogen and oxygen. They use photo-electrodes to convert sunlight into an electrical current that is used to divide molecules of water into its constituent parts, namely, hydrogen and oxygen. They can also use chemical catalysts along with sunlight to transform carbon dioxide into carbohydrates and oxygen. This approach mimics plant photosynthesis but could be made to be even more efficient than the systems that exist in nature.

Researchers at the Energy Futures Lab are exploring how these two techniques could be embedded within any new, integrated energy production system that incorporated fuel-cell and hydrogen-storage technology. Their colleagues in the Centre for Process Systems Engineering are meanwhile helping to identify and evaluate how a hydrogen refuelling infrastructure might fit into the wider energy system, while staff at the Imperial Centre for Energy Policy and Technology are examining the interaction between the technical characteristics of fuel cells and their economic and environmental costs.

Energy Futures Lab Research Overviews explore the key issues that must be addressed if we are to develop more secure and sustainable energy supplies, and explain how research at Imperial College London paves the way to meeting these challenges. Our staff and students conduct multidisciplinary energy research to cut carbon emissions. With strong links to industry, they develop an integrated view of energy supply, demand and distribution that takes into account technological, environmental, economic and security considerations.

Further articles in the Energy Futures Lab Research Overview series:

- Low Carbon Transport
- Clean Fossil Fuels
- Energy Infrastructure
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