Imperial College London

Enterprise

Solutions for air, water and land pollution

TRANSITION TO ZERO POLLUTION

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Reducing carbon emissions to net zero is now at the top of the environmental agenda, but other pollution challenges — in the air, on land, and in water — have not gone away.

Imperial College London's Transition to Zero Pollution initiative is adopting a holistic approach that addresses all forms of pollution. It has been established to build partnerships that bridge academia, government and industry, helping decision-makers face the urgent sustainability changes that lie ahead.

"We see CO_2 as a pollutant, a major and urgent pollutant, but not the only thing we should be thinking of," explains Professor Mary Ryan, who leads Transition to Zero Pollution. "It's really about an entire system. 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."

Imperial is well placed to help decision-makers in the public and private sectors achieve this holistic perspective through research, innovation, independent advice and tailor-made consultancy services. This book explores work Imperial is doing with partners such as HS2, the Greater London Authority, Procter & Gamble, PepsiCo, and Thames Water to help tackle pollution challenges and move society towards a cleaner future.

BY IAN MUNDELL

Connecting air pollution and public health

One reason we care about pollution is that it can harm human health. The INHALE project is working to characterise the impacts and health effects of air pollution and understand which individuals are most at risk.

INHALE is modelling the effects of air pollution at multiple scales, running from neighbourhoods, through individual exposures, right down to the effect pollutants have inside the body.

To link the neighbourhood and personal scales, the project is following volunteers wearing monitors that measure their breathing rate and exposure

to air pollution as they move around London. "If one of them is exposed to a lot of pollution at a road intersection, for example, we might see a substantial physical response five or ten minutes later," says Professor Christopher Pain, who is co-leading the project with Professor Fan Chung.

The next link, from physical responses such as a change in respiration rate to health effects inside the body, is to examine how the lungs and cells from each volunteer's airways reacted to the pollution. "That means how the whole lung performs and cells from the nose, while in a smaller proportion of people cells from the lungs will also be measured," adds Professor Chung.

Once that final link between pollution and health impact has been established, some interesting questions can be addressed with the models. "For instance, you can use them to choose the optimal placement for sensors in the urban environment to get the best possible prediction for the impact of pollution on health," says Professor Pain.

The project also aims to use artificial intelligence (AI) to make lighter versions of the research models so that they can be used by local authorities. "These will be very important for the management of our city environments in the future."

The INHALE project aims to use AI to make lighter versions of the research models that can be used by local authorities to manage city environments.

"Finally, we would use this model to predict which individuals are more likely to be affected by their exposure to pollution in the long term," Professor Chung adds. "This will have important implications in making sure that every individual has the right to breathe clean air."

Cleaning up construction

The connection between pollution and health is fundamental to the Environmental Research Group (ERG), a centre of expertise in Imperial's School of Public Health.

The ERG includes a mixture of academics and experts who work on commercial research projects, although both aim to generate new knowledge.

Our commercial work is about finding where there are knowledge gaps in the industry, where they need academic assistance, how we can do that work and deliver the results to them to bring the maximum benefits.

Daniel Marsh, programme manager for the ERG's Centre for Low Emission Construction.

One example is High Speed 2 (HS2), the project to build a high-speed railway line from London to the West Midlands, which has a commitment to include innovation and learning from its work. When it comes to reducing air pollution, the Centre acts first as a thinktank. "We discuss how ideas that we or HS2 have put forward can be shaped into 'real world' projects, and the benefits these will deliver to HS2 and to the wider construction industry," Mr Marsh says. The Centre then manages the projects that get the green light. "We bring the partners together, both users and solution suppliers, and we also carry out the necessary emission measurements to provide independent evidence to both support new policy development and promote the uptake of cleaner machinery and better working practices on-site."

Initial projects tested diesel emission reduction technologies, but with stringent government net-zero targets attention is now shifting to alternative fuels such as hydrogen for construction vehicles and on-site power generators. This will require a deeper change in practice, from liquid fuels to gases. "We are producing evidence to demonstrate the air quality benefits, how the hydrogen is stored and how you refuel, so there is a template that can be adopted across the wider industry."

Another way that the Centre works is to increase understanding of fugitive dust generated by construction activity, through operating specialist measurement networks. In London, it is working with major construction projects, comparing the local emission results with ambient air quality measurements to improve the process of dust control, as well as supporting the local authorities to more effectively manage their regulatory requirements.

Pollution monitoring for the people

Another part of the ERG, the Measurement Group, specialises in ambient air monitoring, providing local government and the public with insight into the quality of air in their communities, along with the sources of pollution and its impact on respiratory health.

The Measurement Group runs both the London Air Quality Network, which collects detailed pollution data from fixed points around the capital, and the Breathe London network, funded by the Mayor of London, Bloomberg Philanthropies, and the local boroughs.

"Recently there has been a rise in smaller, cheaper air quality monitors that have made it possible for people to monitor air quality by themselves," explains Andrew Grieve, a senior air quality analyst with the ERG. "The Breathe London project aims to bring these monitors to community groups, but also to give them to give them the confidence that scientists at Imperial are looking at the data, assuring its quality, and making sure it is as good as it possibly can be."

Meanwhile, the health connection has been addressed with studies of individual exposure to air pollution and its physiological consequences. One line of research involved giving pollution monitors to people with respiratory disease. "This provides a direct link between their individual health and their environment, and with this we can create actionable recommendations for their own disease management," says Dr Benjamin Barratt, an expert on environmental exposure and public health, and deputy director of the ERG.

At a city level, the ERG's air pollution models have helped shape London's air quality strategy and informed initiatives such as the congestion charge and Ultra Low Emissions Zone.

The Group has also provided independent analysis to assess the impact of these policies on health. "Having a healthy city to live in is essential to London's future," says Dr Gary Fuller, Senior Lecturer in Air Quality Measurement. "Action needs to be underpinned by sound science; to design polices, track outcomes and provide clear information to the public."

There is considerable potential to extend this work. "Going forward, monitoring and analysis – based on that employed in London – could be rolled out globally," says Dr Iq Mead, the ERG's Head of Air Quality Measurement. "This would help local governments plan policies and monitor impact, as well as help communities, schools, hospitals and businesses monitor air quality to protect individuals, staff, students, patients and customers."

Photo: GoRolloe

Consultants from Imperial have helped the creators of **GoRolloe**, a bicycle wheel that purifies the air, assess the environmental impact of their device.

Technologies for cleaner air

Imperial is also fostering a range of technologies that will help make urban air cleaner, such as devices for cars and bicycles that can capture particles and keep them out of the air.

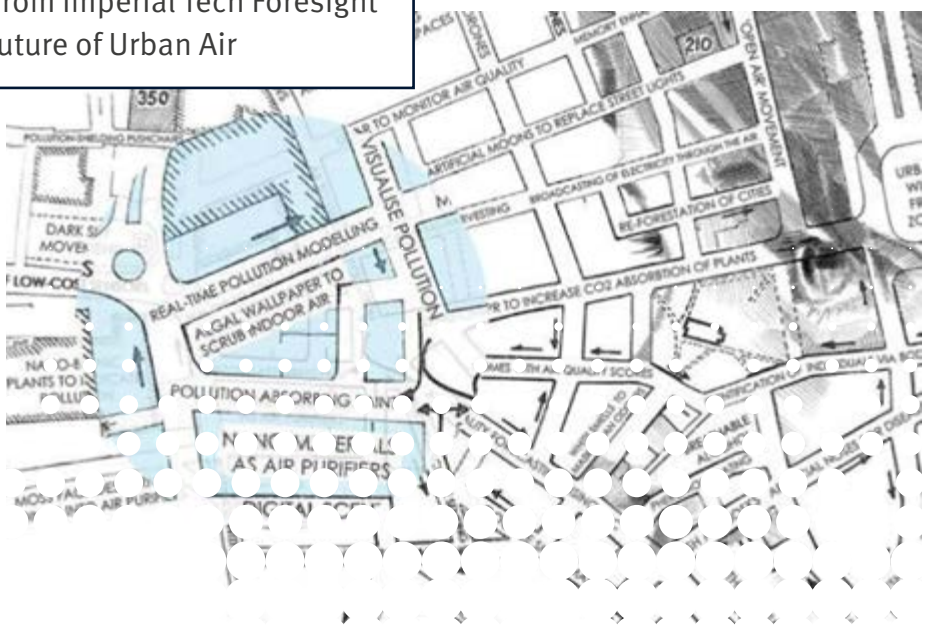
Tech startup The Tyre Collective was set up by four Imperial students to develop a solution to the tiny fragments of tyre thrown into the air every time a vehicle brakes, accelerates or turns a corner. These particles account for up to 50% of air particulate emissions from road transport and will not be diminished by cleaner engines or a shift to electric cars. The students came up with a device that uses electrostatics and the air flowing around the moving wheel to collect particles as they are produced. This material can then be reused in new tyres, or other products such as ink. The Tyre Collective is currently developing its device further within The Greenhouse, a cleantech accelerator in which Imperial is a significant partner.

Tyres account for up to 50% of air particulate emissions from road transport and will not be diminished by electric cars. The Tyre Collective designed a device to collect particles as they are produced.

Thanks to the Mayor of London's Better Futures Programme, Imperial's expertise has also helped GoRolloe, a startup developing a device for bicycle wheels that filters particle matter and other pollutants from the air as the rider crosses the city. Working through Imperial Consultants, sustainability expert Dr Izhar Shah looked at impacts across the life cycle of the product, allowing the company to identify potential environmental hotspots, and consider improvements at the design phase. "Tipping points could also be identified to enable commercial application and future investments in the air filtering capabilities of GoRolloe," says Dr Shah.

Technologies such as these, which could change the character of urban air in the years to come, feature in a map put together by Imperial Tech Foresight, a consultancy service that helps organisations look up to 20 years into the future. The aim was to help individuals and organisations understand the possible future of urban air related technologies, policies and behaviours. "It is agnostic about what that future should look like, but aims to show trends and innovations in that space, to help identify opportunities to improve air quality while also considering how some directions may lead to further co-benefits or trade-offs," explains Dr Audrey de Nazelle, who was involved in the project.

Detail from Imperial Tech Foresight – the Future of Urban Air



Illustrators: Ed Fairburn and Viola Timoncini

Moving mobility to a better place

Dr Audrey de Nazelle specialises in interconnections between technologies, policies and behaviours, particularly in cities, where changes in mobility can result in better air quality and improved public health.

"A lot of my research involves trying to understand what aspects of the built environment will encourage people to walk and cycle, and then how those periods of walking and cycling will impact people's health, negatively through exposure to air pollution, and positively through physical activity," says Dr de Nazelle.

This involves a diverse range of approaches, from surveys that reveal people's behaviour and models that assess its impact on their health, to epidemiological studies and analysis of the health effects of exposure to air pollution. She also studies the policies that shape the urban environment, and the behaviour of decision-makers.

> *By linking different types of impact – on physical activity, on air pollution, on traffic injuries, on CO_2 emissions, on green space – you can create alliances across sectors and help people to work together towards a common goal.*

"All of these different elements are needed to provide a full picture, giving an impetus for policymakers to take action," she says. "And by linking different types of impact – on physical activity, on air pollution, on traffic injuries, on CO_2 emissions, on green space – you can create alliances across sectors and help people to work together towards a common goal." This is essential if meaningful changes are to be made. "Making the case for choosing one kind of policy over the other, by showing all those connections, is the way to promote much more ambitious transitions in urban areas."

Connecting infrastructure planning with water quality and flow

A systems approach is required when considering water pollution, yet the interaction of different water systems is often overlooked in modelling work and infrastructure planning. Dr Ana Mijic is working to develop an integrated model.

Environmental scientists tend to model natural systems such as water catchments, with a focus on water quality, while engineers typically focus on water infrastructure – pipes, drains and reservoirs – and focus on flow. But the two are intimately connected, and decisions involving one will affect the other.

In order to understand the implications for pollution, we need to understand water flow and quality. Any future decisions around water management shouldn't be made without considering both.

This is why Dr Ana Mijic and her colleagues set out to develop an integrated model. "Our Water Systems Integration Modelling Framework can simulate the interaction between the natural system, the infrastructure, and the decisions we take that will change these systems," she explains. "In order to understand the implications for pollution, we need to understand water flow and quality. Any future decisions around water management shouldn't be made without considering both, which is not the case at the moment."

The model also allows the consequences of decisions made by different stakeholders in the water system to be evaluated. That might be a rise in water demand from the public, changes in infrastructure from the water companies, building and development decisions from local planning authorities, or changes in regulation. "We currently have a research project to see how this integrated information can be used by a range of different stakeholders, to support collaborative decision-making."

Versions of the model have already been built for London and Norwich, with a model for Manchester well underway. "Ideally we would like to cover the whole of England, if not the UK, in order to see the differences between systems, the things that can be shared between water companies, and also how environmental regulation can be better aligned at the regional and national scales."

Meanwhile, Inflowmatix, a company founded to commercialise Imperial research, is helping engineers understand what is going on inside urban water systems. Its high-speed pressure monitoring devices, which can

operate for long periods inside water pipes, provide data with a very high spatial and temporal resolution. This data is fed into models and optimisation algorithms that help improve operational decision-making.

For example, efficiency can be increased by reducing water pressure when demand is low and raising it when demand is high, but frequently changing the pressure can also lead to pipes bursting. Inflowmatix's technology allows engineers to optimally balance these two competing requirements. In 2021, the company was acquired by Suez, a worldwide provider of services to the water industry and an early partner in the underlying research.

Greener ways to use chemicals

Imperial researchers and innovators are helping tackle water pollution by developing new techniques for reformulating chemical products and technologies to help use products more efficiently.

Water pollution can be reduced by avoiding excessive use of chemicals such as nitrogen-based fertilisers, but knowing how much nitrogen is already in the soil usually involves sending samples away to a lab. Imperial researchers came up with a simple sensor that can detect how much ammonium is present on the spot.

This is just one form of nitrogen found in the soil, but when levels are combined with other data – on the weather, time since application of fertiliser, pH, and soil conductivity – an AI system can produce a fuller picture.

"Our technology empowers growers to know how much ammonia and nitrate are currently in soil, and to predict how much there will be in the future based on weather conditions. This could let them fine-tune fertiliser use to the specific needs of the soil and crops," explains Dr Max Grell, one of the researchers behind the system. The sensor and associated AI should be available for commercialisation in the next three to five years.

Reformulating chemical products that find their way into waste systems is another way of reducing water pollution, and Imperial researchers are working with industry partners to take on this surprisingly complex challenge. In the case of household detergents, it 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.

Conventional approaches to identifying new ingredients involve a degree of trial and error, but there are far too many combinations to try every possible formulation. Advanced modelling and experimental techniques present a massive opportunity to predict which formulations will deliver the best results. Professor Cabral is leading Imperial's team in a major government-supported research programme with Procter & Gamble that aims to develop tools to predict the functional properties of chemical formulations without requiring trial and error and so create a new generation of cleaning products with more sustainable ingredients.

Plastics that don't harm the planet

Reformulating plastics so that they are biodegradable is among the highest priorities for reducing pollution on land and in the sea. Yet the smartest solutions have multiple benefits, for example because they feed on other waste streams.

The approach developed by Imperial startup Lixea uses low-cost ionic liquids to treat agricultural residues or wood industry by-products, breaking them down into cellulose and lignin. The cellulose can be used to produce biofuels or bioplastics, while the lignin is a feedstock for other biomaterials and chemicals. The process can also be applied to waste wood, with the

advantage that contaminants such as heavy metals can be removed and recovered, preventing them from becoming pollutants. The company is currently building a pilot plant with this technology at Bäckhammar in Sweden.

Meanwhile, student startup The Shellworks has developed a process that converts the biopolymer chitin from seafood waste into a biodegradable and recyclable plastic. The company's initial focus is on cosmetics packaging, and it has carried out pilot studies for a perfume company and a skincare company, working with them to make sustainable bottle caps, trays and outer packaging.

Smarter sorting and recycling

Even when plastics are biodegradable or recyclable, they still need to end up in the right place to fulfil their environmental destiny. This makes waste sorting and processing a crucial step.

Student startup Recycleye has applied machine learning to the problem, replicating the human ability to rapidly sort and classify objects.

"We don't need to read a barcode to know the brand of an item, nor do we need laser spectroscopy or x-ray vision to know the material it is made from," explains co-founder Peter Hedley. Using images from a low-cost camera trained on mixed waste as it passes through a sorting station, the AI can identify recyclable objects, what they are made of, and even the brand. This means that waste can be characterised and valued for future processing or sorted on the spot by robots under the AI's control.

For multi-layer packaging, the challenge is not sorting, but dealing with the different, often incompatible component materials from which they are made. Professor Maria Charalambides is working with colleagues across Imperial, and companies such as PepsiCo and Nestlé, to find solutions to this problem.

One approach is to blend the layers together to make a new material that can be used in new applications. Computational models developed at Imperial make it possible to quantify how the materials will interact, and the effect of functional additives. "For the first time, we've been able to predict what the mechanical performance of this new blend will be."

The ultimate goal, however, is to improve the manufacturing of multi-layer packaging so that it is easier to recycle. "For example, we have tested a water-soluble inter-layer adhesive that can easily be removed in the washing

stage of mechanical recycling." Another option is to find mechanical ways to separate the layers, which is possible if you apply non-uniform adhesion patterns. "If you shred the packaging to a size that is smaller than this adhesive pattern, you release the layers."

Any changes to the manufacturing process will come with a cost, so the engineers are also working with Imperial's Centre for Environmental Policy to explore incentives that might smooth their eventual adoption. "We cannot just work on our own as engineers and scientists. We need to have a systems approach."

Professor Maria Charalambides and research associate Dr Manu Mulakkal are developing ways to make multi-layer packaging easier to recycle.

Photo: James Tye

Systems thinking for the circular economy

While systems thinking is essential in moving to a circular economy with minimal waste and pollution, it requires people from different industrial and scientific backgrounds to collaborate effectively. A tool developed at Imperial is helping close the gap.

"People from a wide range of backgrounds need to speak the same language, and collaboratively explore how something new can be made to work," says Dr Marco Aurisicchio, who, together with Dr Anouk Zeeuw van der Laan, has been developing a tool to close this gap. The Flow Mapper is a highly visual aid to enable collaboration on system and product design. "It creates a holistic view of the system that flows a product through the economy, and how its socio-technical elements across different stakeholders and subsystems in the life cycle interrelate to make that system work."

Photo: Thomas Angus

Dr Marco Aurisicchio and **Dr Anouk Zeeuw van der Laan** have developed the Flow Mapper tool to help consumer companies transition to the circular economy.

The Flow Mapper was developed in a research project carried out with consumer goods giant Procter & Gamble, and it has been used on a number of case studies for the company, such as developing a new generation of Swiffer household care products. “These are products that currently end their life in landfill, so there is an interest in thinking about how we can move these towards the circular economy.”

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One shift in thinking that the Flow Mapper aims to encourage is that resources retain their value as they flow around the life cycle, rather than losing value when a particular product is discarded. “We know that several organisations are keen to take in waste and turn it into a resource. However, unless organisations upstream and downstream of the moment when a product becomes obsolete start to work together and make resources flow effectively, they won’t get maximum value.”

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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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