Green Chemistry and Sound Chemicals Management Workshop

Palm Springs, United States | February 2023

APEC Chemical Dialogue

March 2024

Asia-Pacific
Economic Cooperation

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What is Green Chemistry?

Green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of toxic substances. Green chemistry applies across the life cycle of a chemical product, including its design, manufacture, use, and ultimate disposal.

Twelve principles of green chemistry were originally put forth and published in 1998 by Paul Anastas and John Warner in their book "Green Chemistry: Theory and Practice."[1] These principles are listed below.[2] Others have since put forth variations on the twelve principles by Anastas and Warner and have introduced additional green chemistry principles.

The 12 Principles of Green Chemistry

1. **Prevent waste**: Design chemical syntheses to prevent waste. Leave no waste to treat or clean up.
2. **Maximize atom economy**: Design syntheses so that the final product contains the maximum proportion of the starting materials. Waste few or no atoms.
3. **Design less hazardous chemical syntheses**: Design syntheses to use and generate substances with little or no toxicity to either humans or the environment.
4. **Design safer chemicals and products**: Design chemical products that are fully effective yet have little or no toxicity.
5. **Use safer solvents and reaction conditions**: Avoid using solvents, separation agents, or other auxiliary chemicals. If you must use these chemicals, use safer ones.
6. **Increase energy efficiency:** Run chemical reactions at room temperature and pressure whenever possible.
7. **Use renewable feedstocks**: Use starting materials (also known as feedstocks) that are renewable rather than depletable. The source of renewable feedstocks is often agricultural products or the wastes of other processes; the source of depletable feedstocks is often fossil fuels (petroleum, natural gas, or coal) or mining operations.
8. **Avoid chemical derivatives**: Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.
9. **Use catalysts, not stoichiometric reagents**: Minimize waste by using catalytic reactions. Catalysts are effective in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and carry out a reaction only once.
10. **Design chemicals and products to degrade after use**: Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.
11. **Analyze in real time to prevent pollution**: Include in-process, real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts.
12. **Minimize the potential for accidents**: Design chemicals and their physical forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.

The practice of green chemistry in industrial settings is highly desirable as it prevents pollution at its source. APEC economies strive to preserve the environment but may lack the expertise to design regulatory systems to achieve this outcome. In 2023, the APEC Green

Chemistry Workshop made efforts to bridge this gap with APEC economies presenting on best practices and sharing their experiences within today's green chemistry landscape. During the workshop, presenters spoke to the impacts that green chemistry initiatives have had in improving environmental performance while fostering innovation and a competitive edge. In this report, global innovations are highlighted, including a deep dive into specific case studies on green chemistry applications that have led to reductions in the use of toxic chemicals, energy, water, and generation of chemical wastes. These examples, along with the resources collected, can serve as models for APEC economies looking to adopt and promote green chemistry.

Performance and Cost

The goal of the chemical industry is to create useful products that will be successful in the marketplace. Research and development costs associated with creating new chemicals for the market are immense and businesses will, rightfully so, seek to recoup those upfront costs. The cost equations used by industry when developing new chemicals for the market should explore a green chemistry component. Early chemical design that incorporates green chemistry is ideal for achieving cost savings in reduced manufacturing costs with lower feedstock costs, improved energy efficiency, reduction in solvents used, higher conversion rates, and fewer quantities of unwanted chemical wastes that otherwise would need to be managed, therewith reducing the costs associated with managing chemical wastes. Redesigning chemicals to be greener can also significantly reduce the indirect costs of regulatory compliance (proper storage, treatment, disposal, etc.).

Developing products with green chemistry may also result in an improved brand image and increased consumer confidence for manufacturers. APEC economies may find it beneficial to develop labeling systems that identify products that meet specific environmental and health criteria. For example, EPA's Safer Choice label empowers consumers to make informed decisions about the environmental impacts of the manufacture and use of products available for purchase. Products with the Safer Choice label help consumers and commercial buyers identify products with safer chemical ingredients, without sacrificing quality or performance. Ultimately for industry adoption, green chemistry innovations must deliver a significant competitive advantage in the form of cost savings that incorporate environmental benefit(s).

Greenness Scoring Methods and Tools

Since green chemistry's inception, there has been a demand for green analytical methodology. How can adopters of green chemistry practices verify their actions are cost saving, the formulations developed are effective, and the environmental benefits are real? In response, pharmaceutical companies, along with other industry leaders, academia, and the chemical scientific community have been working together to develop scoring methods, calculators, and other tools. Industry leaders often share open-source data to advance the development of these tools. Below is a list of some of the most implemented methodologies and tools.

Scoring Methods and Tools

Analytical Eco-Scale Assessment (ESA)[3] – is a method that involves a quantitative assessment of the analytical method and is used to compare different analytical methods for the evaluation of greenness. It displays the amount of material being consumed and the waste generated during the experiment.

Analytical Greenness Calculator[4]– is a tool for evaluating the environmental and occupational hazards associated with a particular analytical procedure based on the 12 principles of Green Analytical Chemistry.[5] The result of the assessment is translated into a graph that is easy to interpret and contains an overall score, as well as an indication to what degree the evaluated procedure conforms to each of the 12 principles. It can be used to compare different methods to select the one with the lowest environmental impact or to identify possible trouble spots in terms of "greenness" during the conceptualization and development of novel analytical procedures.

Analytical Method Greenness Score (AMGS) Calculator[6]– the American Chemical Society Green Chemistry Institute's Pharmaceutical Roundtable created the AMGS calculator to inform and guide users toward greener methods. The AMGS metric factors solvent health, safety, environmental impact and cumulative energy demand, instrument energy usage, and method solvent waste to benchmark and compare one method to another.

Bristol Myers Squibb (BMS) Process Greenness Scorecard[7] – is a web-based tool that was developed to capture and analyze several metrics and attributes for each step in the synthetic sequence used to produce an API.

Greenscope[8]– allows for quantifying process sustainability and Life Cycle Inventory (LCI) generation by employing 139 performance indicators in four main areas: material efficiency, energy, economics, and environment. Indicators are summary measures that provide information on the state of, or change in, the system that is being measured. Indicators can translate the following information into a sustainability measurement scale that includes process performance, feedstocks, utilities, equipment, and output information. Greenscope is designed to directly provide process-specific data into the U.S. Life Cycle Assessment (LCA) Commons Database for conducting LCAs.

Green Analytical Procedure Index (GAPI)[9] – evaluates the "green character" of an entire analytical methodology, from sample collection to final determination, and was created using such tools as the National Environmental Methods Index (NEMI) or Analytical Eco-Scale to provide not only general but also qualitative information. In GAPI, a specific symbol with five pentagrams can be used to evaluate and quantify the environmental impact involved in each step of an analytical methodology, mainly from green through yellow to red depicting low, medium to high impact, respectively.

National Environment Methods Index (NEMI)[10] – is a searchable database of environmental methods, protocols, statistical and analytical methods, and procedures that allows scientists and managers to find and compare methods for all stages of the monitoring process. In NEMI, a method can be a traditional determinative method executed in a laboratory setting, a toxicity assay, or a statistical technique reference for use in analyzing data. The NEMI platform has grown to include information on field techniques, sensors, and even statistical methods useful in the environmental monitoring field.

Solvent Selection Tool[11]– allows you to interactively select solvents based on the Principal Component Analysis (PCA) of the solvent's physical properties. Solvents that are close to each other on the map have similar physical and chemical properties, whereas distance solvents are significantly different. In addition to the PCA scores, other data including the physical properties, functional groups, and environmental data has been included to aid in the rational selection of solvents.

Summary of Purpose of the Green Chemistry Project

The objective of this project is to promote collaboration, knowledge sharing, and awareness within APEC member economies on green chemistry innovations, practices, successes, and policies. To this end, the project seeks to extend the application of green chemistry and related source reduction practices for the sound management of chemicals among regulators, industry, and supply chain stakeholders. Policies and initiatives that embrace sustainability and pollution prevention can help support APEC economies and lead to widespread improvements in environmental performance globally among industry sectors.

The APEC Green Chemistry and Sound Chemicals Management Workshop, referred to as "the workshop" in this document, was approved by the APEC Chemical Dialogue as part of the 2023 funding cycle.

The workshop, which took place in February 2023 during the First Senior Officials' meeting in Palm Springs, California, was designed to embrace the three goals of the APEC Chemical Dialogue Strategic Framework, which are to:

1) Facilitate trade and raise the standard of sound management of chemicals by expanding and supporting regulatory cooperation and regulatory alignment in the region;

2) Promote the understanding of the chemical industry's role as a provider of innovative solutions for sustainable economic, environmental, and social development; and

3) Enable effective cooperation between industry and governments to improve chemical product stewardship and environmental performance.

Figure 1: APEC Green Chemistry Workshop participants in Palm Springs, CA. In addition to delivering presentations, speakers took part in a panel discussion on chemical source reduction practices, tools, and barriers to implementation.

Following introductions, the workshop began with UNEP representative, Mr. Achim Halpaap. Mr. Halpaap presented the key findings of the UN Environment Programme's 2019 report, "Global Chemicals Outlook II: From Legacies to Innovative Solutions" and provided examples on how key messages have informed discussions at the UN Environment Assembly (UNEA) on green and sustainable chemistry, negotiations on the strategic approach, and looking towards chemical and waste management beyond 2020.

Dr. Stephen DeVito discussed how the United States Environmental Protection Agency (EPA) leverages information compiled in the EPA's Toxics Release Inventory (TRI) to track the implementation of green chemistry and other source-reduction practices and shared the impact that such practices have had on environmental performance. TRI provides public access to data on toxic chemicals. These data include the quantities of toxic chemicals industrial facilities release annually to air, land, and water, recycle, and treat for destruction or combust for energy recovery. Additional information provided by the facilities include newly implemented source reduction practices, including green chemistry practices, as well as impediments (barriers) facilities have encountered in implementing source reduction activities. Dr. DeVito emphasized that the TRI serves as a powerful tool for analyzing trends and identifying opportunities for improvement. Dr. DeVito encouraged facilities to go beyond the mandatory reporting to share additional details about their green chemistry initiatives as well. Through showcasing industry accomplishments and providing incentives, the EPA aims to foster a culture that promotes green chemistry practices.

Dr. Andrew Liu, a representative from Chemours, explored the industry perspectives on the challenges and benefits of incorporating green chemistry, and the UN Sustainable Development Goals (SDGs) performance indicators, in the innovation process to maximize societal contributions. Dr. Liu spoke of the critical role of the chemical sector in enabling solutions for the SDGs while minimizing their environmental footprint. Dr. Liu discussed the power of innovation in addressing societal and sustainability challenges, citing remarkable advancements in energy efficiency and life expectancy. He also discussed the importance of businesses embracing and leveraging innovation to overcome obstacles and capitalize on other opportunities in the pursuit of greener practices.

Mr. Alexis Gagnon from Environment and Climate Change Canada discussed how the Government of Canada is addressing substitution challenges associated with chemicals of concern, including in products, and how this may support green chemistry initiatives in Canada. Mr. Gagnon spoke on the Canadian Environmental Protection Act (CEPA), which is the primary legislation for preventing pollution and protecting the environment and human health from chemicals. The act sets out several guiding principles including pollution prevention, the precautionary principle, and sustainable development. He then discussed the Chemicals Management Plan (CMP), a science-based program implemented under CEPA to identify, assess, and manage risks posed by new and existing chemical substances. He also discussed proposed amendments to CEPA (Bill S-5)[12] to modernize Canada's chemicals management approach by encouraging progressive substitution, considering class-based assessments for risk assessment, establishing watch lists for chemicals with hazardous properties, and emphasizing the importance of labeling to properly inform Canadians.

Dr. Dieldrich Bermúdez, a representative from Stepan, discussed Stepan's collaborative product safety program. The presentation included a discussion on assessment tools and method selection as well as the coordinated new product development and safety assessment process. Dr. Bermúdez explored how early adoption of innovative processes, such as cross-functional teams and collaborations, is important to achieving better product safety and sustainability, a crucial facet for the long-term success of new products. He also discussed how external engagements and collaborations may give companies a voice in how products are viewed or assessed by both regulatory authorities and non-governmental organizations.

Dr. Chun-sheng Wu of the Chinese Taipei Environmental Protection Administration discussed the green chemistry strategies and experiences of Chinese Taipei. Dr. Wu's presentation covered strategies including Industrial Visiting and the Green Chemistry Application & Innovation Award, which are two programs to encourage industry to adopt green chemistry concepts. Dr. Wu also discussed the applications ChemiCloud, a tool used to strengthen inter-ministerial coordination and quickly collect data about manufacturers and chemical substances, as well as the Searching, Assessment, and Screening System (SAS system), which provides hazard assessments, overall risk levels, and safer alternative chemicals to aid domestic industries in adapting green chemistry principles.

Lastly, Dr. Chun-hsu Lin from Chinese Taipei's Chung-Hua Institution for Economic Research discussed how to promote green chemistry with enterprises from the perspective of non-governmental organizations (NGOs) and shared best practices. Dr. Lin placed a strong emphasis on education, training, and the importance of increased collaboration between academia, industry, and government on green chemistry principles. Chinese Taipei's Center for Green Economy (CGE) has taken on several initiatives to work toward these goals including providing online courses, establishing the Circular Economy Award, and holding Chemical Public Private Dialogue Meetings. Dr. Lin also discussed the lack of quantitative assessment of individual chemical substances and the need for better chemical assessment tools. Dr. Lin closed his presentation that moving forward, cooperation will facilitate the transformation of advancing toward better green chemistry practices.

Figure 2: APEC Green Chemistry Workshop moderator, Hilary French, asks panelists to discuss their advancements of green chemistry.

Post-Workshop Survey and Findings

The workshop drew a total of 43 participants from 10 APEC economies. Of the 43 participants, 29 were in-person and the other 14 were virtual. A post-Workshop survey was sent to each of the participants. The key findings and challenges identified as a result of the workshop and survey are listed below. These findings and challenges were used to develop this report and will have value in informing future discussions on the adoption of green chemistry practices among APEC economies. The findings of the workshop also helped identify case studies that serve as potential examples of green chemistry best practices.

Key Findings	**Challenges**
• There is substantial interest from APEC economies to learn more; specifically, on how best to advance green chemistry. • Actions taken by economies on green chemistry are limited to a few active economies. • Clear guidance for APEC economies on how to implement green chemistry principles are needed.	• As anticipated, there is a knowledge gap in the understanding of what green chemistry is and how it is applied by regulators and industry. • Actions taken by APEC economies on green chemistry are limited to a few active economies. • Adoption by industry is hindered by the length in production time bringing a product to market paired with its economic benefits.

Green Chemistry Case Studies

The adoption of green chemistry practices as the preferred approach for the sound management of chemicals will require the combined efforts of various stakeholders, including government agencies, industry leaders, and innovative companies. The case studies mentioned below are notable successful initiatives that promote green chemistry principles and drive sustainable practices within the chemical industry.

The U.S. EPA's Safer Choice program, Captia Aire LLC's CAIRE™ Technology that converts terpenes into valuable chemicals, Genomatica's sustainable production of Brontide, and Chinese Taipei's Green Chemistry Application and Innovation Awards all highlight the chemical industry's innovation that promote green chemistry. These endeavors encourage the adoption of sustainable practices, inspire innovation, and drive the development of safer and more environmentally friendly products. By encouraging collaboration, promoting the sharing of knowledge, and providing incentives, these initiatives play a critical role in shaping a greener future. They showcase the immense potential for creating a mutually beneficial relationship between industry and the environment, where economic growth goes hand in hand with sustainability and the well-being of individuals while minimizing harmful impacts on ecosystems.

Case Study 1: U.S. EPA's Safer Choice Program

The U.S. EPA's Safer Choice Program[13] is an initiative that promotes the development and use of environmentally friendly products used in cleaning products, automotive maintenance, and personal care products. EPA works in collaboration with a broad range of stakeholders including industry partners and environmental groups to promote the Safer Choice Program's goal of encouraging the use of innovative chemical products and practices that benefit human health and the environment. By providing a labeling system that identifies products that meet specific environmental and health criteria, EPA empowers consumers to make informed decisions about the environmental impacts of the manufacture and use of products available for purchase. Products with the Safer Choice label help consumers and commercial buyers identify products with safer chemical ingredients, without sacrificing quality or performance. Product manufacturers strive to develop products that meet the Safer Choice program's specific environmental and health criteria so that they can market their products with the EPA's Safer Choice label.

Figure 3: The U.S. EPA's Safer Choice Label.

EPA conducts evaluations of product ingredients to assess their impact on human health and the environment. Using technical assistance and expertise, EPA guides companies in the selection of safer chemicals and encourages the use of sustainable manufacturing practices. By participating in the Safer Choice program, companies demonstrate their commitment to producing products that prioritize both human well-being and environmental protection. A survey conducted in 2020 by the Safer Choice program of over 2,000 adult United States residents revealed that 81% of consumers would rely on the Safer Choice label to inform their purchasing decisions, indicating a strong demand for safer and more sustainable products.

The Safer Choice program serves as an example of how collaboration between a federal regulatory agency and industry can drive the development of safer consumer products. By bridging the gap between industry and consumers through a revered and trusted labeling system, the Safer Choice program equips individuals with the knowledge to choose products that meet EPA's Safer Choice criteria. With the Safer Choice program, EPA and its industry partners have showcased the utility of green chemistry in the development of safer chemical products.

Case Study 2: Captis Aire LLC's Greener Reaction Conditions

In 2023, Captis Aire was recognized for the patent pending CAIRE™ Technology that converts terpenes, a waste product produced during the wood manufacturing process, into valuable chemicals. Currently these terpenes, when above normal biogenic levels are an air pollutant and an irritant to eyes, lungs, and skin, are burned as waste which releases greenhouse gases. The CAIRE™ Technology captures over 90% of the terpenes released from the wood products manufacturing process and converts them into many valuable chemicals including those used in products such as biofuels, flavors, and fragrances.

Organic pine chemicals called terpenes are released from wood product manufacturing processes that dry green pine wood. These manufacturing processes are often situated in rural disadvantaged communities. Currently, the baseline management for these terpenes is "end of pipe" treatment, which uses natural gas to burn these molecules, releasing carbon dioxide (CO2), a greenhouse gas (GHG). Rather than directly burning bioderived carbon and emitting GHGs, the patent pending CAIRE™ Technology captures >90% of the terpenes and converts this waste into valuable chemicals. The CAIRE™ Capture Technology has four steps: 1) terpene adsorption using a specialized reusable adsorbent media to clean the air, 2) desorption to release the terpenes in vapor form into nitrogen gas, 3) condensation of vapors to liquid terpenes, and 4) reactivation to superheat the specialized media and maximize capture efficiency. These versatile terpene building blocks can then be processed into many valuable chemicals that can be used as components of biofuels, flavors, fragrances, etc. Three successful demonstrations at commercial wood product manufacturing facilities showed the ability to reduce GHGs and transform hazardous pine chemical wastes into purified terpenes. For its advancements, Captis Aire LLC is the 2023 recipient of the U.S. EPA's and American Chemical Society's prestigious Green Chemistry Challenge Award in the category of Greener Reaction Conditions.[14]

Case Study 3: Genomatica's Environmentally Friendly Manufacturing

In 2020, Genomatica, a biotechnology company that develops biological-based processes for the manufacture of chemicals, undertook a project aimed at developing a more environmentally friendly method for the manufacture of 1,3-butylene glycol, a chemical commonly used in personal care products and cosmetics.[15] The traditional production methods for 1,3-butylene glycol involve the use of petroleum-based chemicals, resulting in substantial greenhouse gas emissions. Genomatica's alternative process for the manufacture of 1,3-butylene glycol utilizes renewable feedstocks and fermentation techniques, specifically the fermentation of certain sugars by *E. coli* in a one-step production process. To address this issue, Genomatica leveraged its expertise in biotechnology to conduct a life cycle assessment on the environmental impact of the company's alternative production process for the manufacture of 1,3-butylene glycol. Genomatica refers to 1,3-butylene glycol manufactured from its biological-based process as Brontide, to distinguish it from 1,3-butylene glycol made from the traditional production methods.

Genomatica determined that the alternative manufacturing method resulted in a reduction of approximately 50% in greenhouse gas emissions and energy consumption compared to conventional butylene glycol production. Also, Genomatica's manufacturing process further enhanced the overall environmental performance by minimizing the release of toxic chemicals and reducing the use of toxic metals. This led to a cleaner and safer production process, aligning with the principles of green chemistry. Lastly, Brontide met the industry's quality standards and demonstrated comparable performance to 1,3-butylene glycol manufactured from petroleum-based materials. 1,3-Butylene glycol manufactured from

Genomatica's process is equally efficacious to 1,3-butylene glycol manufactured from the traditional manufacturing process.

For development of their biobased-process for manufacturing 1,3-butylene glycol Genomatica was the 2020 recipient of the U.S. EPA's and American Chemical Society's prestigious Green Chemistry Challenge Award in the category of Greener Synthetic Pathways.[16] Genomatica's success in developing a green synthetic pathway for the manufacture of butylene glycol exemplifies the utility of green chemistry in the chemical enterprise as the preferred approach to the sound management of chemicals.

Case Study 4: Chinese Taipei's EPA Green Chemistry Application and Innovation Award

Through the pursuit of fostering sustainable chemistry practices, the Chinese Taipei's Environmental Protection Agency (EPA) Green Chemistry Application and Innovation Award serves as an inspiration for the chemical industry.[17] Since its inception in 2018, there have been nearly 150 participants who have worked on projects that showcase innovative methods, scientific excellence, or significant improvements in environmental performance in chemical substance management, green chemistry education, safer material alternatives, or disaster prevention and preparation. By illuminating the importance of these activities, this award program raises awareness and piques the interest of stakeholders, inspiring other leaders in enterprises, research institutions, and education to embrace green chemistry principles.

Through the rigorous application and evaluation process, participants have the opportunity to engage in meaningful dialogue, exchange ideas, and draw insights from one another's experiences. This collaborative environment encourages the sharing of best practices among the many diverse stakeholders, and the widespread adoption of green chemistry principles, while fostering the development of creative solutions to environmental challenges. The award program catalyzes a sense of shared purpose in the chemical industry to collectively drive positive change.

Like the prestigious U.S. EPA's Green Chemistry Challenge Awards program, one of the most significant impacts of the Chinese Taipei's Green Chemistry Application and Innovation Award lies in its ability to incentivize the adoption of green chemistry practices. Winning this accolade serves as a motivator for companies to invest in research and development efforts focused on sustainable chemistry. By highlighting the achievements of award recipients, the program enhances the industry's reputation, leading to increased consumer trust and strengthening market competitiveness.

Current Global Landscape of Green Chemistry

Globally, there have been remarkable advancements in the application of green chemistry practices over the last two decades. Through the work of experts, such as those featured in the 2023 APEC Green Chemistry and Sound Chemicals Management Workshop, and those who pilot the type of work featured in case studies such as those mentioned above, advancements in green chemistry will continue to occur and shape the future of the chemical enterprise.

Looking forward, it is important to consider the many initiatives that are being undertaken throughout the world. These initiatives will prove to be invaluable resources to bolster advancements both in economies that are already investing in green chemistry as well

as in economies that are just starting to invest in these concepts and ideas or considering doing so.

Understanding the perspectives of global leaders in green chemistry is just a starting point, but these initiatives are currently helping to shape the future of the sound management of chemicals. This section of the report is a snapshot of the work being done globally to advance green chemistry. While the examples provided below are by no means comprehensive, the intent is that these examples will motivate others to think about these advancements and frame them as the benefits that green chemistry can bring to each individual local economy.

United Nations Environment Programme (UNEP)

The UN Environment Programme (UNEP) worked with over 100 experts to develop the Framework Manual and the Ten Objectives and Guiding Considerations for Green and Sustainable Chemistry.[18] In 2019, at the 4th session of the United Nations Environment Assembly (UNEA), Resolution 4/8 was adopted. This resolution was to "welcome the analysis of best practices in sustainable chemistry and recognize the value of developing a better understanding of sustainable chemistry opportunities." This resolution was the catalyst to UNEP's work to analyze best practices in green and sustainable chemistry and develop the Framework Manual.

This work was further solidified in 2022 during the 5th session of UNEA where resolution 5/7 on the sound management of chemicals and waste was adopted. This resolution welcomed the UNEP Green and Sustainable Chemistry Framework Manual which can be found in UN resources today. As summarized on the UNEP website, the framework highlights 10 objectives and guiding considerations for green and sustainable chemistry. These 10 objectives, displayed below, "range from green molecular design to ensuring that chemistry works to address societal needs."

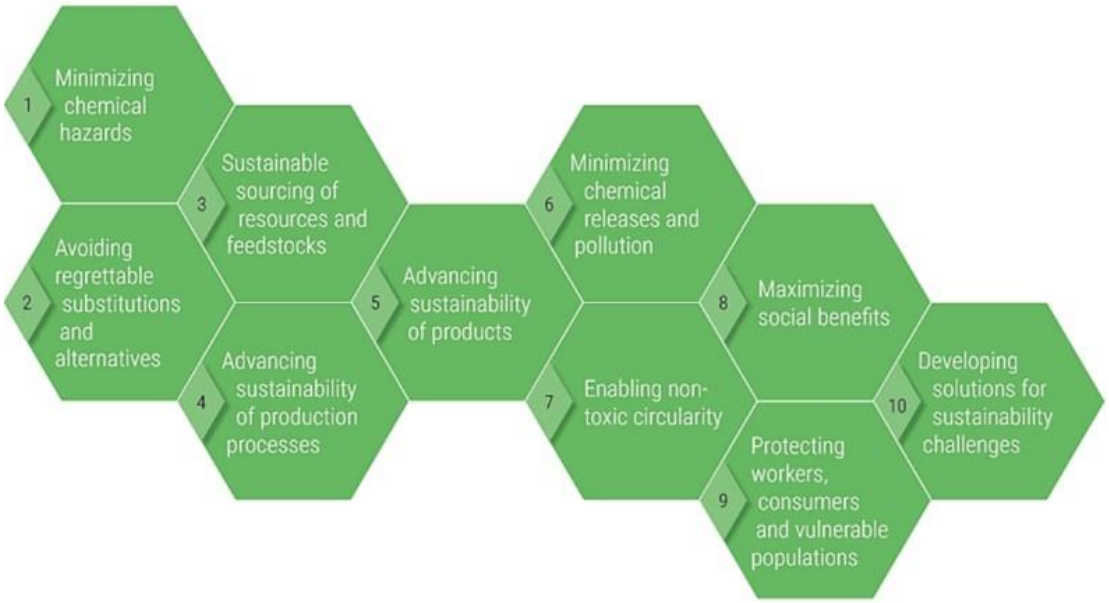

Figure 4: The Ten Objectives and Guiding Considerations for Green and Sustainable Chemistry.[19]

Additionally, the Global Outlook II,[20] launched in 2019 at the meetings of the Parties to Basel, Rotterdam and Stockholm conventions features a report on the evolving chemicals economy and highlights the importance of promoting innovation in chemistry to bridge gaps.

As part of the outcomes of these reports, UNEP has taken part in and hosted an array of workshops and events to promote sustainable and green chemistry.

APEC Economies: Government Programs and Initiatives

Canada

Canada is a leader in initiatives intended to advance chemical management. Environment and Climate Change Canada (ECCC) and Health Canada (HC) held consultations in 2019 to seek input from the Canadian public on "options for advancing informed substitution and alternatives assessment within Canada's chemical's program."[21] In addition, ECCC and HC held consultations in 2022 on mandatory labelling and supply chain transparency for chemicals in consumer products.[22] Work is ongoing to utilize the feedback received through these consultation processes to support the modernization of chemicals management in Canada and improve transparency and innovation. This initiative is still in its early stages as to how the information gathered will impact the global views around green chemistry, however it is notable that there was a large and diverse pool of respondents, and overall, the feedback towards modernization was positive.

Chinese Taipei

As noted in the above case studies, the Chinese Taipei Chemicals Administration (CHA) is a major innovator in the promotion of green chemistry. To encourage the adoption of green chemistry the Chinese Taipei CHA and the Ministry of Education (MOE) jointly held their third annual Green Chemistry Joint Awards Ceremony in May 2023. Chinese Taipei's CHA Green Chemistry Application and Innovation Awards is given to industry, government, academia, or research sectors who have contributed to creating a sustainable environment through green chemistry by making significant contributions in promoting safe alternatives, promoting non-toxic processes, developing environment-friendly approaches to enhance economic benefits, and promoting toxic disaster prevention and response. Individual awards are also given to participants who devote themselves to long-term research in green chemistry and promote the concept of sustainable environmental development.

The MOE holds the College Green Chemistry Innovation Competition and the Senior High School Green Chemistry Innovation Competition. Awards are presented to students working to follow the Twelve Principles of Green Chemistry and advance the concepts of environmental sustainability on campuses. The purpose of the Innovation Awards and Competitions is to create an environment of interdisciplinary cooperation and collaboration to advance the concept of sustainable development, ultimately encouraging all sectors to shift towards sustainable development and promote green chemistry in industry, government, academia, and research sectors.

The Chung-Hua Institution for Economic Research (CIER),[23] a research body that provides economic and industry-related research for the government, and functions as a government think-tank to encourage sustainable development in its economic and industrial policies. By serving as a platform for exchange among academia, government, and industry, CIER has advanced green chemistry by establishing a platform for Taiwan's 'Circular Economy Awards' for constructive industrial dialogue. In addition, CIER has been continuously assisting the Ministry of Environment of Chinese Taipei in tracing and

analyzing the dynamic changes in the production, consumption, import, and storage of toxic chemicals in Chinese Taipei.

United States

The U.S. EPA is a leader in green chemistry and has multiple initiatives that promote innovation and awareness of the importance of green chemistry. Most notably, in addition to the case study above on Safer Choice Labels, the U.S. EPA, in partnership with the American Chemical Society, has a longstanding Green Chemistry Challenge award program.

The U.S. EPA's Green Chemistry Awards program[24] was designed to recognize and promote the environmental and economic benefits of developing and using novel green chemistry. These annual awards recognize chemical technologies that incorporate the principles of green chemistry into chemical design, manufacture, and use. These awards are co-sponsored by the EPA's Office of Chemical Safety and Pollution Prevention in partnership with the American Chemical Society.

Since the inception of the Green Chemistry Awards more than a quarter century ago, there have been more than 1,800 nominations, and presented awards to 139 technologies that decrease hazardous chemicals and resources, reduce costs, and protect public health. Winning technologies are responsible for reducing the use or generation of nearly one billion pounds of hazardous chemicals, saving over 21 billion gallons of water, and eliminating nearly eight billion pounds of carbon dioxide equivalents released to the air.[24]

The U.S. EPA's Toxics Release Inventory (TRI) program tracks industrial implementation of green chemistry and green engineering practices. Facilities are required to disclose any newly implemented source reduction practices in their annual TRI report submissions using codes. Ten of these codes, listed below, are specific to green chemistry and relate primarily to material substitution and process and equipment modification practices.

- Substituted a fuel, S01
- Substituted an organic solvent, S02
- Substituted raw materials, feedstock, or reactant chemical, S03
- Substituted manufacturing aid, processing aid, or other ancillary chemical, S04
- Modified content, grade, or purity of a chemical input, S05
- Reformulated or developed new product line, S11
- Optimized process conditions to increase efficiency, S21
- Instituted recirculation within a process, S22
- Implemented new technology, technique, or process, S23
- Introduced in-line product quality monitoring or other process analysis system, S43

This information informs the U.S. EPA of where assistance is needed with implementation of green chemistry practices by other facilities, parent companies or sectors. Reported green chemistry information is made publicly accessible through several online TRI tools. To view green chemistry information, data can be filtered using the green chemistry activities button under the pollution prevention tab in the TRI Toxics Tracker tool. EPA has also compiled optional information related to solvent substitutions from the most recent 15 years of data on the Solvent Substitutions webpage.

A summary of recent green chemistry activities disclosed through TRI reporting is available within the TRI National Analysis report. In short, since 2017, facilities have

reported 2,041 green chemistry activities for 155 TRI chemicals and chemical categories. The chemical manufacturing and fabricated metals manufacturing sectors reported the highest number of green chemistry activities. Chemical manufacturers used green chemistry to reduce or eliminate their use of TRI solvent and reagent chemicals, such as methanol and toluene. For more information see: www.epa.gov/trinationalanalysis/green-chemistry-activities.

The U.S. EPA also uses the green chemistry information disclosed by facilities in their TRI reports to showcase the achievements facilities, parent companies and industry sectors have made in improving their environmental performance through green chemistry. The EPA provides this information to publicly acknowledge progress in preventing pollution and to encourage industry to move towards preferred waste management practices and safer alternatives.[25]

Industry Leaders in Green Chemistry

As early as 1984, the Responsible Care® initiative began in Canada. Today, domestic chemicals associations in nearly 70 economies are driving continuous improvement in sound chemical management for environmental, health, safety, and security performance.[26] For some organizations such as the American Chemistry Council (ACC), it is a requirement of membership.[27] Updated in 2014, the Responsible Care® Global Charter lists the following six Key Elements.[28]

1. **A Corporate Leadership Culture** that proactively supports safe chemicals management
2. **Safeguarding People and the Environment**
3. **Strengthening Chemicals Management Systems**
4. **Influencing Business Partners** to promote the safe management of chemicals within their own operations
5. **Engaging Stakeholders**, understanding and responding to their concerns and expectations for safer operations and products
6. **Contributing to Sustainability**

The last Element aligns with Objective 10 of UNEP Green and Sustainable Chemistry Framework Manual: "Developing solutions for sustainability challenges; Focus chemistry innovation to help address societal and sustainability challenges." Industry organizations such as the ACC are working to define sustainable chemistry principles and highlight members' sustainable innovations,[29] while the World Business Council for Sustainable Development (WBCSD) has developed the Chemical Industry Methodology for Portfolio Sustainability Assessments (PSA) to steer product portfolios towards improved sustainability outcomes.[30] By using science-based holistic approaches and life cycle thinking, companies are better equipped to design innovative, sustainable solutions.

Many companies have implemented methods to guide their portfolio decisions and innovation programs. Below is a non-comprehensive list of methods that have been published, which may be useful references for APEC economies:

- EVOLVE 2030 (Chemours)[31]
- Sustainable Solution Steering (BASF)[32]
- Sustainable Portfolio Management (Solvay)[33]

Achieving the UN Sustainable Development Goals will require innovations and investments by the chemical industry. By participation in Responsible Care®, practicing Green Chemistry principles, and utilizing assessment approaches such as the WBCSD PSA, companies can and have raised their standard of sound chemical management as well as thoughtfully designed innovative solutions for sustainable economic, environmental, and social development. Hopefully, common programs and frameworks like those listed above will help to facilitate cooperation, regulatory alignment, and trade.

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