Imperial College London

Enterprise

Partners in decarbonisation

Innovations for net zero

TRANSITION TO ZERO POLLUTION

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Most businesses are now convinced that they will have to reduce their carbon emissions and they are increasingly making net zero a concrete goal. Meeting this challenge will require a thorough examination of technologies and business models. Imperial College London aims to be an intelligent partner, providing technological innovation and business insights that support the decarbonisation process.

In 2020, Imperial launched Transition to Zero Pollution, a major programme that will help society face the fundamental changes that lie ahead. It brings together researchers from across Imperial to build new partnerships.

"We see CO2 as a pollutant, a major and urgent pollutant, but not the only thing we should be thinking of. It's really about an entire system," explains Professor Mary Ryan, who is leading the initiative. "Addressing the challenge of global pollution will require a radical shift in industrial systems, technologies, and business models, underpinned by the development of innovative policies and governance structures – all of which will require integrated research across many disciplines."

It also requires partnerships with businesses, so that innovations are fit for purpose and can be translated into practical gains on the road to net zero. The aim of this e-book is to look at the way Imperial is working with businesses such as BASF, Mitsubishi, Procter & Gamble, and Sainsbury's to reduce carbon emissions and other forms of pollution though collaboration, consultancy, and the creation of new companies.

BY IAN MUNDELL

Redesigning products for zero carbon

Clean by name, clean by nature

Imperial researchers are working with industry partners to take on the surprisingly complex challenges involved in reformulating cleaning products. In the case of household detergents, this means juggling 20 or more ingredients in each product. “Each has been added to play a particular role, but they interact at the molecular level in extremely complex ways to determine the qualities of the final product,” explains chemical engineering expert Professor João Cabral.

Reformulating products to use more sustainable ingredients while performing effectively at low temperatures or with minimal water is a major challenge. Conventional experimental approaches involve a degree of trial and error, but there are far too many possible combinations of ingredients to experiment with every possible formulation. Advanced modelling and experimental techniques present a massive opportunity to predict which formulations will deliver the best results.

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

Photo: Dave Guttridge

Professor Cabral is leading Imperial's team in a major government-supported research programme with Procter & Gamble. The aim is to develop tools that will predict the functional properties of chemical formulations without requiring trial and error, and so create a new generation of cleaning products that perform effectively with low energy and more sustainable ingredients.

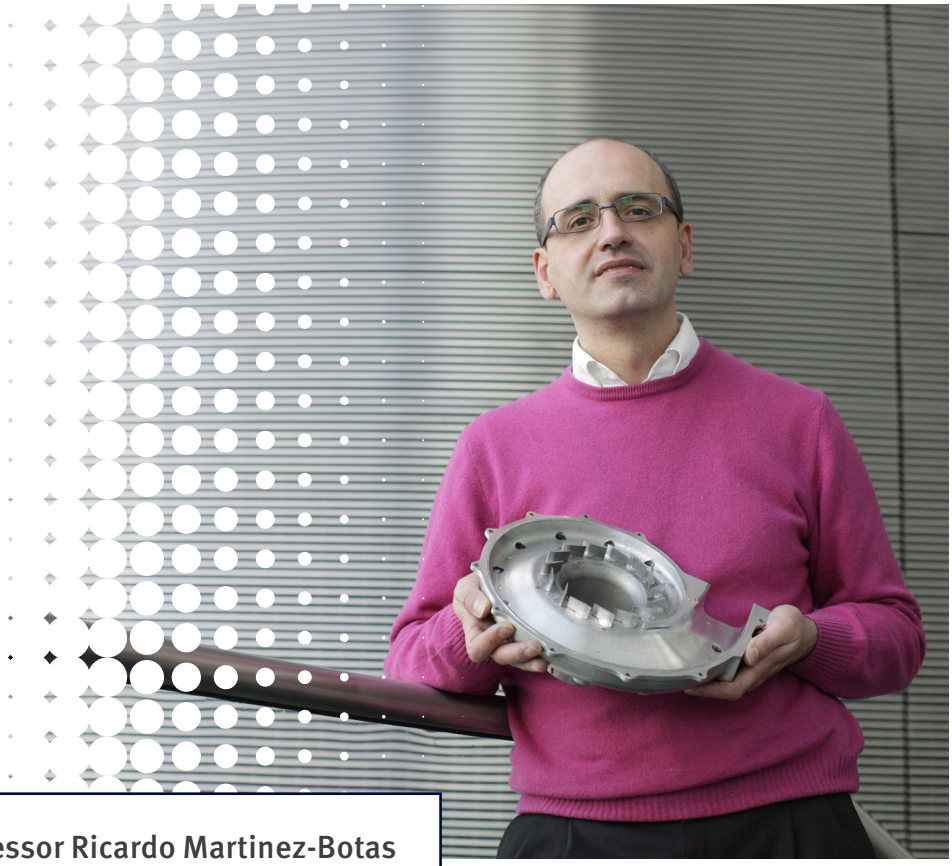
Reformulating cleaning products to use sustainable ingredients and performing at low temperatures is a major challenge. Conventional experimental approaches involve trial and error – but advanced modelling and experimental techniques present a massive opportunity to predict which formulations will deliver the best results.

There is a lot to play for. "We're aiming for game-changing ways of designing these materials, but even a [saving in materials of a] few percent, when you're talking about several megatons of materials, could be megaton of material that you're saving," says Professor Cabral. "P&G is supporting us to look at very fundamental problems that they know will have great value in the medium to longer term."

Greener every generation

Such business collaborations can have long-lasting effects over multiple product cycles. This is clear from Imperial's work on turbochargers with Mitsubishi Heavy Industries. The collaboration began in 2005, producing a modified turbine blade design that was filed for patent in 2013. Series production began in 2016 and the design is now enabling greater fuel economy in millions of vehicles.

The partnership went on to produce other innovative concepts for Mitsubishi, including a new turbine nozzle and compressor volute, and a testing procedure that could significantly improve understanding of engine performance. The latest development is the launch of an innovation centre that has been established to look at thermal management, electrification for hybrid vehicles, waste heat recovery systems, and future compressors for air management of advanced engines.



Professor Ricardo Martinez-Botas is working with the automotive industry to create components that use fuel more efficiently.

Photo: Layton Thompson

"The work with MHI has not just advanced our understanding of exhaust turbochargers for cleaner engines, but it also has enabled new concepts to be created based on this understanding," says mechanical engineering expert Professor Ricardo Martinez-Botas. "My team has worked closely with a leading global player on real and significant problems. All of this makes impact at a large scale."

Unlocking new ways of making

Imperial researchers are also revolutionising product design through tools that help companies get the most out of new manufacturing techniques, such as 3D printing. In the aeronautics and automotive industries, for example, parts are conventionally designed with human imagination and intuition. This is fine when engineers are working within the constraints of traditional manufacturing processes, but with 3D printing these constraints almost disappear, and human ingenuity struggles to take advantage of the limitless possibilities on offer. This is a problem when the optimal design for a component in a cooling system, an engine or a fuel cell is likely to be incredibly intricate.

TOffeeAM can optimise car and aeroplane engines by reducing the total number of parts and increasing resilience. The resulting systems are up to three times more efficient than traditional designs.

Tools developed at Imperial and commercialised through the startup company TOffeeAM bridge this gap. “Our software uses state-of-the-art maths models combined with artificial intelligence to design and improve components, such as those used in aircraft and car engines,” says Dr Marco Pietropaoli, TOffeeAM’s chief technology officer. “We can create more efficient, more resilient and more robust components. They might be lighter, or they might help reduce fuel consumption,” adds Dr Audrey Gaymann, TOffeeAM’s chief artificial intelligence officer.

In addition to optimising 3D printed parts, TOffeeAM can optimise whole systems by reducing the total number of parts and increasing resilience. The resulting systems are up to three times more efficient than traditional designs, with heat exchangers that can be ten times smaller. In the aerospace and automotive sectors, this efficiency translates into lower fuel consumption, lower emissions of CO2 and other pollutants, and higher performance. Optimisation can also cut down the waste materials and the energy used in the manufacturing process.

Decarbonising manufacturing

Rethinking chemical production

Opportunities to decarbonise business can also be found in the manufacturing process, for example in the pharmaceuticals and chemicals industries. In a government-supported partnership with Eli Lilly and Company, Imperial researchers are using digital decision-making and artificial intelligence to design new manufacturing processes for peptide drugs. With just a small number of targeted experiments, this approach is quicker and produces less waste than traditional techniques.

“This is a unique opportunity to make fundamental scientific advances that can have a direct impact on manufacturing at Lilly and across the pharmaceutical industry,” says Professor Claire Adjiman, who is leading Imperial’s involvement in the project.

Manufacturing chemicals at lower volumes using flow chemistry could make it possible distribute manufacturing globally. This would reduce the energy costs of transporting chemicals and the associated carbon emissions.

Meanwhile, supply chains can be radically reconstituted by a shift from traditional batch chemical manufacturing to flow chemistry, with chemicals produced continuously by pumping reagents through a reactor. Chemicals company BASF already uses continuous processes for large-scale manufacturing, producing kilotonnes of product, and it is working with Imperial on applying the approach to agrochemicals and other fields at smaller scales.

This suits production of high-value chemicals, where just a few kilograms are required, but it also opens up possibilities for more distributed manufacturing across smaller plants. This would save energy costs when transporting chemicals and the associated carbon emissions. Klaus Hellgardt, Professor of Chemical Engineering, says: “We are excited to be working with BASF not only to advance the science and engineering, but also to train a new generation of chemists who are familiar and cognate in flow chemistry.”

Growing greener for the textile industry

When manufacturing starts with an agricultural feedstock, decarbonisation opportunities are matched with broader gains in sustainability. Several Imperial startups have made advances in this area, for example SaltyCo and Materra, both targeting the textiles industry.

SaltyCo is a material science company that creates ‘planet-positive’ textiles using resilient crops, agricultural methods designed to heal damaged ecosystems, and novel processing technology. Its first product, BioPuff®, is a plant-based alternative to goose-down or synthetic fillers. In addition to reducing the use of animal products and plastic, the product is biodegradable and sequesters atmospheric carbon.

Materra, meanwhile, is working on a more sustainable way of growing cotton, a crop notorious for its high water consumption. Water and nutrients are delivered directly to the roots of the cotton plants, where absorption can occur most efficiently. Combined with novel methods of recapturing nutrients and water, the system can reduce the volume of water and fertiliser used by up to 80%. The system also produces 30% less CO2 than conventional cotton farming.

Capturing carbon from big emitters

To get big gains in decarbonisation you need to tackle the big emitters, such as cement production, iron ore smelting and steel manufacturing. Since it is hard to reduce emissions in these cases, the focus is on capturing and using or storing the carbon they produce.

One of the main challenges is that carbon capture demands substantial amounts of energy, and so more efficient technologies are a priority. This is something Professor Paul Fennell set out to do for cement manufacturing, with a technique called calcium looping. Calcium oxide in limestone, one of the raw materials in cement production, reversibly reacts with CO2, extracting it from the flue gas, then releasing it to produce a pure stream of CO2, which can then be captured. This can take place without significant energy use, and the calcium oxide simply regenerates.

"My group does a lot of work validating the kinetics of reactions going on in CO2 capture systems," Professor Fennell says. "But we also look at how things fit into the global decarbonisation agenda. For example, we might look at how far we can push to decarbonise cement, and how that might affect how deeply we need to decarbonise air travel. It's a holistic perspective that industry alone may not be able to take, but, as an academic institution, we can provide."

As well as storage, work is under way on reusing captured carbon. An EU-funded project in which Imperial was a partner, identified new catalysts that make it possible to turn carbon monoxide and CO2 from steel production into polyols, which are used to make polyurethane-based insulation materials and wood coatings. This not only deals with the carbon emissions, but replaces the crude oil otherwise used to make polyols.

Business models for the future

Sustainability that builds profits

Beyond the nuts and bolts of products and manufacturing, some companies will need to re-examine their strategies and business models. This is where the new Leonardo Centre on Business for Society, created by Imperial College Business School, can help.

One of its first tasks will be to build a dataset on corporate sustainability behaviour and apply machine learning to identify what works – and what does not work – in companies' commitments to environmental and social impact. This will allow researchers to study what bundles of sustainability

initiatives can generate the best financial performance, together with the best environmental and social outputs.

Meanwhile, Imperial and the Royal Institution have created a centre for climate change innovation to support new and existing businesses in London, and engage policymakers, the public, financiers and investors. The centre will provide support for London's 300,000 climate change innovators and catalyse green business opportunities. Activities will include a business accelerator for cleantech startups, co-funded by HSBC UK, and pilot project to develop a renewable electricity grid enabled by artificial intelligence.

Companies in London with green business models or active in the clean technology sector can also get help from Imperial Consultants and the Grantham Institute – Climate Change and the Environment through the Mayor of London's Better Futures programme. Experts from Imperial help define the scientific or technical support that companies need to take their ideas to the next level, and provide advice and practical solutions to make it happen. That might mean defining new processes and technology development plans, or advice on equipment optimisation and regulations.

Photo: Thomas Angus

Dr Marco Aurisicchio (right) and PhD student Anouk Zeeuw van der Laan are working with industry to develop new concepts for the circular economy.

Don't think product, think service

Experts at Imperial can be instrumental in helping companies radically rethink their business models to shift towards a circular economy. "In this work we take a resource-centric approach in which we put the flow of resources first," says Anouk Zeeuw van der Laan, a PhD student working with Dr Marco Aurisicchio in Imperial's Dyson School of Design Engineering.

Working at the intersection of systems thinking, resource efficiency, behavioural science and business, the School's researchers investigate how material resources flow in production and consumption systems, consumers can be encouraged to perform circular behaviours, and these behaviours can be used to support new business models. This might mean looking at how a business can shift its focus from selling products to selling services or how consumers can be encouraged to close the loop, for example through take-back schemes.

Taken to their logical conclusion, product-service systems could inspire material-service systems, where material suppliers no longer sell semi-finished goods, like stainless steel sheets or plastic granules, but lease them to product manufacturers.

A longstanding partnership between Imperial and Sainsbury's is helping the supermarket chain apply engineering solutions to help it achieve its net zero target.

This has been tested on Imperial's own campuses with a project that offers mobility as a service. Staff could draw on a pool of low-emission cars and folding bikes to complement other modes of urban transport. This has helped acquire data on the uptake of shared mobility schemes and prepare business models for a future when mobility as a service continues to evolve and scale.

"The future of urban transport towards net zero carbon is a critical step in achieving climate goals and delivering a sustainable society," says Professor Ryan. "The holistic approach taken in this project is central to our Transition to Zero Pollution strategy, addressing not just the technology enablers, but community uptake, individual behaviour and economic factors."

Meanwhile, Dr Aurisicchio and colleagues are also working on helping companies at the top of supply chains to rethink ownership of materials resources. Taken to its logical conclusion, this thinking could lead to material-service rather than product-service systems, where material suppliers no longer sell semi-finished goods, like stainless steel sheets or plastic granules, but lease them to product manufacturers with the intention of recovering and reusing them in the future. "By retaining ownership and ultimate control of semi-finished goods, material suppliers will be incentivised to improve the utility of materials and value retention," Dr Aurisicchio says.

Energy-efficient operations

Partnering with Sainsbury's

To achieve net zero targets, it will be vital for major companies to address their energy use, increasing both energy efficiency and the use of renewables. This is at the heart of Imperial's longstanding partnership with supermarket chain Sainsbury's, which has committed to reaching net zero in its own operations by 2035.

Under the partnership, energy and engineering experts from Imperial are working closely with the company on multi-disciplinary research that will help it reduce its carbon emissions from its buildings and transport operations. One project, for example, is developing heat recovery strategies to end the company's use of natural gas in shops. Meanwhile emissions from heavy goods vehicles are addressed with advice on alternative fuels such as hydrogen and biomethane.

"The partnership offers us a fantastic opportunity to understand how our research can be applied in real-world settings and to shape our work so that it helps Sainsbury's transform its business and makes a tangible contribution to the energy transition the world urgently requires," says Professor Nilay Shah.

For example, Imperial researchers and Sainsbury's worked together to examine refrigeration system performance during the unusually hot summer of 2018, learning lessons for the sustainability of refrigeration systems up to 2050 and beyond, when such hot summers are likely to become the norm.

Low-carbon logistics

Storing energy for the fleet

Innovators at Imperial are also developing technologies that could help companies in the logistics business to a low-carbon future. Many will have considered switching to electric vehicles, for example, but this hides some hidden challenges that require new solutions.

One issue is that most conventional connections to the electricity grid are not robust enough to support the demands of charging a fleet of electric vehicles. So, Imperial startup Cheesecake Energy has developed 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 Mike Simpson, CEO of the company. 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.

Recharging when there is no time to stop

Delivery drivers who want to switch electric scooters face a different problem: batteries are small, and stopping to recharge is bad for a business when they need to be on the move. So, researchers at Imperial devised a wireless charging system that can latch onto the small target represented by a scooter and top it up on the go.

"We could place wireless changing pads at strategic locations, such as outside busy takeaways. If drivers had to plug in every time they stop, it wouldn't be worth it. But if they just get a few minutes charge whenever they stop, without doing anything, that would be enough to keep them going, explains Professor Paul Mitcheson.

The technology is being commercialised by the Imperial startup Bumblebee Power. So far it has developed prototypes and worked with companies such as Deliveroo and Elmovo to test its technology. It is also collaborating with Pashley Cycles to roll out wireless charging bays for e-bike hire schemes, and thinking about adapting the technology for drone charging.

Greening heavy goods vehicles

While alternative fuels are already available to partially decarbonise heavy goods vehicles, such as those used by Sainsbury's, the goal of fully electric heavy vehicles still requires work. The most significant barrier is that batteries are not yet available with sufficient energy density to get heavy vehicles moving. But hybrid heavy vehicles, combining electrification with low-carbon fuels, may offer a way of getting close to zero emissions.

"Putting electric propulsion in these vehicles is not too challenging, but we need more compact and power dense fuel cells, and routes to producing those net zero fuels at scale, in order to enable a low-carbon pathway," says Professor Martinez-Botas.

His team has worked extensively with manufacturers of long-haul trucks on thermofluids – the study of how air, fuel and heat are transferred around systems. So far this has focused on optimising combustion engines, but these same approaches can help plan future hybrid vehicles and investigate fuel cells that could power hybrid electric ships and trucks.

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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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