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/永續化學原則與指標

綠色/永續合成化學工作坊

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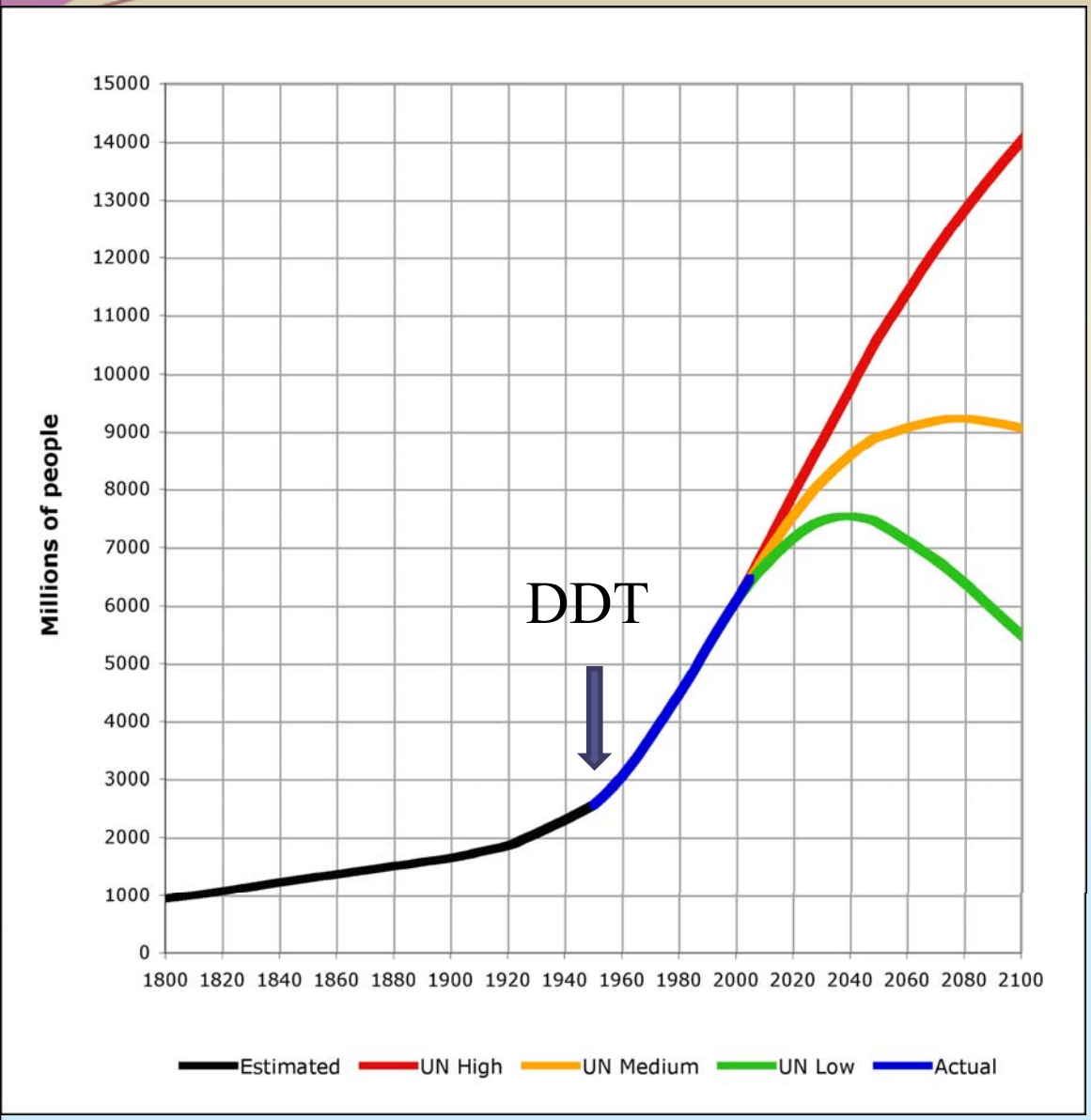
December 3rd, 2010

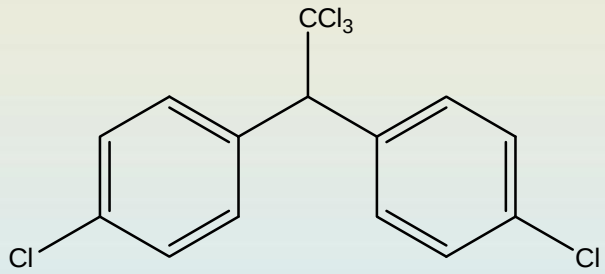
參加 綠色/永續合成講習會　十大理由

✓您的研究用到合成化學。
✓您不熟悉合成化學與永續發展的關聯。
✓您好奇觸媒目前的進展。
✓您不曉得綠色/永續化學也有微波食譜，可用微波來進行反應，節能省時。
✓您不清楚在水中及不揮發性有機溶劑中合成反應的最近發展。
✓綠色/永續化學相關的學術期刊，衝擊指數節節上升。目前三種期刊之中的"Green Chemistry"，2009年衝擊指數為5.836，已超過 "Chem. Commun."。
✓國際主要化學會議都將綠色/永續化學列為重大議題，新世紀的化學人不想落伍必須認識綠色/永續化學。
✓國際主要化學公司致力研發綠色/永續製程，減廢降成本以增商機，已成潮流。
✓美國過去兩年具有綠色/永續化學背景的化學家安然度過經濟衰退帶來的裁員潮。
✓全程參加講習會將獲頒化學學會的結業證明。

為什麼需要綠色化學?

化學改變了世界, 改善了人的衣、食、住、行, 給人們增添財富, 帶來幸福, 帶來了醫藥革命, 製造了大量化肥和農藥, 使農產品增產, 冶煉了各式各樣的合金、合成了塑膠、橡膠、纖維. 以這些為原料製成了汽車、飛機、高樓、電腦、化粧品等數不清的物品. 在這些生產過程中向自然界釋放大量的合成物質. 導至人類賴以生存的環境遭到嚴重的破壞. 綠色化學就是以好的化學替代壞的化學, 新的化學替代舊的化學.





dichloro**d**iphenyl**t**richloroethane

http://en.wikipedia.org/wiki/World_population

What is green chemistry? 什麼是綠色化學?

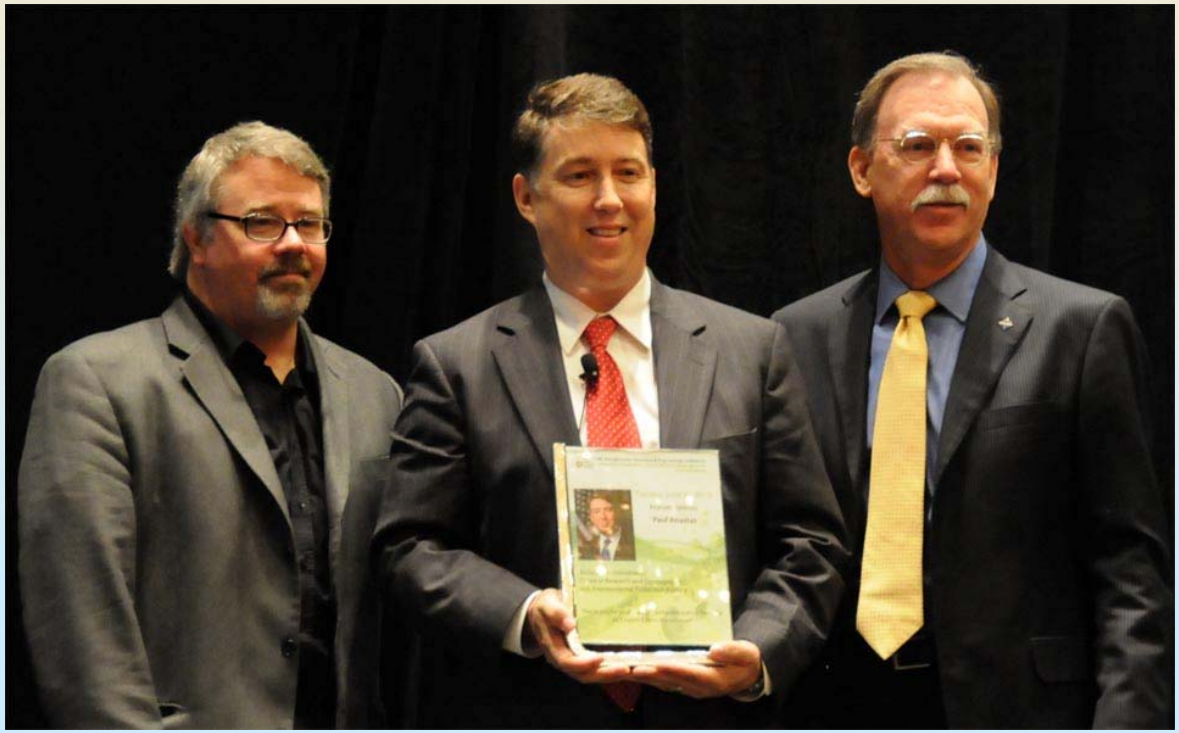
- Green chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances.
- 發明、設計化學產品及其製造過程不涉及或不產生有害物質的化學都可統稱為綠色化學. 由於無害可以永續經營, 亦稱之為永續化學.

- Discovery and application of new chemistry/technology leading to prevention/reduction of environmental, health and safety impacts at source
- 探索並應用致使能防止/減少對環境、健康及安全衝擊之源頭的新化學及技術.

P. Tundo, P. Anastas, D. Black, J, Breen, T, Collins, S, Memoli, J, Miyamoto, M, Polyakoff, and W, Tumas, Synthetic pathways and processes in green chemistry. Introductory overview, *Pure and Applied Chemistry, 2000, 72, 1207-1208*

綠色化學十二項原則

Paul Anastas and John Warner in Green Chemistry: Theory and Practice (Oxford University Press: New York, 1998)



John C. Warner Paul T. Anastas Robert Peoples

綠色化學十二項原則

1. Prevent waste: Design chemical syntheses to prevent waste, leaving no waste to treat or clean up.

避免廢料：設計化學合成使之避免廢料, 不產生需處理或清理的廢料.

<u>廢棄物的代價</u>

原料成本高

廢棄物處理帶來額外的開支

難以處理的公共關係

不利永續經營

健康的危害

環境的破壞

要點：不生產比事後處理強.

E^+-Factor (Environmental factor) =
(sum of waste)(severity factor)/(Wt. of product)(1-diluents)

Hazardous Waste to Land Disposal/Containment	10
Hazardous Waste to Incineration	4
Non-Hazardous Waste to Landfill	2
Waste Water (to Treatment Plant)	0.5

E: 0 (ideal), 0.4 (low), 6 (moderate), 50 (large), >200 (maximum)

Roger A. Sheldon, Chem & Ind., 7-Dec-1992, pg. 903
Roger A. Sheldon, Chem. Commun., 2008, 3352-3365

化學工業之 E-因子值 (E-Factors across the chemical industry)

	年產量(噸)	E-因子值	廢棄物(噸)
煉油	10^6-10^8	約 0.1	10^5-10^7
大綜化學產品	10^4-10^6	<1-5	10^4-5x10^6
精細化學產品	10^2-10^4	5-50	5x10^2-10^5
藥物	10-10^3	25-100	2.5x10^2-10^5

R. A. Sheldon, Chem. Commun., 2008, 3352-3365.

綠色化學十二項原則

2. Design safer chemicals and products: Design chemical products to be fully effective, yet have little or no toxicity.

設計較安全的化學劑和生成物：設計完全有效而毒性很低或不具毒性的化學產物.

Natular™是Clarke 公司研發出殺蚊蟲幼蟲之長期釋發劑.
不溶於水的硫酸鈣和溶於水的PEG (polyethylene glycol) 和spinosad混合而成。由於作用緩慢，一顆藥丸可支持180天。
由於有藥丸的保護，未釋放的藥不易被分解，所以劑量可為一般用藥之一半甚至降低到十分之一，毒性則為一般有機磷殺蟲劑之十五分之一，對野生動植物無害。Natular™ 通過了美國農業部國家有機物的標準以及害蟲管理局最嚴格的檢驗，這些特點表現了此產品在綠色化學方面的革新，因而得到2010 總統綠色化學挑戰獎:**更永續之化合物獎**。

Clarke公司網站: http://www.clarke.com/
綠能及綠色化學第二期. (http://www.bioeng.ttu.edu.tw/issues/issuesindex.html)
Presidential Green Chemistry Challenge Award: http://www.epa.gov/gcc/pubs/pgcc/presgcc.htm

綠色化學十二項原則

3. Design less hazardous chemical syntheses: Design syntheses to use and generate substances with little or no toxicity to humans and the environment.

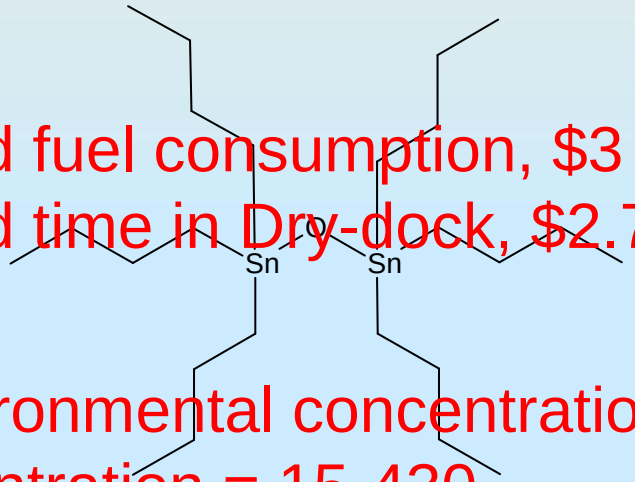
設計危害性低的化學合成：設計的合成是用對人類和環境的毒性都很低或不具毒性的反應物也產生同樣毒性很低或不具毒性的生成物.

1996 Designing Greener Chemicals Award
Rohm and Haas Company
Innovation and Benefits:

Rohm and Haas developed Sea-Nine™, a novel antifoulant (防污物質) to control the growth of plants and animals on the hulls of ships. In 1995, fouling (產生污物) cost the shipping industry approximately $3 billion a year in increased fuel consumption. Sea-Nine™ replaces environmentally persistent and toxic tin-containing antifoulants.

(貝殼類及其他動植物附著船身外殼生長(產生污物)一直是船使用年限的大敵. 因此在保養上所費不貲, 也曾加了燃料的消耗, 間接增加二氧化碳的排放.)

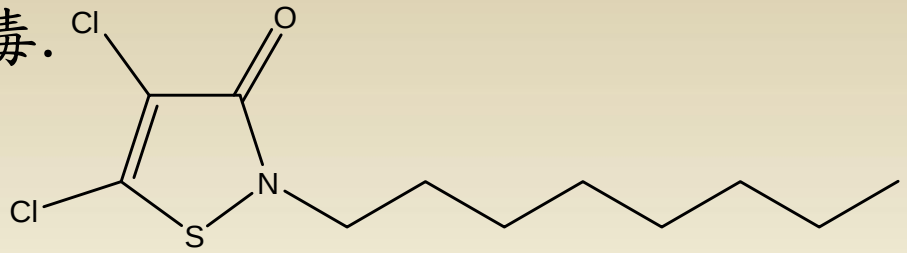
舊防污物質： tributyltin oxide
(三丁烷基錫氧化物)
半衰期大於6個月
對多種海洋生物有影響



Increased fuel consumption, $3 billion/year
Increased time in Dry-dock, $2.7 billion/year

Risk Quotient = predicted environmental concentration / predicted no-effect environmental concentration = 15-430

Rohm and Haas公司篩檢了140多化合物之物, 找到4,5-dichloro-2-*n*-octyl-4-isothiazolin-3-one (Sea-Nine™ antifoulant). Sea-Nine和TBTO一樣對海洋的生物有劇毒.



半衰期小於一小時
降解為無毒物質

Sea-Nine 生物降解途徑

$C_8H_{17}NHC(O)CH_2COOH$

$C_8H_{17}NHC(O)CH_2CH_3$ ← $C_8H_{17}NHC(O)COOH$ ← $C_8H_{17}NHCOOH$

Risk Quotient = 0.024-0.36 vs. TBTO 15-430

D. K. Larsen, I. Wagner, K. Gustavson, V. E. Forbes, T. Lund, Long-term effect of Sea-Nine on natural coastal phytoplankton communities assessed by pollution induced community tolerance, Aquatic Toxicology 62 (2003) 35/44

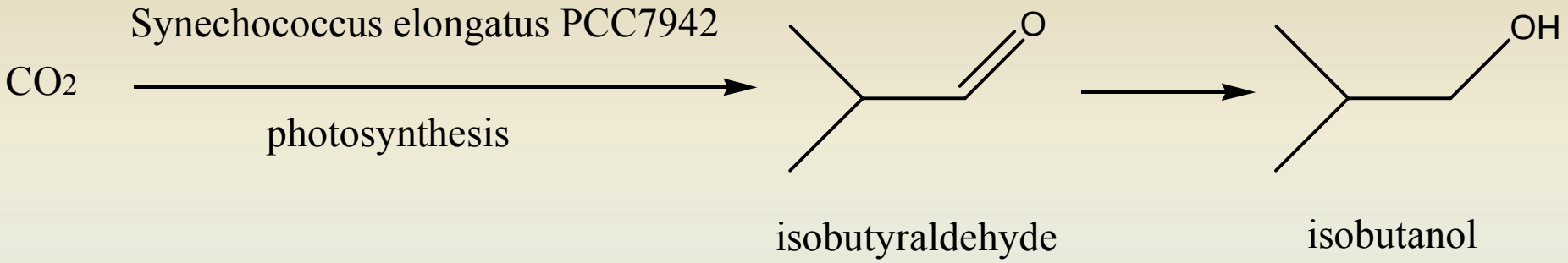
Presidential Green Chemistry Challenge Award: http://www.epa.gov/gcc/pubs/pgcc/presgcc.html

綠色化學十二項原則

4. Use renewable feedstocks: Use raw materials and feedstocks that are renewable rather than depleting. Renewable feedstocks are often made from agricultural products or are the wastes of other processes; depleting feedstocks are made from fossil fuels (petroleum, natural gas, or coal) or are mined.

使用可再生的原料：使用可以再生，而非消耗性，的原始物料和材質．再生性原料通常來自農作物或其它製作過程的廢料．而消耗性原料則來自石化燃料(石油．天然氣或煤)或是由採礦而得．

二氧化碳生物合成多碳原子(3-8)的醇化合物 (higher alcohols).



二氧化碳是眾所週知的溫室氣體.吾人正因它的逐漸增加所引起各種自然災害而煩惱.現能反其道而行將二氧化碳轉變爲燃料和其他化學原料.而且其過程(光合作用)是非常乾淨.碳數比乙醇高的醇的含能量高、吸水性低、蒸氣壓低(不易污染空氣)等優點.如果每年能生產600億加侖(約佔25%之汽油)就可以去除500百萬噸二氧化碳,這數字約等於全美國一年二氧化碳排放量之8.3%.

2010總統綠色化學挑戰獎(四) —學術獎得主James C. Liao教授

Nature Biotechnology **27**, 1177 - 1180 (2009)
綠能及綠色化學第五期. (http://www.bioeng.ttu.edu.tw/issues/issuesindex.html)
Presidential Green Chemistry Challenge Award: http://www.epa.gov/gcc/pubs/pgcc/presgcc.html

綠色化學十二項原則

5. Use catalysts, not stoichiometric reagents: Minimize waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once.

使用**觸媒**而非化學當量的藥劑：利用觸媒反應將廢料減至最低量. 觸媒僅需少量且可重複促成某一反應. 觸媒比化學當量藥劑更為優先使用. 因為後者常需用過量. 且僅能使用一次.

要點：觸媒不但使用量少, 而且可降低激發能, 節省能量. 產品專一, 可減少廢物.

Catalyst Mole % = 100 * (moles of catalyst)/(moles of limiting reagent upon which it acts)

C. M.: >0 (minimun), 1 (low), 10 (moderate), 50 (large), 100 (maximum)

綠色化學十二項原則

6. Avoid chemical derivatives: Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.

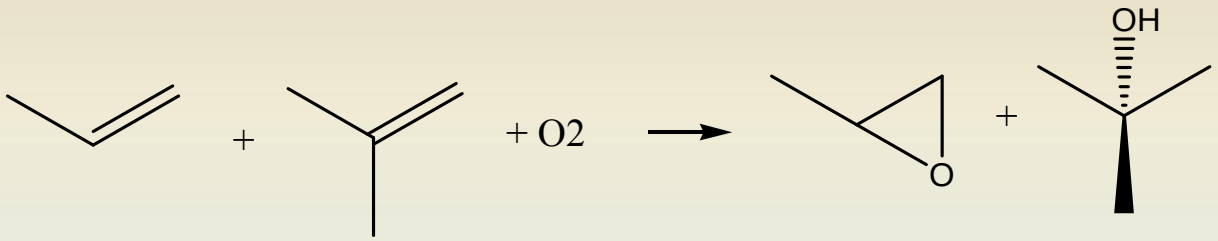
避免化學衍生物：盡可能避免使用阻擋或保護群組或任何暫時的修飾. 衍生物須用更多的藥劑而且產生廢料.

7. Maximize atom economy: Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.

發揮最大的原子經濟：設計合成使得終極產物含有最大部分的原始反應料. 而沒有甚麼浪費的原子. 即便有也是很少.

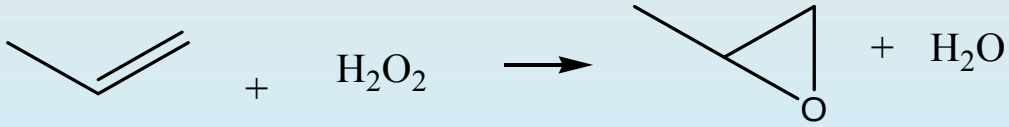
Atom Economy (原子經濟指標) =
m.w. of product x 100%) / Σ (m.w. of reagent)

1,2環氧丙烷 (propylene oxide)



異丁烯　　三級丁醇

A.E. = 58x100%/(42+56+32) = 45%



A.E. = 58x100%/(42+34) = 76%

因而得到2010 總統綠色化學挑戰獎:更永續合成途徑獎。

綠能及綠色化學第四期. (http://www.bioeng.ttu.edu.tw/issues/issuesindex.html)

Presidential Green Chemistry Challenge Award: http://www.epa.gov/gcc/pubs/pgcc/presgcc.html

綠色化學十二項原則

8. Use safer solvents and reaction conditions: Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use innocuous chemicals.

使用較安全的溶劑和反應條件：避免使用溶劑.分離劑或其它輔助劑.如果是必須時則使用無害的化學藥品.

Conceptual basis for preferable solvent selection
（選擇溶劑之考量）

選擇溶劑的要件

化學反應之需求: 溶解度的大小、反應之快慢、產量之多少.

抽取產物之考量: 揮發之難易.

是否對環境及人體健康衝擊: 有無毒性?對環境產生長時問影響.

Green Chemistry Metrics, p.22 (Blackwell, 2009)

Pfizer公司在藥物化學溶劑應用的規範

優先考慮	可用	不理想的
water	cyclohexane	pentane
acetone	heptane	hexane
ethanol	toluene	di-isopropyl ether
2-propanol	methylcyclohexane	diethyl ether
1-propanol	methyl *t*-butyl ether	dichloromethane
ethyl acetate	iso-octane	dichloroethane
isoprophyl acetate	2-methyltetrahydrofuran	chloroform
methanol	tetrahydrofuran	dimethyl formamide
methyl ethyl ketone	xylenes	N-methylpyrrolidinone
1-butanol	dimethyl sulfoxide	pyridine
t-butanol	acetic acid	dimethylacetamide
	ethylene glycol	dioxane
		dimethoxyethane
		benzene
		carbontetrachloride

K. Alfonsi, *et al., Green Chem*. **2008**, *10*, 31-36

Table 2 Solvent replacement table

Undesirable solvents	Alternative
Pentane	Heptane
Hexane(s)	Heptane
Di-isopropyl ether or diethyl ether	2-MeTHF or *tert*-butyl methyl ether
Dioxane or dimethoxyethane	2-MeTHF or *tert*-butyl methyl ether
Chloroform, dichloroethane or carbon tetrachloride	Dichloromethane
Dimethyl formamide, dimethyl acetamide or *N*-methylpyrrolidinone	Acetonitrile
Pyridine	Et_3N (if pyridine used as base)
Dichloromethane (extractions)	EtOAc, MTBE, toluene, 2-MeTHF
Dichloromethane (chromatography)	EtOAc/heptane
Benzene	Toluene

K. Alfonsi, et al., Green Chem. ***2008****, 10, 31-36*

Searching for benign solvents (尋求無害溶劑)

Volatile organic and hazardous solvents (揮發和有害溶劑)

Replaced by

Water (水)

Non-volatile solvents (ionic) (非揮發性溶液)（離子）

Supercritical solvents (超臨界溶劑)

Other benign solvents (其他)

Solventless (無溶劑)

9. Increase energy efficiency: Run chemical reactions at ambient temperature and pressure whenever possible.

增加能源效率：盡可能在常溫常壓下進行化學反應.

要點：用能要考慮對環境及經濟的衝擊.所以能在常溫及常壓下反應最佳.

Temperature Ranges (˚C)	Temperature Factor (f_T)
< -20	5
-20 to 0 (technical cooling)	3
0 to 10 (ice cooling)	2
10 to 20 (water cooling)	1
20 to 30 (room temperature)	0
30 to 90 (hot water heating)	1
90 to 160 (steam heating)	2
160 to 280 (hot oil or electrical heating)	3
> 280	5

Step EE (Energy Efficiency) = $\dfrac{\left(f_T + |1\text{-}Pressure(atm)|\right) * time\ (hrs) * Weight * Heat\ Capacity\ (J/gm\cdot{}^{\circ}K)}{Wt\ Desired\ Product}$

Alternative energy source（其他能源）

- Photochemical reactions（光化學反應）
  - Specific bond targeted
  - Low reaction temperature/higher selectivity
- Microwave-assisted reactions（微波輔助反應）
  - Fast heating rate by rotation friction (10 ºC per second)
  - Target molecules with dipole
- Sonochemistry（超音波化學）
  - Generate local high pressure and temperature
- Electrochemical synthesis（電化學合成）
  - Often water-based
  - Usually mild operating conditions
  - Atom efficient – replacement of reagents by electrons

綠色化學十二項原則

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.

設計使用後能分解的化學藥劑和產物：設計使用後能分解為無害物的化學產物.以使它們不會在自然環境裡累積.

Biodegradation Half-Life	Ultimate Biodeg.
Hours	5.0
Hours – Days (% biodegradation > 50% in 28 days)	4.5
Days	4.0
Days - Weeks	3.5
Weeks (% biodegradation ~ 20-30% in 28 days)	3.0
Weeks - Months	2.5
Months (slow to very slow biodegradation)	2.0
Longer (biodegradation issue – toxic, persistent)	1.0

Expected range: 1 (Minimum), 2 (Low), 3.5 (Moderate), 5 (Large & Maximum)

U.S. EPA BIOWIN program Expert Survey Biodegradation model

綠色化學十二項原則

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.

瞬時分析已防污染：在合成過程中加入瞬時監管和控制.使副產物降至最低或不產生.

要點:要發展分析方法可監控在毒害物質發生之前

Questions

1.Does the potential exist in this process for the formation of hazardous side-products? (30 pts)

2.Are adequate monitoring and control apparatus in place to quickly detect excursions in reactors and storage vessels? (0 to 50 pts)

3.Is the process common practice and/or in the scale-up or commercialization stages of production? (20 pts)

綠色化學十二項原則

12. Minimize the potential for accidents: Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.

使發生意外的可能降到最低：設計化合物及它們的狀態(固態.液態,或氣態)以使發生化學意外的可能降到最低,包括爆炸、起火及波及周遭環境.

什麼是風險評估? 找出危害　評估甚麼人和如何會受到危害 作紀錄　向有關單位匯報

(防災止難,人人有責)

重大的危害

火（不適當化合混合、意外點火、危險動作如燒焊、抽菸、外來的因素如撞擊、閃電、其他地方燒過來）　爆炸（火、撞擊、高壓氣體、不能控制放熱反應）

釋出有毒物質　釋出腐蝕物質

(作最壞的打算)

化學作業處理之管理作業指南及安全操作規範

改變及修飾規範

作業人員訓練

日常檢查及審核

緊急應變措施

工作環境之維護

(大都由人的疏忽而造成.一定要照規章進行)

Designing and operating safe chemical reaction processes

Evaluation:

- Are any extreme conditions (pressure ≥ 10 atm., temperature ≥ 200º C. or ≤ -78º C.) used in the process? (20 pts)
- Does the potential exist for a runaway exotherm under the process or upset conditions (including violent polymerization)? (20 pts)
- Do any of the process materials or mixtures present an explosion hazard (contact, dust and/or peroxide-forming)? (20 pts)
- Are there any process materials present initially or formed during this process that might restrict or exclude its use in the intended production facility (other high hazards than mentioned above, strong odor, etc.)? (20 pts)
- Is pressure between 1.0 and 10 atm or less than 20 mm of Hg used in this process? (10 pts)
- Are temperatures between 150º C. and 200º C. or between -50º C. and -78º C. used in this process? (10 pts)
- Is the reaction mixture flammable? (10 pts)
- Are any of the process mixtures pyrophoric? (10 pts)
- Do any of the process mixtures react violently with water? (5 pts)
- Is a gas generated in any part of this process? (5 pts)
- Are any of the process mixtures corrosive (pH ≤ 2 or ≥12)? (5 pts)
- Are any of the process mixtures irritants or lachrymators? (5 pts)

Risk rank: 5 mild, 10 moderate, 20 high

Safer Chemistry Score = 100 - Total Points

Condensed Principles of Green Chemistry
（綠色化學十二原則再次審視）

P – Prevent wastes（防止廢料）
R – Renewable materials（用可再利用物質）
O – Omit derivatzation steps（省去衍生物步驟）
D – Degradable chemical products（化學物可自行分解）
U – Use safe synthetic methods（採用安全的合成法）
C – Catalytic reagents（利用催化物）
T – Temperature, Pressure ambient（在常溫、常壓下合成）
I – In–Process Monitoring（追踪合成過程）
V – Very few auxiliary substances（少用輔助物）
E – E-factor, maximize feed in product（常將E-因子瞭然於胸）
L – Low toxicity of chemical products（採用低毒化學物）
Y – Yes, it is safe（對, 就是要安全）

Twelve principles of green chemistry written in the form of a mnemonic: PRODUCTIVELY (12原則的英文字頭合起來成了英文PRODUCTIVELY=有成果地)

S. L. Y. Tang, R. L. Smith, M. Poliakoff, Green Chem., 2005, 7, 761-762

12 Principles of Green Engineering

1. Ensure that all materials and energy inputs and outputs are inherently non-hazardous.
2. Prevent waste rather than treat/clean up waste.
3. Separation and purification operations designed to minimize energy & materials use.
4. Products, processes, and systems designed to maximize mass, energy, space, and time efficiency.
5. Products, processes, and systems should be “output pulled” rather than “input pushed” through the use of energy and materials.
6. Recycle.
7. Targeted durability, not immortality, should be a design goal.
8. Design for unnecessary capacity or capability solutions should be considered a design flaw.
9. Material diversity in multi component products should by minimized to promote disassembly and value retention.
10. Design of products, processes and systems must include integration and interconnectivity with available energy and materials flows.
11. Products, processes & systems by designed for performance in commercial “afterlife”.
12. Material and energy inputs should be renewable rather than depleting.

P. T. Anastas and J. B. Zimmerman, Design through the 12 principles of green engineering. Environ Sci Technol. 2003 Mar 1;37(5):94A-101A.

The chemical industry in the 21st century

(21世紀對化學工業及化學家的期望)

- Meeting social, environmental and economic responsibilities

(對社會、環境及經濟是責無旁貸)

- Maintaining a supply of innovative and viable chemical technology

(化學技術要日新又新、精益求精)

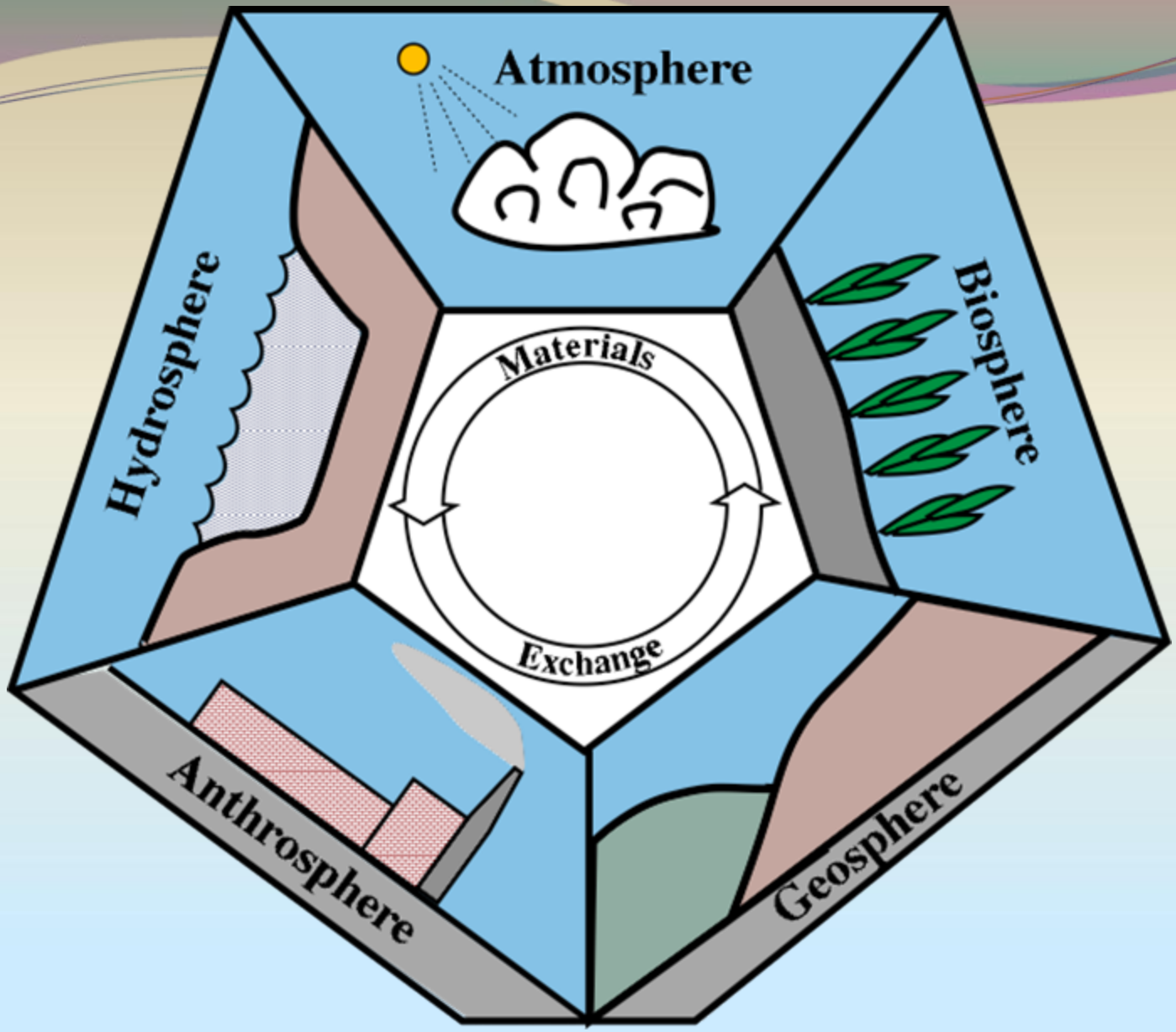
- Environmentally and socially responsible chemical manufacturing

(化學製造要對社會及環境負責)

- Teaching environmental awareness throughout the education process

(推廣教育,喚醒大眾對環境保護的認知)

也是我們的機會



天、地、水、生物與人能和諧共處,生生不息,延綿萬世

S. E. Manahan, Green Chemistry and The Ten Commandments of Sustainability, ChemChar Research, Inc. (2005)

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主辦單位

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附錄
(請勿印製, no print, please)

附錄一

綠色化學十二項原則

Paul Anastas and John Warner in Green Chemistry: Theory and Practice (Oxford University Press: New York, 1998).

1. Prevent waste: Design chemical syntheses to prevent waste, leaving no waste to treat or clean up.

避免廢料：設計化學合成使之避免廢料，不產生需處理或清理的廢料.

2. Design safer chemicals and products: Design chemical products to be fully effective, yet have little or no toxicity.

設計較安全的化學劑和生成物：設計完全有效而毒性很低或不具毒性的化學產物.

3. Design less hazardous chemical syntheses: Design syntheses to use and generate substances with little or no toxicity to humans and the environment.

設計危害性低的化學合成：設計的合成是用對人類和環境的毒性都很低或不具毒性的反應物也產生同樣毒性很低或不具毒性的生成物.

綠色化學十二項原則

4. Use renewable feedstocks: Use raw materials and feedstocks that are renewable rather than depleting. Renewable feedstocks are often made from agricultural products or are the wastes of other processes; depleting feedstocks are made from fossil fuels (petroleum, natural gas, or coal) or are mined.

使用可再生的原料：使用可以再生，而非消耗性的原始物料和材質．再生性原料通常來自農作物或其它製作過程的廢料．而消耗性原料則來自石化燃料（石油．天然氣或煤）或是由採礦而得．

5. Use catalysts, not stoichiometric reagents: Minimize waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once.

使用觸媒而非化學當量的藥劑：利用觸媒反應將廢料減至最低量．觸媒僅需少量且可重複促成某一反應．觸媒比化學當量藥劑更為優先使用．因為後者常需用過量．且僅能使用一次．

綠色化學十二項原則

6. Avoid chemical derivatives: Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.

避免化學衍生物：盡可能避免使用阻擋或保護群組或任何暫時的修飾. 衍生物須用更多的藥劑而且產生廢料.

7. Maximize atom economy: Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.

發揮最大的原子經濟：設計合成使得終極產物含有最大部分的原始反應料. 而沒有甚麼浪費的原子. 即便有也是很少.

8. Use safer solvents and reaction conditions: Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use innocuous chemicals.

使用較安全的溶劑和反應條件：避免使用溶劑、分離劑或其它輔助劑. 如果是必須時則使用無害的化學藥品.

綠色化學十二項原則

9. Increase energy efficiency: Run chemical reactions at ambient temperature and pressure whenever possible.

增加能源效率：盡可能在常溫常壓下進行化學反應.

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.

設計使用後能分解的化學藥劑和產物：設計使用後能分解為無害物的化學產物.以使它們不會在自然環境裡累積.

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.

瞬時分析已防污染：在合成過程中加入瞬時監管和控制.使副產物降至最低或不產生.

12. Minimize the potential for accidents: Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.

使發生意外的可能降到最低：設計化合物及它們的狀態(固態.液態,或氣態)以使發生化學意外的可能降到最低,包括爆炸、起火及波及周遭環境.

附件 二

12 Principles by iSUSTAIN™ Green Chemistry Index v2.0

https://www.isustain.com/

1. It is better to prevent waste then to treat or clean up waste after it is formed.
Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
2. Whenever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
3. Chemical products should be designed to preserve efficacy of the function while reducing toxicity.
4. The use of auxiliary substances (solvents, separation agents, etc.) should be minimized whenever possible and, when used, be innocuous.
5. Energy requirements should be recognized for their environmental and economic impacts and should be minimized. 6.
6.Synthetic methods should be conducted at ambient temperature and pressure.
7. A raw material or feedstock should be renewable rather than depleting whenever technically and economically practical.
8. Unnecessary derivatization (blocking group, protection/deprotection, temporary modification of physical/chemical processes) should be avoided whenever possible.
9. Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. Chemical products should be designed so that at the end of their function they do not persist in the environment and instead break down into innocuous degradation products.
11.Analytical methodologies need to be further developed to allow for real-time in-process monitoring and control prior to the formation of hazardous substances.
12.Substance and the form of a substance used in a chemical process should be chosen so as to minimize the potential for chemical accidents, including releases, explosions, and fires.

附錄三

The **Presidential Green Chemistry Challenge Awards Program** (EPA and GCI, USA)

is an opportunity for individuals, groups, and organizations to compete for annual awards in recognition of innovations in cleaner, cheaper, smarter chemistry.

- Focus Area 1: An industry sponsor for a technology that uses greener synthetic pathways.
- Focus Area 2: An industry sponsor for a technology that uses greener reaction conditions.
- Focus Area 3: An industry sponsor for a technology that includes the design of greener chemicals.
- Small Business: A small business for a green chemistry technology in any of the three focus areas.
- Academic: An academic investigator for a technology in any of the three focus areas.

EXIT Disclaimer

Presidential Green Chemistry Challenge Awards

Since the program's inception in 1995, it has recognized 67 groundbreaking developments out of hundreds of applications. According to EPA statistics, these technologies combined will eliminate an estimated 193 million lb of hazardous chemicals and solvents, 21 billion gal of water, and 57 million lb of carbon dioxide from industrial processing in the U.S. this year *.

*till 2008.
Chem. & Eng. News (Sustainability special issue), August 18, 2008
http://pubs.acs.org/cen/coverstory/86/8633cover3.html

2001 Academic Award Professor Chao-Jun Li ,Tulane University
2000 Academic Award Professor Chi-Huey Wong, The Scripps Research Institute
2010 Academic Award Professor James C. Liao, UCLA
http://www.epa.gov/greenchemistry/pubs/pgcc/presgcc.html

附錄四： 漫談綠色

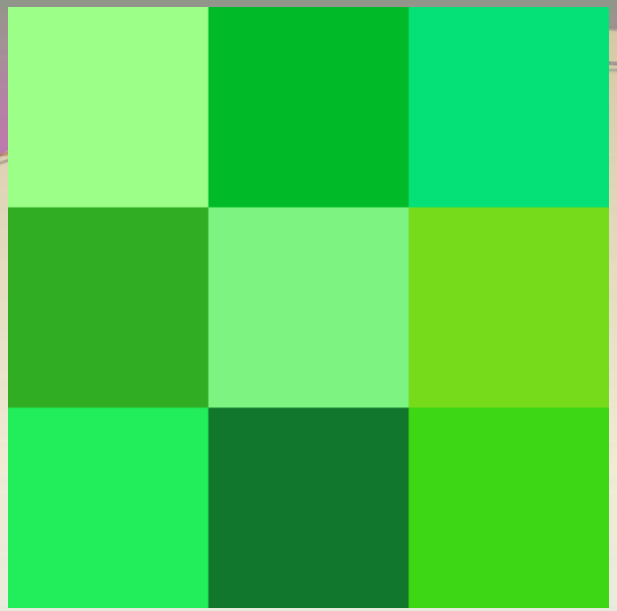
在科學上綠色是落在可見光的範圍內,波長在520-570奈米之間,換句話說發射在這範圍內的光是綠光,物質反射這段波長時則呈綠色.它不是三原色之一.藍色和黃色混合成綠色.比如說青蛙皮膚底層是藍色,表面是黃色,所以看到的青蛙是綠色.大自然界中有許多天然是綠色的,如植物葉綠素,所以植物葉子大都含有它,是綠色的.動物中兩棲類除上述之青蛙外也有許多是綠色的.昆蟲為了保護自己,模擬周遭的環境,也大多有綠色外皮.棲身在綠葉中來躲避天敵,傳延不息.礦石中也有許多綠色的,如翡翠有濃濃的深綠色(如祖母綠),得到人們的喜愛.人們將綠色溶入生活經驗之中就產生不同的代表及意義.比如說美國人稱錢為『綠背』(green back).因為一元美鈔的背面是綠色的.愛爾蘭人特別喜歡綠色,每年St. Patrick日(三月十七日)幾乎每人都要有綠色妝扮.最低程度也要打條綠色領帶上班.伊斯蘭教也特別崇拜綠色,認為天堂中充滿了翠綠.

綠色也有負面的意義,英國古老民俗中綠色代表巫術,妖術,邪惡,腐敗及毒性.所以百老匯上演之吸血鬼劇中 Drucala 的臉是綠色的.因此英國人迷信綠色不吉利,鮮有綠色之汽車或結婚禮服.塞爾提克人也迷信綠色衣服會招來不幸甚至死亡.我國人稱妻子有外遇的男人戴了『綠帽子』.不論中外都以『臉綠了』表示不健康或不舒服.

不過在多數人們心中綠色代表興旺及生生不息,所以許多國家(其中有歐洲國家,南美洲國家,尤其是非洲國家最多)國旗中有綠色.代表繁榮興盛,最甚者為Libya,她的國旗是一片綠布,完全沒有其他顏色或圖案.在人群結社(政治)方面有『綠黨』,『綠色和平組織』.它們的其宗旨為非暴力,愛護環境等.

化學製造之產品原則是符合人類生存之需求.比如說生產肥料及殺蟲劑可使糧食增產,使人類免於饑餓.製造抗生素及疫苗可以使人類免受病痛和延長壽命.但是製造這些有益的化學品同時也會產生不必要的副產物,嚴重污染了環境,妨碍了其他生物的生存,也妨碍了人類的生存.於是乎化學工業必須在其生產過程中減少有害排放物,走向永續經營.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「綠色化學」一詞,取其對環境友善而達到永續經營之意.

由於綠色之意義會因人、因時、因地、因信仰、因政治立場、因風俗習慣等而有不同的解釋.最鮮明的例子是我國股市價格下滑以綠色表示,但在美國卻是牛市的象徵.因此有些地區慣用綠色化學，餘則慣用永續化學，其來有自。



Green color wave length 520–570 nanometres

A frog

Leaves

Emerald

St. Patrick Day

Libya flag