Nature's own chemistry could help reduce waste and improve health

EU-funded researchers are studying chemical processes in nature to develop new, cleaner means of chemical production and computers that can communicate with the human body.

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When Dr Andrés de la Escosura, an organic chemistry researcher at the Institute for Advanced Research in Chemical Sciences (IAdChem) in Madrid, Spain, set out to fundamentally change the way that we produce the chemicals used in everyday life, his rationale was simple. Chemistry in nature is clean and efficient, whilst industrial chemistry is anything but.

'Chemical reactions in nature are incredibly efficient, generating very little waste and consuming very little energy,' said de la Escosura.

He wondered whether, by mimicking biology more closely in industrial reactions, we could create a cleaner, more environment-friendly chemical industry.

Thanks to funding from the EU, de la Escosura was able to join forces with researchers from countries such as Austria, the Netherlands and Switzerland to put these ideas to the test in a research initiative called CLASSY that ended earlier this year.

Natural advantage

Living organisms function using biochemical reactions. Everything, from respiration and photosynthesis through to the digestion of food and the contraction of muscles, involves the movement, breakdown, recombination and synthesis of chemicals. These processes are all very clean and energy efficient.

On the other hand, today's industrial chemical industry that is used to power sectors such as health, energy, transport and housing creates vast amounts of waste. The production of pharmaceuticals, for instance, typically generates 25 to 100 kilograms of waste for every kilogram of final product.

The chemical industry is also very energy intensive. The EU's statistical office reported that the chemical and petrochemical sector is responsible for one-fifth of Europe's industrial energy consumption. This makes it a major polluter and contributor to climate change.

The CLASSY researchers turned to living systems for inspiration. Nature efficiently synthesises an enormous variety of complex chemical products by separating, or compartmentalising, different chemical processes and using natural feedback mechanisms to regulate them.

Continuous flow

The research team explored ways to replicate these processes in what they call "microfluidic reactors" set up to mimic the activity of living cells.

Microfluidics is the manipulation of fluids through tiny channels. Fluids, and the molecules within them, are sorted and guided through a series of chips or microreactors. Different molecules can be sent to different reaction chambers, and their progress through the device is closely controlled in a step-by-step progressive process.

The processing of synthetic chemicals requires several different steps. When you carry out these processes in a closed system, like a flask or industrial reaction chamber, at some point you need to stop, empty the reactor and then start the reaction again, explained de la Escosura.

Microfluidics enables chemical reactions to occur in a more natural fashion. The reactors contain a mix of enzymes and other molecules that produce a chemical reaction. When one chemical reaction finishes, the compounds flow through the system to the next chamber and the next reaction. The benefit of this is that the overall process can run continuously.

The CLASSY researchers have made good progress with these reactors, successfully creating a microfluidic device that breaks down vegetable fats to produce a biofuel to prove their concept.

De la Escosura acknowledges that the efficiency of the process could be further improved, but the hope is that, in the future, such devices could complete different tasks depending on what is fed into the system. More basic research is needed, he said, but the hope is that this approach could dramatically reduce waste and energy consumption, while improving chemical yields.

'The goal is to minimise the impact that the chemical industry has on climate change and other environmental issues,' he said.

This is particularly important as global chemical production is expected to double by 2030, according to the EU, which published its own chemicals strategy in 2020 aimed at reducing the environmental and health impact of the chemicals sector as part of the EU's zero pollution goals and the European Green Deal.

Body chemistry

On a similar path of investigation, researchers from Spain, Denmark, the Netherlands and Switzerland are exploring how complex chemical reaction networks (CRNs) created using microfluidic chips could be used for energy-efficient computing.

This is part of a 4-year research initiative called CORENET, also coordinated by de la Escosura, that received funding from the EU to design "chemical computers" that can solve real-world computing tasks and may ultimately be able to interact with the human body, although that is still some way off and beyond the current scope of CORENET.

This isn't as outlandish as it might sound. 'The most efficient computer in the world is chemical – the human brain,' said de la Escosura. In fact, all our organs, which monitor conditions in our body and produce corresponding outputs, are basically information processors.

Dr Wilhelm Huck, a professor of physical organic chemistry at the Institute for Molecules and Materials of Radboud University in the Netherlands, has recently published a crucial paper that corroborates the potential of chemical computers.

In it, Huck, who is part of the CORENET research team, demonstrated information processing in a network of reactions that resembles those from the cell metabolism.

‘Biological systems do all they do – the functions, the information processing, everything – with molecules,’ said de la Escosura.

A potential advantage of chemical computers is that they could produce information in the form of chemicals that can interact directly with living systems – and respond to input received from them. This could be used to produce wearable medical devices that are able to mimic natural biochemical signalling.

Seamless communication

Most wearable medical devices are still fairly simple. Insulin pumps, for instance, deliver a regular dose of insulin at steady intervals throughout the day to help control blood sugar levels in people with diabetes.

Some more advanced devices being developed can respond directly to blood sugar levels to deliver insulin when needed, and may even be able to offer some dose control.

A wearable chemical computer able to measure the chemical compounds in the blood and, through a series of reactions, produce different chemicals in response would be a real game changer.

‘This type of computing with chemical systems may help us to better model the complexity that we find in biological organisms,’ said de la Escosura.

Although such devices are still a long way off, CORENET researchers believe that they could one day offer personalised treatment for various conditions through the synthesis of drug molecules triggered by cues from the body. They could even be used to create advanced brain–machine interfaces – a vision that goes beyond CORENET.

For Katja-Sophia Csizi, a postdoctoral researcher at IBM Research in Zurich, Switzerland, the work being done in CORENET is extremely innovative because it thinks of chemistry from a completely different perspective. Csizi’s work in the team focuses on how to use CRNs in chemical computing applications.

‘It is easier and far more effective to reach an ambitious goal if you approach it from different perspectives,’ she said.

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**The article has been updated with additional information and clarification from the researchers.*

More info

- CLASSY
- CORENET
- EU research and innovation on chemicals and advanced materials