Gwendoline Fife and
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A Report from an Experts Meeting Organized by the Getty Conservation Institute and The Royal Institute for Cultural Heritage (KIK-IRPA), December 13–14, 2022

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The Getty Conservation Institute (GCI) works internationally to advance conservation practice in the visual arts—broadly interpreted to include objects, collections, architecture, and sites. The Institute serves the conservation community through scientific research, education and training, field projects, and the dissemination of information. In all its endeavors, the GCI creates and delivers knowledge that contributes to the conservation of the world's cultural heritage.

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Front cover: A selection of sensitive materials (artificially aged cellulose acetate plastic, yellow brass, naturally dyed silk, and degraded leather) are immersed in 2H,3H-decafluoropentane during Getty Conservation Institute research into greener solvents in February, 2020. Photograph by Michael Doutre. © 2020 by the J. Paul Getty Trust.

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PREAMBLE

> Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.
>
> —Report of the World Commission on Environment and Development: Our Common Future (1987)

This report summarizes discussions from the two-day Greener Solvents in Art Conservation meeting held at the Koninklijk Instituut voor het Kunstpatrimonium—Institut royal du Patrimoine artistique (KIK-IRPA) in Brussels, Belgium, on December 13–14, 2022, where professionals from art conservation, academia, and industry with expertise pertaining to sustainability and greener solvents gathered to discuss relevant criteria and assessments. It was quickly agreed that the origins of sustainable development provide a useful starting point for framing these findings.

Traditionally described as comprising three[1] main pillars (environmental, economic, and social[2]), "sustainability" can be viewed as an overarching description. Where sustainability provides the "large picture" or goal, "sustainable development" is a practical term referring to the many processes and pathways to achieve it. Accordingly, and since further outlined by the United Nations (UN) in 2015, seventeen Sustainable Development Goals (SDGs) have been set out to address the key social, economic, and environmental issues in ensuring sustainable future development.[3] Within this framework, every professional body is obliged to (re)consider their policies, approaches, methods, and materials, not least those associated with the Arts and Cultural Heritage. Museum collections, for instance, are a significant public inheritance; accordingly, they are afforded a special position in law and protected by international legislation.[4] And in safeguarding cultural heritage artworks and artifacts—both inside and outside of museum collections—conservation itself is indelibly and inextricably concerned with the needs of future generations. With regards to their practice therefore, and specifically in their applications of chemical products, conservators must integrate multiple factors in determining the best treatment options while also including the consideration of sustainable development. With professional guidelines[5] dictating that conservators shall "strive to use only products, materials and procedures, which, according to the current level of knowledge, will not harm the cultural heritage, the environment or people," sustainable development is already embedded in the profession's code of ethics. Greener solvent approaches are an aspect of sustainable development, and the most safe effective solvent application is the most ethical choice. In correspondence with the World Health Organization (WHO) One Health approach—which recognizes that the health of humans, other living species, and the wider environment (including ecosystems) are closely linked and interdependent—greenness of a solvent is bound with its performance in the application for which it is being used and its human and environmental toxicity. Considering these perspectives and in concluding the two days of expert meeting discussions, some "common understandings" regarding the use of greener solvents in conservation were reached.

The participants of the Greener Solvents in Art Conservation meeting at KIK-IRPA. From back, in rows from left to right: Melinda Keefe and Chris Stavroudis; Nicole Onishi, Klaus Kümmerer, and Sarah Nunberg; Gwendoline Fife, Laura Rivers, and Bart Wuytens; Hannes Sels, Rosie Grayburn, Michael Doutre, Katrien Keuen, Tom Learner, and Fransisco Mederos-Henry.

Our Common Understanding

Solvent choice in conservation is a complex issue with implications to the object, conservator, and environment.

Conservators need to be equipped and empowered by knowledge, skills, and values, and instilled with a heightened awareness to implement greener solvent choices.

All solvent use carries costs: toxicological, environmental, and financial.

Minimizing the amounts of solvents used and maximizing the benefit of their use reduces these costs.

Solvents should be chosen that are as non-toxic to the conservator as possible. It is important to stay informed on the latest health information for solvents in use.

Solvents chosen should pollute the environment as little as possible and break down into nonharmful products. Some solvents' sources carry lower environmental costs, including through greener manufacturing, less transportation, and other means.

The possession of any specific property does not imply greenness of a solvent, nor should there be any implication that a greener solvent choice must include all the concepts described here.

Solvent use in conservation must be changed to benefit the health and safety of the conservator and environment.

Meeting attendees with Hélène Dubois (top), Karen Bonne (middle), and Emmanuelle Mercier (bottom) of KIK-IRPA during tours of the paintings and sculpture studios.

OVERVIEW OF THE MEETING

The invited participants included experts on greener solvents and sustainable approaches with differing backgrounds (industry, academia, institutional and private conservation practice) from the United States and Europe. An initial introduction served to present the various uses of solvents in conservation, their selection criteria, and the primary challenges faced in defining and selecting solvents in conservation practice. The critical importance of solvents for various conservation treatments was highlighted—for cleaning, application of polymers (coatings, consolidants, adhesives, in paints), and removal of polymers. The most common substrate types on which solvents were used were described (paints, metals, leather, wood, stone, ceramic/glass, paper, plastics, textiles) alongside an incomplete but representative list of the most common polymers encountered in the field (acrylics, cellulose nitrate, PEOX, polyhexanones, ketones resins, natural resins, polysaccharides, proteins, PVB). The selection criteria for solvents were then specified:

- Their potential to dissolve (for applying or removing) nonoriginal materials while affecting the original materials as little as possible
- Moderate evaporation rates (environmental/working conditions are often uncontrolled)
- Intercompatibility for mixing
- pH/conductivity/gelling/rheology
- Sustainability

However, it was acknowledged that this last criterion has been generally lacking consideration in the field and that dangerous, potentially toxic, problematic solvents are still in use. The number of art conservators varies depending on the location and field of specialization. However, it's a profession with a relatively low number of practitioners worldwide. The American Institute for Conservation of Historic and Artistic Works (AIC) has over 3,000 members and the International Institute for Conservation of Historic and Artistic Works (IIC) has over 2,000 members, but these numbers include conservation professionals from a variety of fields, not only art conservation. Additionally, it's worth noting that not all art conservators are members of these professional organizations. Extrapolating from these figures, we worked from an estimate of 15,000–40,000 cultural heritage conservation professionals in the "developed world" consuming between 1 and 2 liters of solvents per year. The potential toxicity of the solvents, combined with a rough analysis of their life cycle, indicates a major impact (not least in CO_2 release), which needs consideration alongside the large amount of energy required for fume extractors where these are available. For many conservators worldwide, extraction is not a working reality. The following questions were posed for discussion during the meeting:

- What does "greener solvents" mean in the context of conservation?
- What are the research priorities to move the field toward greater sustainability?
- What challenges do conservators face implementing changes?

In starting to tackle these, the twelve principles of green chemistry were considered[6] and the four applicable to conservation highlighted. Some guidelines and tools from governing bodies in the United States and European Union (EU) were briefly reviewed, including the US Environmental Protection Agency guidelines for safer choice criteria for solvents, Significant New Alternatives Policy regulations, and the European Chemicals Agency (REACH) regulation. The discussion was then opened to the floor.

Green, Greener, and Sustainable

Most broadly, "green" refers to environmental practices or products that reduce harmful impacts on the environment, such as reducing pollution or conserving natural resources, while "sustainable" refers to the ability to maintain or continue a certain process or state, such as economic growth or use of resources, without depleting them or causing harm to the environment. In other words, "green" generally refers to a single aspect of environmental impact, whereas "sustainable" refers to the overall long-term health and viability of a system.

Green in the context of solvents traditionally refers to those that are biomass-derived, but the term is often used arbitrarily (e.g., one definition from a Google search is "outsourced from agriculture, friendly to the environment"). Further, a biomass-derived origin in no way reflects a lower human or overall environmental toxicity (e.g., via release and degradation). Also, just as a solvent can only be described as "strong" or effective with respect to a specified solute, so a solvent's "greenness" is comparative to another and dependent on the application for which it is being used. "Greener solvents" is the preferred term since it reflects the comparative nature of assessing efficacy in the application of solvents, and incorporates consideration of human toxicity and environmental fate.[7]

Parameters Discussed

One Health—Human and Environmental Toxicity

The WHO's One Health approach recognizes that the health of humans, other living species, and the wider environment are closely linked and interdependent—the animal–human–environment interface is thereby considered a critical perspective when addressing health threats. On this basis, and with the consideration of a solvent's toxicity to humans deemed a paramount factor, the discussions further focused on the challenges conservators may face when they aim to use solvents that are less toxic. These can be related to practical solutions, mind-set, assessments of long-term toxicity exposure, comparison of environmental impacts, and in general clarity of, and access to, information.

In the first place, it was acknowledged that identifying and comparing toxic and ecotoxic impacts is not necessarily straightforward, especially from nonacute, longer-term exposures for which information may not (yet) be available. Determining information on the effective health impact from habitual exposures to solvents, such as that experienced by conservators, was thereby identified as a challenge. There is anecdotal evidence to suggest potentially significant health impacts for conservators later in life from their professional solvent use, especially neurotoxic effects. Although still not replicating nonacute (below point-of-departure), long-term exposures, animal studies nonetheless provide the best information regarding human toxicology. Since information changes and is updated (and on new solvents is oftentimes incomplete[8]), an intermittent checking of regulatory assessments and safety data sheets is necessary. These aspects are further discussed below. Conservation education must include topics on toxicology/training on environmental aspects, and people should have, and seek out, open-access resources so that they can be informed and make educated choices. Safety procedures should be followed and extraction systems used accordingly.

A further issue identified is that finding practical solutions to replacing specific solvents can be challenging. For instance, low polar, high dispersion force solvents are oftentimes the most toxic but hardest to replace in practice. People may need guidance regarding alternative solutions, and education aspects are similarly very important in this. But, especially given that nowadays conservators must develop so many skills, generally anticipating an inclusion of substitute solvent selection skills may not be a manageable expectation. Further, time and financial "space" are needed for developing and adopting innovative approaches, as well as for testing alternatives in practical applications. Also from a financial perspective, access to chemicals can be difficult as companies generally sell in larger quantities than most conservators need. Where suggested, substitution solvents will require a "practice shift" because they will for sure change how conservators experience their conservation practice (from very tiny but important details, e.g., cotton swab feel on the surface, spreading of the solvent).

But another big challenge was also deemed a change of mind-set. Generally, it is hard for people to "move" into change, and typically no one wants to be the first to change. For conservators, this can be exacerbated by their professional responsibility for the object and consideration of the long term—their job is to be change-adverse. Yet change in solvent use in conservation relies on a decision being made by the individual—specifically, to remove certain materials from their toolkit. Comparisons were made with industrial applications, where it was recognized that regulation is a huge drive for changing mind-set and behavior. In those settings, the use of certain solvents requires the signing of risk waivers (which serve to both clarify the exposure risk and encourage the consideration of alternatives), and regular testing procedures are in place for checking post-exposure health. Hence, there is a heightened awareness of what solvents are being used and the implications of their use. In certain locations, written justification is required for purchasing a hazardous solvent. Within conservation at large, such controls and testing are not currently possible to implement. But ever-increasing restrictions from regulatory bodies can be anticipated, and conservators will face knock-on effects regarding solvent availability and costs. It is critical that conservators assess the toxicity of the solvents they are using and rely on a clear self-understanding that some things should not be used.

In general, and especially for conservators working without the possibility of extraction or perhaps even personal protective equipment, preferentially using solvents presenting the lowest human toxicity must be a primary aim. It is understood that this may present a major mind-set change for many conservators given their professional tendency to prioritize the needs of the object and its treatment over themselves.

Life Cycle Assessments

It was agreed that to determine the environmental impacts associated with materials in general (and counteract false claims of greenness/sustainability, i.e., "greenwashing"), life cycle assessment (LCA) studies were a key element. When conducted in accordance with established ISO standards (series 14000), LCA studies clarify the energy and materials required within the system boundaries set—for example, within a “cradle-to-gate” framework (considering sourcing and production to departure from factory) or a “cradle-to-grave” framework (which would also consider recycling or disposal). LCA systems modeling tools quantify the total resource inputs and environmental burdens of a particular product classified by impact categories, including CO_2 equivalency (in kg). Such a carbon calculator is provided in STiCH (Sustainability Tools in Cultural Heritage), where “the easy comparison of the carbon footprint between products allows the user to select materials with less kg CO_2 equivalent, thus making educated choices, truly lowering the environmental impact of their actions.”[9] Repeated and/or efficient use of materials, whereby less is required, naturally minimizes the carbon footprint. While potentially only a theoretical ideal, were it possible to use solvents that are sufficiently non-toxic to humans in small enough amounts and with application methods whereby extraction could be safely avoided, a large reduction in carbon footprint could also be effected.

Atmospheric Chemistry

Great awareness is needed in conservation regarding solvent disposal. Given that every organic solvent used in conservation applications should never enter water systems and will instead eventually be released into the atmosphere, a solvent’s behavior in the atmosphere must be considered a very important factor. The critical criteria were defined as the solvent’s global warming potential and its ozone-depleting potential.[10] Ozone-depleting potential is a measure of how much damage a chemical can cause to the ozone layer compared with a similar mass of trichlorofluoromethane (which is given an ozone-depleting potential value of 1.0). The higher the number, the more damage a chemical can cause to the ozone layer. Global Warming Potential (GWP) is a measure of how much energy the emissions of 1 ton of a gas will absorb over a certain period of time, relative to the emissions of 1 ton of CO_2. The larger the GWP, the more the gas warms the Earth compared to CO_2 over that time period. Although always compared to CO_2, the consideration of longer or shorter time periods can change the perspective of impacts.

Market and Regulation

Industry experience and perspective on the economic triggers for developing greener solutions highlighted potential avenues for helping to support behavioral changes in solvent use in conservation, as well as some limitations. Given the large environmental impact traditionally inherent in chemical manufacture—not least in energy use—the challenge of going more sustainable is huge. With “chemicals of concern” still frequently a significant percentage of the sales portfolio, the suggested approach is to find less compromising solutions and to try to “make better choices.” The potential power of the end user was illustrated by the personal care space, where companies have been required by customer demand to adjust their ingredients to provide products that are biodegradable, safe, and so on. In this way, a forced change from petroleum-based to carbohydrate-based, for example, is enacted. While an area to consider, there are limitations to the impacts a similar approach may be able to achieve in conservation given its small market. But the inclusion of sustainable principles in corporate responsibility statements of certain supply shops in the field—regarding social responsibility to environmental awareness with a commitment to selling products made from natural materials and the nearby environment as much as possible—bodes well in illustrating the effect of social and, accordingly, market pressure. Practitioners should be informed on their potential in this and encouraged to express this demand through their material choices. The greatest incentive for changing a conservator’s solvent purchase list would be cost, with ideally a list of lower-impact solvents at a cheaper rate, with high-impact solvents more expensive. This is naturally a key issue since solvent and material costs can present a major chunk of a conservator’s budget. Regarding use and purchasing within institutions, people must lead by example. A key aspect agreed on was the importance of localization and adopting the "think global, act local" approach.

Existing standards, regulatory guidelines, and hazard information were discussed with regard to solvent use in conservation and the communication of these within the field. Since regulations change over time and vary according to locality, they must be checked by the practitioner. The databases of certain regulatory bodies[11] can also be accessed and searched for specific solvents. CMR lists (rosters of substances classified as carcinogenic, mutagenic, or toxic for reproduction[12]), the UN's globally harmonized system (GHS), and the safety data sheet of any solvent being considered for use are paramount resources. The European Union has some of the world's strictest chemical controls, but there is a significant backlog in registering chemicals, and the pace of registration is being outstripped by the development of new chemicals. Acknowledging that this registration approach cannot control a rising tide of chemical production and pollution, as well as its health and environmental impacts, the EU announced in 2022 a "Restrictions Roadmap" strategy to "prioritise carcinogenic, mutagenic and reprotoxic substances (CMRs), endocrine disruptors, persistent, bioaccumulative and toxic (PBT) and very persistent and very bioaccumulative (vPvB) substances, immunotoxicants, neurotoxicants, substances toxic to specific organs and respiratory sensitizers substances for (group) restrictions" under REACH for all uses.

Alongside working within these regulations, to be able to compare a solvent's greenness, the conservation field needs to adopt a methodology for solvent assessment. Of the many assessment guides that could be considered, a methodology developed for the pharmaceutical industry, CHEM 21, was discussed. Previously suggested for adopting and adapting for the field,[13] the system assesses the various hazards in the GHS of a solvent according to safety, health, and environmental impact (S,H,E) and gives an overall ranking of recommended, problematic, hazardous, and extremely hazardous. Developed with the concept of being applicable also outside of the pharmaceutical industry, it was agreed that the CHEM 21 demonstrates various advantages. As mentioned above, it includes a default "problematic" rating for solvents that have not yet completed REACH registration, which helps to avoid "greenwashing" and claims of lower toxicity (without due process) with newly introduced solvents. It provides a clear visual guide to which solvents are the most problematic, and the S,H,E ratings further allow a conservator "to make a judgment specific to their priorities regarding these aspects."[14] It was considered that if one can improve something in the S,H,E criteria or preferentially select one solvent over another on this basis (with performance being equal), then one is taking steps in a good direction to "going greener." With the methodology and criteria established, some relatively straightforward adjustments to account for conservation uses would be helpful.

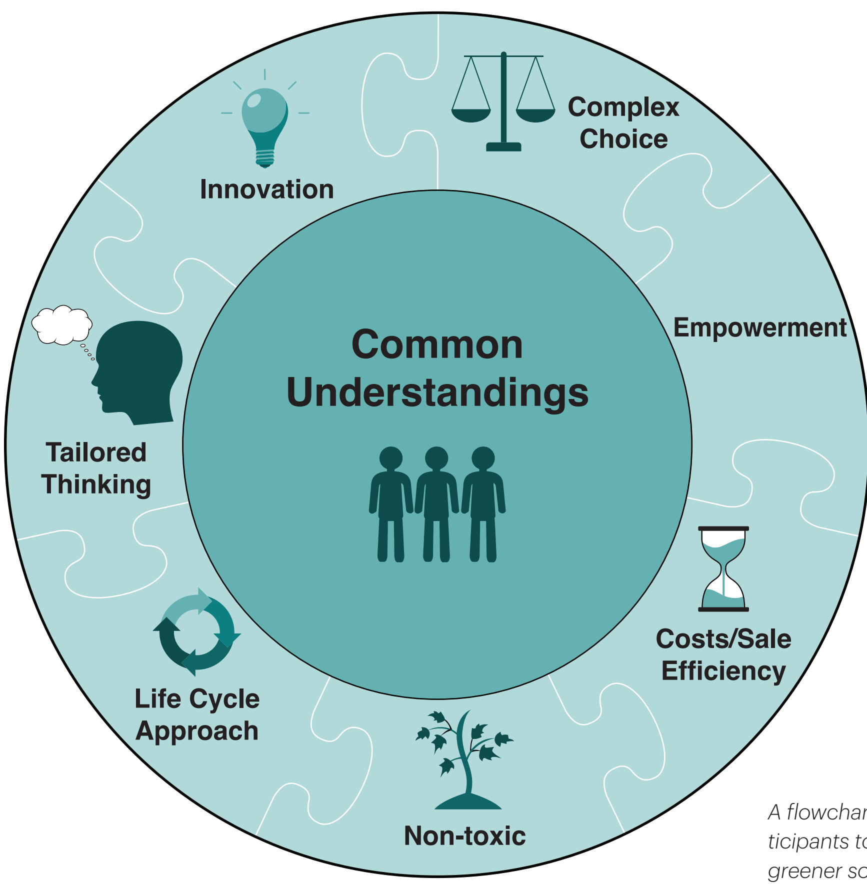
Representing Parameters

This potential mind-set for considering solvent greenness found broad approval. Further, it was agreed that a relatively straightforward way to enable the visual representation for assessment of criteria to compare solvent "greenness" would be highly beneficial.

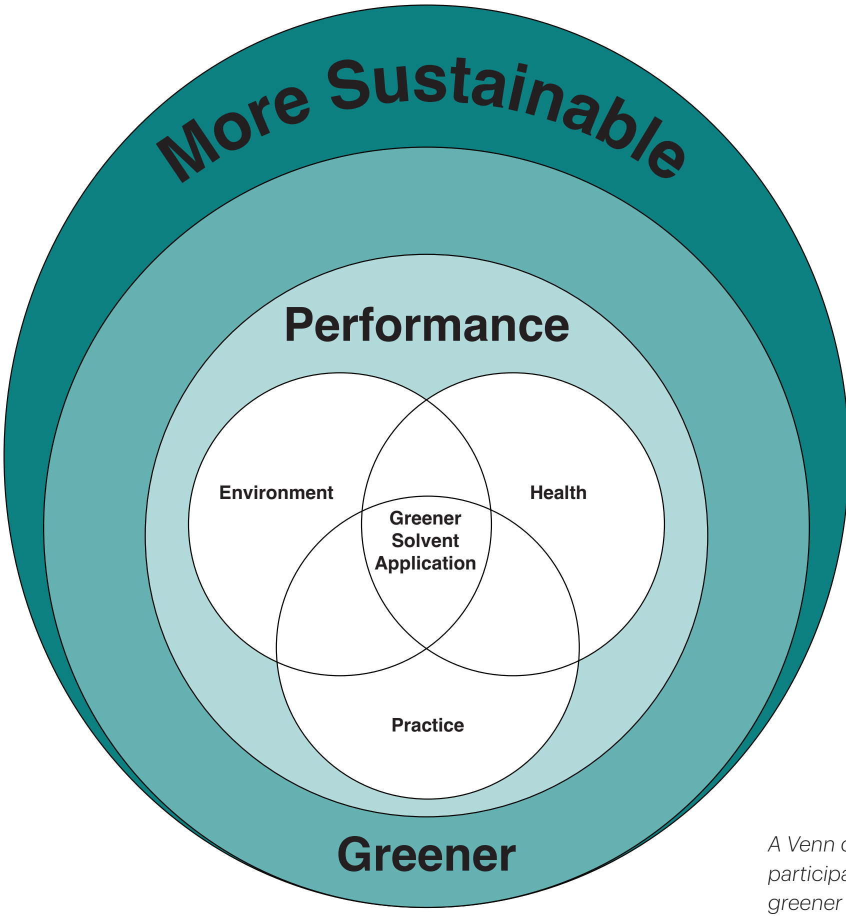
However, in the short time frame of the expert meeting, agreement on how the parameters should be represented in a diagram, as well as whether the discussed parameters should be relatively weighted, was not fully resolved.[15]

From a practical perspective, enabling conservators to compare and select greener solvents in their practice requires some clear definitions and relative ranking. With some highly toxic solvents still considered for use in conservation—albeit as a "last resort"—good arguments were made in favor of a tiered approach to the criteria, perhaps prioritizing human health and putting certain solvents automatically in a "no" list. However, despite the agreement that certain solvents should not be used, very well-founded caution was expressed for a tiered assessment between parameters. Given the complex decision-making involved in solvent selection in conservation and considering that listing solvents in a ranked way can make other solvents less important, it was also argued that all factors be considered of equal importance in determining "greenness." While the goals of using a greener solvent should be clearly defined, it was recognized that these could vary depending on the individual case and that with chemical advancements, these in general may need to be regularly revisited.

Flow charts, Venn diagrams, and various multiaxes diagrams[16] were put forward as ways to help conservators determine which solvents to test for use, perhaps at the beginning of treatments as part of the decision-making process. It is acknowledged that working properties and performance are critical to a solvent's selection. A solvent must be effective—a poor-performing solvent is not useful and just waste—but ideally, its greener credentials could be considered alongside. Tools for assisting selection in this would empower the conservator.



A flowchart created by one group of meeting participants to represent the parameters for assessing greener solvents in conservation.



A Venn diagram created by one group of meeting participants to represent the parameters for assessing greener solvents in conservation.

Research Priorities

For defining and assessing further research goals, the participants were split into two breakout rooms and asked to define their three to five main priorities in terms of actions. Upon rejoining, the suggestions from each group were written on the board and the participants were asked to select their top three. This gave a ranking of the research directions as described below—from most to least:

- Global survey to provide a state of the field in terms of "solvents use" (*which solvents, trends in use, quantities per year, etc.*), seven votes
- Determining toluene/xylene substitutes (*substitute low polarity, large dispersion force solvents for conservation applications*), five votes
- Adapt CHEM21 to the conservation field (*adapting CHEM21 methodological aspects to our discipline*), five votes
- Sustainability in Conservation's Greener solvent project (*evaluating solvent substitution alternatives on different types of substrates*), five votes
- LCA database on solvents, three votes
- Standardized protocols for comparative analysis, three votes
- Deep eutectics, two votes
- Improved gel systems, two votes
- Dewetting technology from adhesive removal, one vote
- Brush cleaning, zero votes

ABOUT THE CONTRIBUTORS

Conference Attendees

Michael Doutre is an Assistant Scientist at the Getty Conservation Institute, working on the Greener Solvents project focusing on the development of alternative treatments and materials to increase sustainability, reduce environmental harm, and protect the health of conservation professionals. He is also part of the Modern and Contemporary Art Research Initiative, with research focusing on the characterization of paints used on contemporary outdoor painted sculpture, the degradation of plastics used in cultural heritage, and the effects of cleaning treatments on modern paints. He graduated with a BSc in Chemistry from Queen's University and previously worked as a research technologist in the Art Conservation Program at Queen's University. Current GCI project: Greener Solvents, Modern and Contemporary Art Research, Outdoor Sculpture, Preservation of Plastics, Modern Paints.

Gwendoline Fife is an independent art conservation consultant, Director of Sustainability in Conservation's Greener Solvent Project, and working for the Rijksmuseum in GOGREEN (Horizon Europe 2022–26). After her chemistry degree from York University, she trained in easel painting conservation at the Courtauld Institute of Art, London. Following her Mellon Fellowship at the Walters Museum in Baltimore, she has worked for over twenty five years as a paintings conservator and researcher in various museums and institutions in the United States, Ireland, and The Netherlands. She has regularly published her work and research, and with expertise in solvent effects on paint films, she has been providing international lectures and workshops on sustainable solvent approaches in conservation practice since 2009. In her consultancy, she aims to provide clients and organizations coordinated solutions with the best treatment for the individual artwork.

Rosie Grayburn is the Head of the Scientific Research and Analysis lab at Winterthur Museum, Garden and Library and Affiliated Associate Professor in the Winterthur/University of Delaware in Art Conservation, where she teaches conservation science and analytical methodologies to graduate fellows in art conservation. In her current role, she facilitates research in a broad variety of materials. Her main areas of research are currently Victorian pigmented bookcloth and the optimization and study of treatments for silver and silverplate. She was previously a postdoctoral fellow in Conservation Science at the Getty Conservation Institute in Los Angeles, where she worked with Alan Phenix on greening organic coatings for outdoor bronze sculpture. She is the Research Coordinator for the Sustainability in Conservation's Greener Solvent Project. Rosie holds a joint PhD in Physics and Analytical Chemistry from Universiteit Gent and the University of Warwick.

Melinda Keefe is an R&D Director in the central research organization within Dow. She is responsible for a global team and capabilities that enable Formulation & Materials Science–based technical solutions for Dow businesses and customers. She is also responsible for Dow's R&D Laboratory Automation team that designs, builds, and implements bespoke robotic and process control systems to enhance the safety, reliability, and speed of Dow R&D. In this role, she collaborates broadly to deliver on a robust portfolio of business projects, corporate innovation-funded projects, and university partnerships. She received a BS in Chemistry from the Pennsylvania State University in 1997 and a PhD in Inorganic

Chemistry from Northwestern University in 2001. She joined Dow in 2001 on the RAP program based in Midland, Michigan.

Katrien Keune, chemist, is Head of Science at the Rijksmuseum Amsterdam and full professor by special appointment of Molecular Spectroscopy at the University of Amsterdam (UvA), Netherlands. The Science department, a subdepartment of Conservation & Science, conducts research on the Rijksmuseum collection in close collaboration with conservators, curators, and (technical) art historians. Keune is specialized in aging and degradation studies of pigments and oil paintings at the micro- and molecular levels. She initiated and (co)led many national and international interdisciplinary research projects funded by programs such as Horizon Europa, EU-H2020, EU-JPI, NWO-NICAS, and NWO-TALENT. One such project is the GOGREEN project (Horizon Europa, 2022–26), of which Keune is the coordinator. This project aims to develop green strategies to conserve the past and preserve the future of our cultural heritage. At the Rijksmuseum, she leads the scientific research of Operation Night Watch, the largest research project on Rembrandt's masterpiece.

Klaus Kümmerer is the Director of the Institute of Sustainable Chemistry, chair of Sustainable Chemistry and Material Resources at the public Leuphana University Lüneburg, where he developed and leads the online study programs "Sustainable Chemistry" (MS) and "Managing Sustainable Chemistry" (MBA). He is also the Director of the Research and Education Hub of the International Sustainable Chemistry Collaborative Centre (ISC3) in Bonn. He serves on national and international committees, including Global Chemical Outlook by UNEP and the EU Technology Platform SusChem Europe, as well as IUPAC Interdivisional Committee on Green Chemistry for Sustainable Development (ICGCSD), and is an active voting member in the European Chemical Society (EuChemS). He has recently been appointed by the European Commission as a member of the European Commission's High-Level Roundtable on the Chemical Strategy for Sustainability. He is also the initiator and chair of the annual interdisciplinary Green and Sustainable Chemistry Conference and the annual Summer School Sustainable Chemistry for Sustainable Development. He is founding editor and editor-in-chief of *Sustainable Chemistry and Pharmacy* (IF 5.5) and *Current Opinion in Green and Sustainable Chemistry* (IF 8.4) journals as well as associate editor of *Chemosphere and Environmental Pollution*. Kümmerer's research and teaching are focused on green chemistry, sustainable chemistry, green pharmacy, sustainable pharmacy, material resources, aquatic environmental chemistry with a focus on micropollutants, and time in environmental and sustainability research. He has published extensively in international scientific peer-reviewed journals; given many invited, keynote, and plenary lectures; and received national and international awards for his interdisciplinary work.

Tom Learner is head of the Getty Conservation Institute's Science department; he oversees all the Institute's scientific research, developing and implementing projects that advance conservation practice in the visual arts. He was a GCI senior scientist from 2007 to 2013, overseeing the Modern and Contemporary Art Research initiative, during which time he developed an international research agenda related to the conservation of modern paints, plastics, and contemporary outdoor sculpture. Prior to his arrival at the GCI, he served as a senior conservation scientist at Tate, London, where he developed Tate's analytical and research strategies for modern materials and led the Modern Paints project in collaboration with the GCI and National Gallery of Art in Washington, D.C. He was a GCI Conservation Guest Scholar in residence in 2001. Learner is both a chemist and a conservator, with a PhD in Chemistry from Birkbeck College, University of London, and a diploma in the conservation of easel paintings from the Courtauld Institute of Art.

Fransisco Mederos-Henry is a heritage scientist, holding a PhD in chemistry of (nano)materials from the Catholic University of Louvain (UCLouvain, Belgium) and a master's degree in conservation-restoration from the Western School of Conservation and Restoration (ECRO, Mexico). He currently holds a professorship in heritage and applied sciences at the Art Conservation-Restoration department of the National School of Visual Arts of La Cambre (ENSAV-La Cambre, Belgium), where he teaches the chemistry of materials and coordinates research activities related to undergraduate thesis projects for the master's program. He is also the leading researcher at the Polychromed Artifacts Laboratory of the Royal Institute of Cultural Heritage (KIK-IRPA, Belgium), where he conducts research on the chemical transformation of oil pictorial layers and the development of new materials and restoration techniques. He has recently been appointed associate researcher and invited professor at the Archaeology and Heritage Research Centre (CreA-Patrimoine) from the Free University of Brussels (ULB).

Sarah Nunberg is an objects conservator in Brooklyn, New York, treating a range of cultural heritage materials while focusing on preventive care and sustainable environmental management. As a Principal Investigator for a National Endowment of Humanities Grant to create STiCH, Sustainability Tools in Cultural Heritage, Sarah leads studies in life cycle assessment (LCA) for sustainable practices in cultural heritage and continues this work as the 2021–22 Adele Chatfield-Taylor Rome Prize recipient in Historic Preservation and Conservation. Sarah is an adjunct professor at Pratt Institute, Math and Science department. She received her advanced certificate in conservation and her MA in Art History from the Institute of Fine Arts Conservation Center at New York University in 1994 and her MA in Archaeology from Yale University in 1990.

Silvia Prati is the Associate Professor, Chemistry for the Environment and Cultural Heritage at the University of Bologna. Her research activities are related to the development of advanced analytical methods for the investigation of artistic and historical objects and of innovative materials for restoration with parts. In particular, she is involved in the setting up of methods based on the integration between hyperspectral spectroscopic techniques and advanced data processing elaboration. Moreover, in the frame of national and international projects, she is coordinating the activities related to the design and testing of new green materials for restoration that are respectful of the work of art, the operator, and the environment. Prof. Prati is the Deputy for the Didactic Activities, member of the Center of Didactic Innovation and PhD Board of the School in Environmental and Cultural Heritage at the University of Bologna; member of the board of the Italian Society of Environmental and Cultural Heritage Chemistry Leader of the WP "Green Cleaning Method" European Project, Green Strategies to Conserve the Past and Preserve the Future of Cultural Heritage, GOGREEN (Horizon Europe 2022–26); and leader of the WP "Development of Cleaning Procedures" National PRIN Project, Sustainable Preservation Strategies for Street Art, SuperStar.

Laura Rivers is an Associate Conservator in the Department of Paintings Conservation at the J. Paul Getty Museum in Los Angeles, where she has worked since 2010. She works primarily on collaborative conservation projects, undertaking the study and treatment of paintings that come to the Getty from other institutions in the United States and abroad. She holds an MA in Art History from the University of Chicago and an MS in Art Conservation from the Winterthur/University of Delaware Program in Art Conservation. Her conservation training has included internships and positions at the National Gallery of Art, Washington, D.C.; the Barnes Foundation; the Philadelphia Museum of Art; and the Menil Collection in Houston, Texas. From 2012 to 2014, she was a member of a project team of Getty Museum conservators and Getty Conservation Institute scientists, working together to study and undertake the conservation of Jackson Pollock's largest painting, *Mural*. Her repeated professional encounters with large wax-lined paintings and acrylic varnishes have inspired her ongoing interest in lower-toxicity solvents.

Hannes Sels has obtained his degree as an engineer in environmental sciences at the Howest University of Applied Sciences in 2009. His master's thesis was about modeling the impact of emission reduction measures on in-stream concentrations in surface water bodies, coupled to an economic optimization model to set up cost-effective emission reduction scenarios. Sels works as a researcher and lecturer at the Karel de Grote University of Applied Sciences and Arts. He teaches organic chemistry and green chemistry, both theory and practice. He is a member of the Research Center on Sustainable Industry, where he focuses on the application and selection of greener solvents and the use of artificial intelligence and other modeling technologies to improve sustainability of the (chemical) industry.

Chris Stavroudis is a paintings conservator in private practice in West Hollywood, California. Chris obtained undergraduate degrees in Chemistry and Art History from the University of Arizona and his master's degree from the Winterthur University of Delaware Program in Art Conservation. He wrote and continues to develop the Modular Cleaning Program (MCP) and has taught over twenty-five workshops on using the MCP. He is one of the four co-instructors of the Getty Conservation Institute's Cleaning Acrylic Paint Surfaces (CAPS) workshops. He was formerly on AIC's Health and Safety and Emergency Committees and is an active AIC CERT volunteer as well as writing the Health and Safety column for the *WAAC Newsletter*.

Bart Wuytens is a Research Leader at Agfa-Gevaert, responsible for the physicochemistry department, with expertise in particle sizing, rheology, tensiometry, dispersion analysis, solubility, and thermal analysis. Bart graduated in 1988 from the Rega-school (KUL) with distinction as a bachelor in Industrial Chemistry and immediately started at Agfa-Gevaert in the lab Functional Analysis. Working in the analytical department, he gained a high level of expertise in structure elucidation using the combination of spectroscopic techniques and chromatography. In 2008, he started the new colloid lab, as part of the IWT Hypercure project (Control of functional properties of UV inks for high-throughput industrial inkjet systems), studying pigment–dispersant interactions, using calorimetry, quartz crystal microbalance, and solubility parameters. In 2013, he became responsible for the physicochemistry department, with strong emphasis on particle sizing in the submicron range, using centrifugal, laser scattering, and fractionation techniques.

Additional Contributors

Fergal Byrne is the Assistant Professor in Sustainable Chemistry at Maynooth University, with extensive knowledge in a wide range of areas of sustainability, circular economy, and bioeconomy. He is also the CEO of Addible, where they are developing a new solvent technology to significantly increase the recyclability of mixed waste streams. Byrne holds a MSc and PhD in Green Chemistry and Sustainable Industrial Technology at the Green Chemistry Centre of Excellence at the University of York. He previously worked as a postdoctoral research associate working on the H2020 BBI-JU funded ReSolve project as well as the Innovate UK funded project, Furafact. He specializes in the design and development of green solvents and their application in plastic recycling, biomass fractionation, synthetic chemistry, and materials production.

Bronwyn Ormsby is Principal Conservation Scientist, Tate, where she leads Tate's Conservation Science and Preventive Conservation team.

Nathalie Palmade-Le Dantec is head of continuing education and assistant to the director of studies at the Institut National du Patrimoine, with research and teaching focus on safer solvent use.

NOTES

Epigraph to the Preamble. UN WCED, A/res/42/187: Report of the World Commission on Environment and Development: Our Common Future (United Nations General Assembly 9th Plenary meeting, December 11, 1987), https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf

1. Ben Purvis, Yong Mao, and Darren Robinson, "Three Pillars of Sustainability: In Search of Conceptual Origins," *Sustainability Science* 14, no. 3 (2019): 681–95.
2. Subdivision to the five pillars (environmental, economic, social, societal, and operational) has been suggested within cultural heritage: David Saunders, "A Methodology for Modelling Preservation, Access and Sustainability," *Studies in Conservation* 67 (2022): 245–52.
3. United Nations Department of Economic and Social Affairs, "Transforming Our World: The 2030 Agenda for Sustainable Development," September 25, 2015, https://sdgs.un.org/2030agenda.
4. https://icom.museum/en/resources/standards-guidelines/code-of-ethics/
5. E.C.C.O. European Confederation of Conservator-Restorers' Organisations A.I.S.B.L.E., "Professional Guidelines (II) Code of Ethics," March 7, 2003, https://www.ecco-eu.org/wp-content/uploads/2021/03/ECCO_professional_guidelines_II.pdf.
6. P. T. Anastas and J. C. Warner, *Green Chemistry: Theory and Practice* (New York: Oxford University Press, 1998), 30.
7. G. R. Fife, ed., *Greener Solvents in Conservation: An Introductory Guide, Archetype Publications and Sustainability in Conservation* (London: Archetype Publications, 2021).
8. Although following CHEM21 methodology is advised—if a solvent is not yet fully evaluated by the governing regulatory body (e.g., REACH), CHEM21 gives default ranking as problematic. This avoids new solvents being suggested as "less toxic" substitutions without due process.
9. https://stich.culturalheritage.org/
10. A known problem with volatile organic compounds (which includes many commonly used solvents) is rather their reactions with NO_x in the creation of ground-level (tropospheric) ozone, where it is not appreciated (smog potential).
11. EU-ECHA database, European Chemicals Agency, REACH legislation (includes POP's, candidates for substitution, etc.), https://echa.europa.eu/; USA-Comptox database, Environmental Protection Agency, https://www.epa.gov/comptox-tools.
12. For instance, classification of CMR substances according to the International Agency for Research on Cancer (IARC) criteria upon which European legislation regarding CRM substances is based. The Classification and Labelling inventory database from REACH lists all dangerous substances, including CMR substances for which CLP legislation is applicable. https://echa.europa.eu/information-on-chemicals/cl-inventory-database?discriminator=DISCLI_HARMONIZED
13. Fife, *Greener Solvents*.
14. G. R. Fife, "Practical Steps to Greener Solutions," in *Greener Solvents in Conservation: An Introductory Guide, Archetype Publications and Sustainability in Conservation*, edited by G. R. Fife (London: Archetype Publications, 2021).
15. However, it is anticipated that these issues will be further tackled in various upcoming projects and organizations (including GOGREEN (Horizon Europe), "Green Strategies to Conserve the Past and Preserve the Future of Cultural Heritage," https://gogreenconservation.eu/.
16. For example, the Solvent Star and GSCE Compass Rose. See G. R. Fife, "The Solvent Star: Assessing and Documenting Solvent Selection," *The Picture Restorer* 56 (2020); V. G. Zuin et al., "Education in Green Chemistry and in Sustainable Chemistry: Perspectives towards Sustainability," *Green Chemistry* 23 (2021): 1594–608.