
聲明

本檔案之內容僅供下載人自學或推廣化學教育之非營利目的使用。並請於使用時註明出處。

[如本頁取材自○○○教授演講內容]。



綠色/永續化學的內涵、 歷史、現狀與面臨的挑戰

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綠色/永續化學之內涵

The design of products and processes that reduce or eliminate the use and generation of hazardous substances

- 著重於避免毒害物質之使用與產生
- 著重於“**Reduction**”的概念
(materials, waste, energy, cost, hazard and risk, non-renewables, environmental impact)
- 不同於環境化學
- 不僅是找尋新能源材料
- 重點在“**Design**”



綠色化學與環境化學之涵蓋範圍

綠色化學

- 有機化學
- 無機化學
- 生物化學
- 分析化學
- 物理化學

環境化學

- 大氣化學
- 土壤化學
- 水化學
- 分析化學

綠色化學帶來的思考模式改變

$$\text{風險} = \text{毒害} \times \text{暴露次數}$$

$$\text{Risk} = f(\text{hazard} \times \text{exposure})$$



綠色化學之精神
從源頭減少毒害



向來以立法的方式控制

歷史與現狀

- 1987年聯合國環境與發展委員會提出：
“...meeting the needs of the present without compromising the ability of future generations to meet their own needs”
- 1990年美國通過「污染防制法案」：建立由源頭預防或降低污染之國家政策。由環境保護署提出「Green Chemistry」一詞。在歐洲許多國家使用「Sustainable Chemistry」。
- 綠色/永續化學的蹤跡：美國 英國 日本 義大利 澳洲 加拿大 德國 中國 韓國 印度 其他



歷史與現狀

2020 Sustainability Goals

Zero Waste: eliminate the concept of waste in product, process, materials and energy

Zero Toxic Substances: eliminate substances known or suspected to be harmful to human health or the health of biological systems

100% Closed Loop Processes: take 100% responsibility for our products at all stages of our product and process lifecycle

Sustainable Growth and Profitability: create an economy the planet is capable of sustaining indefinitely

(Zero Waste Alliance, 2001)



歷史與現狀

- **'Green chemistry' movement sprouts in colleges, companies** *The New York Times* March 25, 2009
 - The **University of Oregon** began an outreach program nine years ago that **teaches professors nationwide** about integrating green chemistry into a curriculum.
 - ...balancing **environmental, social and economic** decisions. Many universities are responding by creating a **green-chemistry curriculum**. Their efforts require addressing a **fundamental problem in chemistry education: a lack of toxicology training**.



歷史與現狀

- **'Green chemistry' movement sprouts in colleges, companies** *The New York Times* March 25, 2009
 - ...**get the market working properly**, ...demand for trained chemists who understand green chemistry and toxicology will ramp up. Universities will respond, as will research.
 - Green chemistry applications make up **1 percent** of the total chemical market share. ...the field has tremendous potential for growth.
- 學校老師未開課，**UC Berkeley**的學生自行安排課程：**Green Chemistry and Sustainable Design**
<http://sites.google.com/site/berkeleygreenchemistry/Home>



歷史與現狀

- 一般學校打先鋒 近來超級名校加入
 - University of Oregon, University of Massachusetts, University of Scranton, Hendrix College, St. Olaf College...
 - University of York (UK), Monash University (Australia), Carnegie Mellon, University of Illinois, Urbana-Champaign...
 - Center for Green Chemistry & Green Engineering at Yale (2007; First Director: Paul Anastas)
 - MIT Green Alternatives Wizard
 - The Berkeley Center for Green Chemistry (2009)
A collaboration among the College of Chemistry, Haas School of Business, School of Law, College of Natural Resources, and School of Public Health.



歷史與現狀

- **Presidential Green Chemistry Challenge Awards**
(USA EPA 1996)
 - Greener **Synthetic Pathways** Award
 - Greener **Reaction Conditions** Award
 - Designing **Greener Chemicals** Award
 - **Small Business** Award
 - **Academic** Award

- **The European Sustainable Chemistry Award**
(EuCheMS 2010)
 - Alternative **Synthetic Pathways**
 - Alternative **Feedstocks**
 - Alternative **Reactor Design and Reaction Condition**
 - Design and Use of **Less Hazardous Chemicals** and Chemical Products



歷史與現狀

- **Presidential Green Chemistry Challenge Awards**
 - *C&EN* **2008**, 86(33), 59-68: The **67 winners** have collectively made **1.1 billion lb** of progress in eliminating hazardous chemicals and emissions over the **13 years** of the program. It's the result of "cleaner, cheaper, and smarter chemistry," *C&EN* **2008**, 86(33), 59-68.
<http://pubs.acs.org/cen/coverstory/86/8633cover3.html>
- **IUPAC Green Chemistry Directory** 中整理了其他國家之相關獎項（如：澳洲、英國、日本）
<http://www.incaweb.org/transit/iupacgkdir/awards.htm>



歷史與現狀

- **Joseph Breen Memorial Fellowship**
 - Sponsors a young international green chemistry scholar to participate in an international green chemistry technical meeting, conference, or training program.
 - “Young” international scholar is defined as undergraduate students, graduate students, post-docs, and above, but below the level of Assistant Professor and within the first seven years of a professional career.
- **ACS Summer School on Green Chemistry and Sustainable Energy**
 - Graduate students and postdoctoral scholars



歷史與現狀

- **ACS course: Toxicology for Chemists**
- **Free video course: Carnegie Mellon Univ. The Institute for Green Science** (Under construction).
 - Introduction to Green Chemistry
 - Toxicology for Green Chemists
 - Endocrine Disruption for Green Chemists



歷史與現狀

- 值得觀察與瞭解的組織：
 - **ACS Green Chemistry Institute** (美)
 - **ACS GCI Industrial Roundtables**
 - ACS GCI Pharmaceutical Roundtable
 - ACS GCI Formulator's Roundtable
 - ACS GCI Suppliers Roundtable under development
 - **Green Chemistry Network** (英)
 - Very informative **Newsletter**
 - Great **education materials**
 - **SusChem** (歐)
 - **Strategic Research Agenda** 提出創新方向
 - **Brokerage Database** 提供媒合平台



Pharmaceutical Roundtable

加入**Roundtable**之企業討論出以下之項目

應優先找「綠色途徑」，並向外徵求研究計畫

- Amide formation
 - OH activation
 - Amide reduction
 - Green Mitsunobu reactions
 - Oxidation/Epoxidations
 - C-H activation of aromatics
 - Chiral amine synthesis
 - Asymmetric hydrogenation
 - Green fluorination methods
 - *N*-centered chemistry
- Outside the reaction theme
- Solvent-less reactor cleaning
 - Green alternatives to dipolar aprotic solvents

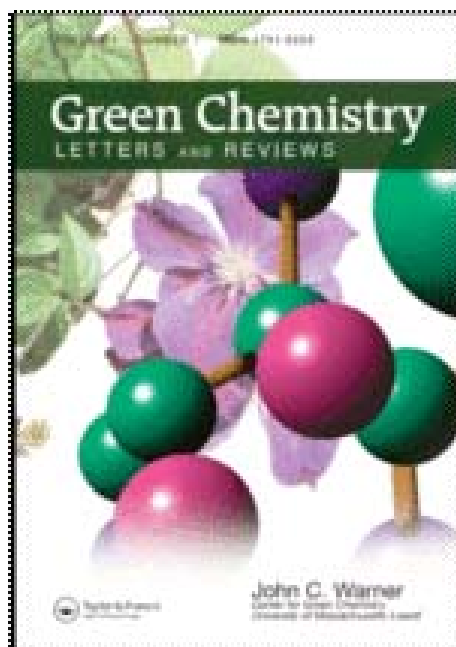
歷史與現狀

■ Journals

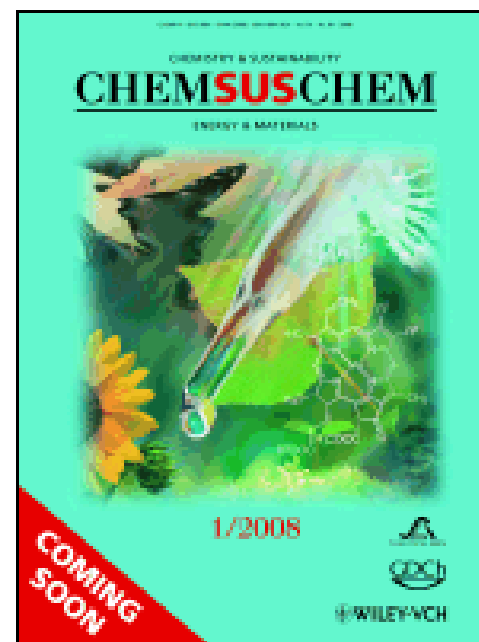
- Green Chemistry (RSC)
 - 2008 impact factor: 4.542; 40% increase in 4 years
- Green Chemistry Letters and Reviews (Taylor & Francis)
- ChemSusChem (Wiley)



Since 1999



Since 2007



Since 2008



面臨的挑戰

- **Alternative feedstocks**
 - Move from petroleum to renewable or biologically derived sources
 - Petroleum chemistry => need oxidation chemistry
 - Sugar => need reduction chemistry
 - CO₂ => need new catalysts
- **Alternative solvents**
 - No solvent (neat solution; grinding)
 - Supercritical CO₂, ionic liquid
- **Alternative synthetic pathways**
 - New catalysts
 - Move to biocatalysts (no toxic metals; intrinsically safer)
 - Research into reuse and recycling catalysts still in infancy



面臨的挑戰

- **Education:** 聯合國教科文組織(UNESCO)已定2005-2014為[永續發展教育的10年](Decade of Education in Sustainable Development)，與永續發展汲汲相關的化學界，應速起領導作用
 - 1991年即有綠色化學一詞，綠色/永續化學的重要性無庸置疑，為什麼2006年IUPAC才第一次召開綠色化學大會？ACS National Meeting 2010年才有主題為“Chemistry for a Sustainable World”之年會？
 - 為什麼世界上有綠色化學課程的學校仍不多？
 - 國外的綠色化學在教些什麼？
 - 如何自學？



面臨的挑戰

- **Lack of toxicology training**
- **Address the problems of waste, toxicity, energy consumption altogether, rather than individually.**
- **When to use what metrics**



Key References

- Beach, E. S.; Cui, Z.; Anastas, P. T. “Green Chemistry: A Design Framework for Sustainability” *Energy Environ. Sci.* **2009**, 2, 1038-1049.
- Tundo, P.; Aricò F. “Green Chemistry on the Rise: Thoughts on the Short History of the Field” *Chemistry International* **2007**, 29(5)
- Anastas, P. T.; Kirchhoff, M. M. “Origins, Current Status, and Future Challenges of Green Chemistry” *Acc. Chem. Res.* **2002**, 35, 686-694.
- Poliakoff, M.; Fitzpatrick, J. M.; Farren, T. R.; Anastas, P. T. “Green Chemistry: Science and Politics of Change” *Science* **2002**, 297, 807-810.
- Constable. D. J. C.; Dunn, P. J. ; Hayler, J. D.; Humphrey, G. R.; Leazer, J. L. Jr. ; Linderman, R. J. ; Lorenz, K. ; Manley, J.; Pearlman, B. A. ; Wells, A. ; Zaks, A. ; Zhang, T. Y. “Key Green Chemistry Research Areas—A Perspective from Pharmaceutical Manufacturers” *Green Chem.* **2007**, 9, 411-420.



Good Starting Points

Internet

- Green Chemistry Network
- ACS Green Chemistry Institute
- SusChem
- 綠色/永續化學網路資源共享網

Book

- Green Chemistry : An Introductory Text
by Mike Lancaster

Course materials

- 永續化學概論、永續性有機製備
請向台大化學系劉廣定教授索取 ktliu@ntu.edu.tw



座談會可能之討論事項

- 工作坊改進的方向
- 資訊的流通與分享對臺灣綠色/永續化學的影響（如Pharmaceutical Roundtable, Strategic Research Agenda, Brokerage Database）
- 未來的運作方式
- 中文用詞