Imperial College London

Enterprise

Innovations for sustainable energy

TRANSITION TO ZERO POLLUTION

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To decarbonise the world's energy systems, we need new technologies and effective strategies for rolling them out. Imperial is providing the energy sector with the technological innovation and systems thinking needed to reach net zero and create new business opportunities along the way.

Imperial last year launched Transition to Zero Pollution, a major College-wide initiative that brings together academics and businesses to help create a sustainable society. It adopts a whole-system approach to the transformation of energy and other industrial systems that considers not only carbon emissions but all forms of pollution.

"We need to be wary when, for example, somebody proposes making the most efficient, highest capacity battery that's ever been made, without a sense of where the raw materials for that will come from and whether it's recyclable and how that links into a broader infrastructure of power supply," explains Professor Mary Ryan, who is leading the initiative.

Imperial is well placed to help companies involved in energy achieve this holistic perspective and exploit the opportunities it opens up. From technological innovations to analysis of the energy economy, Imperial is providing the tools companies need to succeed in the energy transition. The book explores the innovations Imperial is developing alongside startups and partners such as ABB, EDF Energy, Shell and the National Grid to create a sustainable global energy system.

BY IAN MUNDELL

Energy systems

A whole-system approach is being applied to the energy sector by the IDLES programme (Integrated Development of Low-carbon Energy Systems), which is looking for ways to optimise energy in fields such as electricity, heating, cooling and transport, and devising systems that produce less pollution.

A key component to transforming an energy system is optimising interfaces between different technologies and systems. For example, when wind turbines generate more electricity than immediately required, this should be used to produce resources such as hydrogen or charge electric vehicles. When the wind drops, other energy sources must be ready to fill the gap in energy supply.

Drawing on Imperial's expertise in modelling complex systems, IDLES is working in partnership with companies such as EDF Energy, Hitachi, the National Grid and SMEs in the energy sector. The research will produce software tools that map possible futures for the UK's energy system, advice on how to make each option a reality, and insights into the technologies needed to support it.

Professor Mary Ryan leads Transition to Zero Pollution, a major Imperial programme to realise a zero pollution future.

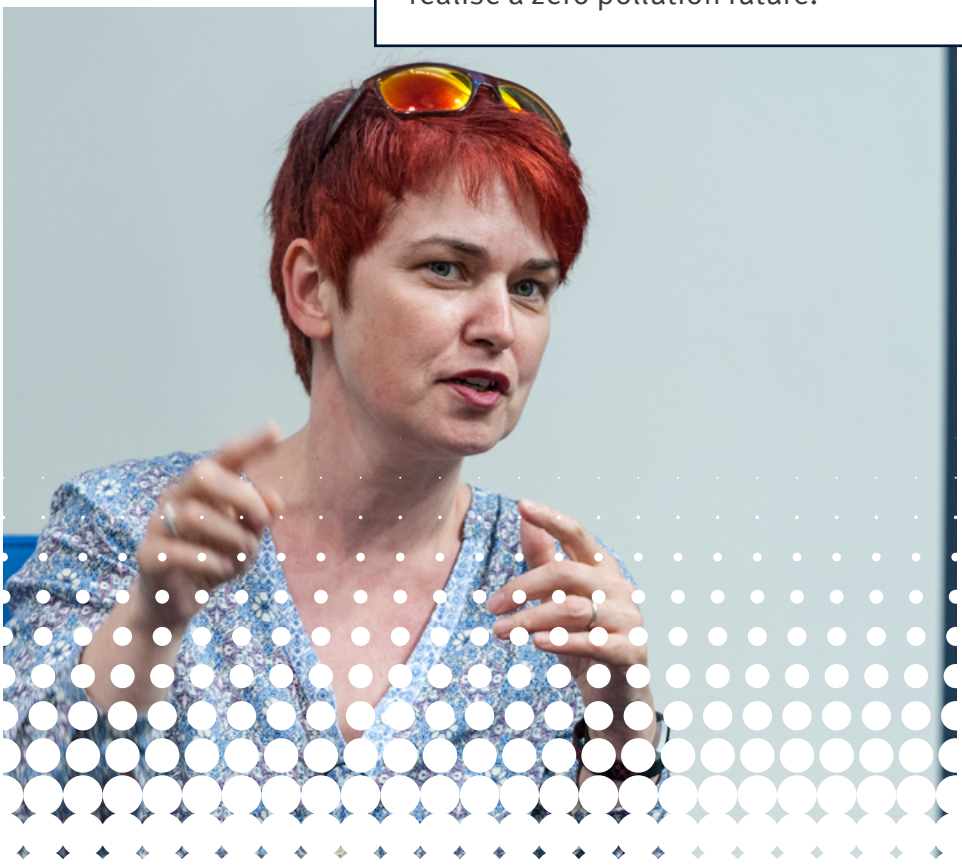

Photo: Dave Guttridge

"The UK has made good progress toward our climate targets but there is a long way to go, especially outside of the electricity sector, and fundamental change is needed for us to have a positive impact on the environment," says Professor Tim Green, IDLES principal investigator and co-director of the Energy Futures Lab. "This will be much simpler with a truly integrated system that works for the whole country and the economy. We believe that IDLES can deliver the data and tools needed to do this."

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Technology interfaces

A whole-system approach is also central to InFUSE, a new government-supported research programme that brings together Imperial, Shell and the Diamond Light Source. The programme examines how technologies such as batteries, electric vehicles, chemical production, and carbon capture and storage can be improved through attention to the interfaces in these systems.

The partnership explores technological interfaces across Shell's business units, for example in grid-scale battery systems, lubricants for use in electric vehicles, new catalysts for producing sustainable chemicals, and techniques for carbon storage. "These new insights will support development of many technologies needed for decarbonisation," said David Bunch, Chairman of Shell UK Ltd.

"Transitioning to renewable, sustainable energy needs us all to think a little differently," explains Professor Ryan, the academic lead on the project. "This partnership will build on our existing relationships to pursue exciting new directions where we aim to control interfaces in energy systems to optimise efficiency, function, and lifetime, ultimately reducing greenhouse gases and helping to fight climate change."

Green hydrogen

Hydrogen could offer a zero-emission way to power vehicles, buildings and industrial technologies that cannot easily be electrified. Imperial researchers are developing technologies to produce it efficiently using solar power.

Energy innovators are currently very interested in hydrogen, since it offers a potentially clean and flexible way to store and deliver energy.

The conventional way of producing hydrogen is from methane in chemical plants. This can be made more environmentally friendly by coupling the process with carbon capture and storage, turning what is termed grey hydrogen into blue hydrogen. But if you want green hydrogen, the gas must instead be produced with renewable electricity from either an independent source or the grid.

Professor James Durrant, pictured here in 2017 with then PhD student **Dr Shababa Selim,** leads a group developing materials that could be used to produce hydrogen using sunlight.

Photo: Thomas Angus

It is already possible to produce hydrogen using solar power by connecting a regular solar panel to an electrolyser, a cell that can split water into hydrogen and oxygen. But this is expensive, and there is great interest in making a more cost-effective single device that turns sunlight into hydrogen to use as a 'solar fuel' for electricity generation or for powering vehicles or planes.

Photochemistry expert Professor James Durrant is working on novel materials that could be used in such a system to capture sunlight energy. "My group builds systems to measure what happens when light shines on these materials and how we can couple the excitations generated by sunlight to catalysis," he explains.

While choosing the right materials and putting them together in innovative new ways is a great challenge, energy businesses are already taking an interest. "The catalysts in electrolysers are the same catalysts that can be applied to photoelectrodes, and some of the materials we use as light absorbers are also used in solar cells, so companies already making those materials are interested in exploring the opportunities for applying them to integrated systems."

A solar fuel reactor

Dr Anna Hankin and her group are working to create photoelectrochemical reactors that use innovative materials to produce hydrogen from sunlight.

Dr Hankin's ultimate goal is to produce a prototype that industry could try out, to see how well it integrates and delivers hydrogen on the spot. "That could be with any industry that is developing hydrogen-based technologies, including car manufacturers or companies working on hydrogen-powered flight," she says.

The task of designing a reactor begins with modelling to predict the thermodynamics, kinetics, heat transport, light transport, and mass transport of the proposed system. "We calculate where the main losses in the systems are expected to occur, and then optimise the design to decrease those losses as much as possible," she explains. "Then we build the reactor, we test it, and see how its performance compares with what we predicted."

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Dr Anna Hankin and her team are working to produce a prototype photoelectrochemical reactor that converts sunlight into hydrogen.

Photo: Jason Alden

Each reactor can only be exposed to a finite amount of sunlight, so systems are likely to be comprised of many small devices. Scaling up therefore raises a specific set of challenges. “You’re going to have lots of small photochemical reactors coupled together, and for each one you will have to flow reactant in, extract the reactant again, and then separate out the product. Doing that is quite complicated.”

Hydrogen power

Imperial is also working on fuel cells that use hydrogen and other fuels to produce electricity.

Imperial has produced a steady stream of startups that are developing fuel cells and related technologies, stretching back to Ceres Power, launched in 2001 and now the UK's most valuable cleantech company. Ceres makes a solid oxide fuel cell on a steel backbone that is highly efficient, robust and economic. Reducing cost is an important factor in making fuels cells accessible for applications including transport, data centres, and combined heat and power systems.

Then there is Bramble Energy, which is making fuel cells for vehicles. Sweetgen will use wastewater to generate electricity using a device similar to a fuel cell. And RFC Power is developing regenerative fuel cells for energy storage. "All of these companies are underpinned by a scientific breakthrough. Either in materials – whether that's a catalyst, or the ability to integrate different materials together into a device – or some novel chemistry," says Professor Nigel Brandon, a founder of both Ceres Power and RFC Power.

Dr Vladimir Yufit is an Imperial researcher and a founder and director of RFC Power, a startup developing low-cost flow batteries that can be used to store the electricity generated by renewables.

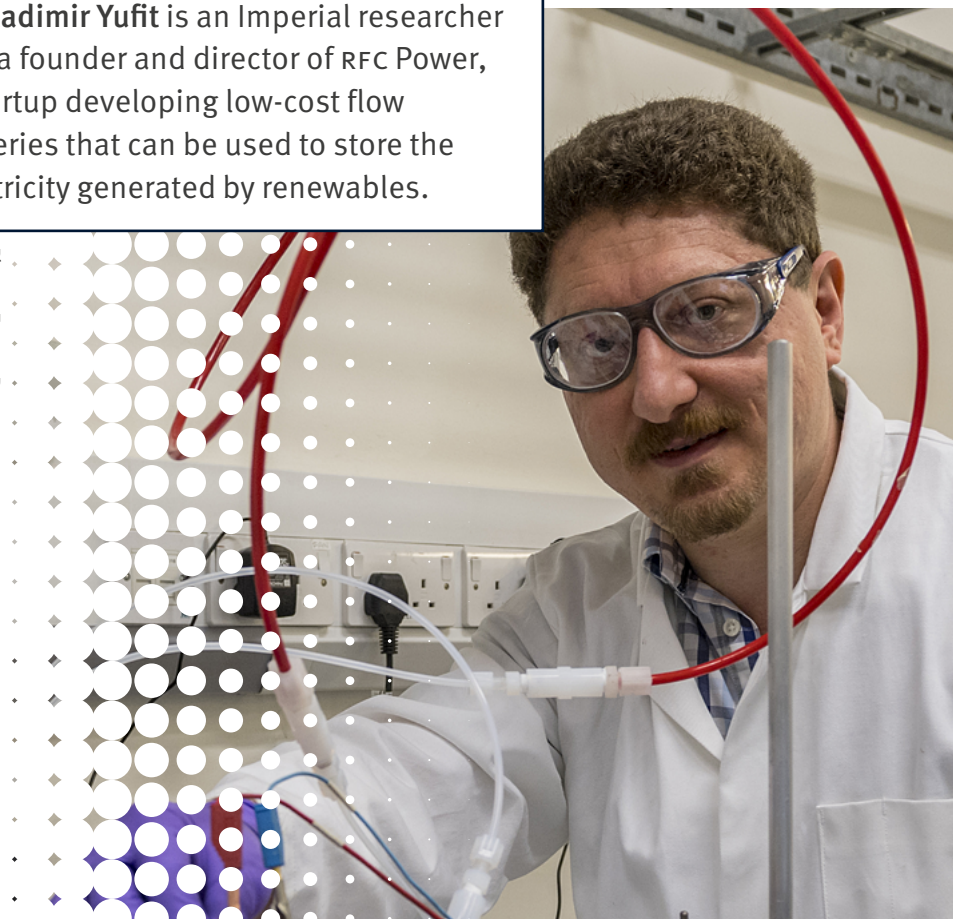

Photo: Fergus Burnett

Better batteries

Imperial's electrochemical expertise is also helping get more out of batteries, whether to power vehicles or to store energy produced by renewables and enable a stable supply of renewable electricity.

For Professor Gregory Offer, the key to improving batteries is not to tweak their design but to fundamentally rethink the way a battery is put together. Modelling heat transfer within existing battery systems has allowed his group to identify heat transfer bottlenecks that hold back overall performance.

> *"By redesigning cells to remove thermal bottlenecks and allow the heat to be properly moved out of the battery, the system as a whole can operate more efficiently. If widely adopted it should significantly accelerate vehicle electrification, as well as other sectors that use energy storage," says Professor Offer.*

The models could also help manufacturers design advanced batteries without the costs of creating numerous prototypes to test every new material, or cell type and configuration.

On top of work with industry partners, a team led by Dr Ian Campbell from Professor Offer's group created a startup, Breathe Battery Technologies. This is developing models that can run on existing battery management hardware in electric vehicles, for example. By adapting charging processes to the evolving health of each battery, the models promise to unlock significant hidden performance.

Meanwhile, Imperial startup RFC Power uses a different battery technology – flow batteries – together with elements of fuel cell technology to efficiently convert electrical energy to chemical energy and back again. These batteries use manganese, a cheap and widely available mineral, rather than the rarer and more expensive vanadium commonly used in flow batteries. RFC has just signed a deal that will see Ceres Power use its vast experience in fuel cells to help scale-up this technology, with an option for an even closer alliance in future.

Businesses of all kinds can tap into Imperial's electrochemical expertise through Galvanic Energy, a consultancy service that carries out industry analysis and technology assessments that help companies drive forward project development.

Renewables roll out

Imperial's researchers are also working on innovations that directly support the global roll out of renewable energy such as wind and tidal power.

One important area of research on renewables is Professor Matthew Piggott's work with digital twins. "Our aim is to build computer models that can be used to optimise the design and operation of wind and tidal turbine farms to maximise their energy yield or their profitability, and to mitigate any negative impacts they may cause."

One important issue that his models address is the way turbines change local wind and tidal flows once they are in place, a factor many planning tools overlook. "If this is not taken into account, offshore renewable energy farms may not deliver the power yield predicted at the design stage and improved farm designs, for example using non-standard staggering of turbines, may not even be considered."

The challenge is to accurately resolve a huge range of spatial scales, covering individual turbines, farms and entire regions, while also producing timely results. Professor Piggott achieves this with a combination of traditional physical process models and machine learning. "We are using a wide variety of data within our models, including from very high-resolution computational fluid dynamics simulations, weather stations, as well as from satellites and drones."

Imperial is helping several industrial partners in the wind and tidal sectors to address their needs with this work. "Collaboration with industry is vital to us since these companies are the target users of the tools we are developing, but they also provide access to the data that is vital for this work."

Beyond power generation, more mature renewable energies can raise other challenges that are being addressed by technologies nurtured at Imperial. Wind turbines, for example, require regular inspection and maintenance, a risky procedure when the turbines are off-shore. So the startup BladeBUG, which has been part of Imperial's prototyping community the Advanced Hackspace, is developing a robot capable of climbing a turbine and inspecting its long blades, reducing the risks for human technicians.

Carbon capture and storage

Carbon capture and storage technologies, which Imperial is helping to develop and model, could help meet global energy demand while achieving net zero targets.

While the world transitions away from fossil fuels, producers and consumers of legacy fuels such as coal and gas will have to improve their environmental performance. This where the Sustainable Gas Institute comes in, a group of researchers at Imperial who work on the role of natural gas, hydrogen and biogas/biomethane in low-carbon energy systems. The Institute has looked into future uses of natural gas that would be consistent with climate targets.

"With high-quality carbon capture and storage (CCS) and low methane emissions on the supply side, and sensible uses on the demand side, natural gas may have a future yet," says Professor Adam Hawkes, the Institute's director.

Imperial carries out a range of research into carbon capture and storage. Pictured here, Alok Sharma MP, now president of COP26, visits the ABB pilot carbon capture plant at the South Kensington campus.

Photo: Fergus Burnett

Researchers at Imperial have considerable experience in CCS, and the College even has its own carbon capture pilot plant on campus with partner ABB. Imperial also led the UK's participation in ELEGANCY, an international effort to make CCS more economic by linking it with the production of hydrogen. Its researchers contributed ground-breaking research in CO_2 storage, and the development of integrated hydrogen-CCS chains. One result was a detailed national case study, identifying cost-effective opportunities for the government and business to develop hydrogen-CCS systems.

"CCS is recognised as an essential component in reducing global emissions, yet immediate up-front costs have stalled implementation by industry," says Professor Martin Trusler, who led the project for Imperial. "By coupling hydrogen production from fossil fuels with carbon capture and storage, and tapping into existing infrastructure, we are aiming to off-set initial investment costs and kickstart CCS in Europe."

Economic insights

Imperial researchers are active in energy planning, helping policymakers and businesses make smart choices for sustainable energy.

A study carried out for power generator Drax revealed that in 2020, for the first time, the UK generated more power through renewables than through fossil fuels.

While due in part to reduced demand caused by the pandemic, it points the way to the future. "The next steps we must take towards a net zero power system will be more challenging – driving out the last sources of fossil carbon will require us to go beyond just having more wind and solar power. New business models, backed by policy and investment, will be needed to bring advanced-but-proven technologies into the mainstream," says Dr Iain Staffell, who authored the study.

Experts in the business school addressed perceptions in the financial sector that low-carbon technologies may be risky. By capturing environmental, social and governance factors, they were able to provide a more accurate view of the true risk-reward trade off.

In a report produced for the bank HSBC, the researchers set out technology readiness levels for CCS, heat pumps and solar photovoltaic systems, along with a risk assessment from a bank lending perspective.

Professor Goran Strbac and colleagues carried out a study for SSE Renewables to quantify the value of new long-duration pumped hydro storage in Scotland. The technology uses excess renewable energy to pump water into an elevated reservoir, and releases it through turbines to produce electricity when needed, perhaps days or weeks later. The study found that new pumped hydro storage could save £690m per year by 2050 by avoiding the capital expenditure on technologies such as nuclear that would otherwise be needed to meet the UK's net zero target whilst meeting security of supply.

Imperial is also helping companies through the energy transition with courses. Professor Adam Hawkes provides courses tailored to the needs of executives and senior managers, on methane science, methane reduction strategies and planning, measurement techniques, technology, policy, and where to get guidance and support. These courses are available through Imperial Consultants – and are used by organisations like Methane Guiding Principles, a stakeholder group that focuses on reducing methane emissions across the natural gas supply chain.

Energy use

To reach net zero, we also need to use energy more smartly and efficiently. Imperial is using its expertise to transform how we use energy in businesses, homes, and cities.

Imperial startup Cheesecake Energy set out to solve a problem experienced by some companies operating electric vehicles fleets: all the vehicles need to be charged at the same time, but regular connections to the electricity grid cannot cope. Its solution is the eTanker, a system that draws electricity from a conventional grid connection when charging demand is low, stores it as compressed air and heat, then releases it when needed to charge vehicles.

"We realised that current technologies were not feasible for key sectors like transport and commercial industries where longer discharge durations are needed and batteries become uneconomic," explains company CEO Mike Simpson. A first pilot system for vehicle charging is being developed with Nottinghamshire County Council. Meanwhile, the technology will also have applications in local renewable microgrids and heavy industry.

Another Imperial startup, Sitigrid, has developed a peer-to-peer trading platform to support local energy markets. Today's energy markets were created to ensure supply matches demand in a centralised system and are less well suited for distributed generation or for new technologies such as electric vehicles and heat pumps.

> ***Sitigrid's distributed ledger technology is designed to offer households with renewable power sources such as solar panels a new way to sell excess energy that creates efficiencies in the distribution system and brings economic benefits to both buyers and sellers in a local energy market.***

Also on the home front, design engineer Dr Kate Simpson is working with householders who are thinking about making their properties more energy efficient. She is particularly interested in the early stages, and how tapping into freely available information can dispel doubts and smooth the way to a decision. Her co-design research will pinpoint the information that people find most useful for particular house types, which could then be brought together on an open portal.

Dr Simpson is also working with business partners active in this sector. "One is a company that is setting up a retrofitting service, and is keen to tailor that to different household and persona groups," she says. She has also begun a project looking at technologies that householders can use to collect more data about their homes, for example measuring the heat transfer characteristics of walls. This is another area where business partners are interested in developing services. "Eventually I see these projects joining up in terms of what different actors in the supply chain need to be able to offer to answer householders' uncertainties."

Transition to sustainable energy

With the transition to a sustainable energy system now urgent, Imperial is helping businesses at every point in the system, from energy generation, through storage and distribution, to its use by industry and consumers. Technologies developed at Imperial are creating new products and services and helping to make business models fit for a sustainable energy future.

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About us

Imperial is a world top-ten university, and Reuters calls us the UK's most innovative. But we're not here to top league tables – we're here to change the world.

Our Transition to Zero Pollution initiative goes beyond zero carbon and considers pollution in all its forms. To reach zero pollution, we need a radical shift in industrial systems, technologies, and business models.

That's why we're bringing businesses, researchers, and students together to inspire and empower one another, and unleash some of the world's brightest minds on some of its biggest challenges.

Get in touch

To learn more about our work or to start a conversation about our solutions for businesses working toward zero pollution, visit: enterprise.imperial.ac.uk/transition-to-zero-pollution

You can follow Imperial's Enterprise team on Twitter at @ImperialIdeas and on LinkedIn at our showcase page, Enterprise at Imperial College London

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