Revolutionising fertiliser production: the CONFETI project

Agriculture is crucial to many economies, supporting global food production largely through the use of synthetic fertilisers, urea being one of the most popular, with global annual demand reaching 180–200 million tons. However, conventional urea fertiliser production is environmentally unsustainable, consuming large amounts of fossil fuels and contributing significantly to carbon dioxide (CO_2) emissions. Its use also generates high nitrogen levels in natural waters, adversely affecting aquatic ecosystems. These environmental impacts require urgent solutions.

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In a world striving for sustainability, the EU-funded CONFETI project emerges as a beacon of hope, aiming to revolutionise fertiliser production with an innovative, eco-friendly approach. CONFETI is developing a self-sustaining system for urea production and in situ fertilisation that extracts chemical reagents and energy directly from the natural environment, becoming one of the most environmentally sustainable systems available to produce synthetic nitrogenous fertilisers.

The project aims to transform urea fertiliser production and use with a groundbreaking photo-electrochemical process. The scientists behind CONFETI seek to convert CO_2 and nitrogen (N_2) into urea, reducing both the need for fossil fuels and the environmental impact. In addition, the project pursues the recovery of nitrogenous by-products generated from fertilisation (e.g. nitrates), which are potentially polluting, and transform them back into other fertilisers (e.g. ammonia or urea). This ambitious endeavour aligns with the current European directives of the EU Green Deal and the Zero Pollution Action Plan adopted by the European Commission in May 2021, which recommend the transition towards a more sustainable and cost-effective agricultural model.

Making urea sustainable

Current urea fertilisers have significant drawbacks: they are difficult to store, expensive to use and often lose their effectiveness because their fertilising mechanism requires them to be converted to ammonia, which can eventually volatilise. In addition, it is difficult to apply to crops: urea must be applied about seven days before sowing to be effective because it takes time to convert to ammonia. It is difficult to know exactly how much urea to apply: ammonia volatilisation can reduce its effectiveness, while over-application can damage and even kill crops. On the other hand, production costs have recently increased due to rising raw material and energy prices.

To address these issues, CONFETI will develop a system powered by renewable energy sources. The final proof-of-concept system will combine three pocket-scale reactors:

i. an electrochemical reactor for capturing, storing and converting CO_2 and N_2 into urea
ii. a soil microbial fuel cell (SMFC) that generates energy from soil microorganisms
iii. a photochemical reactor for reducing nitrate (NO_3^-) to ammonia/urea using photocatalytic technology with sunlight.

The system in detail

CONFETI technology will make precision agriculture more sustainable and autonomous by reducing the carbon footprint and using net zero energy vectors and chemicals. "Because of the ambitious design behind CONFETI technology, new materials and processes will need to be developed that go beyond the state-of-the-art, ranging from direct-air CO_2 and N_2 capture systems to optimised catalysts for electro-induced urea production and photo-induced nitrate reduction," explains CONFETI's coordinator, professor Gonzalo Guirado, from Universitat Autònoma de Barcelona (UAB).

"The best way to produce and deliver fertilisers should be on site (without the need to store or transport them) through self-sustaining smart systems, with minimal residue production, and powered through renewable energy sources," explains Guirado. To get there, he says, we need to consider three key aspects: the chemical reactor—photo- or electrochemical—to produce the fertiliser on site; the energy source, to power the system without interruption; and the electronic circuits to control and synchronise operations while managing energy flows.

Let's look at the complete process (Figure 1):

Capturing CO_2 and N_2 from the air and converting it into urea

The core concept of CONFETI is to combine direct air capture of CO_2 and N_2 (or of NO_3^- from soil) with simultaneous electroreduction to produce urea. "One way to make fertilisers in a sustainable way is to use air as a raw material instead of syngas. This could help us to use less natural raw materials and avoid too much nitrogen in soil and water. Another sustainable source of nitrogen is nitrates, which are found in soil and water. The main goal of CONFETI is to use these renewable materials to make urea directly," describe Guirado and Jordi Hernando, members of the UAB GEFRO Group.

This innovative strategy relies on two key points. The first is the development of **novel materials for CO_2 and N_2 sorption from air** to ensure high local concentrations of these gas reagents (or NO_3^-) near the electrocatalyst while maintaining good conductivity and favouring reaction selectivity toward urea production. These are demanding features, as materials for nitrogen and CO_2 capture have traditionally been developed separately. In addition, they are normally designed to sorb CO_2 from high-concentration sources such as flue gases, while direct capture from air remains a challenge. In response, CONFETI is exploring the potential of new formulations of environmentally friendly electrolytes based on water, ionic liquids, deep eutectic solvents or biopolymers, which should ensure both the combined and efficient sorption of CO_2 and nitrogen from various sources as well as having suitable ionic conductivity. "Different approaches will be tested to integrate these capture materials into the electrochemical reactor, ranging from the incorporation into the channels of porous carbon electrodes to the preparation of 2D self-standing membranes or printable inks," comments Christophe Coudret of the Centre National de la Recherche Scientifique (CNRS), who is leading the development of CO_2 and nitrogen capture and activation materials.

Another crucial component is the **electrocatalyst of the reactor**, which should warrant efficient and selective urea electrosynthesis from CO_2 and N_2 (or NO_3^-).

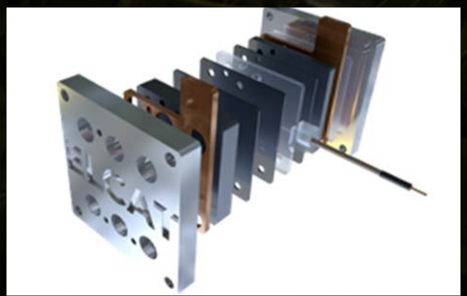
Tom Breugelmans and Nick Daems from ELCAT (University of Antwerp), in charge of the development of electrode materials and the electrochemical CO_2/N_2 valorisation point out that, although a few materials exist that can synthesise urea from CO_2 and N_2 (or NO_3^-), new materials with better electrocatalytic activity, selectivity, faradaic efficiency and compatibility with the electrolyte and electrode materials need to be designed and synthesised. This is crucial for the electrochemical synthesis of urea. The catalyst design will also be explored and optimised through computer simulations by Computational BioNanoCat at the UAB.

Soil-powered solution

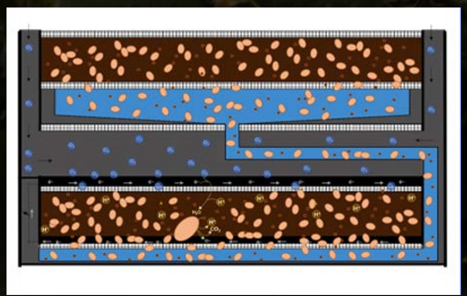
CONFETI's innovative hybrid solution combines panels and SMFCs to extract energy directly from soil microorganisms and from sunlight.

"The combination of solar panels and soil microbial fuel cells in a hybrid system can maximise renewable energy production by harnessing solar energy during the day and the energy generated continuously day and night by microbial activity in the soil, providing a more consistent and efficient energy source", points out Pablo Vidarte, CONFETI's innovation manager and CEO of the SME BIOO, leader of the development of the self-powered fertiliser system for the project.

Electrochemical reactor



Soil fuel cells



Photochemical reactor

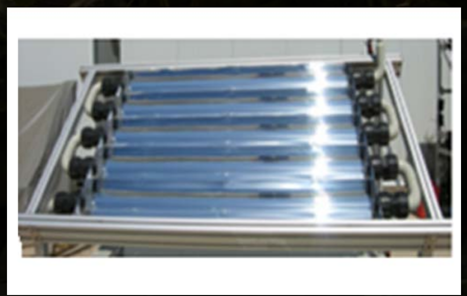


Figure 1: CONFETI research areas to reach technological objectives.

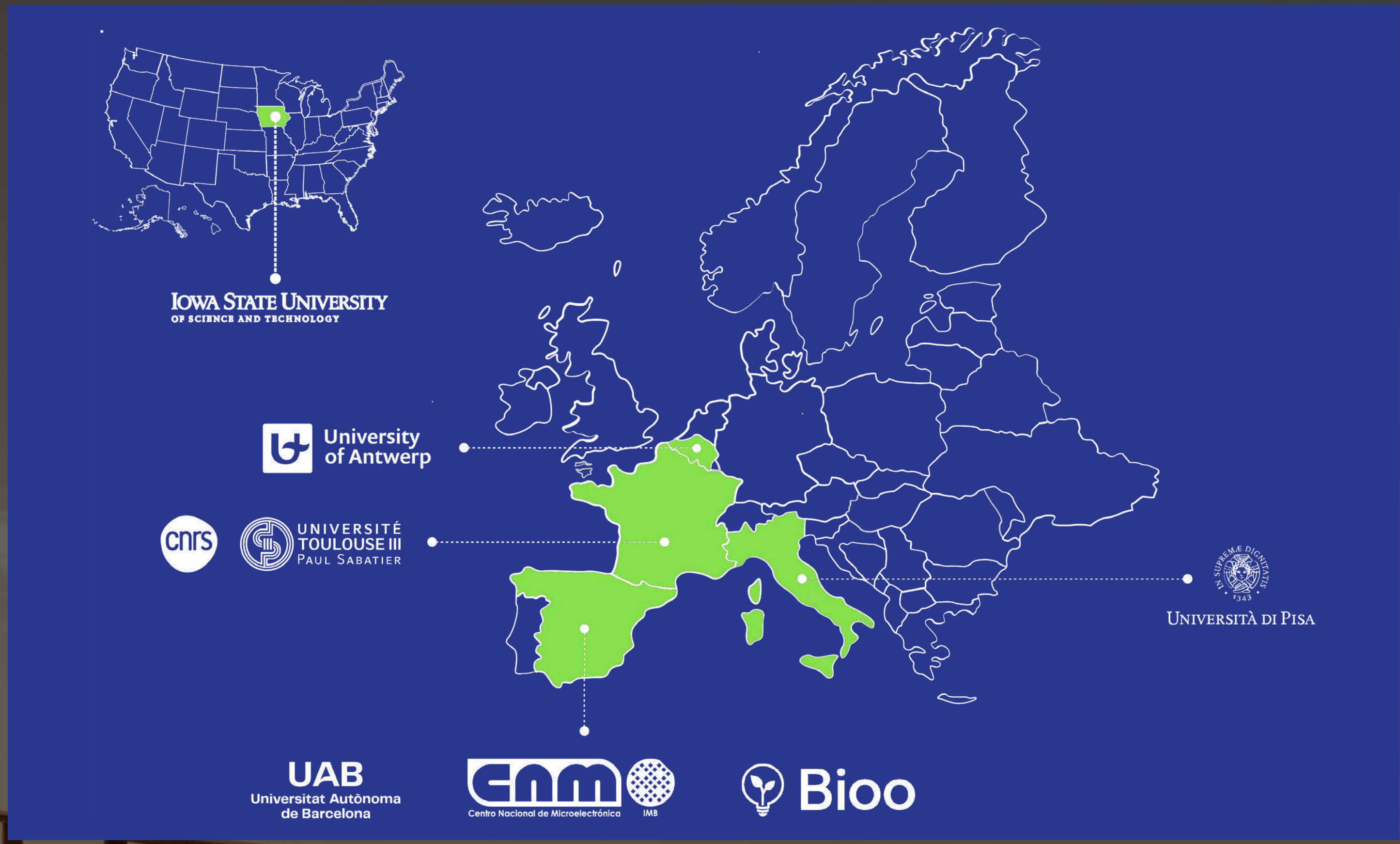


Figure 2: CONFETI's consortium.

CONFETI aims to optimise urea production to meet the specific needs of the field. This will avoid harmful overproduction and ensure that the energy generated by the SMFC is not wasted. "We are working to make our SMFC systems more energy efficient and adapt them for use in agriculture. We're focusing on improving the design and making the most of the soil as the core element of energy production," says Naroa Uria from BIOO.

"SMFC technology has been around for a while, but the improvements in CONFETI will really speed up the start-up time and efficiency of the fuel cell. It will even be possible to produce and deliver the daily fertiliser amount necessary to keep the plant healthy right there on the spot," says Xavier Muñoz-Berbel, a researcher at the Institut de Microelectrònica de Barcelona (IMB) belonging to the National Research Council (CSIC).

Recycling nitrates

Fertilisers that are not used by plants lead to an excess of nitrogen in the soil, which ends up as soluble nitrate (NO_3^-). Nitrate concentrations above 10 ppm are linked to health and environmental problems, including adverse changes in the human digestive tract and eutrophication, which can damage aquatic ecosystems. One way to remove nitrate from water and soil is through heterogeneous photocatalysis, a simple chemical process that uses a safe, harmless solid conducting material to absorb solar light to reduce nitrate to ammonia.

"The photocatalytic reduction of NO_3^- has only been evaluated on a laboratory scale. We want to recycle the NO_3^- not consumed by plants and convert it into ammonia or urea using photocatalytic technologies powered by sunlight," states Alba Ruiz from Plataforma Solar de Almería, part of the Centre for Energy, Environmental and Technological Research, who is leading the work on NO_3^- photorecycling.

The team is putting together some new and improved photocatalysts for this transformation. Javier Vela of Iowa State University points out that one of the keys to making a successful photocatalyst is to put the light-absorbing and charge-separating components close together. To make the most of the photocatalyst, CONFETI will use robust metal oxide semiconductors and test new nitrate reduction materials as building blocks for this technology.

The project is carefully designing the initial prototypes from a life cycle perspective, considering the material, energy and environmental impacts of each process throughout its production, use and end of life. This life cycle approach will facilitate the eco-design of the prototypes to guarantee their sustainability. "We need to ensure that our technology is based on circular economy strategies, such as repairability and recyclability, and that it doesn't compromise environmental goals, such as global reduction of CO_2 emissions or use of critical raw materials," says Laura Talens from the Sostenipra research group at Institute of Environmental Science and Technology (ICTA-UAB), who leads the eco-design process and environmental assessment.

Joint efforts for a common goal

At the heart of CONFETI lies a multidisciplinary consortium led by the UAB (Figure 2), including experts from various fields across Europe and the United States.

CONFETI is one of the eight EU research projects funded under the "Carbon dioxide and nitrogen management and valorisation" challenge and selected for the EIC portfolio on CO2 and N management and valorisation. With a total budget of €29 million, the portfolio projects aim to build a common roadmap to identify and accelerate the development of the most promising EU technologies in this field to address the challenges of climate change, global warming and water/soil pollution in line with the European Green Deal objectives.

As global demand for fertiliser continues to rise, initiatives such as CONFETI offer a glimpse of a greener, more efficient future. Although it focuses on the urgent need to develop new fertilisation systems, CONFETI technology is not only intended to be used in precision agriculture but to become a reference in other fields, such as the pharmaceutical industry, where it could enable sustainable production of drugs, or the manufacturing industry, where it could reduce the environmental impact of greenhouse gases. By paving the way for a new era of CO_2 and nitrogen valorisation, CONFETI is an example of the power of collaboration and creativity in science and innovation to address pressing global challenges.

Credits from the following research groups and institutions:

Universitat Autònoma de Barcelona (UAB)
- Electrochemistry, Photochemistry and Organic Reactivity Group (GEFRO-UAB)
- Computational BioNanoCat (UAB)
- Sostenipra (ICTA-UAB) Groups
- Parc de Recerca UAB (PRUAB)

Agencia Estatal Consejo Superior de Investigaciones Científicas (CSIC)
- GTQ Group

Universiteit Antwerpen (UANTWERPEN)
- ELCAT Group

SOFTMAT Group
- Centre National de la Recherche Scientifique (CNRS)
- Université Paul Sabatier (UPS)

Arkyne Technologies SL (BIOO)

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas-Ciema (CIEMAT)
- FQM374 Group

Iowa State University (ISU)
- Vela Research Group

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CONFETI

PROJECT NAME
Green valorization of CO_2 and Nitrogen compounds for making FErTIlizers

PROJECT SUMMARY
The EIC-funded CONFETI project aims to develop innovative lab-scale technology that captures and converts CO_2 and N_2 from air or flue gases into urea using renewable energy, bypassing critical raw materials. It also plans to recycle nitrates into ammonia or urea through sunlight-driven photocatalytic technology, promoting a circular and sustainable carbon and nitrogen economy.

PROJECT PARTNERS
Autonomous University of Barcelona (UAB), The Institute of Microelectronics of Barcelona (IMB-CNM-CSIC), Research Centre for Energy, Environment and Technology (CIEMAT), Bioo, the University of Antwerp (UANTWERPEN), University of Pisa (uniPi), French National Centre for Scientific Research (CNRS), University Toulouse III - Paul Sabatier (UPS) and Iowa State University (IOWA).

PROJECT LEAD PROFILE
Gonzalo Guirado is a full professor at the Universitat Autònoma de Barcelona, specialising in sustainable chemistry, including green valorisation of CO_2. He has advised 18 PhD and 33 Master theses, published over 105 peer-reviewed articles, and holds three patents. He has coordinated or participated in over 32 research projects funded by European, national, regional, university and industrial sources.

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