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The role of the chemical sciences in 'decarbonizing' the conversion of energy and industrial and agricultural emissions

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The winning entries of the second year of the annual Essay Competition, Young Voices in the Chemical Sciences *for Sustainability*, are published in this issue of *RSC Sustainability*. Organized and managed by the International Organization for Chemical Sciences in Development (IOCD) and sponsored by the Royal Society of Chemistry,[1,2] the competition aims to highlight the roles of the chemical sciences in promoting sustainability and to encourage young people to explore the relevance of scientific approaches to tackling sustainability challenges. In essence, it provides them a special opportunity to present their perspectives. The theme of the 2024 IOCD Essay Competition was "*How can the chemical sciences contribute to 'decarbonizing' the energy sector and to eliminating the generation or release of greenhouse gasses from large-scale manufacturing and agricultural processes?*"

The Essay Competition was open to entrants who were aged under 35 on 31 March 2024. The entries were assessed by a global team of volunteer evaluators, who this year selected 24 finalists essays as Finalists based on their relevance and quality. From within this group, essays that were very highly rated were chosen as Regional Winners, with regions being defined according to the World Bank geographic classification.[3]

The seven essays designated as 2024 Regional Winners show a wide range of

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Federico Rosei

Federico Rosei has held the Chair of Industrial Chemistry at the University of Trieste since March 2023. Previously he was Professor, Canada Research Chair and UNESCO Chair at Institut National de la Recherche Scientifique near Montreal (Quebec, Canada). He pursues research on structure/property relationships in nanoscale materials, coupled with efforts in capacity building, mentoring and outreach cross disciplinary and geographical boundaries. He has been Executive Director of IOCD since 2021, where he leads the group Materials for Energy Conversion, Saving and Storage (MATECSS) and is also on the Organizing Committee of the IOCD Essay Competition Young Voices in the Chemical Sciences for Sustainability.

approaches to the theme, as summarized below:

Amanda Tolentino (East Asia and Pacific) (https://doi.org/10.1039/D4SU90046D) in the Philippines begins her essay by stressing that achieving a net-zero future requires global multi-sectoral efforts, with the chemical sciences playing an indispensable role through technology, education, and policy. She ranges over the use of renewable energy sources and, meanwhile, the role that emissions capture can play on the route to carbon-free exploitation of energy, as well as the importance of innovations that enable circular production that reduces natural resource consumption and facilitates recycling for added value creation and responsible waste management. She also addresses emissions from agriculture, where activities such as livestock farming, crop residue burning, and the use of nitrogen-based fertilizers are common sources of emissions. Looking beyond the technological aspects, she highlights the importance of integrating sustainable practices and concepts into education curricula to orient the worldview of young scientists, and also the need to influence society and policy-makers to reorient public policy.

Alexandre Jorge (Europe and Central Asia) (https://doi.org/10.1039/D4SU90047B) in Portugal, notes the important contributions that clean energy technologies such as solar photovoltaics, wind, nuclear, heat pumps, and electric cars, already play in reducing the amount of greenhouse gasses (GHGs) emitted. Photoelectrochemical cells for water splitting have potential to be a large-scale source of hydrogen for use as a clean energy carrier, while more research is required to improve the economics of the technology. The essay discusses the need for large-scale energy storage and highlights advances in smaller and safer nuclear technologies, such as small modular reactors, to provide constant energy flow and also power CO_2 capture and sequestration technologies. Ongoing research seeks innovative solutions to challenges in nuclear waste management, such as by developing glass-ceramic composites, to remove, repurpose and/or stabilize the radioactive compounds. Solutions to GHG emissions linked to agriculture referred to include precision agriculture employing artificial intelligence, nanotechnology, energy-efficient frameworks, and sensor networks, as well as optimizing the management of CH_4 emissions from manure storage and treatment. However, the essay also refers to the need for governments and society as a whole to tackle climate change and environmental degradation by ensuring the effective implementation of the technological possibilities.

Tales da Silva Daitx (Latin America and the Caribbean) (https://doi.org/10.1039/D4SU90051K) in Brazil focuses on ways that, alongside reductions in burning fossil fuels, the capture and use of CO_2 can contribute to reducing global warming and also provide a feedstock for the development of new materials. This includes development of materials that can be used in agriculture and can also reduce future emissions associated with agriculture (Fig. 1). Examples cited in the essay include biodegradable polymers that can act as agrochemical supports and hydrogels, releasing active compounds in a slow and/or controlled manner and being able to provide moisture to a plant for a prolonged time while reducing dosage and leaching less material that is lost to the plant.

Yana Walia (Middle East and North Africa) (https://doi.org/10.1039/D4SU90050B), writing from the United Arab Emirates, advocates the reduction of GHGs grounded in the principles of green chemistry. One cited approach involves the capture of CO_2 released by industrial processes and its subsequent transformation into methanol using biocatalysis. Hydrogen production by steam methane reforming is an interesting sector where carbon capture can be of great importance for the development of green hydrogen applications. To follow, Walia pinpoints agriculture, a sector that is both partly responsible for and directly

Philippe Lambin

Philippe Lambin holds a PhD in physics. He has been professor in the Physics Department of the University of Namur, Belgium, where he is now emeritus professor. Most of his recent research work has been devoted to the electronic properties of carbon nanostructures and 2D materials. Since 2019, he has been a full professor at the Pedagogical Institute for Higher Education in Bukavu, Democratic Republic of Congo. He was elected member of the Royal Academy of Belgium in 2013. He is Treasurer of IOCD and is also on the Organizing Committee of the IOCD Essay Competition Young Voices in the Chemical Sciences for Sustainability.

Lei Jin

Lei Jin holds a PhD degree in Energy and Material Science. She served as a FRQNT Postdoctoral Scholar at McGill University, Canada. She was also a joint Postdoctoral Fellow (research team leader) at the Institut National de la Recherche Scientifique, Canada. She is currently a postdoctoral fellow (Outstanding Postdoctoral Program) at the Southern University of Science and Technology, China. She is the Project Manager of the IOCD Essay Competition Young Voices in the Chemical Sciences for Sustainability.

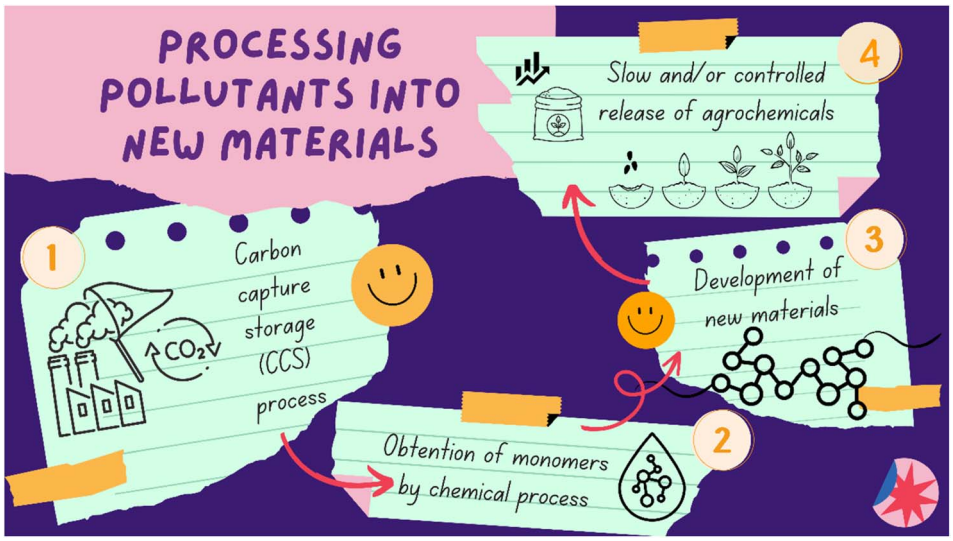

Fig. 1 Proposed cycle for transforming pollutants into new materials to mitigate the greenhouse effect (from da Silva Daitx, https://doi.org/10.1039/D4SU90051K).

victim of the climate crisis. She focuses on methane emission as a result of manure storage and the digestive process of ruminant animals. As she points out, working on feed composition and quality can reduce the level of methane, but this has a cost that farmers in low- and middle-income countries often cannot afford. An alternative, promising strategy consists in feed additives that specifically work on the enzyme responsible for methane release by the ruminant.

Govind Nanda (North America) (**https://doi.org/10.1039/D4SU90048K**) in Canada focuses his essay on diverse manipulations of light, aiming at obtaining clean energy from the sun, improving the energy efficiency of buildings and reaching other decarbonization objectives. In the energy sector, he outlines the merits of silicon–perovskite tandem panels for photovoltaics and describes the promise of low-emissivity materials and smart windows based on electrochromic materials for thermal insulation. At the same time, Nanda recognises that these high-tech devices exert a pressure on the supply of precious metals and will raise recycling problems at their end-of-life. In the domain of intelligent agriculture, he highlights the use of infrared spectroscopy to monitor the growth of plants and thereby collect information to know precisely when and where irrigation or fertilizers are needed, enabling reductions in their use.

Sarah Geo (South Asia) (**https://doi.org/10.1039/D4SU90045F**) in India discusses the advantages of nuclear technology to mitigate the emission of CO_2 in the quest for zero emissions. She remarks that, in the nuclear sector, chemistry is involved everywhere, from uranium mining to purification, from enrichment of the fissile component to the production of combustible rods. She adds that the processing of spent fuel to extract interesting isotopes involves complex chemical operations. She comments on the worrying problems of nuclear waste, while being confident that scientists will soon or later propose robust solutions for the storage of radioactive elements over very long periods. She continues with a few applications of radioactivity that increase the sustainability of different activity sectors. An example she takes from agriculture is the sterilization of insect pests by gamma ray irradiation and their dispersion in some regions of the world offering the possibility to reduce the need for pesticides. Another illustration she cites is the use of ionizing radiations for the sterilization of medical instruments or the treatment of medical waste without heat and, therefore, with less energy consumption.

Faith Mwende Johnson (Sub-Saharan Africa) (**https://doi.org/10.1039/D4SU90049A**) in Kenya reviews several important routes leading to decarbonization of industrial processes and energy consumption. She starts with green chemistry being a highly desirable alternative to traditional chemical processes that most often are energy-intensive and environmentally damaging. She takes bio-based polymer manufacturing as a convincing example for which different green production routes exist. She continues with transition-metal catalysis employed in fuel-cell technology for carbon-free production of electricity. She cites more complex catalysts showing a high potential for carbon capture and utilization (CCU), emphasizes the important role of chemical sciences in developing new CCU processes and cites different examples of how the captured CO_2 can be transformed into useful minerals or chemicals. She closes with energy conversion and storage, such as through solar energy trapping and green hydrogen production, and describes recent research efforts towards alternatives to lithium-based batteries.

Notably, several of the 2024 Finalists, including the MENA Regional Winner, were under 18 years old at the competition closing date. The wide spectrum of approaches to decarbonizing they

describe reflect the centrality of the chemical sciences in tackling the emissions from the conversion of energy and from industrial and agricultural processes that are responsible for the Earth's climate crisis. The essays also reflect the recognition that technological solutions alone are not enough and that chemical scientists must engage more actively with society and policy-makers to convince them of the urgency of seeking and adopting decarbonizing innovations.

Essays from the 17 additional finalists in the 2024 competition are being published on IOCD's website (**http://www.iocd.org**) and provide further stimulating examples of the perspectives of young people on chemistry's role in 'decarbonization'. The 2025 Essay Competition (**https://doi.org/10.1039/D4SU90052A**) is being launched by IOCD and *RSC Sustainability* in this current issue of *RSC Sustainability*.

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