出國報告（出國類別：其他）

參加第 25 屆綠色化學與工程年會線上國際會議視訊報告

（The 25th Annual Green Chemistry & Engineering Conference）

服務機關：行政院環境保護署毒物及化學物質局
姓名職稱：蕭寶桂特約高級環境技術師、魏宇鴻技士
派赴國家/地區：臺灣/中華民國
出國期間：110 年 6 月 14 日至 6 月 19 日
報告日期：110 年 9 月 27 日

摘要

為接軌國際趨勢，邁向永續綠色化學，建構「安全永續的化學環境」，行政院環境保護署毒物及化學物質局持續依據行政院核定之「國家化學物質管理政策綱領」推動策略中，於「國家治理」「降低風險」及「知識建立」施政目標中，進行分眾推廣綠色化學，以促進多面向溝通鏈結及安全替代制度，目前包括有針對大專校院、小學、多元族群設計適合教材及講義；針對產業部分辦理「綠色化學應用及創新獎」，以鼓勵產業界朝向安全替代與減毒目標，並持續蒐研國際安全替代推動作法，建立安全替代資訊平臺，以達到「降低風險」及「管理量能」。

美國化學學會綠色化學研究機構（American Chemical Society Green Chemistry Institute, ACSGCI）舉辦之第25屆綠色化學與工程年會（The 25th Annual Green Chemistry & Engineering Conference），本（2021）年因受嚴重特殊傳染性肺炎（COVID-19）疫情影響，改以視訊方式召開，會議主題為「永續生產促進循環經濟（Sustainable Production to Advance the Circular Economy）」，會中計有5場主題演講（Keynote Address）及多篇海報展示，此外，研討會期間講述議題涵蓋推動綠色化學教育做法、因應COVID-19疫情辦理綠色化學遠距授課作法及經驗、美國綠色化學總統挑戰獎獲獎者之分享、運用綠色技術解決環境問題、綠色設計、循環經濟等各面向議題。

藉由參加本次研討會，可以瞭解國際上綠色化學在化學工程發展現況及展望，該會議參與之對象包含產、官、學、研，符合本局對於推動綠色化學須建立多元利害關係人夥伴關係，持續蒐集國外推動綠色化學教育、美國綠色化學總統挑戰獎辦理之情況、瞭解現今國際推動綠色化學之趨勢，將可提供我國業務執行及未來政策規劃之參考。

目錄

壹、目的

為接軌國際趨勢，邁向永續綠色化學，建構「安全永續的化學環境」，行政院環境保護署毒物及化學物質局持續依據行政院核定之「國家化學物質管理政策綱領」推動策略中，於「國家治理」「降低風險」及「知識建立」施政目標中，進行分眾推廣綠色化學，以促進多面向溝通鏈結及安全替代制度，目前包括有針對大專校院、小學、多元族群設計適合教材及講義；針對產業部分辦理「綠色化學應用及創新獎」，以鼓勵產業界朝向安全替代與減毒目標，並持續蒐研國際安全替代推動作法，建立安全替代資訊平臺，以達到「降低風險」及「管理量能」。

藉由派員參加由美國化學會辦理之第 25 屆綠色化學與工程年會，可以瞭解國際上綠色化學在化學工程發展現況及展望，該會議參與之對象包含產、官、學、研，符合本局對於推動綠色化學須建立多元利害關係人夥伴關係，有助於我國後續業務推動與施政之參考。

貳、過程

一、研討會概述

本(25)屆綠色化學與工程年會(The 25th Annual Green Chemistry & Engineering Conference)於美東時間 2021 年 6 月 14 日上午 11 時至 6 月 18 日下午 6 時（臺灣時間為 2021 年 6 月 14 日晚上 11 時至 6 月 19 日上午 6 時）舉行，因受嚴重特殊傳染性肺炎(COVID-19)疫情影響，主辦單位美國化學學會綠色化學研究機構(American Chemical Society Green Chemistry Institute, ACSGCI)改以視訊方式(https://www.gcande.org/)辦理，會議主題為「永續生產促進循環經濟(Sustainable Production to Advance the Circular Economy)」（如圖 1），主要係強調運用生命週期思維(LIFE CYCLE THINKING)方法，使化學家和工程師能夠系統地思考在化學生命週期階段所做的選擇如何影響化學物質的命運以及化學物質對社會和環境的最終影響；為了強調生命週期思維方法對化學和工程的重要性並促進對相關議題的討論，每年 GC&E 研討會主題會聚焦於化學生命週期的一個階段討論，包含設計(Design)、製造(Make)、使用(Use)和關閉循環(Closing the Loop)（如圖 2）。

本屆研討會中內容非常豐富，年會期間計有 5 場專題演講(Plenary Keynotes)、多場議程及多篇海報發表（如圖 3），年會議題涵蓋推動綠色化學教育策略及作法，例如因應 COVID-19 疫情影響，學校及教師辦理綠色化學遠距授課作法及經驗、2020 年美國綠色化學總統挑戰獎獲獎者之獲獎經驗及心得分享、如何運用綠色技術解決環境問題、綠色設計及綠色化學鏈結循環經濟等各面向議題。

圖 1 第 25 屆綠色化學與工程年會 LOGO

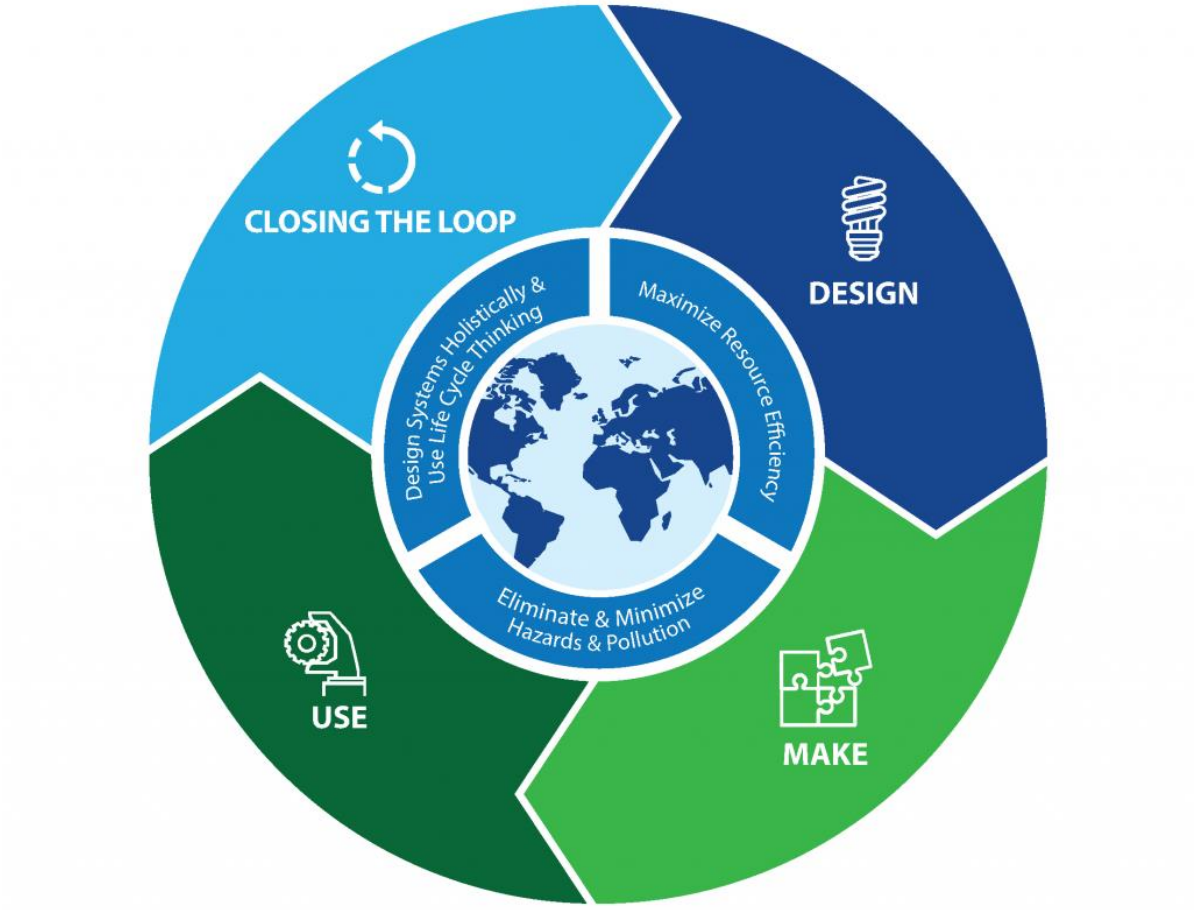


圖 2 化學生命週期示意圖

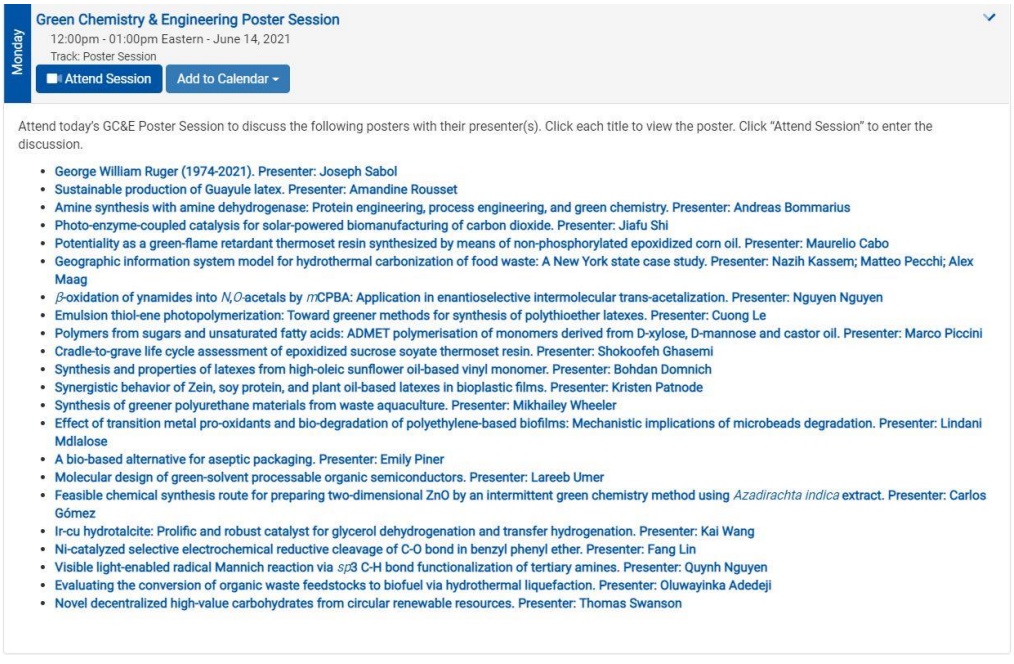


圖 3 線上海報展示

二、行程概述

本次主辦單位因應因受嚴重特殊傳染性肺炎(COVID-19)疫情影響，改以視訊方式舉辦，本次參與人員則以彈性調整工作時間方式參加第 25 屆綠色化學與工程年會視訊會議，參與行程安排如表 1。

表 1 每日行程概要

日　　期	工 作 內 容 概 要
110.6.14~110.6.19	參加線上國際會議（年會）

三、會議議程（美東時間）

(一) 110 年 6 月 14 日

Time	Event
11 a.m. – 12 p.m.	Welcome Remarks and Keynote Address: Eunice Heath
12:00 -12:55 p.m.	GC&E Poster Session ACS Symposium Series eBooks: Sustainability & Green Polymer Chemistry. Sponsored by ACS Publications
1:00 – 4:50 p.m. (Break 2:45 – 3:05 p.m.)	Technical Sessions: ○ Earth-Abundant Metal Catalysis ○ Chemistry Curricula Designed to Achieve Responsible Consumption & Production: Rapid-Fire Session 1 ○ Electrosynthesis of Chemicals & Fuels ○ Finding Parallels: Sharing Approaches Toward Sustainability & Product Stewardship ○ Greening Classrooms: Lessons Learned From Adapting Chemistry Curricula & Teaching Delivery Methods During the COVID-19 Pandemic ○ Leaving Organic Solvents Behind: Chemistry in Aqueous Media ○ Sustainable Manufacturing Powered by Synthetic Biology ○ Decreasing the Environmental Footprint by Decreasing Agriculture Waste
5:00 – 6:00 p.m.	Networking Happy Hour ○ Roundtable Green Chemistry Tools from ACSGCIPR ○ Creating Inclusive Classrooms

(二) 110 年 6 月 15 日

Time	Event
11 a.m. – 12 p.m.	Welcome Remarks, GCCA Winner Announcement, and Keynote Address: Gregg Beckham
12:00 - 12:55 p.m.	GC&E Poster Session Meet the Editors of ACS Sustainable Chemistry & Engineering: A Conversation About Community Outreach & Inclusion Initiatives, Front Matter, and Videos. Sponsored by ACS Publications
1:00 – 4:50 p.m. (Break 2:45 – 3:05 p.m.)	Technical Sessions: • New Strategies in Biocatalysis for Sustainable Chemical Production • Earth-Abundant Metal Catalysis* • Symposium in Honor of Dr. Nina McClelland** • Integrating and Scaffolding Green Chemistry, Systems Thinking and the UN Sustainable Development Goals through an Equitable and Inclusive Chemistry Curriculum • Chemistry Curricula Designed to Achieve Responsible Consumption and Production – Rapid-Fire* • General Session** • EPA Green Chemistry Challenge Awards – Past and Present • Decreasing the Environmental Footprint by decreasing Agriculture Waste • Sustainable Production and Circularity in the Electronics Supply Chain • Rethinking the Plastic Problem: Plastic Waste as a Valuable Resource
5:00 – 6:30 p.m.	Networking Happy Hour • Diversity, Equity & Inclusion: How to Catalyze Corporate Sustainability and Green Chemistry Success. Sponsored by Pfizer

(三)110 年 6 月 16 日

Time	Event
10:30 a.m. – 12 p.m.	Welcome Remarks and Keynote Address: 2021 Lectureship Award Speakers Jeremy Luterbacher, Jun Huang & Meagan Mauter
12:00 - 12:55 p.m.	GC&E Poster Session Meet the Editors of Organic Process Research & Development (OPR&D) / EPA Safer Choice program Information & Networking Session. Sponsored by ACS Publications and Washington State Department of Ecology
1:00 – 4:50 p.m. (Break 2:45 – 3:05 p.m.)	Technical Sessions: • Data-Rich Experimentation in Flow Chemistry • Making Organic Chemistry more Sustainable (Special Student Session) • Greener Peptide and Oligonucleotide Synthesis • Integrating and Scaffolding Green Chemistry, Systems Thinking and the UN Sustainable Development Goals through an equitable and inclusive chemistry curriculum • Design of Chemicals, novel chemistries, synthetic pathways and processes that enable a circular, more sustainable economy • Carbon Dioxide Pivot Point: Advancing the Circular Economy • Sustainable Chemical End-Of-Life Management to Advance their Circular Economy • Rethinking the plastic problem: Plastic waste as a valuable resource* • General Session 2**
5:00 – 6:00 p.m.	Networking Happy Hour • Learn About Green Chemistry Education Modules. Presented by the ACS GCI

	• Research to Commercialization: When to Seek Regulatory Review and Approval. Sponsored by The Acta Group and Bergeson & Campbell, P.C.

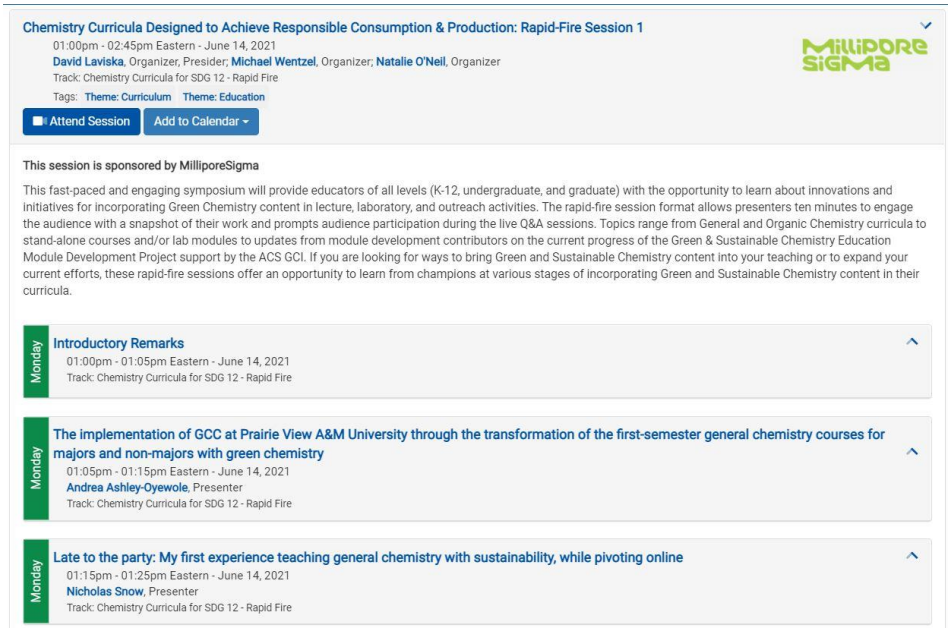
(四)110 年 6 月 17 日

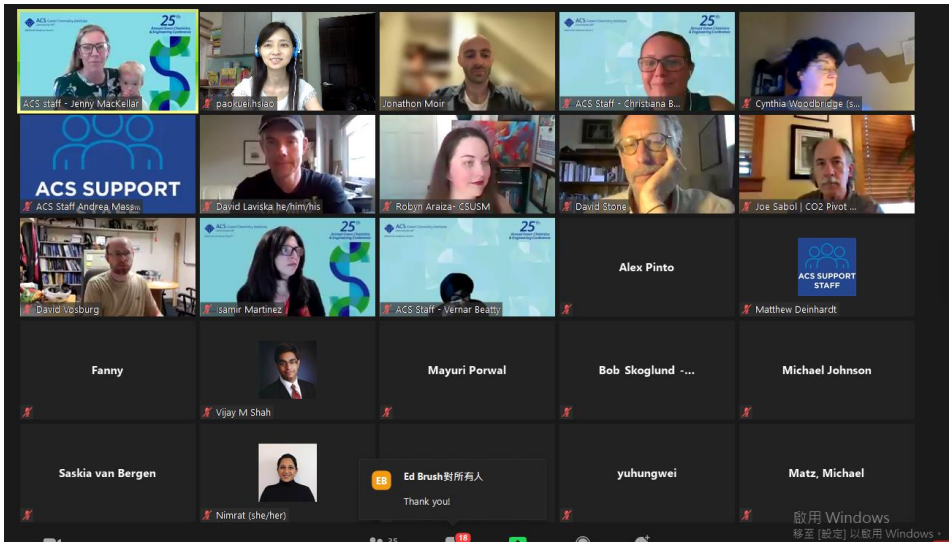
Time	Event
11 a.m. – 12 p.m.	Welcome Remarks and Keynote Address: Frank Gupton
12:00 - 12:55 p.m.	GC&E Poster Session Meet the Editors of ACS Agricultural Science & Technology and ACS Food Science & Technology and Learn More About These Exciting New Journals. Sponsored by ACS Publications
1:00 – 4:50 p.m. (Break 2:45 – 3:05 p.m.)	Technical Sessions: • Using Computers to Deliver Green Chemistry: In Silico Techniques for Designing and Developing Chemical Reactions • Flow Chemistry & Continuous Processing Enabling Sustainable Chemical Development and Manufacturing • Integrating Sustainable Production Practices into Teaching and Research Laboratories • Design of Chemicals, novel chemistries, synthetic pathways and processes that enable a circular, more sustainable economy • Biobased Materials and Processes for the Energy and Petrochemical Industry • Carbon Dioxide Pivot Point: Advancing the Circular Economy • Sustainable Production of Biobased Polymers • Green and Sustainable Chemistry in Manufacturing for More Sustainable Household and Personal Care Products (Formulator's' RT)
5:00 – 6:00 p.m.	Networking Happy Hour • The Green Chemistry Commitment. Sponsored by Washington State Department of Ecology

(五)110 年 6 月 18 日

Time	Event
11 a.m. – 12 p.m.	Welcome Remarks and Keynote Address: Amy Prieto
12:00 - 12:55 p.m.	GC&E Poster Session Publishing in ACS Journals – Sponsored by ACS Publications
1:00 – 4:50 p.m. (Break 2:45 – 3:05 p.m.)	Technical Sessions: • The Circular Economy in Action: Industrial Ecosystems Implementing Circularity at Commercial Scale* • Undergraduate Context Session** • Integration of Greener, Process-Friendly Approaches for Monitoring Reactions for Pharmaceutical End-Game Chemistry • The PFAS-Free Future: Greener Solutions for a Circular Economy • Flow Chemistry & Continuous Processing Enabling Sustainable Chemical Development and Manufacturing* • Towards sustainable and complete life cycle processes in industry** • Novel Developments for Bio-based and Renewable Chemicals to Advance the Circular Economy • Sustainable Production of Biobased Polymers • Bioprocessing Separations: Advancing a Research Agenda • Food & The Circular Economy: Improving the Sustainability of Waste Stream Valorization Products
5:00 – 6:00 p.m.	Networking Happy Hour Wrap-up Celebration: Cheers to Another Successful Conference!

四、視訊會議參與情形


Chemistry Curricula Designed to Achieve Responsible Consumption & Production: Rapid-Fire Session 1
01:00pm - 02:45pm Eastern - June 14, 2021
David Laviska, Organizer, Presider; Michael Wentzel, Organizer; Natalie O'Neil, Organizer
Track: Chemistry Curricula for SDG 12 - Rapid Fire
Tags: Theme: Curriculum Theme: Education
Attend Session
Add to Calendar
This session is sponsored by MilliporeSigma
This fast-paced and engaging symposium will provide educators of all levels (K-12, undergraduate, and graduate) with the opportunity to learn about innovations and initiatives for incorporating Green Chemistry content in lecture, laboratory, and outreach activities. The rapid-fire session format allows presenters ten minutes to engage the audience with a snapshot of their work and prompts audience participation during the live Q&A sessions. Topics range from General and Organic Chemistry curricula to stand-alone courses and/or lab modules to updates from module development contributors on the current progress of the Green & Sustainable Chemistry Education Module Development Project support by the ACS GCI. If you are looking for ways to bring Green and Sustainable Chemistry content into your teaching or to expand your current efforts, these rapid-fire sessions offer an opportunity to learn from champions at various stages of incorporating Green and Sustainable Chemistry content in their curricula.
Monday
Introductory Remarks
01:00pm - 01:05pm Eastern - June 14, 2021
Track: Chemistry Curricula for SDG 12 - Rapid Fire
Monday
The implementation of GCC at Prairie View A&M University through the transformation of the first-semester general chemistry courses for majors and non-majors with green chemistry
01:05pm - 01:15pm Eastern - June 14, 2021
Andrea Ashley-Oyewole, Presenter
Track: Chemistry Curricula for SDG 12 - Rapid Fire
Monday
Late to the party: My first experience teaching general chemistry with sustainability, while pivoting online
01:15pm - 01:25pm Eastern - June 14, 2021
Nicholas Snow, Presenter
Track: Chemistry Curricula for SDG 12 - Rapid Fire


ACS staff - Jenny MacKellar
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Jonathon Moir
ACS Staff - Christiana B...
Cynthia Woodbridge (s...
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ACS Staff Andrea Masga...
David Laviska he/him/his
Robyn Araiza- CSUSM
David Stone
Joe Sabol | CO2 Pivot ...
David Vosburg
Isamir Martinez
ACS Staff - Vernar Beatty
Alex Pinto
ACS SUPPORT STAFF
Matthew Deinhardt
Fanny
Vijay M Shah
Mayuri Porwal
Bob Skoglund -...
Michael Johnson
Saskia van Bergen
Nimrat (she/her)
Ed Brush對所有人
Thank you!
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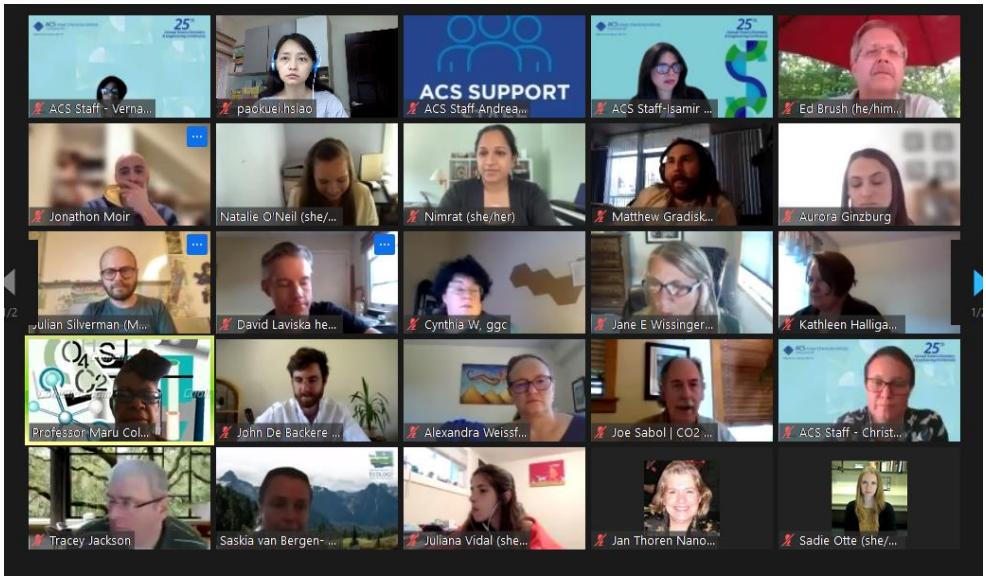
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Ed Brush (he/him...
Jonathon Moir
Natalie O'Neil (she/...
Nimrat (she/her)
Matthew Gradisk...
Aurora Ginzburg
Julian Silverman (M...
David Laviska he...
Cynthia W, ggc
Jane E Wissinger...
Kathleen Halliga...
Professor Maru Col...
John De Backere ...
Alexandra Weissf...
Joe Sabol | CO2 ...
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Tracey Jackson
Saskia van Bergen- ...
Juliana Vidal (she...
Jan Thoren Nano...
Sadie Otte (she/...


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David Allen
Peter Licence
Julio Serrano
Freddy Tellez
檢視
Paul Anastas
解除靜音
停止視訊
53
與會者
12
聊天
分享畫面
錄製
回應
離開


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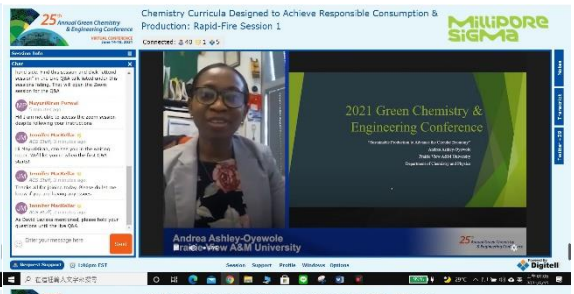
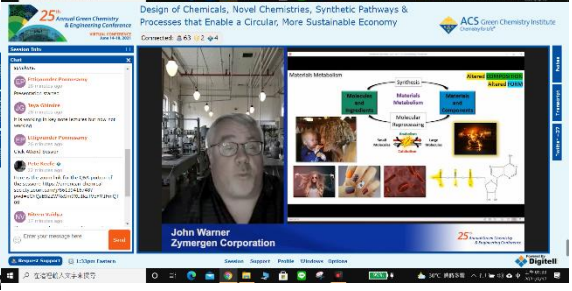
Keynote Address by Eunice Heath of Dow
Eunice Heath, MBA


Chemistry Curricula Designed to Achieve Responsible Consumption & Production: Rapid-Fire Session 1
2021 Green Chemistry & Engineering Conference
Andrea Ashley-Oyewole
Texas A&M University

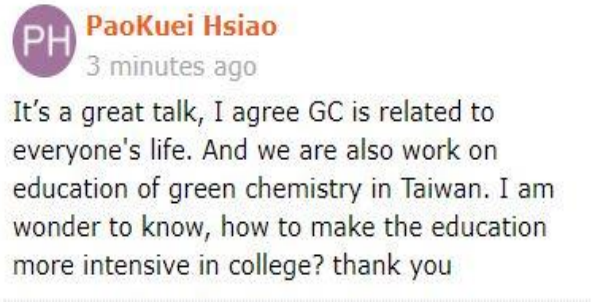

Keynote Address by Gregg Beckham of NREL

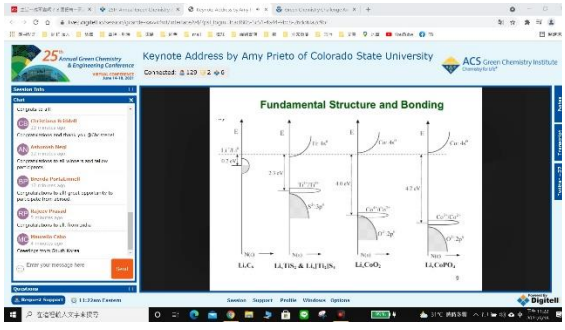

EPA Green Chemistry Challenge Awards: Past & Present
Chen Wen
US Environmental Protection Agency


Keynote Address by Frank Gupton of Virginia Commonwealth University
Searching for Greenness in a Post-Pandemic World


Design of Chemicals, Novel Chemistries, Synthetic Pathways & Processes that Enable a Circular, More Sustainable Economy
John Warner
Zymergen Corporation


Integrating & Scaffolding Green Chemistry & Engineering, Systems Thinking & the UN Sustainable Development Goals Through an Equitable & Inclusive Chemistry Curriculum
Conclusion
Jane Wissinger
University of Minnesota


PaoKuei Hsiao
3 minutes ago
It's a great talk, I agree GC is related to everyone's life. And we are also work on education of green chemistry in Taiwan. I am wonder to know, how to make the education more intensive in college? thank you


Keynote Address by Amy Prieto of Colorado State University
Fundamental Structure and Bonding

五、會議重點摘錄

（一） 國際推廣綠色化學教育策略及作法：

1. 現今全球因應新冠肺炎（COVID-19）疫情嚴峻，導致校園停課，在考量教育不能中斷前提下，學校及教師採取線上（遠端）授課，重新設計適合遠端授課之教材、教具及教案等，並採取視訊軟體授課，其中以使用 ZOOM 視訊軟體授課居多。在經過多次的授課模式、教材、教具及教案等調整及磨合，雖與傳統的現場講座形式不同，但透過視訊授課，並配合採取線上分組討論、思考及虛擬實驗方式，可發現視訊授課仍可建立學生對於科學、綠色化學等課程之主題、內涵瞭解，且學生也能有即時回饋，顯示視訊課程亦可有良好的教學成效。
2. 另外為將綠色永續化學設計及開發概念融入教學和研究實驗室中，Millipore Sigma 為此開發 DOZN™ 工具，該工具係依據綠色化學的 12 原則（作為模式開發及建立設計規則）進行化學品設計、合成及製程方式等評估並選擇更綠色的方式，該評估工具可讓學生瞭解綠色化學價值所在及尋找更適宜、友善的綠色化學作法。

（二） 2020 年美國綠色化學總統挑戰獎獲獎者之分享：

本獎項主要目的為鼓勵減少或排除有害物質的使用及產生之化學產品和製程的設計，達到於源頭即防止或降低污染，今（2021）年為綠色化學總統挑戰獎成立 25 週年，在過去的 25 年中，榮獲本獎項之技術每年減少了 8.3 億磅危害性化學品和溶劑的使用、減少 78 億磅二氧化碳當量排放等，綠色化學推廣對於環境效益極為龐大，亦可增進企業的競爭力，美國環保署及美國化學會共同辦理此獎項之成效亦可作為我國辦理之參考，獲獎之內容亦可作為新知，下列摘述獲獎者分享內容：

1. 榮獲 2021 年小企業獎的公司，其以主要研究-各種吸附營養物質的金屬氧化物所製成的多孔材料，以吸附方式去除水生系統中的氨、磷酸鹽、硝酸鹽，並進而將其轉變成可用作肥料的顆粒。當吸附劑添加到農業土壤中時，它不僅會緩慢釋放植物養分，而且在未來可以提高土壤的養分保持能力，防止肥料流失並保護該場域的流域。
2. 因塑膠垃圾已成為當今世界面臨的最重要的生態危機之一，除在環境中的持久性問題外，塑膠在製造過程中，會增加健康安全風險及碳足跡， Srikanth Pilla 教授為解決此一問題，研發出 100%不含異氰酸酯、可回收、無毒的非異氰酸酯聚氨酯 (NIPU)，可以做為取代傳統的聚氨酯使用，並因此榮獲學術獎。

（三） 綠色化學鏈結循環經濟：

在此議程中，其中有發表者提到「無 PFAS (Per/Poly fluoro alkyl substances, PFAS)的未來-循環經濟的綠色解決方案」，全氟烷基物質和多氟烷基物質(PFAS)是一廣泛的化學品，因其特性為不沾黏、防油、防水和防污性被廣泛使用。發表者提到因其可用於抗風化、延長屋頂使用壽命，並可反射太陽輻射，使建築物保持涼爽，因此長期使用於建築行業，包括屋頂材料、地板、油漆和塗料、密封劑、玻璃等，除建築行業外，另因其具除污功能而用於地毯。PFAS 具持久性、在環境中不會輕易分解，PFAS 會長期存在於環境中，包含水體、灰塵等，進而影響到人體健康，因此發表者鼓勵選購有成分揭露之產品，選擇使用更安全的替代品，避免使用 PFAS 類產品等。

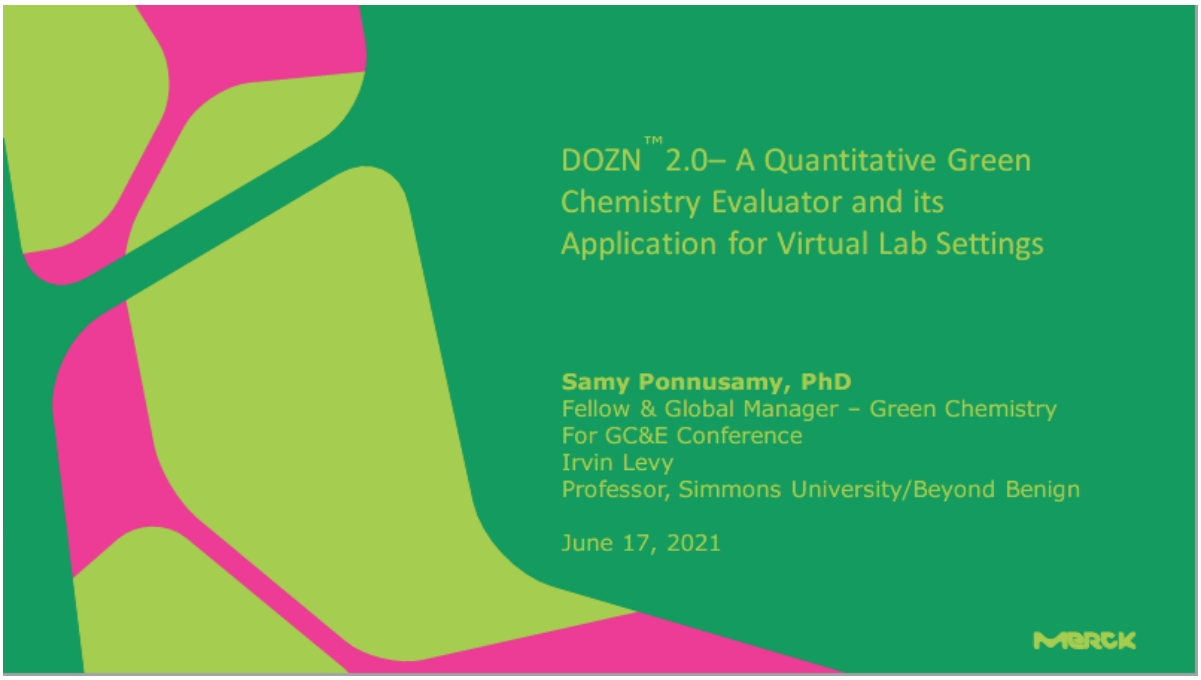
參、心得及建議

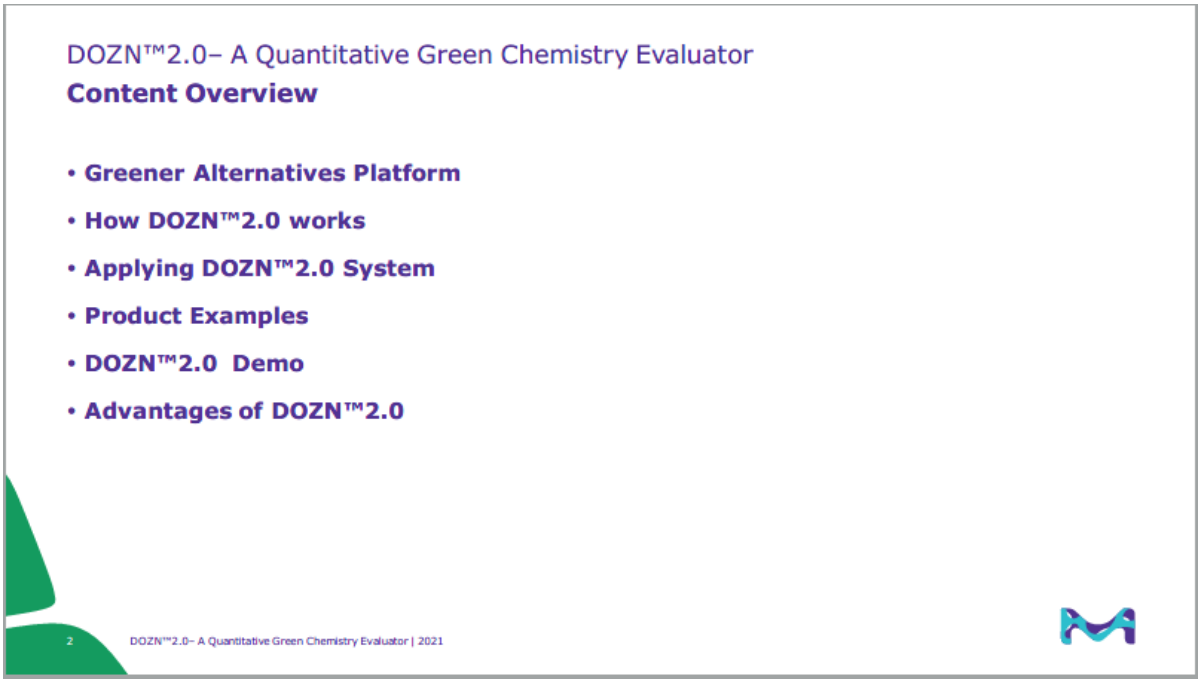
一、本次年會受國際新冠肺炎疫情影響，改採取視訊方式辦理，5 天內容多元且完整，受益良多。現今國際及國內疫情仍然嚴峻，我國各級學校更是因應嚴重特殊傳染性肺炎（COVID-19）疫情的管制措施，中央流行疫情指揮中心指揮官陳時中宣布，自 5 月 15 日起雙北（臺北市、新北市）提升疫情警戒至第三級，爾後更擴展到全國各區，在停課不停學的前提下，學校及教師改採遠距教學，針對此一情況可汲取國外目前採行視訊方式辦理綠色化學及科學教育之經驗，作為我國推廣及執行之參考。

二、美國綠色化學總統挑戰獎係由美國環境保護署、美國科學院、國家科學基金和美國化學會聯合主辦，辦理迄今已 25 年，其為第一個實施綠色化學獎勵制度之國家，該獎項分為 5 類，藉由該獎勵制度以防止工業污染並促進生態平衡，逐步達成環境永續，其所產生之環境效益極大，包含每年逐步減少危害性化學品及溶劑使用、將低碳排放等；經檢視我國亦有依據「毒性及關注化學物質管理法」辦理綠色化學應用及創新獎，美國綠色化學總統挑戰獎辦理之獎項方式亦可作為我國於產業端、學術研究端推行綠色化學政策之參考，將持續以獎勵方式鼓勵企業、學校將綠色化學理念融入企業經營及研究發展中。

三、本次會議針對教育、產業及研發均有相關議程及議題，均與本局推動綠色化學之業務直接相關，其中更於會中瞭解分享綠色化學總統挑戰獎獲獎內容及心得，可藉由此次會議瞭解綠色化學相關新穎安全永續之作法，及應用之作為，未來若有綠色化學相關國際會議，建議可持續派員參與，多方吸收資訊，以做為我國執行業務及政策推動之參考，促進我國綠色化學發展。

附件-將可持續生產實踐整合到教學和研究實驗室(Integrating Sustainable Production Practices Into Teaching & Research Laboratories)簡報





Greener Alternatives Platform

Overview

4 CATEGORIES

- **Re-Engineered**
- **12 Principles-Aligned**
- **Enabling Technologies**
- **Design for Sustainability (DfS) Developed Products**

TM

Our Greener Alternative Products are marked with this icon

Greener Alternatives Platform
12 Principles of Greener Chemistry

Prevention
It is better to prevent waste than to treat or clean up waste after it has been created.

Atom Economy
Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

Use of Renewable Feedstocks
A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

Reduce Derivatives
Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.

Less Hazardous Chemical Syntheses
Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

Designing Safer Chemicals
Chemical products should be designed to affect their desired function while minimizing their toxicity.

Catalysis
Catalytic reagents (as selective as possible) are superior to stoichiometric reagents

Design for Degradation
Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.

Safer Solvents and Auxiliaries
The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.

Design for Energy Efficiency
Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.

Real-time analysis for Pollution Prevention
Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

Inherently Safer Chemistry for Accident Prevention
Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

Greener Alternatives Platform
Major Groups

An industry first, **DOZN™** is our proprietary Quantitative Green Chemistry Evaluator that enables us to consistently evaluate different products and processes against the 12 Principles of Green Chemistry—clarifying what's "greener" about our greener alternatives.

To evaluate products and processes using DOZN™, we group the 12 Principles of Green Chemistry into three major groups:

1. **Improved Resource Use**
2. **Increased Energy Efficiency**
3. **Reduced Human and Environmental Hazards**

Then, an aggregate score on a scale of 0-100 is given, with 0 being the most desired.

Greener Alternatives Platform
Major Groups 1/3

1 Improved Resource Use

Aimed at improving the material efficiency of the chemical or process

- Waste Prevention
- Reduce Derivatives
- Atom Economy
- Catalysis
- Use of Renewable Feedstocks
- Real-time Analysis for Pollution Prevention

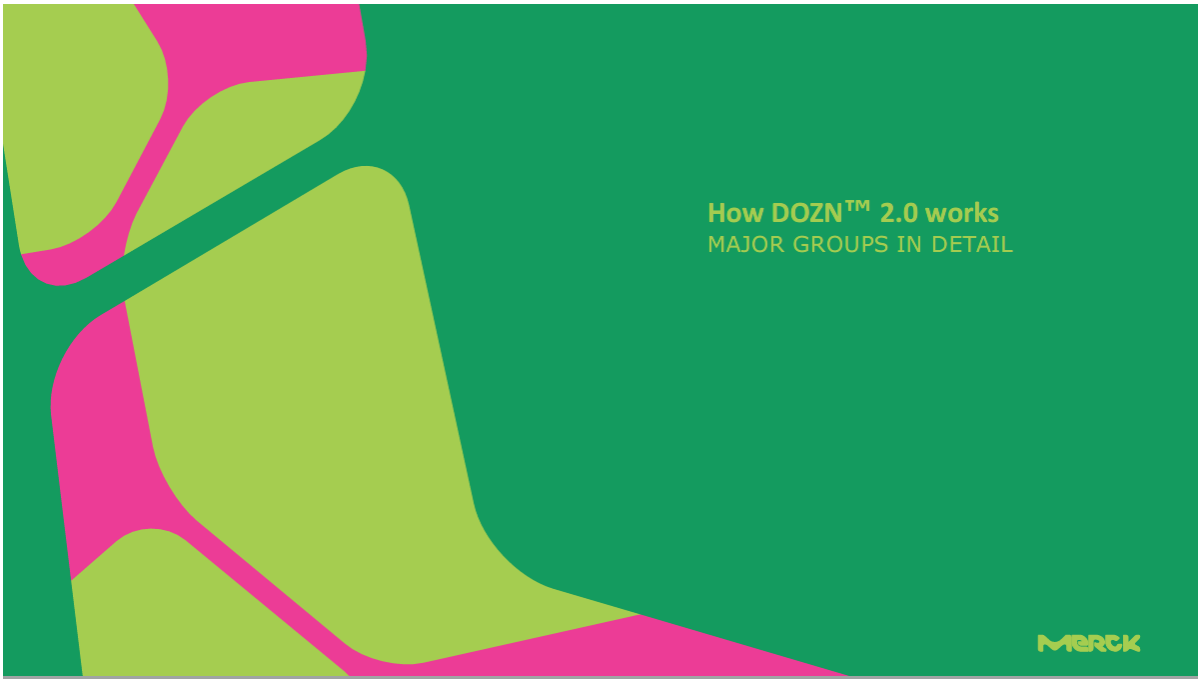
Greener Alternatives Platform
Major Groups 2/3

2 Increased Energy Efficiency

Aimed at improving the energy efficiency of the chemical or process

- Design for Energy Efficiency

Greener Alternatives Platform
Major Groups 3/3



How DOZN™2.0 works – Major Groups in Detail

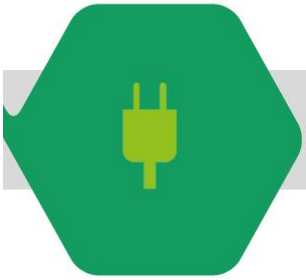
Group 1: Improved Resource Use

$$\frac{\sum Principles\ 1,\ 2,\ 7,\ 8,\ 9,\ \&\ 11}{6}$$

This group is aimed at improving the material efficiency of the chemical or process

How DOZN™2.0 works – Major Groups in Detail

Group 2: Increased energy efficiency



$$\text{Group } 2 = \text{Principle } 6$$

Group 2 acknowledges that there is more than just raw material input that contributes to greenness and is aimed at improving the energy efficiency of the chemical or process

How DOZN™2.0 works – Major Groups in Detail

Group 3: Reduced human and environmental hazards

$$\frac{\sum Principles\ 3,4,5,10,\&12}{5}$$

Group 3 aims at improving the safety of humans and the environment by minimizing potential risks

How DOZN™2.0 works – Major Groups in Detail

The Aggregate score

$$\frac{\sum Group\ 1,2,3}{50}$$

The Aggregate score gives greenness, a quick summary of the 12 principles

The Aggregate score is on a scale of 0-100 with 0 being the most desired

The DOZN™ system was verified and validated by third party and also published

DOZN™2.0– A Quantitative Green Chemistry Evaluator

Analysis

Procedural Run-through and Data Gathering

↓

Matrix Data Entry

↓

Score Calculation

Product examples

MERCK

DOZN™2.0– A Quantitative Green Chemistry Evaluator

Product Example: β-Amylase

β-Amylase—an enzyme commonly found in sweet potatoes—hydrolyzes starch into sugar.

6,000 lbs
of sweet potatoes

1,900 gallons
of acetone

Significant use
of electricity

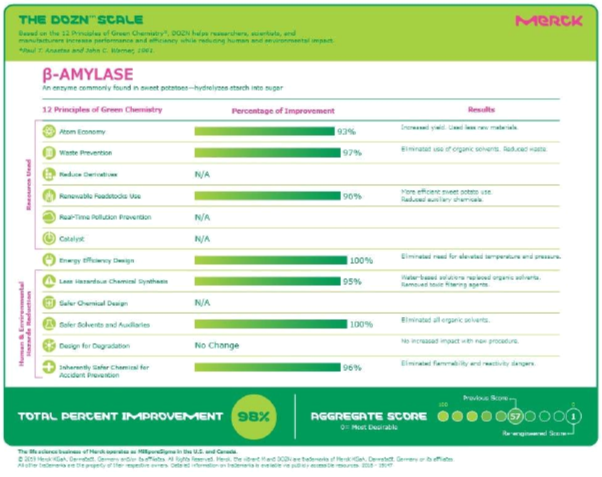
2,000 lbs
of sweet potatoes

No organic solvent required

No additional electricity required
to increase temperature and pressure

DOZN™2.0– A Quantitative Green Chemistry Evaluator

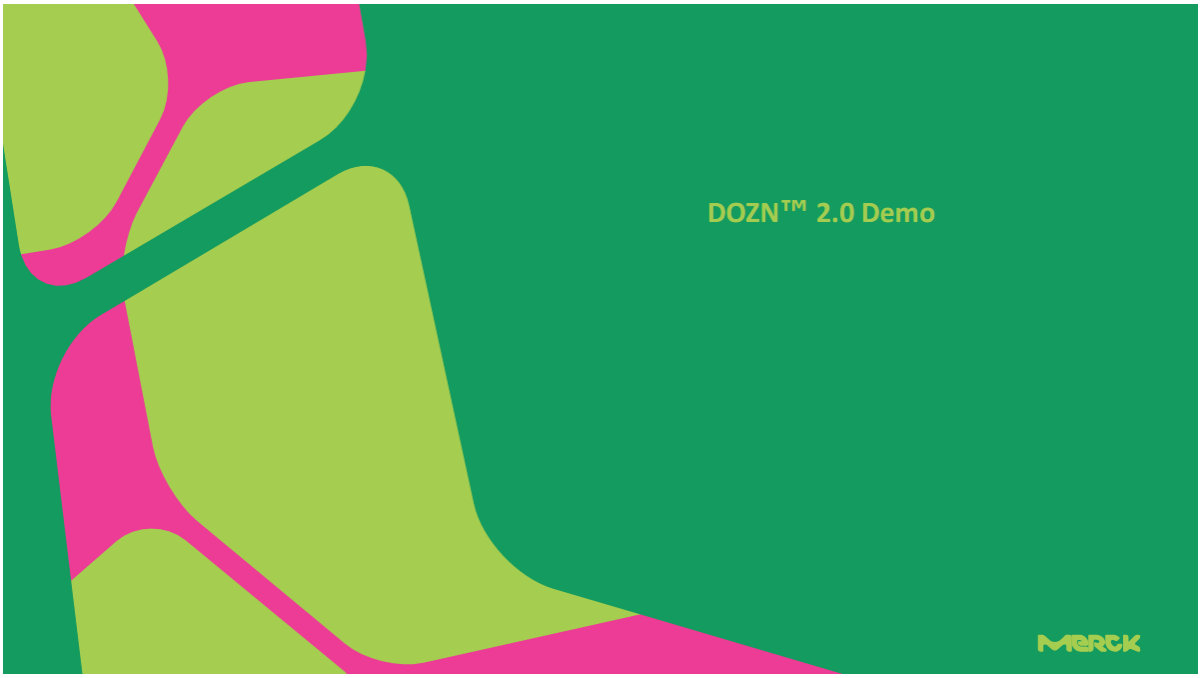
Product Example: ß-Amylase Scorecard

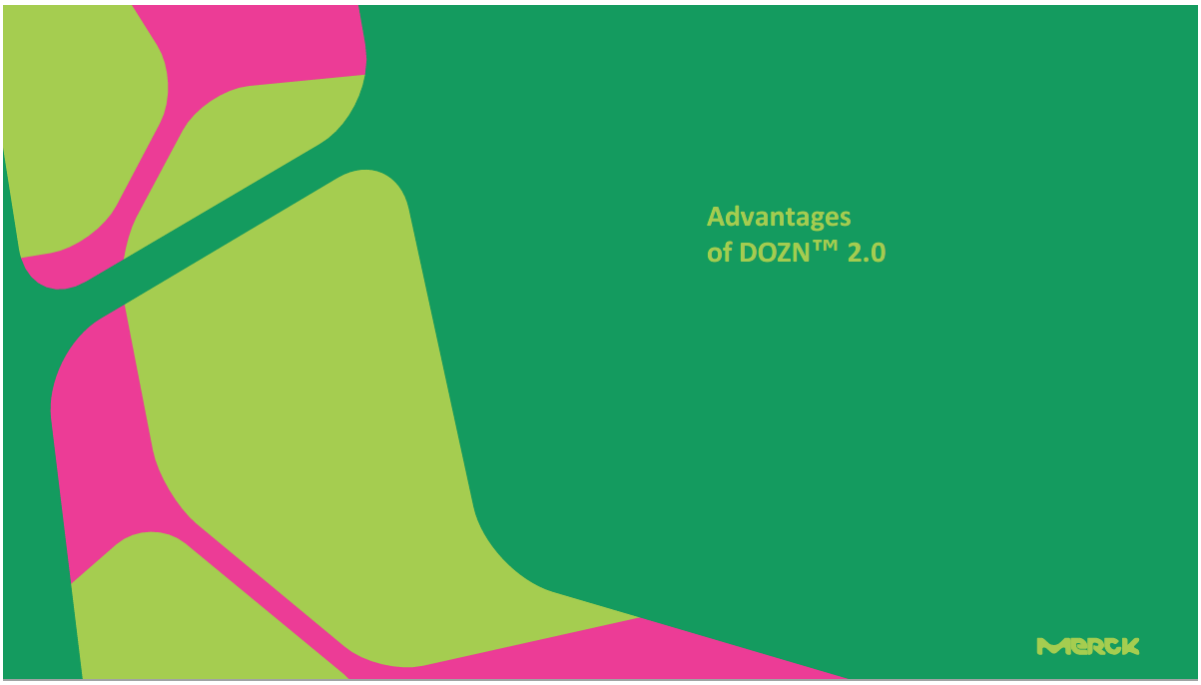


DOZN™2.0– A Quantitative Green Chemistry Evaluator

Product Examples: Re-engineered Products & DOZN™ Scores

Product Name	Old Score	New Score
1-Aminobenzotriazole	93	46
1,3,5-Tris(4-Iodophenyl)benzene	100	4
(DHQD)2 PHAL	13	3
N-Benzoyl-L-threonine methyl ester	21	4
(S)-(-)-3-Chloro-1-phenyl-1-propano	55	5
5β-Pregnane-3α,20α-diol	83	7
N-Maleoyl-β-alanine	17	6
β-Nicotinamide adenine dinucleotide hydrate	57	1
4-Nitrophenyl β-D-xylopyranoside	100	49


DOZN™ 2.0 Demo
MERCK



DOZN™2.0– A Quantitative Green Chemistry Evaluator

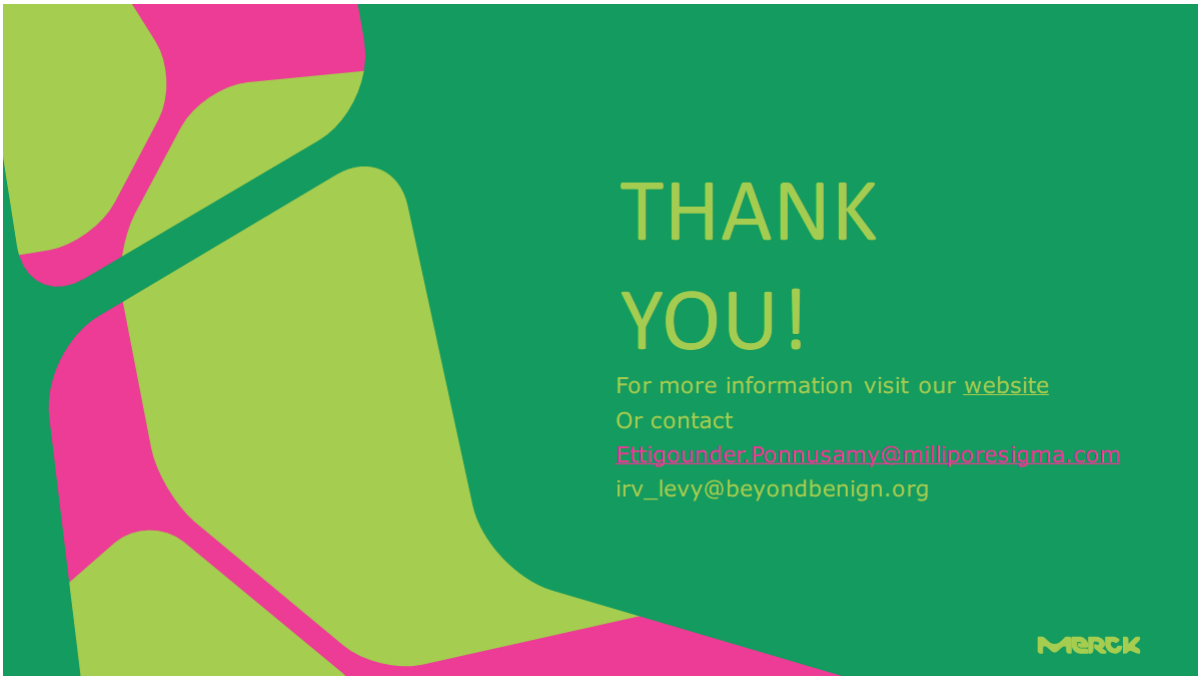
Advantages

- **Measurement:** Ability to use on-hand data sources or establish straightforward data collection programs
- **Calculations:** Ability to utilize well-defined metrics to calculate the benefits of the 12 principles of green chemistry
- **Communication:** Ability to transparently communicate greener alternatives to customers

- **Data privacy**—users can evaluate their processes and products in a secure manner
- This free web-based tool enables customers to choose more environmentally friendly approaches for their research/manufacturing projects to promote overall sustainability
- The DOZN™ system was verified and validated by third party and also published

For more information visit www.sigmaaldrich.com/greener


MilliporeSigma
MilliporeSigma is a business of Merck KGaA, Darmstadt, Germany


THANK YOU!
For more information visit our website
Or contact
Ettigounder.Ponnusamy@milliporesigma.com
irv_levy@beyondbenign.org
MERCK

The “problem” with a very green lab curriculum

- Do students understand the green development work that you have done?
- Can it be improved?
  - Here is where DOZN comes in!

Needed Impactful lab experience in a online environment

- First used with face-to-face class of junior/senior
- A new experience for students who will gain
  - Deeper appreciation of green chemistry
    - Including ability to discern greener approaches and key areas for improvement of a process
  - Better understanding of the value of an SDS
  - Familiarity with a genuine industrial tool

Benefits to using DOZN™ 2.0

- Freely available industrial tool after registration
- Showcases to your students that your personal focus on green chemistry is not isolated
- Significant, non-trivial, team-amenable experience
- Students must use SDS to gather relevant data

Case study, Synthesis of benzaldehye

Classic 1978 synthesis

- Glaros, G. The Oxidation of Primary Alcohol to Aldehydes with Pyridinium Chlorochromate. *J. Chem. Educ.* **1978**, *55*, 410.
- Semi-macroscale; 500 mL RBF; 100 mmol

Many Greener Alternatives

- The green and effective oxidation of alcohols to carboxylic acids with molecular oxygen via biocatalytic reaction
- Green and Efficient: Iron-Catalyzed Selective Oxidation of Olefins to Carbonyls with O_2
- Selective oxidation of alcohols and aldehydes over supported metal nanoparticles
- Ionic Liquids in Selective Oxidation: Catalysts and Solvents.
- Silver catalysts for liquid-phase oxidation of alcohols in green chemistry: Challenges and outlook
- The green and effective oxidation of alcohols to carboxylic acids with molecular oxygen via biocatalytic reaction

Our choice

- Ming-Lin, G.; Hui-Zhen, L. Selective oxidation of benzyl alcohol to benzaldehyde with hydrogen peroxide over tetra-alkylpyridinium octamolybdate catalysts. *Green Chem.* **2007**, *9*, 421-423.
- Pedagogical advantages:
  - Novel catalyst; compared to 50% stoichiometric excess of PCC Tetrakis(benzyltriethylammonium) octamolybdate $(C_{13}H_{22}N)_4[Mo_8O_{26}]$
    - Demonstrates organometallic synthesis
  - Uses benign 3% hydrogen peroxide as oxidizer (cf. paper 15%)

Walkthrough of benzaldehyde analysis

- Gather and enter data- not a trivial project.
- Gather data from the Experimental Method (using the template) – lots of data is examined
  - Substance
  - Supplier, catalog #
  - Amount (mass) may require calculations
  - SDS files
- Calculate score

Aggregate score: 8 (0-100 scale)

Groups	Principles	Score
#1 Improved Resource Use	1, 2, 7, 8, 9, 11	60.46
#2 Increased Energy Efficiency	6	244.77
#3 Reduced Human and Environmental Hazards	3, 4, 5, 10, 12	78.14

Note: The intent of the DOZN tool is to compare relative "greenness" for similar products or processes, as indicated by a lower DOZN score.

- Glaros, G. The Oxidation of Primary Alcohol to Aldehydes with Pyridinium Chlorochromate. *J. Chem. Educ.* **1978**, *55*, 410.

Same analysis on the octamolybdate method

- Two steps:
- Preparation of the catalyst
- Reaction and isolation of product by steam distillation

Agreggate scores

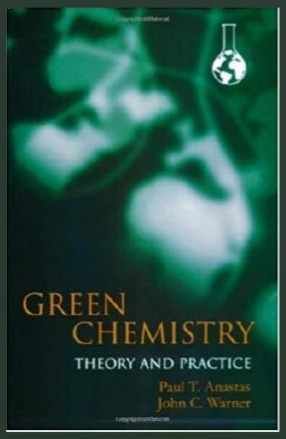
- Classic method, one step
- Score: 8
- Greener method, two steps
- Scores: 1; 2 (clearly greener choice)

Not being critical of the classic authors

- From a different time 40 years ago – labs were different!
- Before microscale
- Before green chemistry

And even green chemists did funny things once upon a time

- Anastas & Warner, 1998



And even green chemists did funny things once upon a time

The Wittig Reaction in the Undergraduate Organic Laboratory

John C. Warner, Paul T. Anastas, and Jean-Pierre Anselme[1]
University of Massachusetts at Boston, Harbor Campus, Boston, MA 02125

- *J. Chem. Educ.* **1985**, *62*, 346.

Excellent student project after walking through the aldehyde synthesis

JOURNAL OF CHEMICAL EDUCATION

Synthesizing Stilbene by Olefin Metathesis Reaction Using Guided Inquiry To Compare and Contrast Wittig and Metathesis Methodologies

Timothy J. Bannin, Partha P. Datta, Elizabeth T. Kiesewetter and Matthew K. Kiesewetter*

- Bannin T. J.; Datta, P. P.; Kiesewetter, E. T.; Kiesewetter*, **M.K.** Synthesizing Stilbene by Olefin Metathesis Reaction Using Guided Inquiry To Compare and Contrast Wittig and Metathesis Methodologies. *J. Chem. Educ.* **2019**, *96*, 143-147.

Want to brainstorm?

- lrv.levy@simmons.edu