

Empowering Students for a Sustainable World through the Green Chemistry Working Sessions: A Case of Success in Academia

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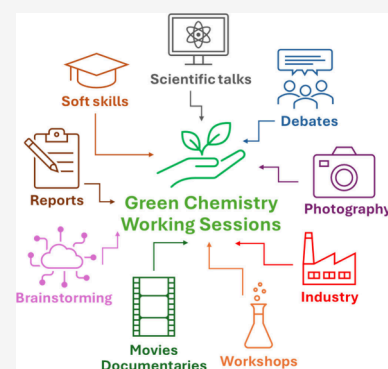
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ABSTRACT: Climate change, a long-standing issue, is consistently ranked as one of the top global threats by society. Addressing it is, in part, a scientific imperative. Therefore, providing young students with an academic perspective that empowers them to confront this challenge is more of an obligation than an option. In this regard, the Faculty of Chemistry at the Universitat Rovira i Virgili, in Tarragona, Catalonia, Spain, organizes annual editions of a module for undergraduate students called Green Chemistry Working Sessions (GCWS). This module consists of a series of scheduled activities, compulsory for all the students pursuing a BsC Degree in Chemistry, as GCWS is part of the third-year Citizenship course. Throughout its 17 editions by 2024, the GCWS has been framed around the goals of Green Chemistry, with climate change being a recurring theme. The activities during the GCWS typically include scientific talks, documentary viewings, debates, round tables, visits to industrial plants, and experimental workshops, among others. By offering such a module to university students, our aim is to empower them with climate awareness by exposing them to environmental challenges and their intersections with economic, political, and societal frameworks. We also seek to raise awareness of sustainable chemistry, emphasizing their roles as professional chemists with ethical foundations. This article presents a case of success in academia, where industry professionals, researchers, students, and society are brought together to find solutions to a serious and urgent issue.

KEYWORDS: *Upper-Division Undergraduate, Environmental Chemistry, Interdisciplinary/Multidisciplinary, Communication/Writing, Green Chemistry*



INTRODUCTION

The consequences of climate change (CC) are a pressing global concern in today's world,^{1–4} often placed at the top in several rankings along with violence, inflation, poverty or threats related with the misuse of new technologies. A median of 75% out of 19 countries in North America, Europe and the Asia-Pacific region label global CC as a major threat.⁵ Climate awareness may be attributed to the widespread access to abundant and reliable information in some countries,^{6,7} but it might also be considered a fact that the Northern Hemisphere has suffered the largest atmospheric temperature increase in the last decades.⁸ However, despite growing consciousness of the problem, there are numerous obstacles hindering swift action to address CC.⁹ These include the economic incentives to maintain energy-devouring societies, individual reluctance to change daily-life habits, technological challenges associated with alternative energy vectors, and a long list of *et cetera*.^{10–13}

The physicochemical origin of CC, beyond the popular knowledge that it is mostly caused by burning fossil fuels,¹⁴ remains unfamiliar for most of society.¹⁵ Of course, it involves

complex concepts of science, such as the molecules responsible for the greenhouse effect, the vibrational features of such molecules, radiation absorption, and collisional energetics in the atmosphere. However, in the world of scientific Academia, the scenario is somewhat different. The fundamentals of CC are presumed to be better understood by university students of sciences than by the average member of society or, at least, they possess the foundational knowledge to readily grasp these concepts,^{16–19} even though few, if any, standard courses explicitly focus on the issue of CC.^{20,21} Thus, incorporating specific activities such as courses, seminars, or other initiatives that approach CC from different perspectives becomes imperative to enhance awareness of the phenomenon and

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foster a deeper scientific and technical understanding of it. Specifically, Chemistry is very closely related to CC in several ways.^{22–24} First, the ultimate cause responsible for the global temperature increase is the growing concentration of greenhouse gases present in the atmosphere, such as CO₂ and CH₄, and the concomitant growth of absorption of solar radiation. The study and properties of these and other molecules are based on the principles of Chemistry (and Physics).²⁵ Second, alternative solutions other than the combustion of fossil fuels as the main energy source are being conceived and developed across the world, with chemical knowledge playing a crucial role alongside Physics and Engineering.^{26–28}

Therefore, chemical education must empower students to engage more effectively with climate-related issues by integrating knowledge, critical thinking, and creativity into this field. This approach mirrors successful strategies in other fields. These include providing comprehensive training in research methodologies to prepare students for productive careers in scientific research,²⁹ offering courses in micro-marketing to enable students to promote sustainable practices and solutions within various industries,³⁰ implementing programs to improve students understanding and management of stress and mental health,³¹ and embedding ethics education within research laboratories to empower students to navigate ethical dilemmas and promote integrity in their professional conduct.³² The assumption behind these approaches is that active involvement in discussions enhances students' sense of ownership and encourages deeper engagement with these critical topics. In our field of chemical education, this translates to empowering students for a sustainable future. Given that it is a highly interdisciplinary topic, we believe that the participation of several stakeholders, not just faculty staff, is necessary.^{33,34}

The present article describes a successful long-standing academic initiative known as *Jornades sobre Química Verda* (Green Chemistry Working Sessions, GCWS). It was initiated 17 years ago at the Faculty of Chemistry of the Universitat Rovira i Virgili (URV)³⁵ under the leadership of Inorganic Chemistry Professor Pilar Salagre, who is now retired. The URV is a medium-sized public university located in Catalonia, in the northeastern part of Spain, renowned for its excellence in research and teaching.

Initially conceived as an elective module, the GCWS later became compulsory as part of the Citizenship course of the BsC Degree in Chemistry³⁶ for students at the URV. The main goal of the GCWS is to cultivate sustainability-related skills, specifically focusing on the principles of Green Chemistry.^{37,38} Some of these principles directly or indirectly align with research lines and actions that can contribute to mitigating CC, such as 'Real-time analysis for pollution prevention' (Principle 11) or 'Design for energy efficiency' (Principle 6).

In some editions, the GCWS has tackled themes of alternative energy vectors, with particular emphasis on green hydrogen. What makes the GCWS a unique activity is its reliance on alternative learning methodologies and its dedicated focus on environmental issues. Participants are far more actively engaged compared to regular lectures, confronting urgent issues related to their future professional career. Typically, the schedule includes visits to industrial plants, viewing and discussion of documentaries, participation in debates, practical demonstrations or laboratory work, among other options. Consequently, the GCWS demands a markedly critical yet constructive attitude. This is one of the basic

commitments of the Faculty of Chemistry with their students. We aim for them not to take things for granted, to actively listen to diverse viewpoints, and to understand the diverse realities faced by all stakeholders involved in every issue. These include political, economic, environmental, and societal interests, which are integral players in our complex world.

This article is structured as follows: first, a background section provides context on the reality of the students involved in the GCWS, including their environmental and economic ecosystems and some associated aspects. This is followed by a concise description of the GCWS. Next, a historical overview of the 17 editions of this activity is presented, with particular emphasis on those more closely aligned with addressing CC. Finally, the article discusses the educational outcomes expected from these activities.

■ CITIZENSHIP IN THE CHEMISTRY DEGREE CURRICULUM AT THE URV

The URV offers the Chemistry Degree in the local official languages, Catalan/Spanish, and in English. As part of the curriculum, students engage in the Citizenship course during their third academic year. This subject is compulsory and carries 3 ECTS (European Credit Transfer System of the Bologna model),³⁹ and it encompasses various learning outcomes associated with the transversal competence CT7 defined by the URV: "Apply the ethical principles and of social responsibility as a citizen and as a professional".⁴⁰ Within this definition, several aspects stand out: Equality (Knowing the main inequalities and discriminations that occur between men and women and understanding their causes), Environment (Identifying the main environmental problems), Social Responsibility as Citizen (Recognizing and reflecting on social needs and issues, and engaging in community improvement), and Ethics (Recognizing the ethical and deontological concepts of the knowledge area, demonstrating critical and dialogical capacity, and making responsible use of the rules that affect it as a member of the university community).

Citizenship is a dynamic and unconventional course, which has incorporated and/or changed the activities offered along the years. Typically, various activities are offered, which are presented to students by the course coordinator early in the academic year. In 2023–24, the list included: the GCWS, Promotional activities of the Faculty of Chemistry, Mentorship for first-year students, Challenge Experiment, Cooperative Online International Learning focused on the Sustainable Development Goals related to Chemistry and Environment, and Scientific outreach through social networks. To successfully pass the course, students are required to freely enroll in three activities, with the GCWS being the only mandatory one. By satisfactorily completing the three activities of their choice, each worth 1 ECTS, students fulfill the requirements to pass the Citizenship course. The only activity that a student is allowed to do in more than one edition is the GCWS, since it covers a different topic every year. The final course grade is determined by calculating the arithmetic average of the marks obtained in the three completed activities.

■ CONTEXTUALIZATION OF THE GCWS

Description of the Module

The GCWS is an academic module mostly oriented to URV students of the BsC Degree in Chemistry. As mentioned above, all students pursuing this degree are required to complete and

pass the GCWS at least once as part of the compulsory third-year Citizenship course. However, registration for the GCWS is open to all undergraduate students (excluding first-year students) enrolled in the Bachelor's Degrees in Chemistry, as well as Biochemistry and Molecular Biology. Usually, all activities take place during a single week of the second semester, scheduled after the first-term exams, when students are expected to have lighter academic loads.

The GCWS comprises approximately 10 h of face-to-face activities, corresponding to 1 ECTS of the Citizenship course. Additional work is conducted autonomously or in small groups of students. An organizing committee takes care of the GCWS and is responsible for the preparation and management of every edition. The composition of the committee has varied over the years, being among four and six professors of the Faculty of Chemistry with teaching duties in the BsC Degrees in Chemistry and in Biochemistry and Molecular Biology, mostly. Their responsibilities include conceiving, preparing, and leading the activities as well as inviting any guest participants. Additionally, they are tasked with evaluating the students. The committee's duties are supported by technical staff who contribute to office work and logistical support.

Each academic year, the GCWS adopts a motto signifying the topic covered by the scheduled activities. These usually include: an introduction to the history and principles of Green Chemistry; a visit to an industry in the Tarragona area; a seminar by a prominent researcher related to the GCWS theme; screening of a relevant movie or documentary followed by a guided debate; and different workshops. Each activity aims to cover different aspects of the edition's subject matter:

- The seminar provides insight into scientifically advanced aspects of the theme, offering an overview of current research related to the central topic.
- Industry visits contextualize the application of sustainable practices discussed in the GCWS within real-world industrial settings. Students learn about companies' policies on Green Chemistry and sustainability and gain an understanding on how these principles are applied.
- Movie screenings and debates offer a broader perspective on sustainability, encouraging students to consider political, economic, and ethical dimensions of the theme and fostering critical thinking.
- Workshops, when possible, provide hands-on and participatory experiences, allowing students to engage in practical exercises, experiments, demonstrations, or oral presentations, often conducted in teams.

During the editions from 2011 to 2022, in collaboration with the URV-Dow Chair for Sustainable Development,⁴¹ a photography contest ran concurrently with the GCWS. This contest welcomed submissions from all GCWS-registered students as well as external participants on the condition that the photographs reflected the theme of the GCWS.

The activities of the GCWS are assessed by a committee, taking into account the quality and level of active engagement demonstrated by students across various activities. This evaluation includes monitoring the attendance and reviewing supplementary materials handed out, such as a critical individual report focused on one of the activities of that particular edition.

This structure is fundamentally different from other green chemistry modules described in the literature. Examples

include courses featuring case studies, journal article activities, and a combination of written and reading assessments,^{42,43} as well as the integration of green chemistry into existing courses.^{44–46} There are no examples of courses that combine seminars, industry visits, debates, and workshops, involving different participants and featuring a changing motto each year. This approach ensures that the GCWS is unique in each session and contributes to its long-term success, adding a novel aspect compared to other courses.

Historical Review of the GCWS. Each of the 17 editions of the GCWS organized so far has focused on a subject of interest linked to one or more principles of Green Chemistry. Table 1 provides a comprehensive list of all of the editions

Table 1. Motto in Each Edition and the Green Chemistry Principle(s)³⁷ to Which They Are Directly or Indirectly Related

GCWS Edition	Year	Motto	Principle(s) of Green Chemistry
1	2008	Sustainable chemistry	All
2	2009	Green chemistry	All
3	2010	Avoid waste generation	2, 6, 7, 8
4	2011	Make sustainable processes	All
5	2012	Chemistry in sustainable energy	1, 6
6	2013	Chemistry for a more sustainable environment	All
7	2014	Sustainable production and consumption in food and cosmetics	1, 2, 3, 7, 8, 9, 10
8	2015	Reuse waste	1, 7
9	2016	Air: a good to preserve	11, 12
10	2017	Build a sustainable world through circular economy and Green Chemistry	All
11	2018	Alternative energy vectors	6
12	2019	Chemical Elements at risk	2, 7
13	2020	The role of chemistry in food	5, 7
14	2021	Medicines and sustainability. Synthesis, use, abuse and recycling	2, 3, 4, 5, 8, 9
15	2022	Green hydrogen (H ₂), where are we?	1, 2, 6, 7, 10, 11
16	2023	Ethics and Chemistry	All
17	2024	The challenge of new sustainable materials	1, 2, 6, 7, 9, 10

along with their respective mottos and their connection to Green Chemistry principles. The choice of each motto is also influenced by the evolving field of sustainability in society, aiming to address various pressing topics at that time. Additionally, some editions directly address CC, such as the 2012, 2016, 2018, and 2020 editions.

As explained above, the program of activities and the central theme evolve to align with the specific objectives of each edition. Figure 1 illustrates the distribution of activities across the various editions organized to date.

Two recurring activities are integral to each edition: first, students visit nearby companies or industrial facilities; second, the central event of the module features a scientific-diffusional conference led by an expert in the topic's field.

Regarding visits to the chemistry-related companies, given the significant industrial activity in the region of Tarragona (the most important petrochemical park in southern Europe), most of the visited industries are related to petrochemical activity or related service industries, accounting for 43% of the industry types visited (Figure 2). Waste management

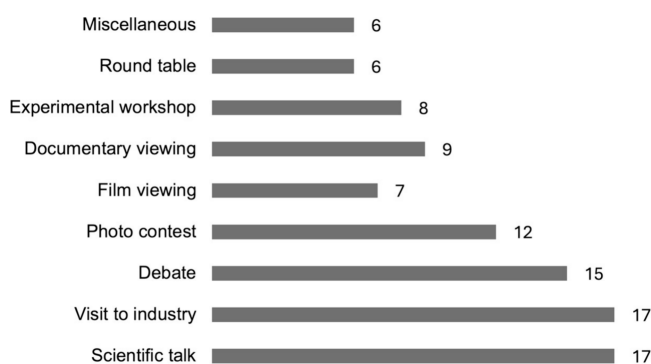


Figure 1. Intensity of the different activity types held along the 17 editions of the GCWS.

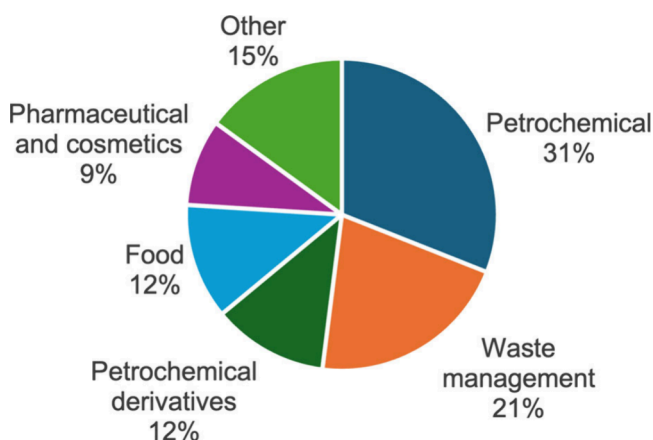


Figure 2. Sectorial distribution of the industries visited during the different editions of the GCWS.

industries, including incinerators, composting plants, and recycling facilities, are also common, making up 21% of visits. These visits aim to familiarize the students with the productive landscape surrounding Tarragona city as well as to teach them about the corresponding sustainable policies applied in each industry and regulation alignment, with the final goal to mitigate or prevent CC.

As for the scientific talks, aligned with the theme of each edition, they are carried out by experts in the field coming from Academia, research centers, or industry. For example, Professor Nora Ventosa, from The Institute of Materials Science of Barcelona,⁴⁷ is an expert in compressed fluids used as green solvents in various processes to produce materials and control molecular self-assembly in solution. Specifically, she presented two conferences entitled “Green solvents for efficient chemistry”, during the “Green Chemistry” workshop in 2009, and “Processing with compressed fluids: impact on the quality of food ingredients and cosmetics”, in the 2014 edition “Sustainable Production and Consumption in Food and Cosmetics”. In 2018, Professor José R. Galán Mascarós, from the Institute of Chemical Research of Catalonia (ICIQ)⁴⁸ presented the lecture “Artificial photosynthesis: Clean energy for society future”.

Scientific talks are also given by researchers with expertise in Chemistry dissemination, which is particularly beneficial given the primary audience of Chemistry Degree students, many of whom have limited background knowledge. For instance, Professor Xavier Domènech, from the Universitat Autònoma de Barcelona,⁴⁹ known for his extensive experience in

delivering dissemination talks and writing articles and books to promote Chemistry, carried out the lecture “The contribution of Chemistry to sustainable human development”, during the 2017 edition “Chemistry for a more sustainable environment”.

In total, 5 out of 17 conferences were delivered by professionals from the chemical industry or related fields. Notably, Mr. Miquel Torres, president of Miguel Torres S.A.,⁵⁰ one of Catalonia’s largest wine cellars, presented carbon-footprint reduction strategies adopted by its company in vineyard fields and wine production⁵¹ during the 2017 edition “Building a sustainable world through circular economy and Green Chemistry”. Some of these initiatives have received awards,⁵² highlighting their impact.

Additionally, the opening session of the GCWS featured the viewing of contestant photographs and recognition of winning students from 2011 to 2022, organized by the URV-Dow Chair for Sustainable Development.⁴¹

Another activity commonly featured in most editions (totaling 16) is the screening of a film (7 out of 16) or documentary (9 out of 16) that directly or indirectly addresses the theme of the edition. For example, *Soylent Green*⁵³ is a 1973 American ecological dystopian thriller film directed by Richard Fleischer. Set in a future where overpopulation, global warming, and pollution have led to severe shortages of food and resources worldwide, the film portrays a society where most people rely on highly processed food wafers made by the Soylent Corporation, including Soylent Green, which is made from human corpses. This film was screened during the 2014 edition, which focused on “Sustainable Production and Consumption in Food and Cosmetics”, indirectly addressing the impact of CC on the food and cosmetic industries.

Another noteworthy documentary is *Congo, My precious: The curse of Coltan mines in Congo*,⁵⁴ screened during the 2019 edition “Chemical Elements at Risk”, chosen to commemorate the 150 anniversary of the periodic table of elements. This documentary portrays the challenges faced in the Democratic Republic of Congo regarding the extraction and commercialization of rare minerals, since this country is abundant in such resources. These minerals are in high demand for various applications in high-technology instrumentation and devices, leading to a shortage. Consequently, the chemical industry and researchers are exploring novel green materials as alternatives to these rare minerals.

Following the screening of films or documentaries, a discussion moderated by professors, industry researchers, etc. is held with students to analyze relevant ideas related to Green Chemistry and climate change.

Whenever possible, an experimental workshop is organized in each edition, totaling 8 experimental workshops. Table 2 provides a detailed list of workshops along with their respective editions.

As depicted in Table 2, the different experimental workshops cover a broad range of chemical disciplines and applications, all intimately related to the motto of each edition. For instance, the process of biodiesel preparation is detailed in Figure 3. This procedure involves the reaction of triglycerides from recycled cooking oil with alcohol in basic media to yield an ester (the biodiesel) and glycerin, which must be separated and thoroughly cleaned with water.

A total of six round tables have been organized during various editions of the GCWS, serving as an excellent forum for discussion among experts from different sectors (research,

Table 2. List of Experimental Workshops during Different Editions

Edition	Experimental workshop	Motto
2014	Preparation of different galenic forms in cosmetics	Sustainable production and consumption in food and cosmetics
2015	Manufacture of soap from recycled oils	Reuse waste
2016	Computational Chemistry applied to the study of greenhouse effect gases	Air: a good to preserve
2017	Industrial innovation projects	Build a sustainable world through circular economy and Green Chemistry
2018	Production of biodiesel from used cooking oil	Alternative energy vectors
2020	Decode the labels of what we eat	The role of chemistry in food
2021	Availability of medicines at home: doses, expiration date and use	Medicines and sustainability. Synthesis, use, abuse and recycling
2022	The H ₂ battery-powered vehicle	Green hydrogen (H ₂), where are we?

industry, outreach, etc.). In the latest edition, focused on “The Challenge of New Sustainable Materials”, a round table was held under the motto “Sustainable Materials for a Sustainable Future”. During the colloquium, four prominent representatives from the sector, including Juan Carlos Neira and Enrique Trallero from Ravago,⁵⁵ Antoni Prunera from Elix Polymers,⁵⁶ Sandra Fernández from GCR Group⁵⁷ and Joan Carles Ronda from the Sustainable Polymers research group (SUSPOL)⁵⁸ at the URV, addressed key topics such as the importance of material recycling and reuse, the relevance of eco-design, and the issue of greenwashing. They emphasized the need for additional information and education for the end consumers.

Finally, various leisure activities in a more relaxed atmosphere were also offered, tailored to the theme of each edition. Some examples include a scavenger hunt (proposed in

different editions), chemistry outreach events for the Tarragona community, a visit to a museum exhibition dedicated to 3D printing and the materials used, and more.

GCWS and Climate Change

Despite all the editions of the GWCS being related to CC, some are more directly related to it than others, such as “Chemistry in Sustainable Energy”, “Air: a good to preserve”, “Alternative Energy Vectors” and “Green hydrogen (H₂), where are we?” (see Table 1). For example, the program of the 2012 edition was primarily focused on studying alternatives to fossil raw materials as an energy source, which were considered one of the main contributors to CC at that time. In this edition, the conference titled “Algae fuels” by Dr. Enrique Espi (bioenergy consultant at the Repsol Technology Center)⁵⁹ was based on Repsol’s experiences in using algae biomass as an energy source. Additionally, the film screened in that edition, *Ashes from the Sky*,⁶⁰ explored the experiences of a neighborhood near a thermal power plant. Finally, the round table “Energy, chemistry, and sustainability” was held with representatives from various alternative energy industries, including biofuels, solar energy, combined cycle power stations, and energy cogeneration. Through these activities, students gained fundamental insights into fossil energy, alternative energies, and their impact on CC. Also, they developed a general and critical perspective on these concepts, preparing them to address these issues both as future professionals and as citizens.

These skills have been addressed in each edition of the GCWS, and students have encountered several challenges hindering the transition to cleaner energy sources, such as industry rigidity in adapting to new production processes or economic interests of lobbies, among others. Hearing diverse viewpoints helps students gain a more comprehensive understanding of the real-life factors that contribute to unresolved issues.

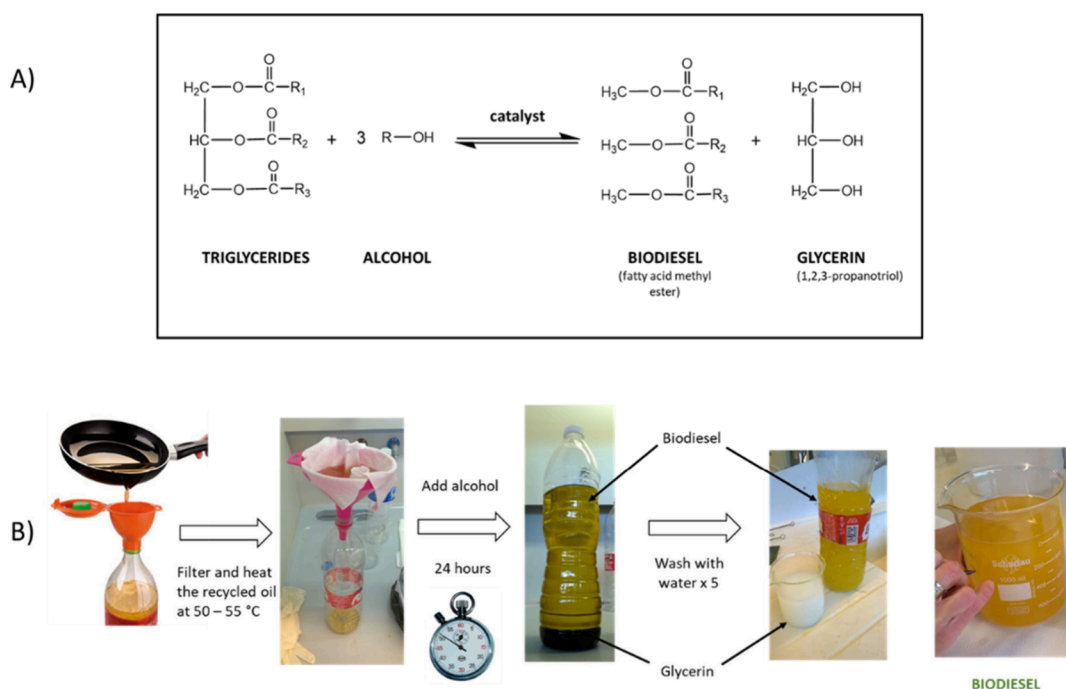


Figure 3. Production of biodiesel from used cooking oil (2018 edition). (A) Main chemical reaction and (B) procedure to obtain homemade biodiesel from recycled cooking oil.

In the 2018 edition, with the motto “Alternative energy vectors”, the program was aligned with different policies toward CC, allowing students to explore renewable energy strategies, their advantages, disadvantages, and future possibilities. Activities included a scientific talk on “Artificial photosynthesis: Clean energy for society future” by Professor José R. Galán Mascarós from the Institute of Chemical Research of Catalonia.⁴⁸ This talk provided an overview of strategies for capturing carbon dioxide (by mimicking the mechanism of plants), perfectly aligned with policies aiming at addressing CC. The screening of the documentary *The 4th Revolution – Energy Autonomy*,⁶¹ presented a vision of a global community powered entirely by renewable energy sources. Two experimental workshops were also organized, one on biodiesel preparation (already detailed in Figure 3) and another on “Carbon footprint in vehicles”. In the latter, the students learned, with the aid of an online real-time application,⁶² how to calculate the amount of fossil or renewable energy consumed per country in everyday activities such as transportation of people and goods, or domestic heating. In this way, they gained awareness of the actual scenario concerning the different energy sources. In this edition alongside the technological benefits and constraints involved in transitioning to alternative energy vectors, it was emphasized that reality is exceedingly complex. Often, the policies of different countries are not in harmony with each other, which significantly impedes substantial progress in the field of alternative energy on a global scale.

In a more recent edition, which took place in 2022, alternative energies were thoroughly explored under the motto “Green hydrogen (H₂), where are we?” This theme was well aligned with the objectives of the Hydrogen Valley hub in Catalonia,⁶³ a big initiative that brings together numerous industrial companies, associations, research institutions and public administrations, all united in the pursuit of large-scale green hydrogen generation in the Tarragona region. In 2022, there was an energy global shortage, which raised significant concerns within society. During this edition, we had the participation of professionals from multinational companies such as Repsol⁶⁴ and Messer,⁶⁵ which are committed to generating green hydrogen at their facilities, replacing the commonly used gray hydrogen derived from fossil fuels. Following these visits, the scientific talk “Artificial Photosynthesis: from H₂O to CO₂ to green fuels”, was carried out by young researcher Sergio Fernández Martín from the Institute of Chemical Research of Catalonia.⁴⁸ This presentation focused on the state of the art electrocatalytic reduction of CO₂ to produce green fuels.

Building on the insights gained from activities related to green hydrogen, students experienced a hands-on demonstration involving the use of a hydrogen cell to power a small vehicle. Consequently, by the end of the edition, students established a foundational understanding of green hydrogen as a possible alternative to fossil fuels, not only within the chemical industry but also as citizens. This experience is expected to foster greater commitment and motivation toward topics related to Green Chemistry and CC in the future.

GCWS Indicators and Feedback from the Students

In this section, we present some indicators collected at the conclusion of each GCWS session, including students’ attendance and participation data, feedback from the students, and comments from the invited speakers and personnel from

the visiting industries. These indicators are carefully discussed by the organizing committee and faculty members to assess both the strengths and areas for improvement within the GCWS program.

Regarding students’ attendance and participation, each edition consistently attracts 80–100 students, totaling up to 1500 students across multiple editions. These high attendance numbers demonstrate the program’s broad reach and sustained interest among students.

As illustrative examples, we highlight recent comments and statements from students who participated in different editions of the GCWS. These comments have been sourced from opinion polls that all students participating in the GCWS are required to complete, reflecting a high level of engagement and satisfaction. The selected remarks represent the most widely supported and effectively articulated viewpoints among the participants. Their empowerment on climate issues signifies a combination of heightened awareness, confidence in their own abilities, and a resolute determination to advocate for their future. This section is presented by grouping the most relevant and recurrent students’ comments into three main topics and highlighting some (adapted) quotes correspondingly.

Urgency and extent of change. Chemistry students at the URV have the feeling that changes must be big, global, and fast to improve (or not worsen) the current scenario of CC. That is, the feeling is that there is no room for speculation, which might be related to the inputs that the students receive. Some comments point out that it is about to be late to avoid too serious negative consequences. Some of the following quotes point in this direction:

- “It is a first-order crisis, and we are running out of time.”*
- “[...] the importance of being aware about the climate problem that we are living in, which can get worse in the future if we do not change the situation right now.”*
- “The theme of the GCWS get us all involved.”*
- “The planet is in danger, and we must act immediately.”*
- “Thanks to Science we will manage to solve the biggest issue of humanity so far.”*
- “It is important to work as a team, globally.”*
- “It is highly necessary that we all get awareness of the problem and join our forces, knowledge and technology to deal with it.”*
- “[...] they showed us that we have to be ready for a big change, since in the very near future we have to leave dependency on fossil fuels and start applying green energy and hydrogen since these are the ones that can help us maintain civilization as we know it today.”*

Role of Chemistry and of (future) professionals in the field. Another aspect that has probably been possible thanks to the role of the GCWS stems from the extensive belief that Chemistry will be part of the solution. The technologies based on new materials, catalysts, alternative fuels, etc., all of which are intimately linked with the chemical branch, are seen as necessary parts of the complex evolution to a more sustainable society. Students, as future professionals in the field, see themselves as part of a prospective solution. A positive point is that, in general, they consider that steps are being taken in the right direction. A selection of the students’ quotes is:

- “The GCWS give us the opportunity to change the planet as future professionals of chemistry.”*
- “It is very important to raise awareness among people, but especially on future professionals of the chemical industry.”*

"The conferences were very engaging because I was very interested in how the companies of the energy sector will face the problems and the climatic emergency."

"Thanks to these sessions, we are more aware of how inappropriate it is to continue with the present energetic habits, and the need to focus research to these problems."

"In these GCWS we have grasped what is the implication of Chemistry in the change toward a more sustainable world. [...] It has been stressed the values that a chemist must have."

"The GCWS have a clear goal in the field of Chemistry as they intend to make future chemists reflect on their acts, [...] because they can have unwanted effects on many global aspects."

"We see firsthand how today's chemical companies try to implement changes into their processes trying to make Chemistry more sustainable for the environment and more ethical to our society."

"[...] they are teaching future chemists that not everything is worth it [...] and how we should approach problems or how we can evaluate whether a solution is appropriate. I also think that the GCWS gives fresh air in terms of the topic, because the topic of climate change is very present."

A complementary and appropriate way of learning. Despite that the GCWS has evolved since their beginnings thanks to reflection and adaptation to change, its philosophy has always been indisputable and the original spirit remains. Not basing its program on lectures or other traditional teaching methodologies is appreciated by the students. What is more, visiting industrial plants and exhibits, attending state-of-the-art scientific conferences, watching films or documentaries, and performing hands-on work are, probably, the most appreciated aspects among the studentship of the GCWS. It is, by far, the most diverse, unconventional course in the Chemistry URV program. Beyond extra knowledge on technical-scientific topics acquired, they develop transversal skills that include enhanced critical thinking and reflection moments important for their future as professionals and as citizens. See below a selection of quotes:

"I would like to support the GCWS that get better year after year and deal with very important topics and it is a different but very effective way of learning."

"The GCWS have been a very gratifying and didactical experience since they propose real and current issues of the world."

"It is highly important to do these activities to raise awareness among people about the relevance of preserving the environment."

"The GCWS give us the opportunity of changing the planet as future chemists."

"Personally, these days have helped me to consider situations that I had never stopped to think about since. After the activities, I was able to observe the importance of chemistry to face the issue of climate change. It is very important to be aware of the factors that we have discussed in the GCWS because our actions can be very harmful in many global aspects."

"The GCWS have a beneficial purpose in the field of chemistry, intending to make the chemist reflect on his actions, knowing that their actions can have an unfavorable impact on many global aspects."

"This course for me has been incredible because I have learned so many things that are very interesting for me. For instance, the different origins of hydrogen as a fuel and the importance of being aware about the climate problem that we are living in and in the future can be worse if we do not change the situation right now. I think that this course is necessary for the students because they can understand the importance of the green hydrogen as a future fuel and the commodities that the green hydrogen can offer for a sustainable world".

In summary, from the comments one can detect the student's empowerment on CC issues signifies a combination of heightened awareness, confidence in their own abilities, and a resolute determination to advocate for their future.

In addition to the students' comments, we have gathered feedback from participants in talks, round tables, and industry personnel. It is noteworthy that the industries invited have consistently welcomed visits as part of the GCWS, except in cases of urgent prior commitments. Moreover, following these visits, they expressed genuine gratitude for such initiatives.

Some of the most representative comments are collected below:

Participant in a round table in 2024 edition: *"Meeting other people from both the industry and the university, understanding some facts that we did not know about the university, seeing the number of students who participated, their interest, being able to have contributed minimally to contribute our ideas and the subsequent colloquium that we had in a small committee, are truly worthwhile."*

Personnel in the industry in edition 2020: *"The industry needs this kind of activities so that the students and the industry can be approached in a relaxed atmosphere. I congratulate you for this."*

■ CONCLUDING REMARKS

The compulsory academic activity for undergraduate Chemistry students, the Green Chemistry Working Sessions (GCWS), was presented as an opportunity to empower students on the topics of sustainability and climate change. With the latter major threat in mind, this module was conceived to develop awareness of the problem and to explore opportunities for addressing it. The approach extends beyond the purely scientific field. In the Faculty of Chemistry at the Universitat Rovira i Virgili we conceive each edition of this module as part of the third-year Citizenship course, emphasizing transversal competences in sustainability. By 2024, this module had been held 17 times, with several editions directly addressing the issue of climate change through their mottos and programs.

The activities included in the GCWS typically encompass scientific talks, documentary screenings, debates, roundtables, visits to industrial facilities, and experimental workshops. Through these activities, students directly engage with environmental challenges and explore their intersections with economic, political, and societal dimensions. Ultimately, the GCWS aims to enhance the student's awareness of sustainable chemistry as both citizens and professionals. In the final section of the article, relevant comments by the students are collected, where they emphasize the importance of the GCWS for their training and awareness of the Climate Change issue. The participants specifically and recurrently stress the urgency and the need for a global scale of the solutions, the key role of

Chemistry and the professionals in the field, and the way the GCWS gives an alternative approach to the issue and its possible solution. We believe that the success of this initiative serves as a compelling example of student empowerment.

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Notes

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REFERENCES

- (1) World Health Organization. Climate Change. 2023. <https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health> (Accessed April 2024).
- (2) Jackson, C. T. Climate Change: Global Inequalities and Poverty. In *Climate Change Literacy and Education Social Justice, Energy, Economics, and the Paris Agreement*. Vol. 2. Peterman, K. E.; Foy, G. P.; Cordes, M. R., Eds.; ACS Symposium Series, 2017; pp 25–39. DOI: 10.1021/bk-2017-1254.ch003.
- (3) Raihan, A. A Review of the Global Climate Change Impacts, Adaptation Strategies, and Mitigation Options in the Socio-economic and Environmental Sectors. *JESCAE* 2023, 2 (3), 36–58.
- (4) Rawat, A.; Kumar, D.; Khatri, B. S. A Review on Climate Change Impacts, Models, and its Consequences on Different Sectors: a Systematic Approach. *J. Water Clim. Change* 2024, 15 (1), 104–126.
- (5) Poushter, J.; Fagan, M.; Gubbala, S. Change Remains Top Global Threat Across 19-Country Survey. *Pew Research Center* 2022. <https://www.pewresearch.org/global/2022/08/31/climate-change-remains-top-global-threat-across-19-country-survey/> (Accessed April 2024).
- (6) Bayes, R.; Bolsen, T.; Druckman, J. N. A Research Agenda for Climate Change Communication and Public Opinion: The Role of Scientific Consensus Messaging and Beyond. *Environ. Comm.* 2023, 17 (1), 16–34.
- (7) Lee, T. M.; Markowitz, E. M.; Howe, P. D.; Ko, C. H.; Leiserowitz, A. A. Predictors of Public Climate Change Awareness and Risk Perception Around the World. *Nature Clim. Change* 2015, 5, 1014–1020.
- (8) Global Climate Highlights 2023. *Copernicus: 2023 is the Hottest Year on Record, with Global Global Temperatures Close to the 1.5 °C Limit*. Copernicus. Climate Change Service, 2024. <https://climate.copernicus.eu/copernicus-2023-hottest-year-record> (Accessed April 2024).
- (9) Santos, F. D.; Ferreira, P. L.; Pedersen, J. S. T. The Climate Change Challenge: A Review of the Barriers and Solutions to Deliver a Paris Solution. *Climate* 2022, 10 (5), 75.
- (10) Lee, S.; Paavola, P.; Dessai, S. Towards a Deeper Understanding of Barriers to National Climate Change Adaptation Policy: A Systematic Review. *Clim. Risk Manag.* 2022, 35, 100414.
- (11) Hafner, S.; James, O.; Jones, A. A Scoping Review of Barriers to Investment in Climate Change Solutions. *Sustainability* 2019, 11 (11), 3201.
- (12) The World Bank. *Overcoming Political Economy Barriers to Climate Action*. 2023. <https://www.worldbank.org/en/news/feature/2023/11/16/overcoming-political-economy-barriers-to-climate-action> (Accessed April 2024).
- (13) Katz, A. An Overview of Psychological Barriers to Climate Change Response and Their Implications for Improved Climate Change Communication, 2018. *Independent Study Project (ISP) Collection* 2954. https://digitalcollections.sit.edu/isp_collection/2954.
- (14) Kohse-Höinghaus, K. Combustion, Chemistry, and Carbon Neutrality. *Chem. Rev.* 2023, 123 (8), 5139–5219.
- (15) Taddicken, M.; Reif, A.; Hoppe, I. What Do People Know About Climate Change — and How Confident Are They? On Measurements and Analyses of Science Related Knowledge. *JCOM* 2018, 17 (03), A01.
- (16) Versprille, A. N.; Towns, M. H. General Chemistry Students' Understanding of Climate Change and the Chemistry Related to Climate Change. *J. Chem. Educ.* 2015, 92 (4), 603–609.
- (17) Jeffries, H.; Stanistreet, M.; Boyes, E. Knowledge About the “Greenhouse Effect”: Have College Students Improved? *Res. Sci. Technol. Educ.* 2001, 19 (2), 205–221.
- (18) Walz, K. A.; Kerr, S. C. “Holes” in Student Understanding: Addressing Prevalent Misconceptions Regarding Atmospheric Environmental Chemistry. *J. Chem. Educ.* 2007, 84 (10), 1693.
- (19) Mazzalai, E.; Chiappetta, M.; La Torre, G. Knowledge on Causes and Consequences of Climate Change in a Cohort of Italian Students. *Eng. World* 2022, 4 (4), 44–56.
- (20) Flener-Lovitt, C. Using the Socioscientific Context of Climate Change to Teach Chemical Content and the Nature of Science. *J. Chem. Educ.* 2014, 91 (10), 1587–1593.
- (21) D'eon, J. C.; Faust, J. A.; Browning, C. S.; Quinlan, K. B. Exploring the Phases of Carbon Dioxide and the Greenhouse Effect in an Introductory Chemistry Laboratory. *J. Chem. Educ.* 2019, 96 (2), 329–334.
- (22) Hirsch, R. F. (2023). Critical Aspects of Climate Science That Can Be Incorporated into Chemistry Courses. In *Engaging Chemistry Students with Real-World Context: Vol. 2*; King, D. B., Webster, G. H., Eds.; ACS Symposium Series; 2023; pp 101–113.
- (23) Etkorn, F. A.; Ferguson, J. L. Integrating Green Chemistry into Chemistry Education. *Angew. Chem., Int. Ed.* 2023, 62 (2), DOI: 10.1002/anie.202209768.
- (24) Versprille, A.; Zabih, A.; Holme, T. A.; McKenzie, L.; Mahaffy, P.; Martin, B.; Towns, M. Assessing Student Knowledge of Chemistry and Climate Science Concepts Associated with Climate Change: Resources To Inform Teaching and Learning. *J. Chem. Educ.* 2017, 94 (4), 407–417.
- (25) Hall, W. P.; Gunning, L. Physical Chemistry in Context: Using Quantum Mechanics to Understand the Greenhouse Effect. *J. Chem. Educ.* 2023, 100 (3), 1333–1342.
- (26) Sandaka, B. P.; Kumar, K. Alternative Vehicular Fuels for Environmental Decarbonization: A Critical Review of Challenges in

Using Electricity, Hydrogen, and Biofuels as a Sustainable Vehicular Fuel. *Chem. Eng. J. Adv.* **2023**, *14*, 100442.

(27) Kovil, N. The Indigenous Conversation: Exploring Solutions to Climate Change and Equality In *Global Consensus on Climate Change: Paris Agreement and the Path Beyond*; Peterman, K. E.; Foy, G. P.; Cordes, M. R., Eds.; ACS Symposium Series; 2019; pp 55–64. DOI: 10.1021/bk-2019-1313.ch006.

(28) Hemes, K. S.; Runkle, B. R. K.; Novick, K. A.; Baldocchi, D. D.; Field, C. B. An Ecosystem-Scale Flux Measurement Strategy to Assess Natural Climate Solutions. *Environ. Sci. Technol.* **2021**, *55* (6), 3494–3504.

(29) Mabrouk, P. A. Research Skills and Ethics—A Graduate Course Empowering Graduate Students for Productive Research Careers in Graduate School and Beyond. *J. Chem. Educ.* **2001**, *78* (12), 1628–1631.

(30) Shapiro, S.; Beninger, S.; Domegan, C.; Reppel, A.; Stanton, J.; Watson, F. Macromarketing Pedagogy: Empowering Students to Achieve a Sustainable World. *J. Macromarketing* **2021**, *41* (1), 104–115.

(31) Mousavi, M. P. S.; Sohrabpour, Z.; Anderson, E. L.; Stemig-Vindedahl, A.; Golden, D.; Christenson, G.; Lust, K.; Bühlmann, P. Stress and Mental Health in Graduate School: How Student Empowerment Creates Lasting Change. *J. Chem. Educ.* **2018**, *95* (11), 1939–1946.

(32) Hildt, E.; Laas, K.; Miller, C.; Taylor, S.; Brey, E. M. Empowering Graduate Students to Address Ethics in Research Environments. *Camb. Q. Healthc. Ethics* **2019**, *28* (3), 542–550.

(33) Reimers, F. M. The Role of Universities Building an Ecosystem of Climate Change Education. In *Education and Climate Change. International Explorations in Outdoor and Environmental Education*; Reimers, F. M., Ed.; Springer, Cham, 2021; pp 1–44. DOI: 10.1007/978-3-030-57927-2_1.

(34) McCright, A. M.; O'Shea, B. W.; Sweeder, R. D.; Urquhart, G. R.; Zeleke, A. Promoting Interdisciplinarity Through Climate Change Education. *Nature Clim. Change* **2013**, *3*, 713–716.

(35) Rovira i Virgili University Home Page. <https://www.urv.cat/en/> (Accessed April 2024).

(36) Universitat Rovira i Virgili. Bachelor's Degree in Chemistry (2009) <https://www.urv.cat/en/studies/bachelor/courses/plans/ciencias/bach-chemistry/> (Accessed April 2024).

(37) ACS Green Chemistry Institute. 12 Principles of Green Chemistry. ACS Chemistry for Life. <https://www.acs.org/greenchemistry/principles/12-principles-of-green-chemistry.html> (Accessed April 2024).

(38) Anastas, P. T.; Warner, J. C. *Green Chemistry: Theory and Practice*; Oxford University Press: New York, 1998.

(39) European Education Area. *Bologna Process and the European Higher Education Area*. European Commission. <https://education.ec.europa.eu/education-levels/higher-education/inclusive-and-connected-higher-education/bologna-process> (Accessed April 2024).

(40) Educational Guide. Bachelor's Degree in Chemistry (2009). *Competences - Transversal*. Universitat Rovira i Virgili. https://guiadocent.urv.cat/docnet/guia_docent/?centre=13&ensenyament=1320&consulta=competencies&idioma=eng (Accessed April 2024).

(41) URV-Dow Chair for Sustainable Development Home Page. <https://www.urv.cat/en/society-business/chairs/sustainable-development/> (Accessed April 2024).

(42) Kennedy, S. A. Design of a Dynamic Undergraduate Green Chemistry Course. *J. Chem. Educ.* **2016**, *93* (4), 645–649.

(43) Haley, R. A.; Ringo, J. M.; Hopgood, H.; Denlinger, K. L.; Das, A.; Waddell, D. C. Graduate Student Designed and Delivered: An Upper-Level Online Course for Undergraduates in Green Chemistry and Sustainability. *J. Chem. Educ.* **2018**, *95* (4), 560–569.

(44) Cann, M. C.; Dickneider, T. A. Infusing the Chemistry Curriculum with Green Chemistry Using Real-World Examples, Web Modules, and Atom Economy in Organic Chemistry Courses. *J. Chem. Educ.* **2004**, *81* (7), 977.

(45) Aubrecht, K. B.; Bourgeois, M.; Brush, E. J.; MacKellar, J.; Wissinger, J. E. Integrating Green Chemistry in the Curriculum:

Building Student Skills in Systems Thinking, Safety, and Sustainability. *J. Chem. Educ.* **2019**, *96* (12), 2872–2880.

(46) Armstrong, L. B.; Rivas, M. C.; Zhou, Z.; Irie, L. M.; Kerstiens, G. A.; Robak, M. T.; Douskey, M. C.; Baranger, A. M. Developing a Green Chemistry Focused General Chemistry Laboratory Curriculum: What Do Students Understand and Value about Green Chemistry? *J. Chem. Educ.* **2019**, *96* (11), 2410–2419.

(47) Institute of Material Science of Barcelona Home Page. <https://icmab.es/about> (Accessed April 2024).

(48) Institute of Chemical Research of Catalonia (ICIQ) Home Page. <https://www.iciq.org/about-us/> (Accessed April 2024).

(49) Universitat Autònoma de Barcelona Home Page. <https://www.uab.cat/web/universitat-autonoma-de-barcelona-1345467954774.html> (Accessed April 2024).

(50) Familia Torres Home Page. <https://www.torres.es/en> (Accessed April 2024).

(51) Familia Torres. *Beyond Sustainability*. <https://www.torres.es/en/beyond-sustainability> (Accessed April 2024).

(52) Familia Torres. *Familia Torres Presents the VII Torres & Earth Awards to Distinguish Actions Against the Climate Emergency*. <https://www.torres.es/en/news/beyond-sustainability/familia-torres-presents-vii-torres-earth-awards-distinguish-actions> (Accessed April 2024).

(53) Fleischer, R.; Myrow, F. *Soylent Green*, 1973, United States of America.

(54) Trofimova, A. *Congo, My Precious. The Curse of the Coltan Mines in Congo*. 2017. Russia.

(55) Ravago Home Page. <https://www.ravago.com/> (Accessed April 2024).

(56) Elix Polymers Home Page. <https://www.elix-polymers.com/> (Accessed April 2024).

(57) GCR Home Page. <https://gcrplasticsolutions.com/> (Accessed April 2024).

(58) Sustainable Polymers (SUSPOL) Home Page. <https://www.suspul.urv.cat/en/> (Accessed April 2024).

(59) Repsol Technology Lab Home Page. <https://www.repsol.com/en/technology-and-digitalization/technology-lab/index.cshtml> (Accessed April 2024).

(60) Quirós, J. A. *Ashes from the Sky*, 2008, Spain.

(61) Fechner, C. A. *The 4th Revolution: Energy Autonomy*, 2010, Germany.

(62) Electricity Maps Home Page. <https://app.electricitymaps.com/map> (Accessed April 2024).

(63) Hydrogen Valley of Catalonia Home Page. <https://www.h2valley.cat/en/> (Accessed April 2024).

(64) Repsol Home Page <https://www.repsol.com/en/index.cshtml> (Accessed April 2024).

(65) Messer Home Page. <https://www.messer.es/> (Accessed April 2024).