
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

中央研究院化學所

趙奕婷

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

綠色化學之父：Paul Anastas and John C. Warner



甘魯生攝

綠能及綠色化學電子月刊
第二期(August, 2010)



C&E News October 4, 2010

在Berkeley Green Chemistry Center之演講

<http://www.youtube.com/watch?NR=1&v=mrSy6RK0ge8>



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

- 著重於安全與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)
- 不等同於環境化學
- 不僅是找尋新能源材料
- 強調 “Design” (Smart Chemistry)



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。
 - 美國環境保護署提出「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)
- 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

Annual benefits derived from the technologies implemented by the past **82 winners**

- Eliminating 199 million lb of hazardous chemicals and solvents
- Saving more than 21 billion gal of water
- Avoiding 57 million lb of carbon dioxide emissions

C&EN 2011, 89(26), 11. <http://cen.acs.org/articles/89/i26/2011-Green-Chemistry-Awards.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/iupacgdir/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: 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
- **Presentation** files available **on line!**



歷史與現狀

■ On-Line Learning

- ACS course: **Toxicology for Chemists**
- Free ACS webinar: **Green Chemistry Series**

Webinar

- [Green Chemistry: Innovation and Application for the New Decade](#)
- [Green Chemistry and Renewable Energy – Two Peas in a Pod](#)
- [Going Green in the Chemistry Teaching Laboratory](#)

■ Free App

- Green Solvent



歷史與現狀

- 值得觀察與瞭解的組織：
 - **ACS Green Chemistry Institute** (美)
 - The Nexus Newsletter
 - ACS GCI Industrial Roundtables
 - ACS GCI Pharmaceutical Roundtable
 - ACS GCI Formulator's Roundtable
 - ACS GCI Chemical Manufacturer's Roundtable
 - **Warner-Babcock Institute for Green Chemistry** (美)
 - **SusChem** (歐)
 - Strategic Research Agenda /Implementation Action Plan



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

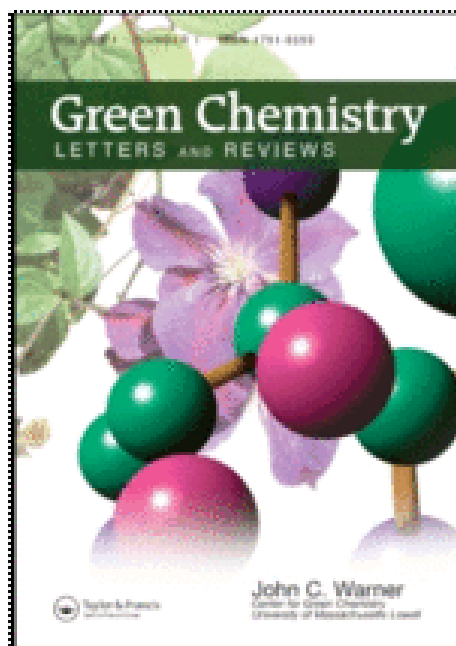
歷史與現狀

■ Journals

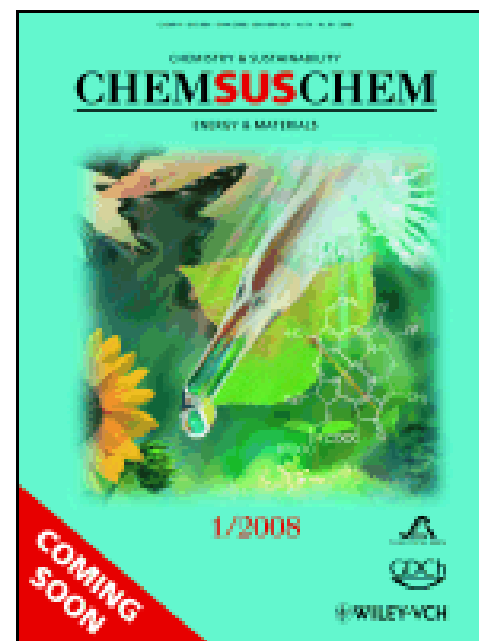
- Green Chemistry (RSC) 2010 impact factor: 5.472
- Green Chemistry Letters and Reviews (Taylor & Francis)
- ChemSusChem (Wiley) 2010 impact factor: 6.325



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



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

Website

- ACS Green Chemistry Institute
- ACS Summer School on Green Chemistry
- 綠色/永續化學網路資源共享網

Book

- Green Chemistry: An Introductory Text (2nd Ed.)
by Mike Lancaster

Course materials

- 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



More Advanced Materials

Philip Jessop's

Presentations about **metrics** and **solvents**

(Presentations in 2011 ACS Summer School on Green Chemistry)

- Choosing the Greenest Synthesis
- Green Solvents

Perspective about **solvents**

- *Green Chem.* **2011**, *13*,
1391–1398



Philip Jessop's Talk about Green Solvent

OUTLINE

1. Reducing the Impact of Solvents
2. Solvent Properties
3. Greener Conventional Solvents
4. Unconventional Solvents
 - Ionic Liquids
 - Liquid Polymers
 - Switchable Solvents
 - Supercritical Fluids
 - Gas-Expanded Liquids
5. Conclusions





More Advanced Materials

Paul T. Anastas's articles

- Toward a Comprehensive **Molecular Design** Framework for **Reduced Hazard**
Chem. Rev. **2010**, *110*, 5845–5882
- Towards Rational **Molecular Design**: Derivation of Property Guidelines for **Reduced Acute Aquatic Toxicity**
Green Chemistry **2011**, DOI: 10.1039/c1gc15651a
- Toward **Molecular Design** for **Hazard Reduction**-- Fundamental Relationships between Chemical Properties and Toxicity
Tetrahedron **2010**, *66*, 1031–1039

John C. Warner引發的感想

- 看清事情的本質
 - 化學家不熟悉毒物學毒理學所遭致的後果
- 開放心胸向周遭學習
 - Non-Covalent Derivatization
- 整體性的思考
 - Economy, Environment, Society
- 創造性的行動力
 - Presidential Challenge Award
 - Academic Green Chemistry Program
 - Warner-Babcock Institute for Green Chemistry
 - Beyond Benign
 - iSUSTAIN



致謝



- 劉廣定教授 甘魯生教授 周德璋教授
- 廖俊臣教授 劉陵崗教授 凌永健教授
- 林育靜小姐 陳秋雲小姐 曹春梅小姐
- 施玉枝小姐 蕭竣先生
- 中國化學會
- 中央研究院化學研究所
- 清華大學化學系
- 國科會化學中心

