國立交通大學應用化學系

科學二館210演講廳

綠色化學12項原則 - 解鈴還須繫鈴人

2014年1月10日 16:00 – 17:30

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大同大學生物工程學系綠能及綠色化學月刊 顧問 (2010-2011)

大同大學 講座教授 (2008 -2010)

財團法人傑出人才基金會傑出人才講座

永續(綠色)化學與永續(綠色)工程：

永續化學之精義是設計化學產物及過程時要減少或消除廢物及有毒物質之產生。永續工程的意義是生產商品時要降低對人類健康及環境的危害，在過程中也要符合經濟原則，都是生產必需用品但不污染環境。所以永續化學和永續工程是延續人類生存的重大基石。本課程將闡述永續化學和永續工程十二項原則並佐以實例，俾使人人有正確的認識並落實於生活之中。

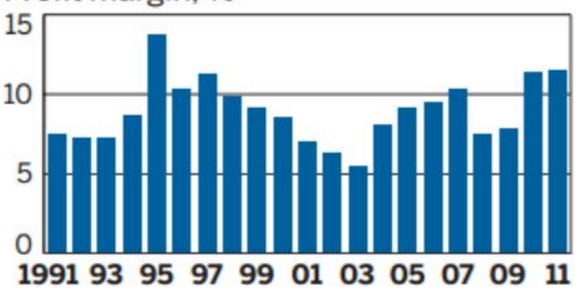
GLOBAL TOP 50

Chemical companies saw strong growth in sales and operating profits again in 2011

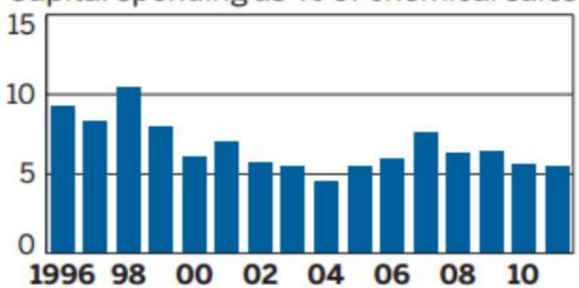
RANK 2011	RANK 2010	COMPANY	CHEMICAL SALES ($ MILLIONS) 2011	CHANGE FROM 2010	CHEMICAL SALES AS % OF TOTAL SALES	HEADQUARTERS COUNTRY	CHEMICAL OPERATING PROFITS[a] ($ MILLIONS)	CHANGE FROM 2010	CHEMICAL PROFITS AS % OF TOTAL OPERATING PROFITS	OPERATING PROFIT MARGIN[b]	IDENTIFIABLE CHEMICAL ASSETS ($ MILLIONS)	CHEMICAL ASSETS AS % OF TOTAL ASSETS	OPERATING RETURN ON CHEMICAL ASSETS[c]
1	1	BASF	$85,603	15.8%	83.6%	Germany	$9,021	19.3%	75.4%	10.5%	$70,971	83.3%	12.7%
2	2	Dow Chemical	59,985	11.8	100.0	U.S.	4,522	24.7	100.0	7.5	69,224	100.0	6.5
3	3	Sinopec	57,068	29.1	15.0	China	3,915	71.3	24.8	6.9	22,095	12.6	17.7
4	4	ExxonMobil[d]	41,942	18.1	9.0	U.S.	4,383	-10.8	10.7	10.5	27,107	8.2	16.2
5	7	SABIC	41,730	23.8	82.4	Saudi Arabia	14,452	25.8	87.2	34.6	72,027	81.2	20.1
6	6	Formosa Plastics[e]	37,612	1.2	63.0	Taiwan	4,120	-22.3	86.9	11.0	38,914	64.9	10.6
7	8	DuPont[f]	34,763	15.6	91.6	U.S.	5,547	22.8	98.8	16.0	18,819	67.9	29.5
8	9	LyondellBasell Industries	32,214	16.4	63.1	Netherlands	3,301	23.8	82.6	10.2	na	na	na
9	10	Mitsubishi Chemical	29,687	3.6	73.8	Japan	806	-55.5	49.2	2.7	26,243	65.9	3.1
10	12	Total	27,134	11.4	10.5	France	917	-31.7	2.7	3.4	na	na	na
11	13	Bayer	25,198	6.5	49.5	Germany	1,665	14.8	28.8	6.6	25,057	34.1	6.6
12	11	Ineos Group	24,500	-6.0	100.0	Switzerland	2,430	5.4	100.0	9.9	12,940	100.0	18.8

STRONG RESULTS Profit margins improved again, and spending held steady.

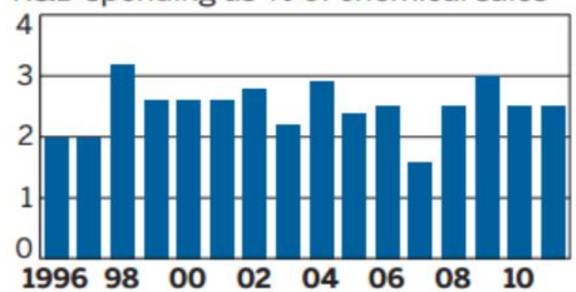
Profit margin, %



Capital spending as % of chemical sales[a]



R&D spending as % of chemical sales[b]



NOTE: Based on C&EN's annual listing of the Global Top 50 chemical producers. **a** For companies reporting chemical capital spending. **b** For companies reporting chemical R&D.

化學工業帶來工作機會

歐洲　雇用一百二十萬人

美國　雇用八十萬人

台灣

製造業分為四大產業；分別為金屬機械、資訊電子、化學工業與民生工業

- 2000年生產產值比例依序為24.68%、37.39%、22.84%(1.92兆)與15.09%
- 2008年生產產值比例依序為27.96%、31.94%、30.36%(3.03兆)與9.75%
- 2012年生產產值比例依序為26.08%、32.74%、31.34%(3.13兆)與9.85%

資訊電子與化學工業近年來分佔第一、二位，且差距變小

延長壽命

- 1900 --- 47 years old
- 1990 --- 75 years old

摘自趙奕姼綠色/永續化學:導言與原則

為什麼化學製品及副產物是天災之外的恐懼來源?

Answer: Our growing ecological foot print significantly exceeds the carrying capacity of the earth.

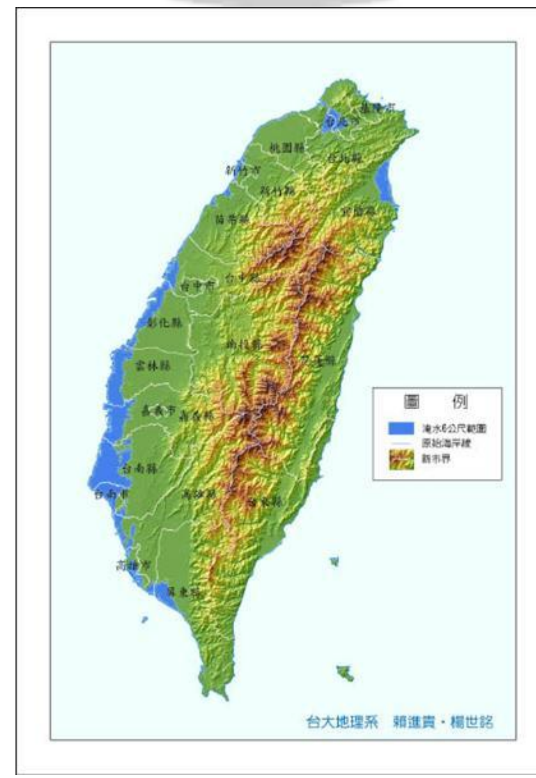
Ecological footprint: a measure of the amount of biologically productive space needed on average to support a human being.

Sustainability (永續)

(A system state that can endure indefinitely)

Its Major Challenges

Population(人口)
Energy(能源)
Global Change(全球變遷)
Resource Depletion(資源枯竭)
Food Supply(糧食供應)
Toxics in Environment(環境毒物)（All are closely related to Chemistry）



Our growing ecological foot print significantly exceeds the carrying capacity of the earth. *Thus we are drifting toward a catastrophe beyond comparison. We shall require a substantially new manner of thinking if mankind is to survive.*

-*Albert Einstein*

Green chemistry: A tool to foster sustainable development.

Design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances.

Minimize waste, energy use, and resource use.

Principles and Commandments

- **Twelve principles of green chemistry**
  (Anastas and Warner, 1998)
- **Twelve more green chemistry principles**
  (Winterton, 2001)
- **Twelve principles of green engineering**
  (Anastas and Zimmerman, 2003)
- **Twelve principles of green science and technology**
  (Manahan, 2005)
- **Ten commandments of sustainability** (Manahan, 2005)

Baran’s eight commandments of synthesis

1. Avoid redox reactions that don’t form C-C bonds
2. Maximize the proportion of C-C bond-forming reactions
3. Make disconnections that maximize convergence
4. Gradually increase the oxidation state of successive intermediates
5. Maximize structural change in each step-use cascade (tandem) reactions
6. Avoid protecting groups-exploit the reactivity of functional groups
7. Incorporate biomimetic pathways
8. Seek new methodology and reactivity

The Baran Group http://www.barangroup.com/

Report http://www.barangroup.com/SiteFiles/File/Report_internet_2.pdf

綠色化學指標 (Anastas and Warner)

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.

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.

低危險的化學合成: 無論在何地,只要實際可行,合成方法應設計成用的原料及製出的成品都無害於人類健康和環境,或是毒性很低.

設計更安全的化合物: 化學產品應設計成能在使它們的毒性縮到最小下實現達到所希望賦與的功能.

更安全的溶劑和輔助劑: 有關(化學合成)的輔助物質(即: 溶劑、分離劑等)儘可能不用,若用也要是無害的.

為用能效率而設計: 化學過程中能的需求應該被認定為對環境和經濟的衝擊縮為最小.如果可能,合成方法應該在常溫和常壓下進行.

使用可再生的原料: 衹要技術和經濟可行時儘量用再生而非消耗的生物料和原料.

減少衍生物: 儘可能減少或避免不需要的衍生反應(阻擋基、保護物/去保護物、物理/化學過程中之暫時修飾),因為此步驟需額外的試劑和產生廢料.

催化作用: 儘可能使用有選擇能力之催化劑,且優先於使用化學當量的試劑.

為分解而設計: 化學產物的設計應考慮到當它們的功能結束時會分解為無害的降解物而不會存留在環境中.

即時分析以防止污染: 發展出能即時和在線上監控和管理的分析方法,使在危險物質發生之前及時得到訊息,防止污染.

本質上更安全的化學以防止意外: 在化學反應中由一物質形成另一物質應該選擇能縮小化學意外的途徑,包括釋出(能)、爆炸及火災之可能性.

Anastas, P. T.; Warner, J. C. Green Chemistry: Theory and Practice, Oxford University Press: New York, 1998, p.30.

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

長久以來化工業者對所產生的廢物或由於無知或出於故意,並不十分在意.法律規範也不週延.開發國家如此,開發中的國家就更不用說了.不過這些未經過妥善處理的廢物堆積一定量或經過一段長時間之後造成了很大的災害.

實例: 日本痛痛症(Itai itai disease) (鎘中毒)

日本水俣病 (Minamata disease) (汞中毒)

印度波帕爾(Bhopal)異氰酸甲脂(methyl isocyanate)外洩事件

美國那夫運河(Love Canal)事件 (化學廢棄物)

廢棄物的代價 :健康的危害 環境的破壞

廢棄物處理帶來額外的開支 難以處理的公共關係 原料成本高

不利永續經營

RCA污染事件

日月光公司K7廠排放重金屬廢水

從設計開始將廢料去除或降至最低才是根本之道.

廢物之度量法

產率(yield): 目標產物的當量和化學反應式平衡之後應得的產物當量之比.

產率(Y) = 產物之實當量(或重量)/由化學反應式計得之當量(或重量)

原子經濟(atom economy): 產率值對化學反應之優劣可說是一目了然,但它卻沒說明目標產物在眾產物所佔之比.原子經濟之定義是目標產物中的原子在反應物所佔的份量.

原子經濟(AE) = 產物分子量/反應物分子量之和

原子效率(atom efficiency): 是同時考慮了上二項的結合體.

原子效率(AF) = AE x Y

有效質量產率(effective mass yield): 目標產物和所有反應物中有害物質之重量比.有害物質除了反應物及產物副產物外也包括所有參與的物質,如溶劑.

有效質量產率(EMY) = 產物的總量(公斤)/有害反應物的重量(公斤)

碳原子效率(carbon efficiency): 無論是有機物或藥物.碳原子是結構的要素.所以針對碳原子有一個度量,即碳原子效率.它是產物中之碳原子量和所有反應物中碳原子量總和之比.

碳原子效率(CE) = 產物中碳原子總重量/反應物中碳原子總重量

反應質量效率(reaction mass efficiency): 產物和留在溶液中的反應物重量之比.

反應質量效率(RME) = 產物重量/未反應之反應物總和

(未完成反應物量等物反應物之總和x產率.)

環境因子(environmental factor): 反應後產物和反應中所有廢物之比.廢物包括了副產物及溶劑、催化劑、補助劑等.

環境因子(E) = 廢物的總量(公斤)/產物的重量(公斤)

接下頁

過程質量強度 (Process Mass Intensity, PMI)

A key, high-level metric for evaluating and benchmarking progress towards more sustainable manufacturing, has chosen by American Chemical Society Green Chemistry Institute's Pharmaceutical Roundtable.

http://www.acs.org/content/acs/en/greenchemistry/industriainnovation/roundtable.html

PMI=total mass in a process or process step (kg)/mass of product (kg)

= E + 1

C. Jimenez-Gonzalez, C. S. Ponder, Q. B. Broxterman, and J. B. Manley, "Using the Right Green Yardstick: Why Process Mass Intensity Is Used in the Pharmaceutical Industry To Drive More Sustainable Processes", Org. Process Res. Dev. 2011, 15, 912–917. (dx.doi.org/10.1021/op200097d)

溶劑強度(solvent intensity, SI)

SI = 溶劑總量(公斤)/產物總量(公斤)

E$^+$-Factor (Environmental factor) = 環境因子(E) = F[廢物的總量(公斤)/產物的重量(公斤)]

(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)

16 Future Trends for Green Chemistry in the Pharmaceutical Industry

Table 16.1 Current and aspirational E factors for industry segments.

Roger Sheldon 1992			Aspiration target	
Industry segment	E-factor		Industry segment	E-factor
Bulk chemicals	1–5	→	Bulk chemicals	Low
Fine chemicals	5–50		Fine chemicals	1–5
Pharmaceuticals[a]	25–>100		Pharmaceuticals[a]	5–>50

a) Refers to small molecule pharmaceutical drugs not biologics.

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

2. 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.

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.

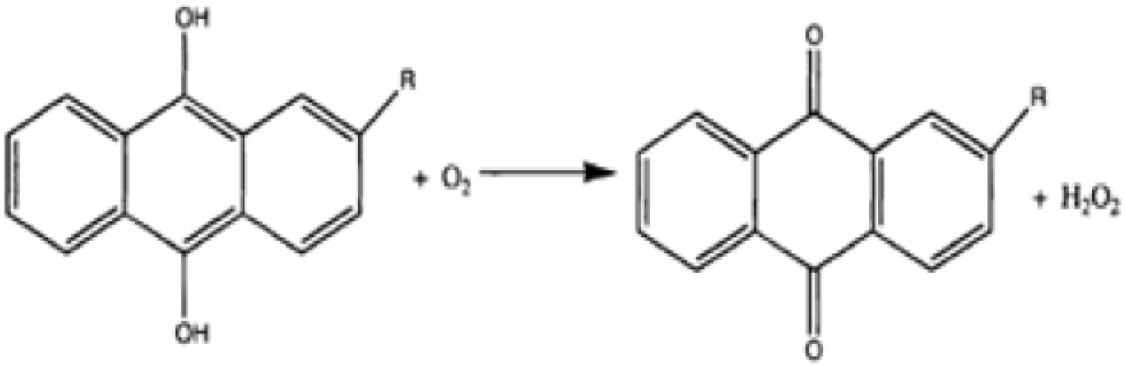
Atom Economy (原子經濟指標) = 產物/作用物之和

(Introduced by Barry Trost, Stanford University)

Barry Trost

例: $H_2 + O_2 \rightarrow H_2O_2$ A.E.= 34/(2+32)=100%

2007 US President Green Chemistry Challenge Award
US patent #: US6,630,118 B2
Process for the direct synthesis of hydrogen peroxide



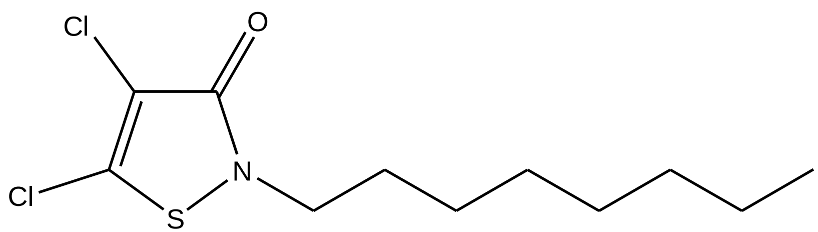
Synthesis of hydrogen peroxide from Anthraquinone

A.E.= 34/(210+32)=14%

Addition
Rearrangement

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

Risk Quotient (R) = predicted environmental concentration / predicted no-effect environmental concentration



1996 Designing Greener Chemicals Award
Rohm and Haas Company

Antifoulant 4,5-dichloro-2-*n*-octyl-4-isothiazolin-3-one (Sea-Nine™) (R=0.024-0.36) replaces tributyltin oxide (R=15-430)

2013 12 18 蘋果動新聞

2013 Small Business Award: **Faraday Technology, Inc.**
Functional Chrome Coatings Electrodeposited from a Trivalent Chromium Plating Electrolyte
Faraday has developed a plating process that allows high-performance chrome coatings to be made from the less toxic trivalent chromium. This nearly drop-in replacement can reduce millions of pounds of hexavalent chromium without comprising performance.

A pilot-scale plating Cr^{+3} line

美國環保署認定有毒物質的前20名

1. 鉛
2. 砷
3. 汞
4. 乙烯基氯
5. 苯
6. 多氯雙苯基
7. 鎘
8. 苯菲芘
9. 氯仿
10. benzo(b)fluoranthene
11. DDT
12. 多氯聯苯1260
13. 三氯乙烯
14. 多氯聯苯1254
15. 鉻
16. 氯丹
17. dibenz[a,h]anthracene
18. 六氯丁二烯
19. p,p-dichlorodiphenyl cichloroethane
20. 狄氏殺蟲劑.

心得: 有毒物質為重金屬, 含氯化合物及苯物質.

台北榮總毒藥物防治中心
http://www.pcc.vghtpe.gov.tw/index.asp

Relative Toxicities

Substance	Approximate LD_{50}*
	10^5
Ethanol	10^4
Sodium chloride	
Malathion	10^3
Chlordane	
Heptachlor	10^2
Parathion	10
	1
Tetrodotoxin#	10^{-1}
Inland taipan venom	
	10^{-2}
	10^{-3}
	10^{-4}
Botulinus toxin	10^{-5}

Toxicity rating

1. Practically nontoxic $> 1.5 \times 10^4$ mg/kg
2. Slightly toxic, 5×10^3 to 1.5×10^4 mg/kg
3. Moderately toxic, 500 to 5000 mg/kg
4. Very toxic, 50 to 500 mg/kg
5. Extremely toxic, 5 to 50 mg/kg
6. Supertoxic, < 5 mg/kg

* **LD_{50} values are in units of mg of toxicant per kg of body mass.**

\# **Puffer (河豚) fish toxin   taipan (眼鏡蛇)   botulinus (肉毒桿菌)**

酒駕達零點二五即開罰，達零點五五構成公共危險罪。

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

2013 Academic Award Winner: Richard P. Wool,U of Delaware
Sustainable Polymers and Composites: Optimal Design

high oleic soy oil → pressure sensitive adhesives and elastomers, composite resins, a hermoplastic polyurethane (TPU) substitute
plant oils → isocyanate-free foam.
“Eco-Leather” from chicken feather which avoids the traditional leather tanning process.
Less energy, water, hazardous wastes

http://www.che.udel.edu/pdf/facultycv/471cv.pdf

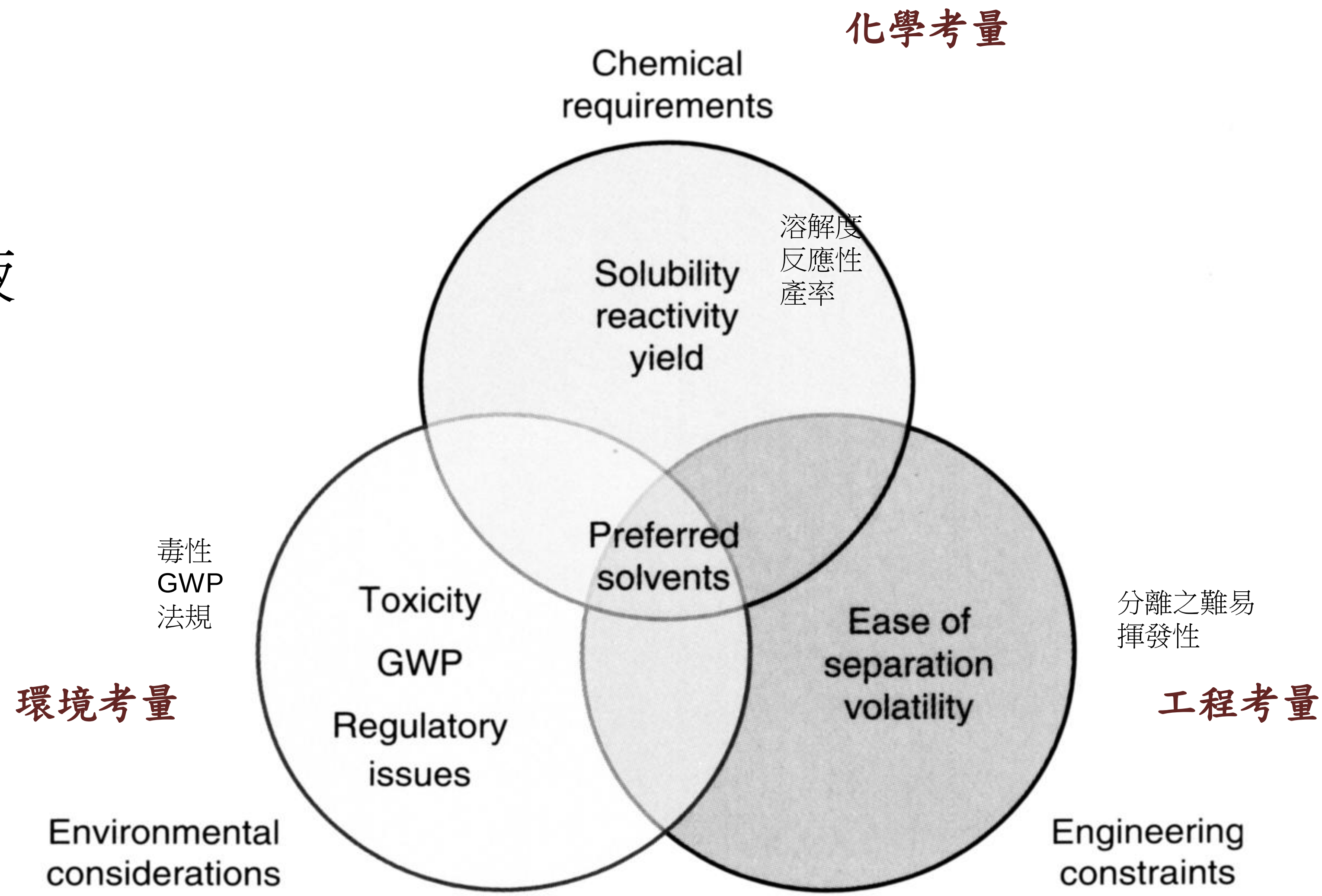
Dixie Chemical Makes Bio-based Composite Resin Available

Dixie Chemical has launched a bio-based composite resin that offers a combination of bio-based content over 55% and physical and mechanical property performance comparable to standard unsaturated polyester resins. According to Dixie, the product is a Maleinated Acrylated Epoxidized Soybean Oil (MAESO) and meets the growing interest of composite manufacturers to use bio-based materials, without sacrificing performance.
Publication date: 12/05/2012
Link: http://www.dixiechemical.com/

5. 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.

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

有機溶劑
水
超臨界溶液
離子溶液
無溶液
其他



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

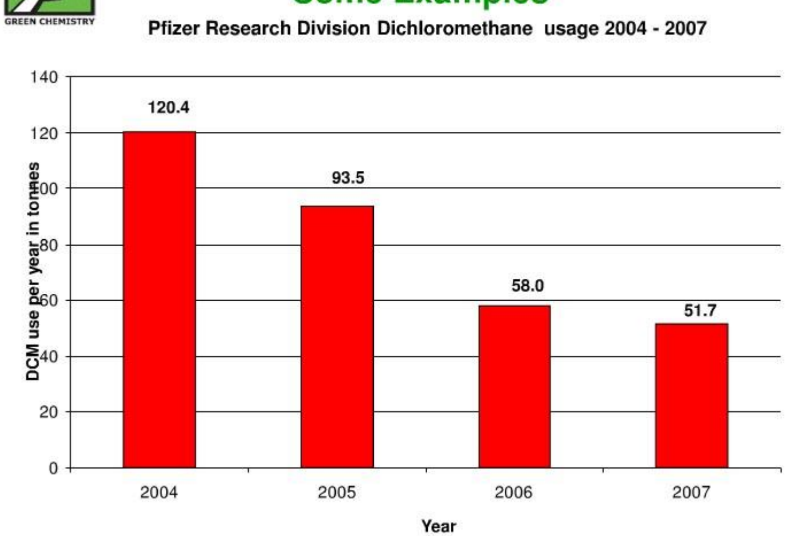
K. Alfonsi, *et al.*, *Green Chem*. **2008**, *10*, 31-36

Table 2 Solvent replacement table

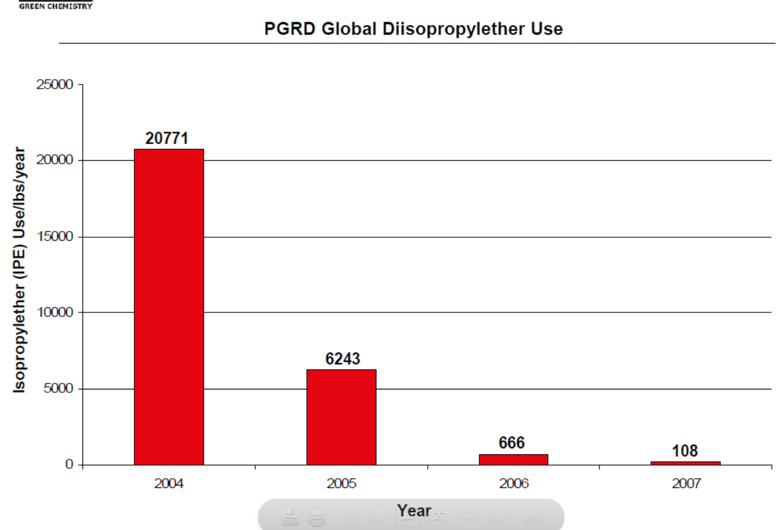
Undesirable solvents	Alternative
Pentane	Heptane
Hexane(s)	Heptane
Di-isopropyl ether or diethyl ether	2-MeTHF or *tert*-butyl methyl ether
Dioxane or dimethoxyethane	2-MeTHF or *tert*-butyl methyl ether
Chloroform, dichloroethane or carbon tetrachloride	Dichloromethane
Dimethyl formamide, dimethyl acetamide 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*

Pfizer Green Chemistry Results – Some Examples



Pfizer Solvent Switching Program



http://www.dbu.de/media/130508051211a525.pdf

Searching for benign solvents (尋求無害溶劑)

無溶劑 > 水 > 超臨界溶劑 > 離子溶液 > 揮發性有機溶劑 (>為優於之意)

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）

Replace
(替代)

←

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

Table 5.4 *Advantages and disadvantages of using water as a solvent* 水

Advantages	*Disadvantages*
Non-toxic	Distillation is energy intensive
Opportunity for replacing VOCs	Contaminated waste streams may be difficult to treat
Naturally occurring	High specific heat capacity – difficult to heat or cool rapidly
Inexpensive	
Non-flammable	
High specific heat capacity – exothermic reactions can be more safely controlled	

Lancaster, p. 149

Odorless and colorless (contamination is easy to recognize)	Some compounds or catalysts react with water in an adverse way.
	Water-soluble catalyst is difficult to recover.

Water in organic reaction

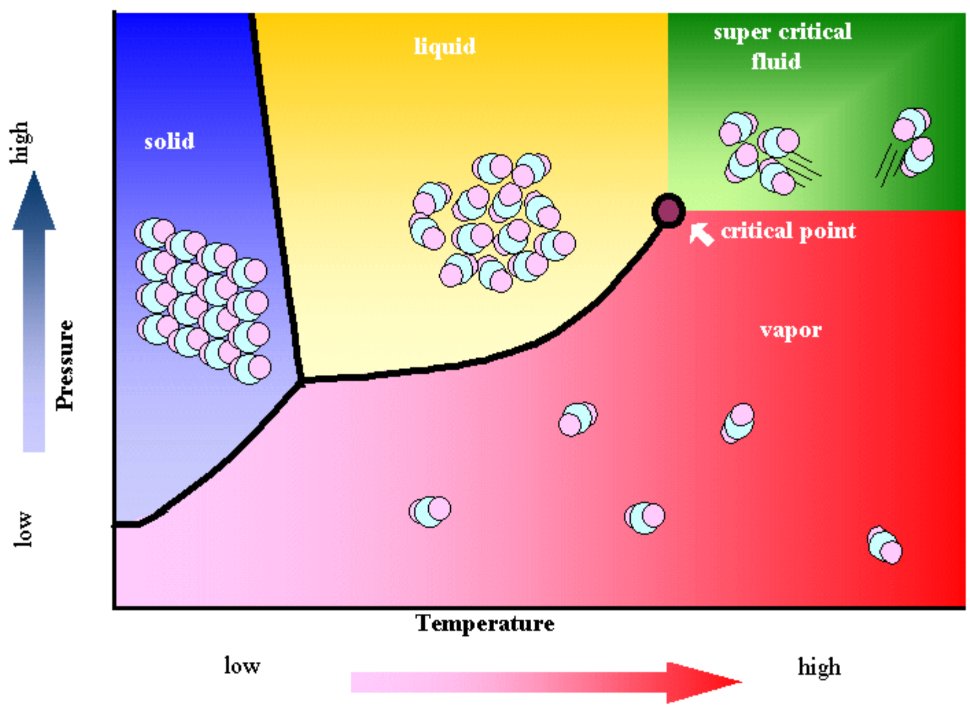
回顧論文(1) Li, C.-J., "Organic Reactions in Aqueous Media with a Focus on Carbon- Carbon Bond Formation", Chem. Rev., (1999), 93, 2023-2035; (2) Li, C.-J., "Organic Reactions in Aqueous Media with a Focus on Carbon-Carbon Bond Formations: A Decade Update", Chem Rev., (2005), 105, 3095-3165.

書 (1) Li, C.-J., "Organic Reactions in Aqueous Solution", John Wiley, 1997. (2) Li, C.-J., Chan, T.-H., "Comprehensive Organic Reactions in Aqueous Media", 2nd ed., Wiley- Interscience, 2007.

Supercritical Fluid (超臨界液體)

當系統溫度及壓力達到某一特定點時，氣-液兩相密度趨於相同，兩相合併為一均勻相。若超過此點時，無論壓力如何增加皆無法使之液化，溫度如何升高亦無法使之返回氣相，我們稱此高於臨界溫度及臨界壓力的均勻相為超臨界流體。

此一特定點即定義為該物質的臨界點，所對應的溫度、壓力和密度則分別定義為該純物質的臨界溫度(T^C)、臨界壓力(P^C)和臨界密度(ρ^C)。



Advantages and disadvantages of using CO_2 as a solvent

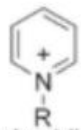
Advantages	*Disadvantages*
Non-toxic	Relatively high pressure equipment
Easily removed	Equipment can be capital intensive
Potentially recyclable	Relatively poor solvent
Non-flammable	Reactive with powerful nucleophiles
High gas solubility	Possible heat-transfer problems
Weak solvation	
High diffusion rates	
Ease of control over properties	
Good mass transfer	
Readily available	

(Lancaster, Table 5.3)

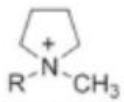
Ionic liquid

Cations

1-alkyl-3-methylimidazolium



1-alkylpyridimium



1-alkyl-1-methylpyrrolidinium

R_4N^+

tetraalkylammonium

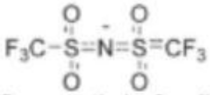
R_4P^+

tetraalkylphosphonium

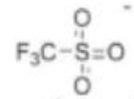
R_3S^+

trialkylsulfonium

Anions



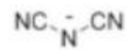
bis(trifluoromethylsufonyl)imide
$[NTf_2]^-$



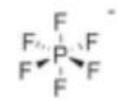
trifluoromethanesulfonate
triflate, $[OTf]^-$

RSO_4^-

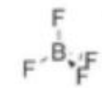
alkylsulfate
$[C_nSO_4]^-$



dicyanamide
$[N(CN)_2]^-$



hexafluorophosphate
$[PF_6]^-$



tetrafluoroborate
$[BF_4]^-$

- air stable
- no measurable vapor pressure (non volatile)
- lack of flammability
- high conductivity
- high thermal and chemical stability for wide temperature range by fine tuning the variation of cations or anions
- recycling of ionic liquids for re-use was possible without decrease in yield--environmentally friendly

http://ilthermo.boulder.nist.gov/ILThermo/

(1) Olivier-Bourbigou, H.; Magna, L.; Morvan, D. Appl. Catal., A (2010), 373, 1. (2) Parvulescu, V. I.; Hardacre, C. Chem. Rev. (2007), 107, 2615. (3) Welton, T. Coord. Chem. Rev. (2004), 248, 2459. (4) Dupont, J.; de Souza, R. F.; Suarez, P. A. Z. Chem. Rev. (2002), 102, 3667, and (5) Wasserscheid, P.; Keim, W. Angew. Chem., Int. Ed. 2000, 39, 3772; (6) Jason P. Hallett and Tom Welton, Chem Rev. (2011), 11, 3508-3576.

Ionic solvents (離子溶劑)

2005 Academic Award, Professor Robin D. Rogers The University of Alabama

A Platform Strategy Using Ionic Liquids to Dissolve and Process Cellulose for Advanced New Materials

Innovation and Benefits: Professor Rogers developed methods that allow cellulose from wood, cloth, or even paper to be chemically modified to make new biorenewable or biocompatible materials. His methods also allow cellulose to be mixed with other substances, such as dyes, or simply to be processed directly from solution into a formed shape. Together, these methods can potentially save resources, time, and energy.

1-butyl-3-methylimidazolium chloride ([C4mim]Cl),

氯化1-丁基-3-甲基咪唑鎓

J. Am Chem Soc. 2002 May 8;124(18):4974-5.

recyclable

以離子溶劑替代有機溶劑

1-butyl-3-methyl-4,5-dihydroimidazolinium iodide and
1-butyl-3-methyl-4,5-dihydroimidazolinium hexafluorophosphate
替代高極性有機溶劑如dimethyl formamide, 1,3-dimethyl-2-imidazolidinone, 和 dimethyl sulphoxide 高溫度下反應.
產率大多數能達九成以上.

Gok, Ozdemis, Cetinkaya, Chinese Journal of Catalysis, vol. 28, 489-491 (2007).

Solventless synthesis (無溶劑合成)

2009 **Greener Synthetic Pathways Award**

Eastman Chemical Company

A Solvent-Free Biocatalytic Process for Cosmetic and Personal Care Ingredients

Innovation and Benefits: Esters are an important class of ingredients in cosmetics and personal care products. Usually, they are manufactured by harsh chemical methods that use strong acids and potentially hazardous solvents; these methods also require a great deal of energy. Eastman's new method uses immobilized enzymes to make esters, saving energy and avoiding both strong acids and organic solvents. This method is so gentle that Eastman can use delicate, natural raw materials to make esters never before available.

Organic Process Research & Development 2011 IF: 2.391; Citation: 3.609
Editor-in-Chief: Trevor Laire
http://pubs.acs.org/journal/oprdfk
Published: January 5, 2012 by Trevor Laire
"The journal encourages researchers to consider the environmental consequences of the way in which they perform their experiments and to minimize waste." and
"From 2012 the policy on use of organic solvents has been changed to discourage scientists from using particular solvents and to encourage them to seek alternatives wherever possible; papers containing strongly undesirable solvents (e.g., benzene, carbon tetrachloride, chloroform, HMPA, carbon disulfide, etc.) will only be considered if accompanied by an analysis of alternatives or if a convincing justification for such use is presented."

ChemSusChem IF: 6.827
Editorial by G. M. Kemeling (Editor-in-chief), ChemSusChem 2012, 5, 2291 – 2292
Specifically, we ask of our authors the following:
* to avoid, if possible, the use of harmful solvents and replace these with less-harmful alternatives;
* to rationalize the choice of solvent in manuscripts.

We ask of referees:
* to closely scrutinize the use of solvents as described in the Results and Discussion and Experimental paragraphs;
* to ask for clarification and justification in case the choice of solvent is not commented on.

6.**增加能源效率：盡可能在常溫常壓下進行化學反應.**

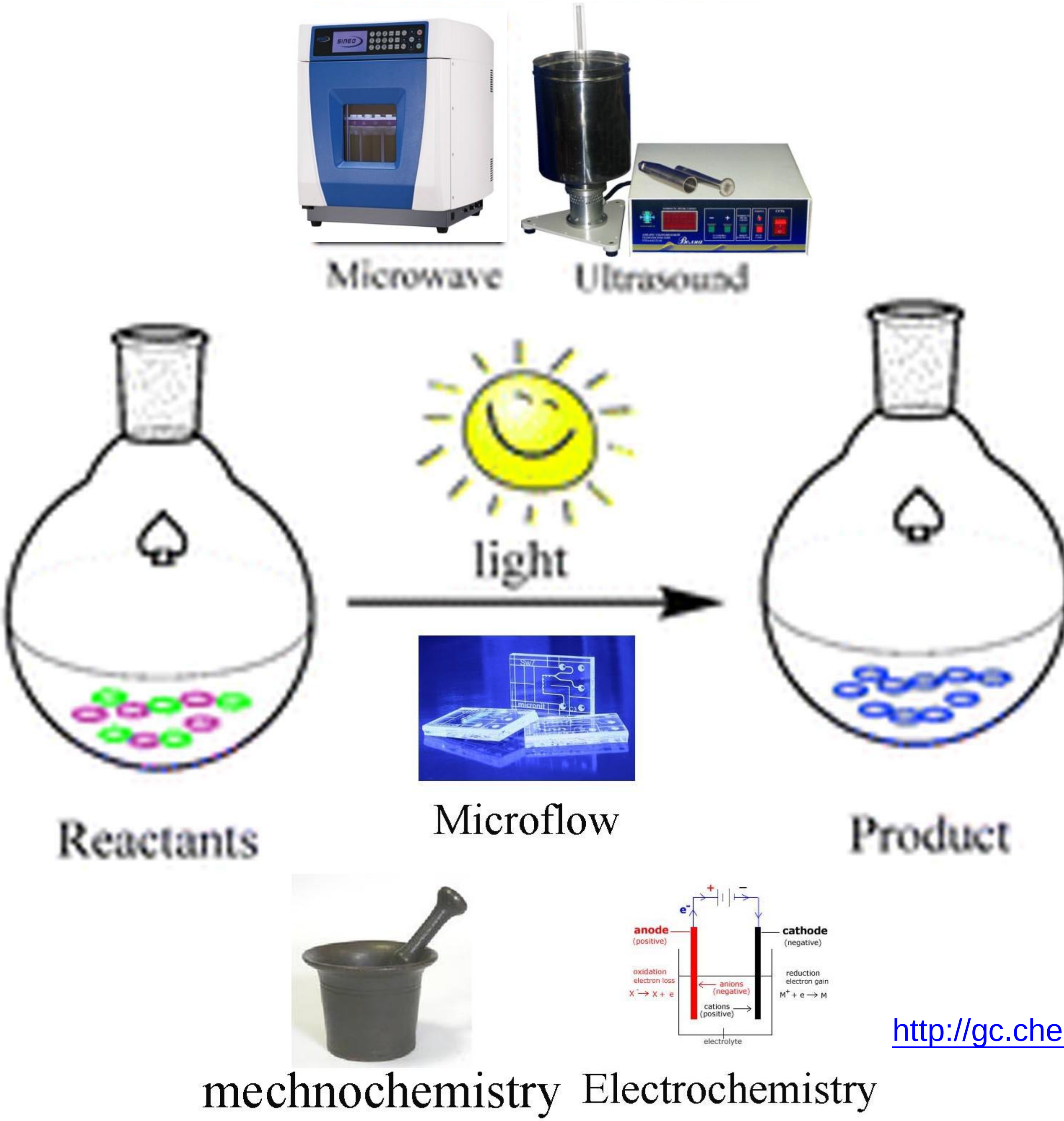
Increase energy efficiency: Run chemical reactions at ambient temperature and pressure whenever possible.

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

Alternative organic synthetic methods



- Microwave
  - polar or ionic materials
- Microflow
  - solution
- Sonochemistry
  - solution
- Mechanochemistry
  - solid
- Electrochemistry
  - conductive media
- Photochemistry
  - chromophore

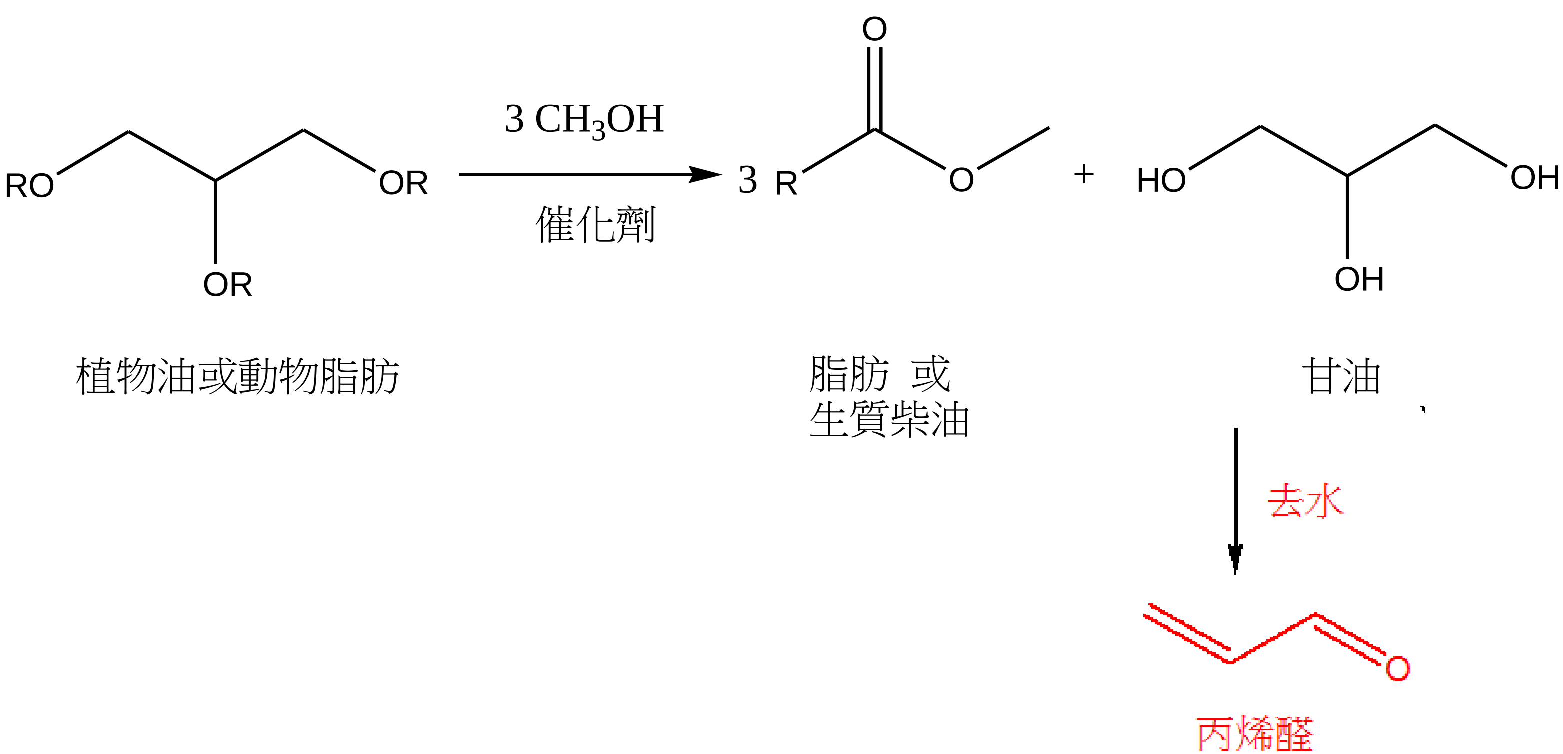
S. K. Sharma, A. Chaudhary, and R. V. Singh, “Gray Chemistry vs. Green Chemistry: Challenges & Opportunities, RASĀYAN JOURNAL OF CHEMISTRY (RJC), (2008), **1**, 68-92.

http://gc.chem.sinica.edu.tw/workshop/notes.php

7. **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.**

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.

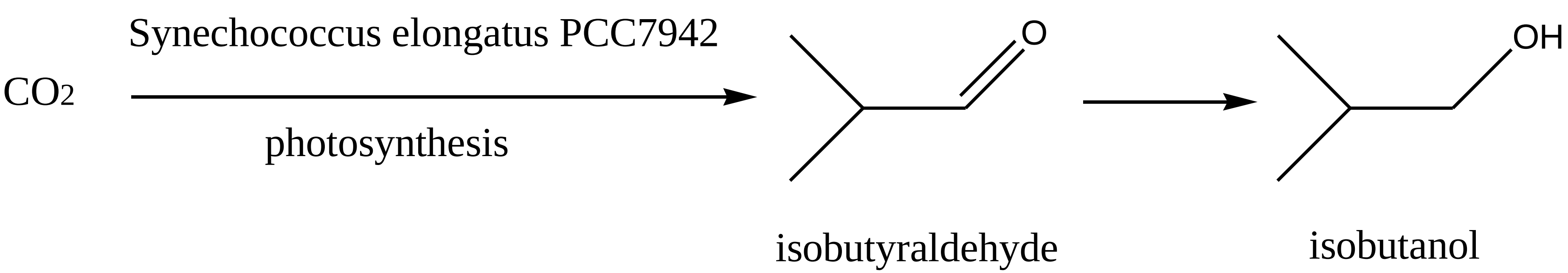
甘油(glycerol)轉變為丙烯醛(acrolein) http://en.wikipedia.org/wiki/Acrolein



將二氧化碳轉變為柴油

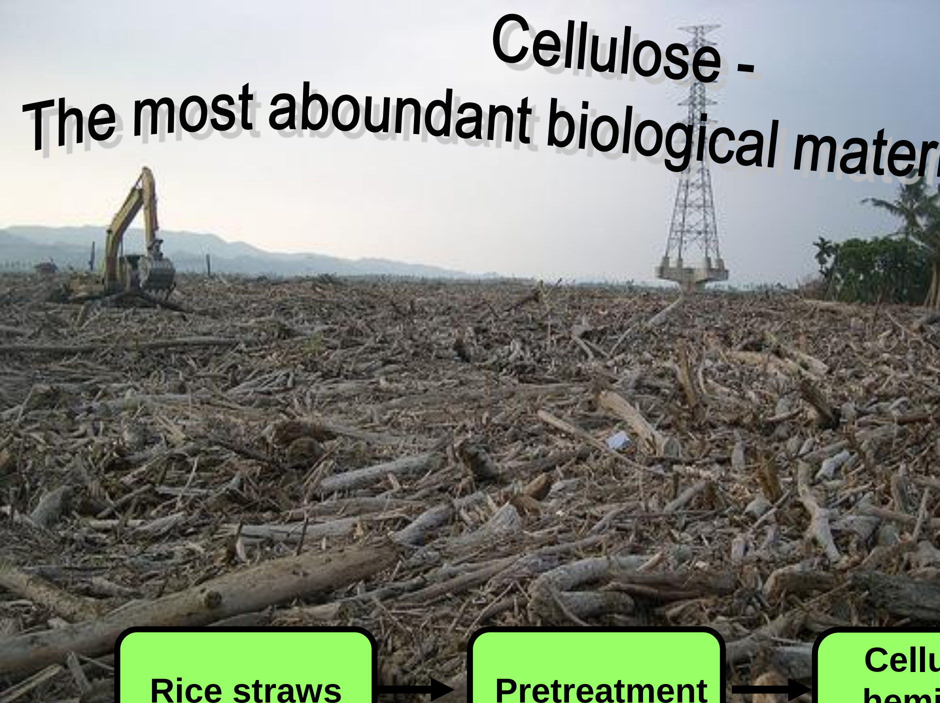
CO_2 emissions in 2006 were 29 billion metric tons, an increase of 35% from 1990
atmospheric levels of CO_2 have increased by ~25% over the past 150 years
二氧化碳是眾所週知的溫室氣體.吾人正因它的逐漸增加所引起各種自然災害而煩惱.現能反其道而行將二氧化碳轉變為燃料和其他化學原料.而且其過程(光合作用)是非常乾淨.碳數比乙醇高的醇的含能量高、吸水性低、蒸氣壓低(不易污染空氣)等優點.如果每年能生產600億加侖(約佔25%之汽油)就可以去除500百萬噸二氧化碳,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

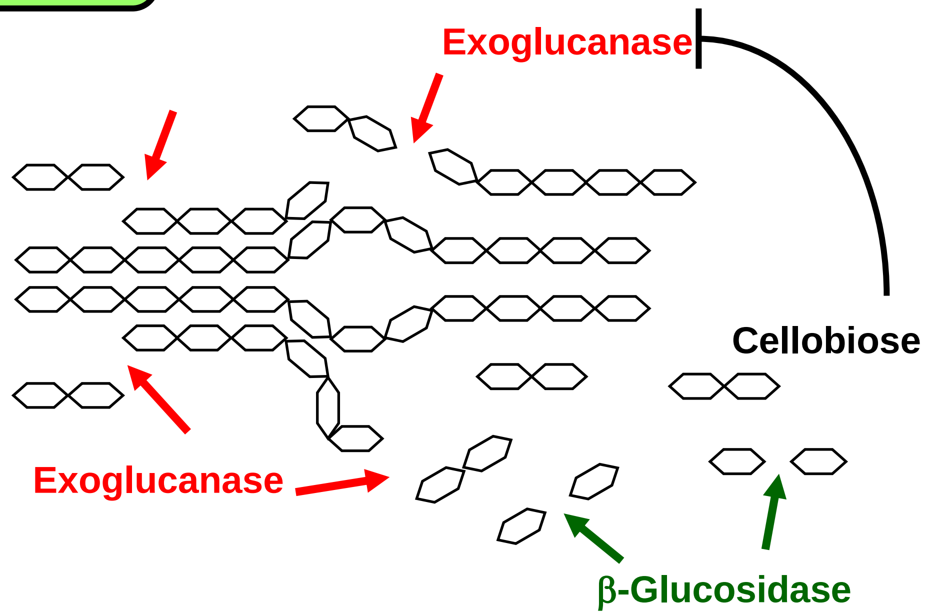


http://www.chemeng.ucla.edu/people/faculty/james-c-liao

Cellulose -
The most aboundant biological material on earth

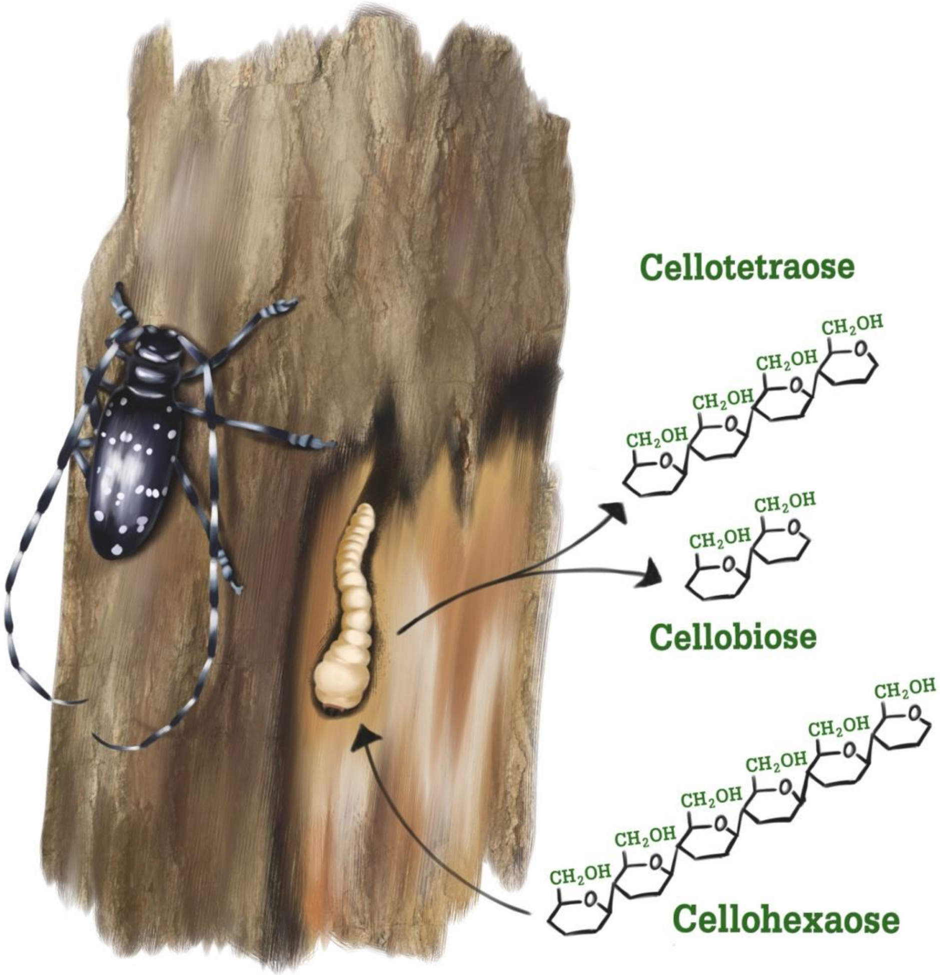


Rice straws → Pretreatment → Cellulose and hemicellulose saccharification → Sugar fermentation → Ethanol



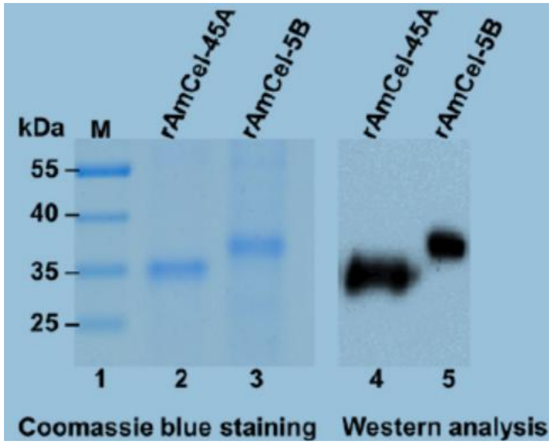
From T. H. Ho

Decomposition of cellulose using cellulase

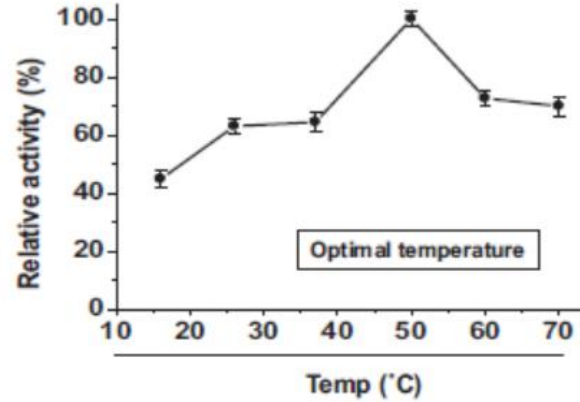


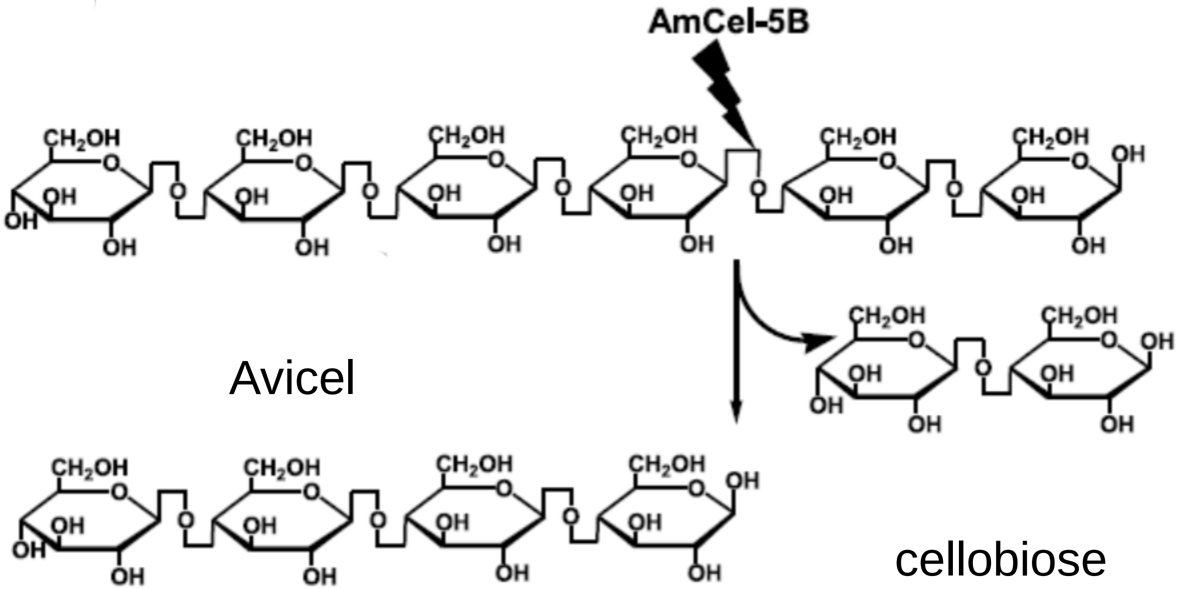
Drawn by Chao, A-L
from Chang, C-J et al.,
Insect Biochemistry and Molecular Biology 42 (2012) 629-636.

A novel exo-cellulase fromwhite spotted longhorn beetle (Anoplophora malasiaca)
Cloning, expression and purification of AmCel-45A and AmCel-5B from recombinant baculovirus-infected silkworm

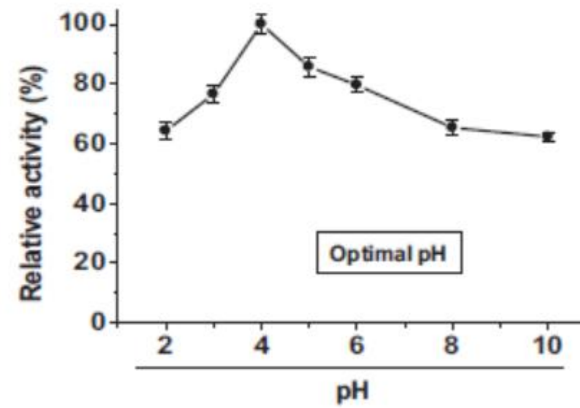


The optimal condition of enzymatic activity was found to be 50 C and pH 4.0.





Avicel



cellobiose

cellotetraose

C.-J. Chang, C. P. Wu, S.-C. Lu, A.-L. Chao, T.-H. David Ho, S.-M. Yu, Y.-C. Chao
Insect Biochemistry and Molecular Biology 42 (2012) 629-636

趙裕展

Isolation of microbes from various sources
各種來源材料分離微生物

稻桿、蔗渣堆肥

2005.09.19 (AVRDC)

羊胃

Rumen of Nubian Goat

朽木

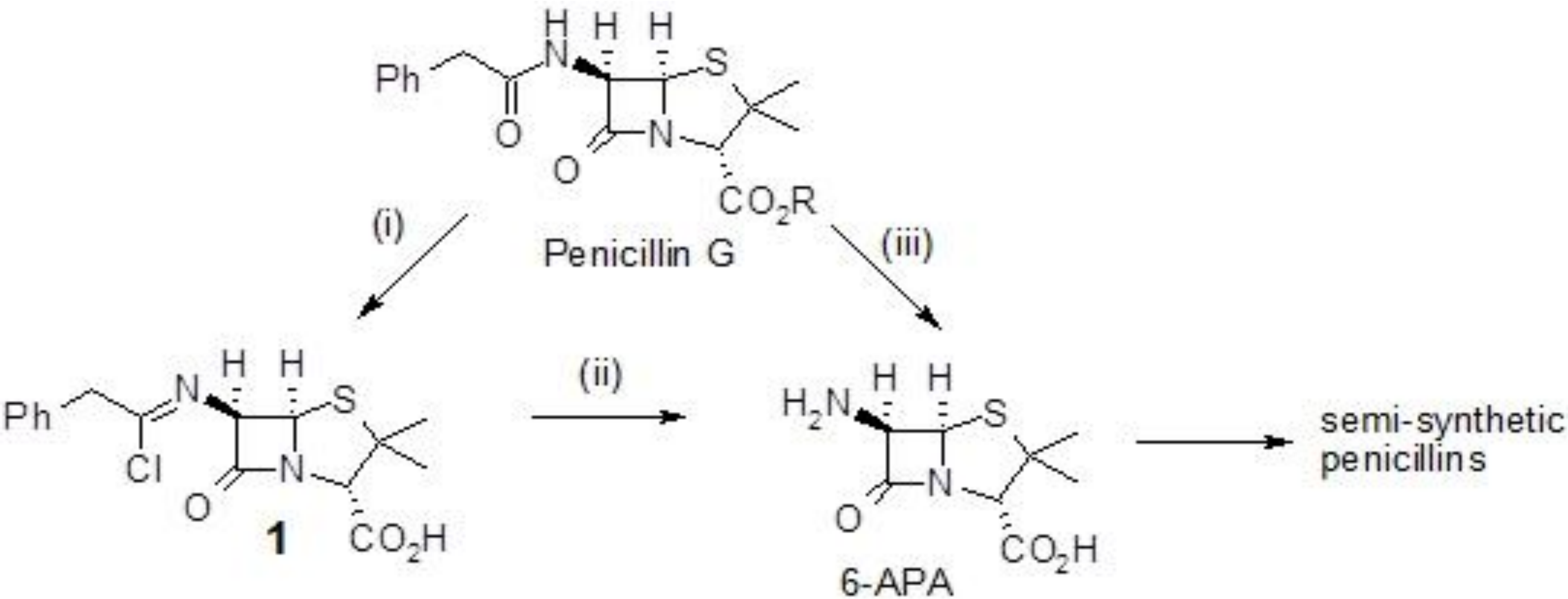
天牛: 木材的天敵，纖維酵素的新領域

Institute of Molecular Biology
Academia Sinica
中央研究院分子生物研究所

中央研究院 南部生物技術計畫中心
Academia Sinica Biotechnology Experimental Center in Southern Taiwan (AS-BEST)

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

例: Synthesis of penicillins from penicillin G without blocking group by enzyme



(i) TMSCl then PCl_5, $PhNMe_2$, CH_2Cl_2, -40^{o}C
(ii) n-BuOH, -40^{o}C, then H_2O, 0^{o}C
(iii) Pen-acylase, water

Use enzymes!

9. 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.

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.

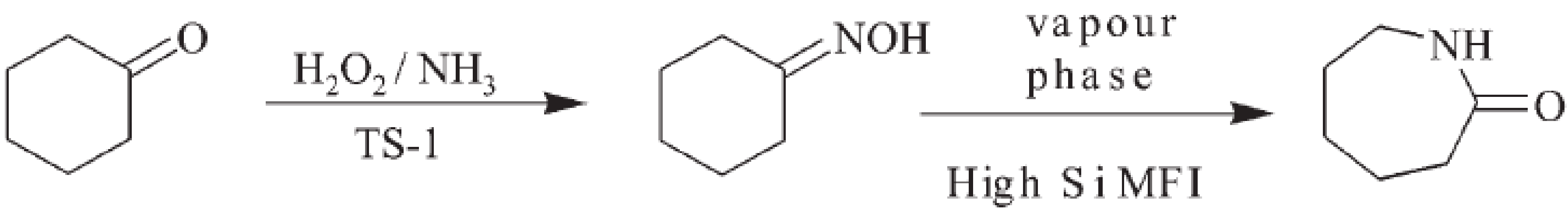
催化劑降低了反應所需的能量(活化能)及增加了反應的速率但本身不反應。所以催化劑不出現在反應方程式中。反應前、後催化劑的性質、質量都不改變。

提供反應新的途徑.
增加過渡狀態的穩定度.
增加親核性的反應能力.
增加親電子性的接受能力.
增加離去基的穩定度.

- Homogeneous catalysis
- Heterogeneous catalysis
- Organo-catalysis
- Bio-catalysis
- Photo-catalysis

Brønsted Acid-Base Catalysis
Lewis Acid-Base Catalysis
Transition-metal catalysis
Organocatalysis
Asymmetric Catalysis
Biocatalysis
Photocatalysis

Synthesis of Caprolactam (raw material for the nylon 6)



Ammoximation

Beckmann rearrangement

Current process:

$$C_6H_{10}O + 0.5(NH_3OH)_2SO_4 + 1.5H_2SO_4 + 4\ NH_3 \longrightarrow C_6H_{11}NO + 2\ (NH_4)_2\ SO_4$$

Atom efficiency =29% ; E = 4.5

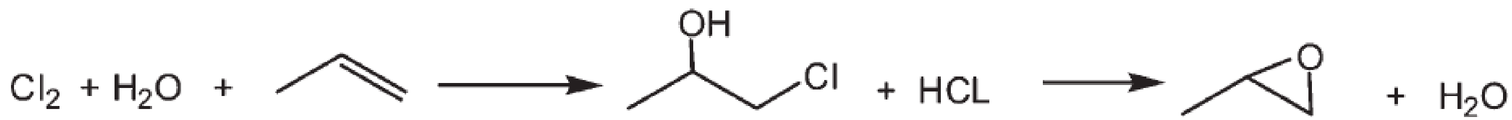
New process Sumitomo Chemicals (住友化學株式會社)

$$C_6H_{10}O + H_2O_2 + NH_3 \longrightarrow C_6H_{11}NO + 2H_2O$$

Atom efficiency = 75% ; E = 0.32 (<0.1)

Propylene oxide, polyurethane (聚氨酯,PU)的原料.PU是黏合劑、塗層！低速輪胎、墊圈、車墊等工業領域、各種泡沫和塑料海綿和醫用器材。

1. Chlorohydrin route



2. Hydroperoxide (coproduct) processes

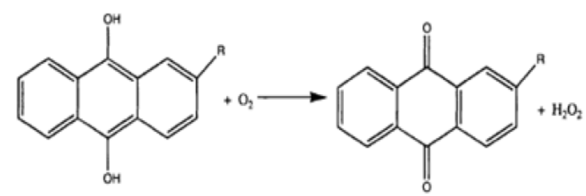
R = t-Bu , PhCH(CH_3)- , PhC(CH_3)$_2$-

Headwaters Technology Innovation
Direct Synthesis of Hydrogen Peroxide
by Selective Nanocatalyst Technology

3. Direct hydrogen peroxide process

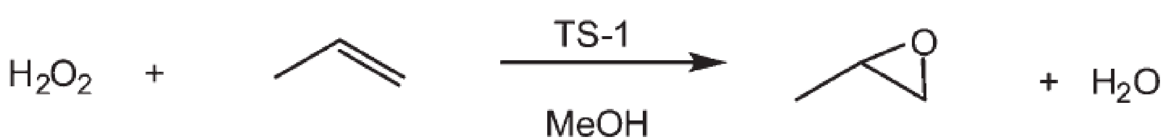
$$H_2 + O_2 \xrightarrow{\text{Pd-Pt (4nm)}} H_2O_2$$

代替了



Synthesis of hydrogen peroxide from Anthraquinone

Enichem



2007年較綠之反應條件總統挑戰獎

Oxidations

Classification of oxidizing agents

- Dangerous: CrO3/H2SO4, (pyH)ClCrO3 , KMnO4, Pb(OAc)4, etc.
- Dirty: MnO2, Ag2CO3, etc.
- Clean: H2O2/catalyst, H2O2/Ti-MS, O2/Pt, etc.

"Green" oxidation agents

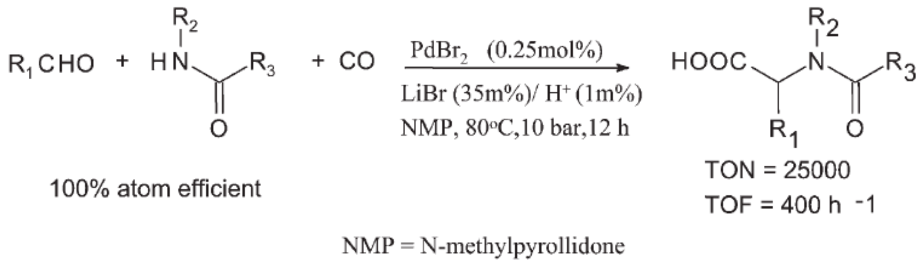
Oxygen donors	Active oxygen content (%)	Product derived from the oxidant
H_2O_2	47.0 (14.1 [a])	H_2O
N_2O	36.4	N_2
O_3	33.3	O_2
AcO_2H	21.1	AcOH
Bu^tO_2H	17.8	Bu^tOH
HNO_3	25.4	NO_x (?)
NaOCl	21.6	NaCl
NaO_2Cl	35.6	NaCl
NaOBr	13.4	NaBr
$n\text{-}C_5H_{11}NO_2$	13.7	$n\text{-}C_5H_{11}NO$
$KHSO_5$	10.5	$KHSO_4$
$NaIO_4$	7.5	$NaIO_3$
PhIO	7.3	PhI

[a] For a 30% aqueous solution.

劉廣定提供

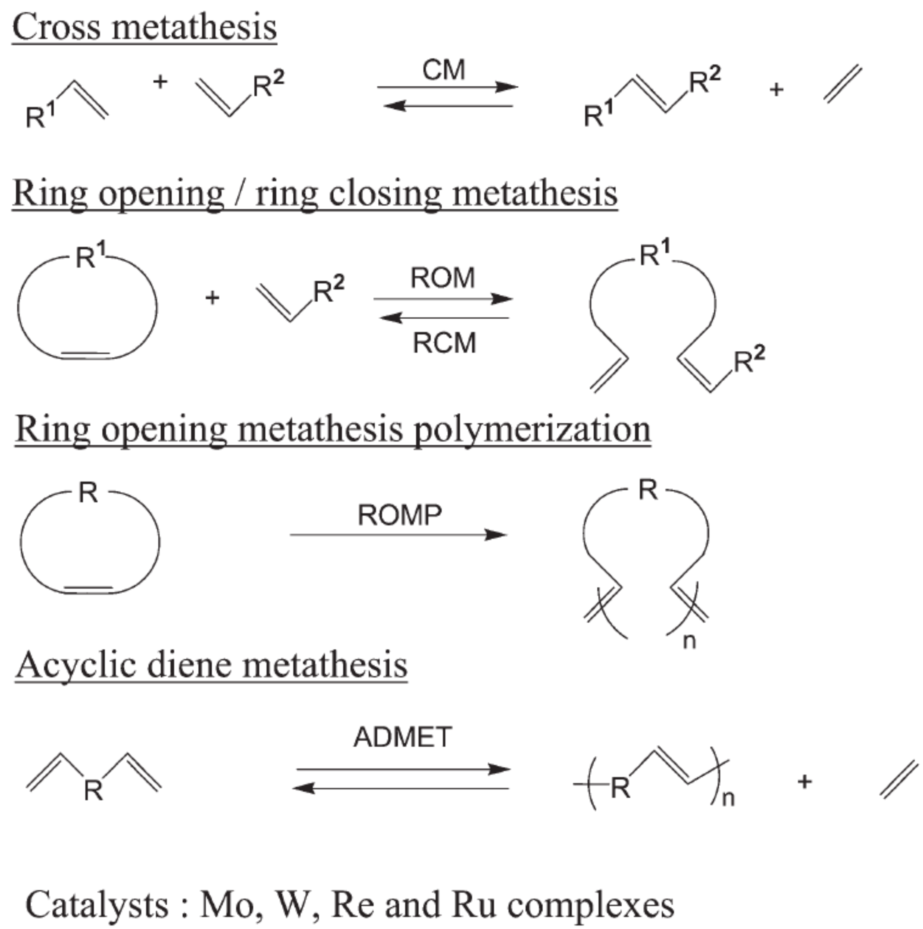
The formation of C-C bond

Hoechst-Celanese process for ibuprofen



Synthesis of α–amino acid derivatives from an aldehyde, CO, and an amide.

Olefin metathesis



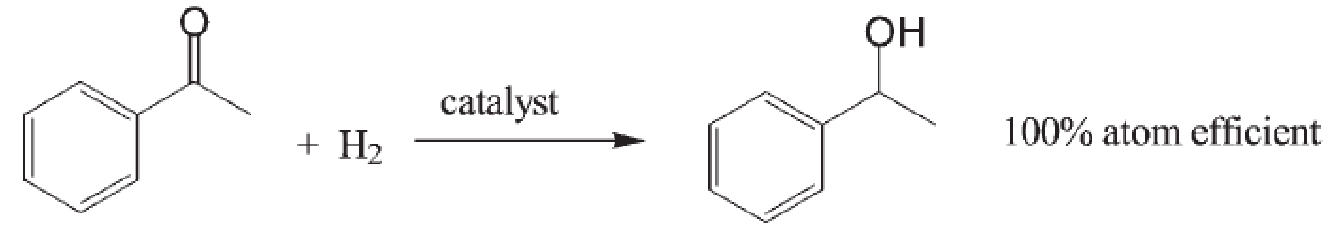
Robert H. Grubbs

Yves Chauvin

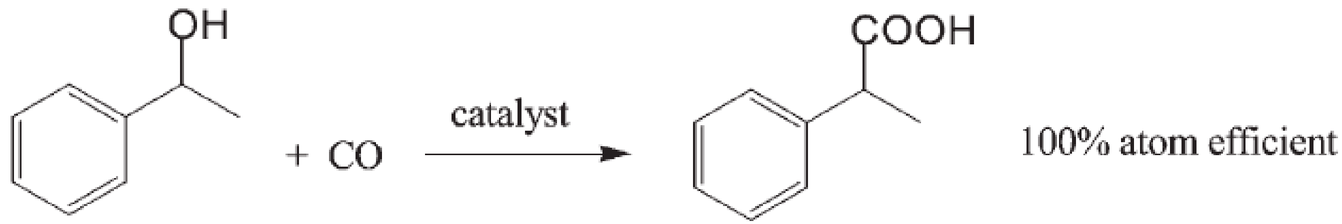
Richard R. Schrock

Chauvin, Grubbs, and Schrock, Nobel Prize of Chemistry, 2005

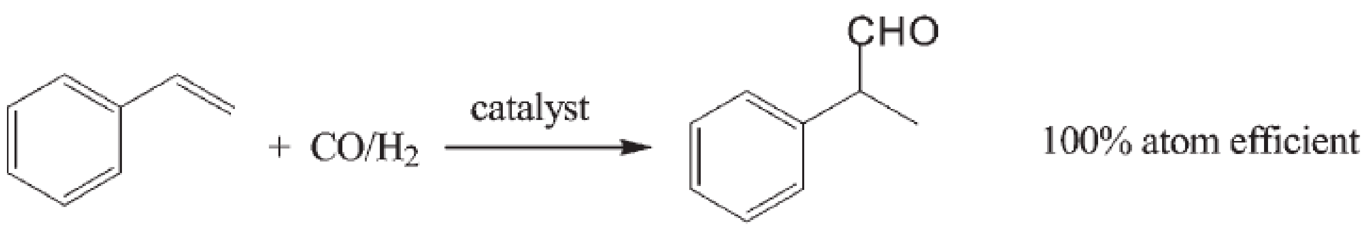
Hydrogenation:



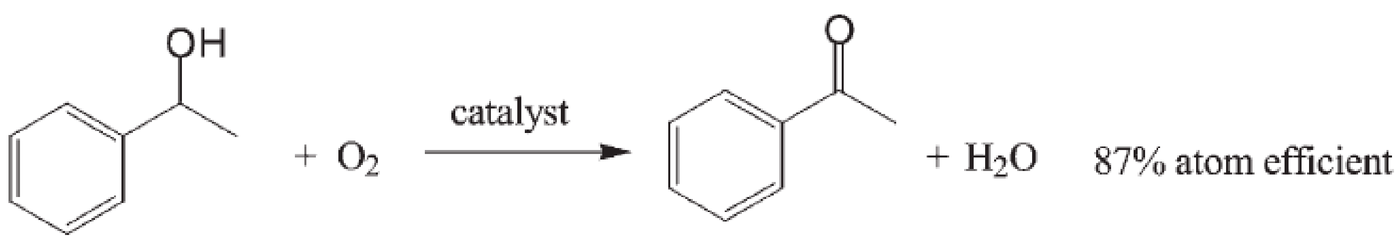
Carbonylation:



Hydroformylation:



Oxidation:



Calcium catalyzed hydroalkoxylation

Anastasie Kena Diba, Jeanne-Marie Begouin, Meike Niggemann

Tetrahedron Letters 53 (2012) 6629–6632

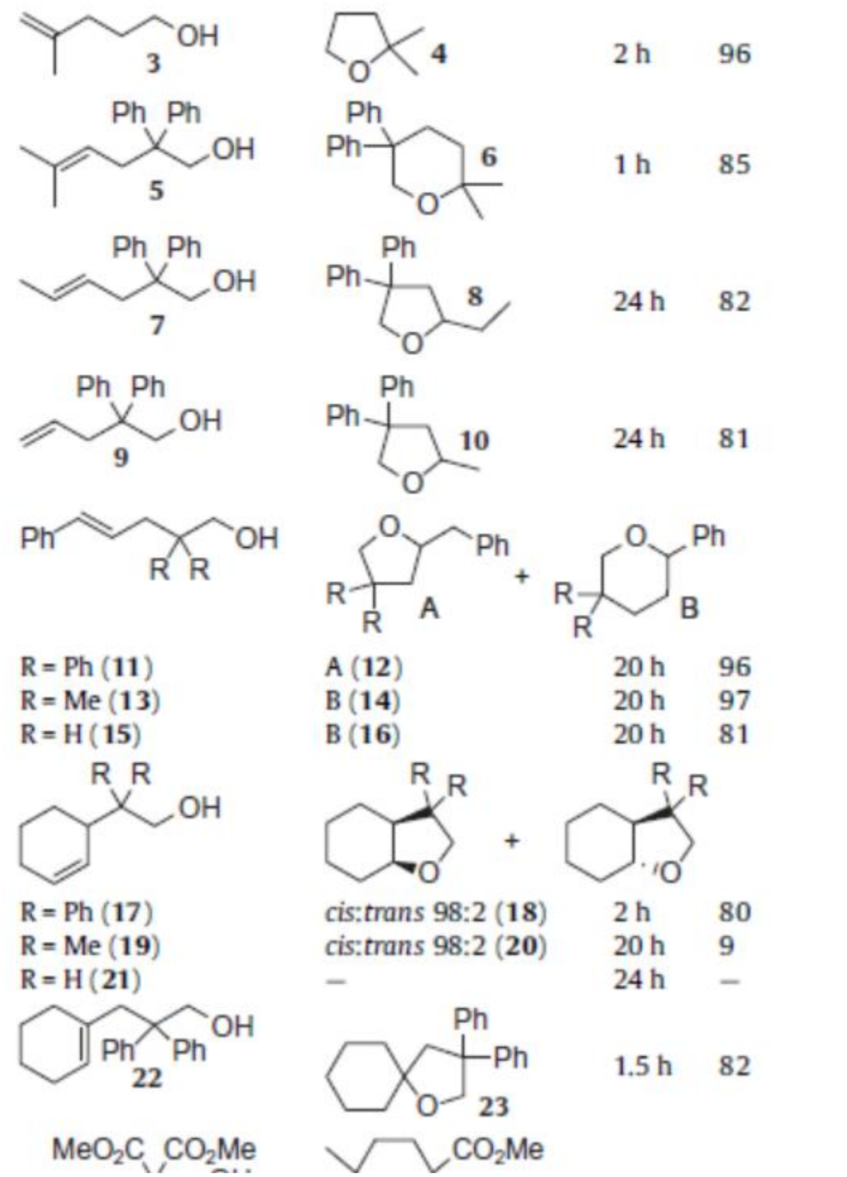
A calcium catalyzed intramolecular hydroalkoxylation reaction is presented, as a transition metal free, inexpensive, and very mild process for the highly atom economic formation of cyclic ethers from γ,δ-unsaturated alcohols. In contrast to most of the previously reported procedures, room temperature conditions are fully sufficient in most cases for a high yielding cycloisomerization in the presence of a combination of 5 mol-% $Ca(NTf_2)_2$ and 5 mol-% Bu_4NPF_6. Full regioselectivity is observed in all transformations.

Calcium-Catalyzed Cyclopropanation

Tobias Haven, Grzegorz Kubik, Stefan Haubenreisser, and Meike Niggemann

Angewandte Communications
DOI: 10.1002/anie.201209053

Table 2
Cyclization of different alcohols



Entry[a]	Alcohol	Product	*t*	Yield[b] (%)
1	3	4	2 h	96
2	5	6	1 h	85
3[c]	7	8	24 h	82
4	9	10	24 h	81
5[c]	R = Ph (11)	A (12)	20 h	96
6[c]	R = Me (13)	B (14)	20 h	97
7	R = H (15)	B (16)	20 h	81
8	R = Ph (17)	*cis:trans* 98:2 (18)	2 h	80
9[c]	R = Me (19)	*cis:trans* 98:2 (20)	20 h	9
10	R = H (21)	–	24 h	–
11	22	23	1.5 h	82
	MeO_2C CO_2Me	CO_2Me		

Tetrabutylammonium hexafluorophosphate

Calcium(II) bis(trifluoromethanesulfonimide)

5 mol-% Bu_4NPF_6/$Ca(NTf_2)_2$, 0.25 mmol of alcohol, in CH_2Cl_2 (2 mL) stirred at rt for the time indicated.

Green Catalysts

Green catalysts are eco-friendly catalysts which

are highly efficient;

are recyclable;

are biodegradable;

are non-toxic;

can be made from renewable sources;

can convert toxic substances into less or non-toxic ones.

Bio-catalysis

- Fast reaction due to correct catalyst orientation（加快反應）
- High degree of selectivity; possible for asymmetric synthesis （立體結構選擇性高）
- Water soluble（水溶, 可在水溶液進行）
- Naturally occurring; non-toxic, low hazard（自然發生, 毒性低）
- Energy-efficient reactions under moderate conditions of pH, temperature （反應溫和, 省能）
- Possibility for carrying out sequential one-pot synthesis（可進行一罐反應）

2000 Presidential Green Chemistry Challenge Award: Academic
Professor Chi-Huey Wong
The Scripps Research Institute
Enzymes in Large-Scale Organic Synthesis

Innovation and Benefits: Professor Wong developed methods to replace traditional reactions requiring toxic metals and hazardous solvents. His methods use enzymes, environmentally acceptable solvents, and mild reaction conditions. His methods also enable novel reactions that were otherwise impossible or impractical on an industrial scale. Professor Wong's methods hold promise for applications in a wide variety of chemical industries.

10. 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. 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.

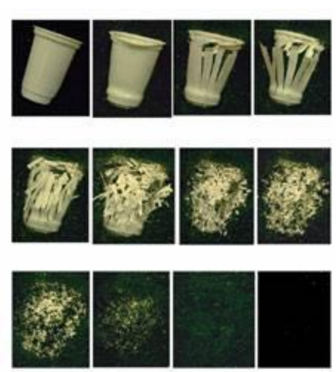
To optimize the commercial function of a chemical while minimizing its hazard and risk. Biodegradation, hydrolysis, and photolysis can be designed into chemical products.

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

實例：可分解塑膠



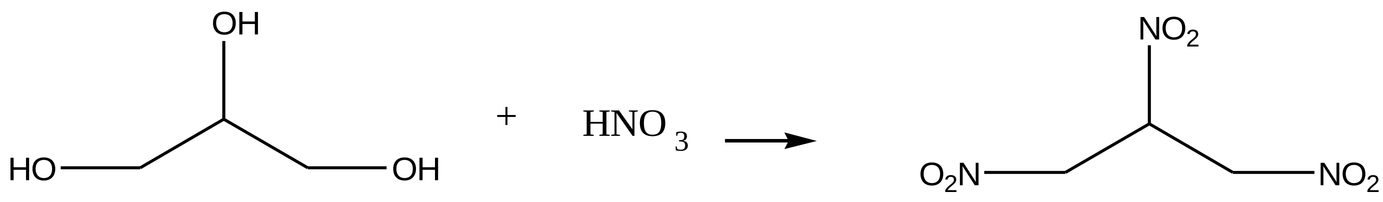
http://russia-ic.com/search/link/2/8804/

11.瞬時分析以防污染：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

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.

例： Nitroglycerin 硝化甘油之合成



甘油加 1:1 濃硝酸及濃硫酸而成.

此反應產生大量之熱,要時時注意反應爐不能過熱.昔日工人坐在一枝腳的椅子上,只要一打瞌睡,人就會從椅子上跌下來.

反應爐中裝太多東西是因為反應太慢.於是要改良鍋爐.

新的反應器如同一水的噴射器,酸從噴口噴出,產生的真空將甘油吸入,混合非常均勻,另外一個好處是可控制比例.

反應器裝一緊急洩氣閥,一打開真空被打破,就會停止供應甘油.

改變合成步驟：將攪拌式改為循環式,加快反應.

Center for Process Analysis & Control

12.**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.** 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.

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

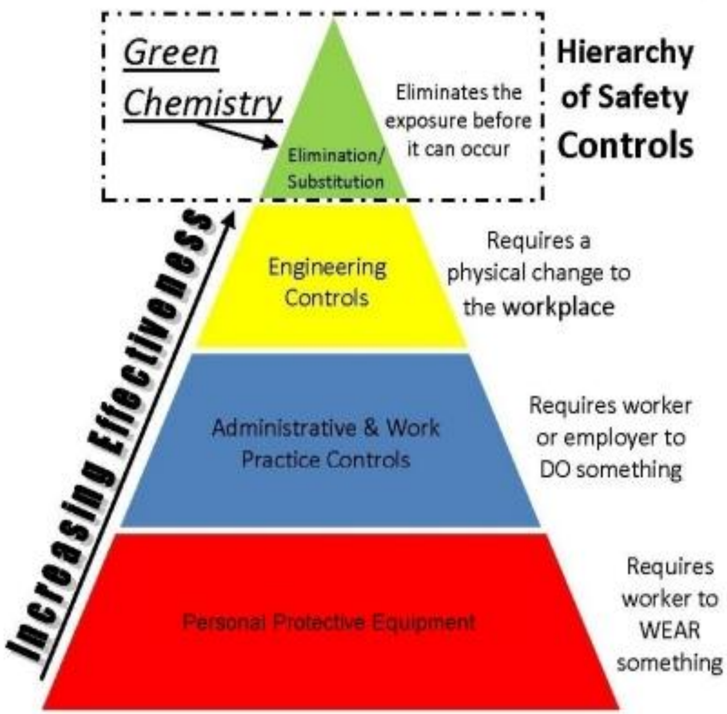
日常檢查及審核

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




加州大學洛杉磯分校化學系Patrick Harran教授因重罪入獄
-『實驗室安全』事件後續
中央研究院 化學研究所 甘魯生

美國化學會會刊『Chem & Eng News』今(2012)年元月二日的電子期刊上(註一)披露加州大學洛杉磯分校化學系Patrick Harran教授將因違反加州勞工法犯了導至其實驗室助理Sheharbano (Sheri) Sangji死亡之重罪,已發出逮捕令(註二).

起因是Harran教授的二十三歲助理Sheri在實驗時被火焚身而不幸死亡之事件.此事件之始末請參考本刊第六八卷第313至319頁.本文為此事件最新之發展.

洛杉磯郡地檢署指控Harran 教授及加大董事會三項罪名:未能做到改善不安全工作場所、未要求僱員穿著保護工作服裝及未給予僱員安全訓練以致人於死。如罪名成立，Harran 教授將面臨四年半有期徒刑，每一項罪名學校將被處以一百五十萬美元罰款。

起訴之法源來自加州勞工法規:若僱主和主管持續的(不包括意外及故意觸犯法律)違反職業安全和健康而導至僱員死亡和長期身體傷害是有罪的.

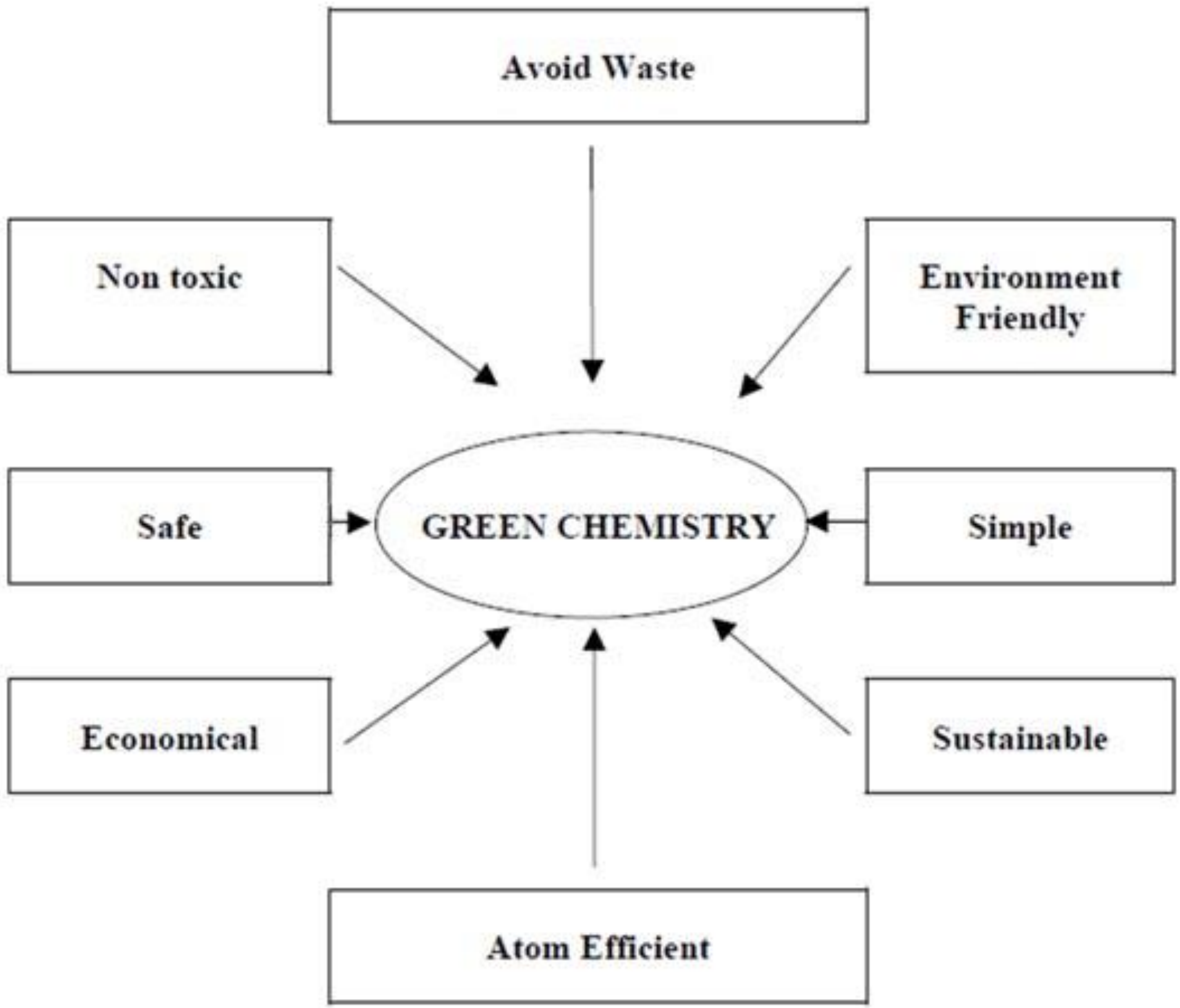
加州大學洛杉磯分校當局認為這是一項粗暴的指控,Reed副校長認為Sheri之死是一悲劇而非犯罪行為.將盡力申辯.

此一訴頌恐曠日費時,但Harran教授現已身陷囹圄.此事非同小可.因此要落實實驗室安全為萬全之策.

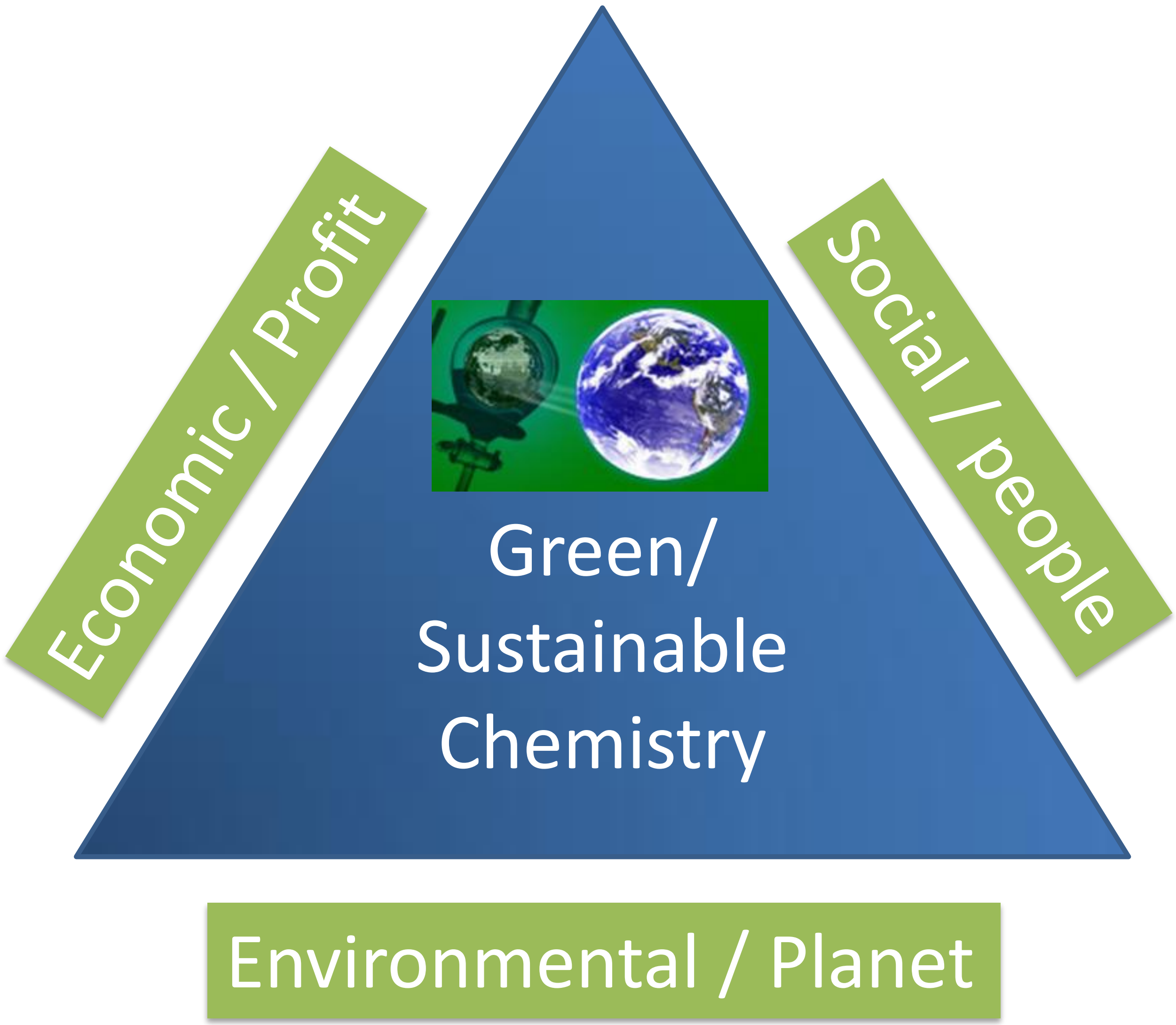
註一:
http://www.cendigital.org/cendigital/20120102_sub?sub_id=lKob10pGIFLP&folio=7#pg9
註二: 雖然Harran教授當時外出渡假,未被立即扣押.但在銷假後即向看守所報到.
12/28/11 Los Angeles Times

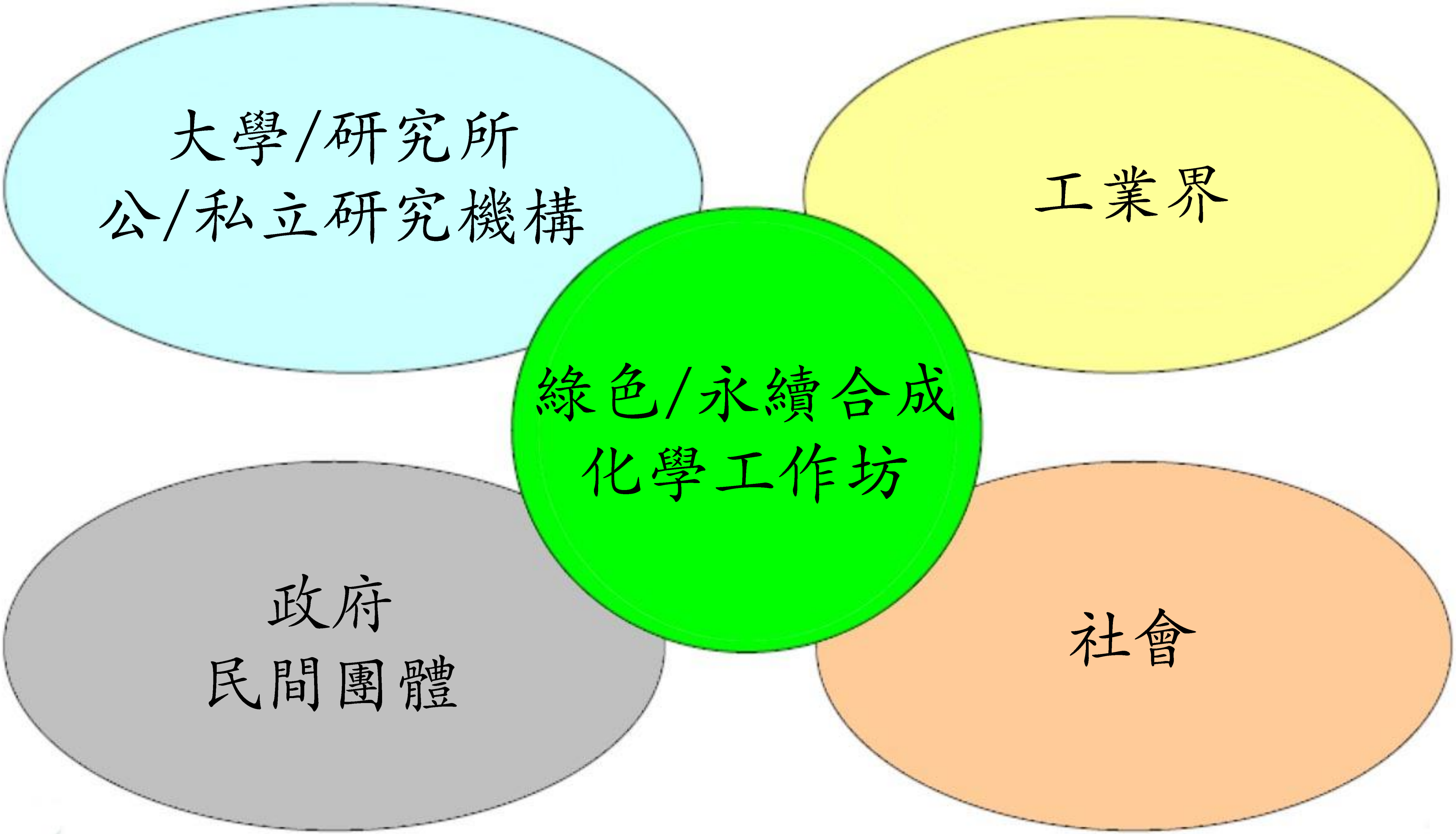
Letter from a friend in UCLA: “Thank you for the articles. So far as I know, Patrick Harran not only is still employed, he also won the Hanson-Dow award for excellence in teaching. Whether he'll be prosecuted remains to be seen.”
http://scienceblogs.com/usasciencefestival/2012/10/18/new-feature-chemistry-in-the-spotlight-submitted-by-joe-schwarcz-usa-science-engineering-festival-nifty-fifty-speaker/

My response: I did some research and found a dramatic twist of the case, to Dr. Harran’s favor in result. Dr. Harran was arrested and a trial date was set. However, Dr. Harran’s attorney introduced the OSHA investigator who was involved a crime case when he was a juvenile.
http://www.chemistry.ucla.edu/news/2013-departmental-awards-ceremony


Avoid Waste
Non toxic
Environment Friendly
Safe
GREEN CHEMISTRY
Simple
Economical
Sustainable
Atom Efficient

Chemistry and Sustainability




大學/研究所
公/私立研究機構
工業界
綠色/永續合成
化學工作坊
政府
民間團體
社會

對化學工業及化學家的期望

對社會、環境及經濟是責無旁貸
化學技術要日新又新、精益求精
化學製造要對社會及環境負責
推廣教育,喚醒大眾對環境保護的認知

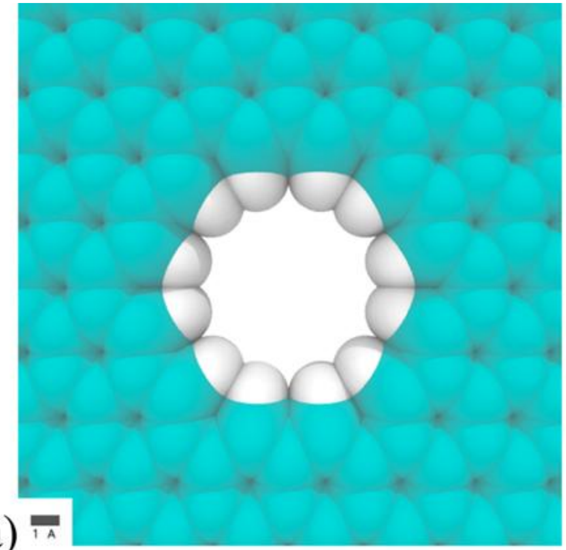
化學工作者自我認知

全球變遷的腳步在加快中.
綠色化學能產生新一代的安全物品,而且是創新的和具競爭力的.
綠色化學要從分子開始設計健康的,永續的產品.
重新設計對環境健康的安全產品有無限商機.
將現有的商品從市場上去除有時是非常困難的事,所以把握綠色化學的原則至為要緊.

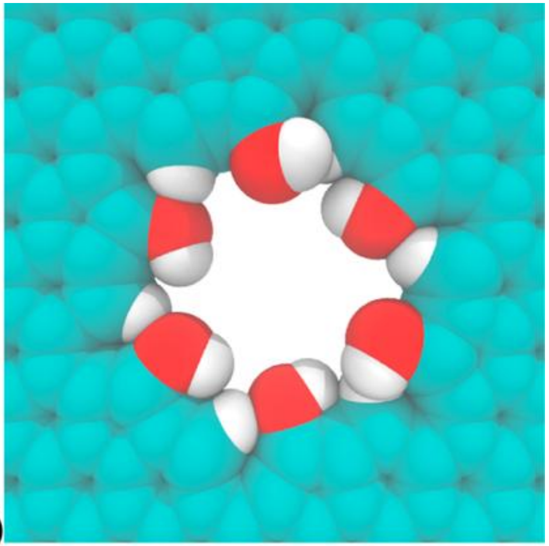
“Delicate motion should reside in all ordinary things around us, revealing itself only to him who looks for it”, E. M. Purcell

奈米科技: 單層graphene淨化水

Water Desalination across Nanoporous Graphene

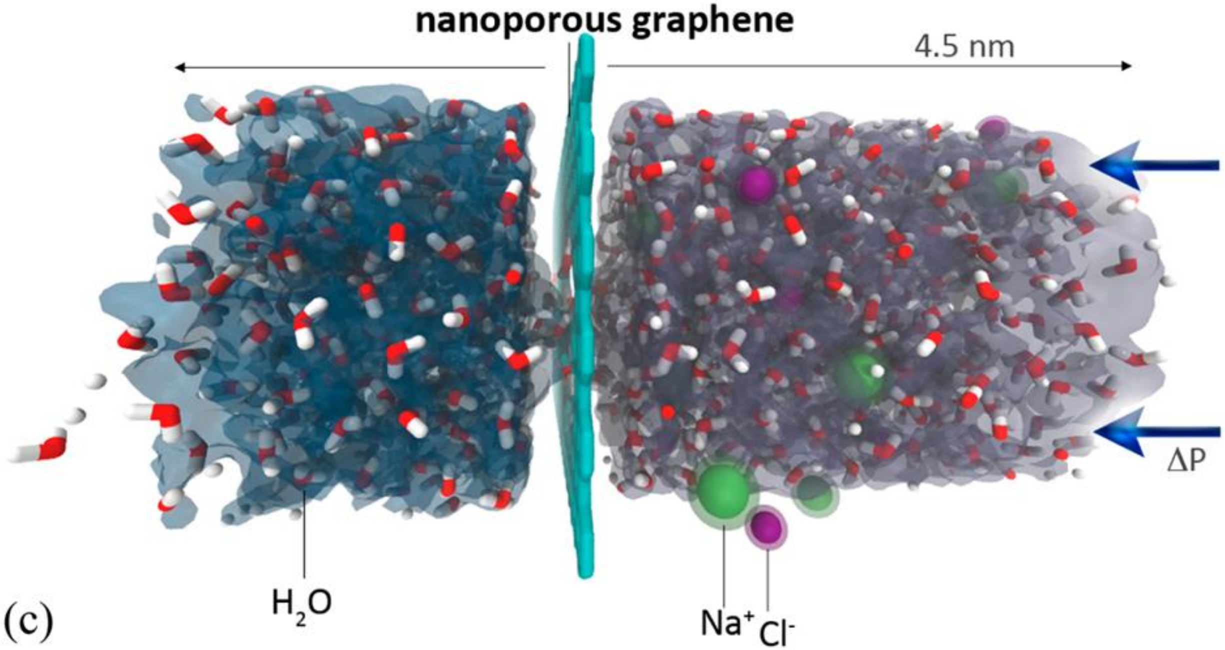


(a)



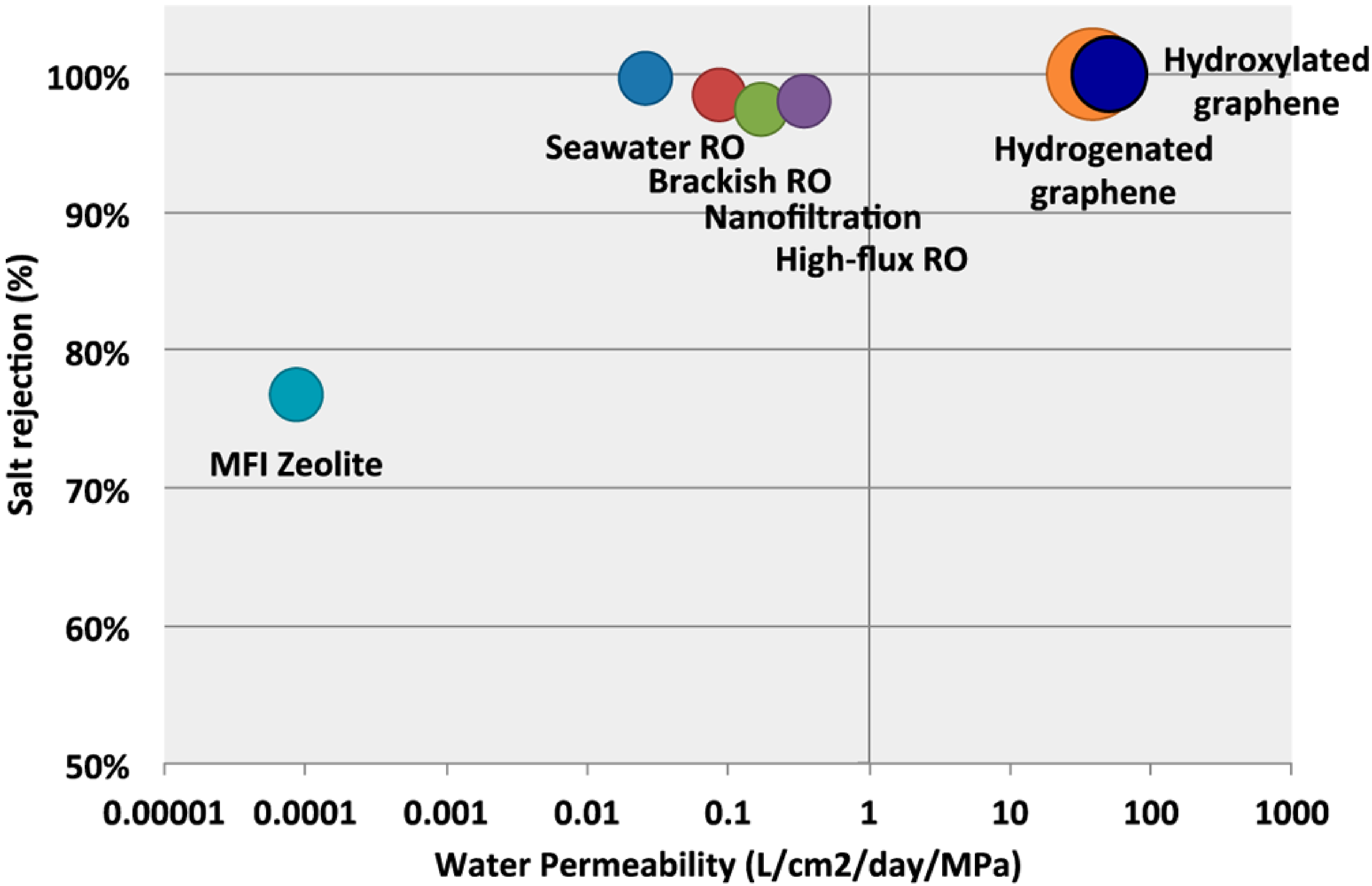
(b)

pore diameter < 5.5 A



(c)

The size of hole < 24 A^2



David Cohen-Tanugi and Jeffrey C. Grossman
dx.doi.org/10.1021/nl3012853 | Nano Lett. 2012, 12, 3602−3608

奈米科技: Cluster carbon nanotube淨化水

Highly Effective Bacterial Removal System Using Carbon Nanotube Clusters

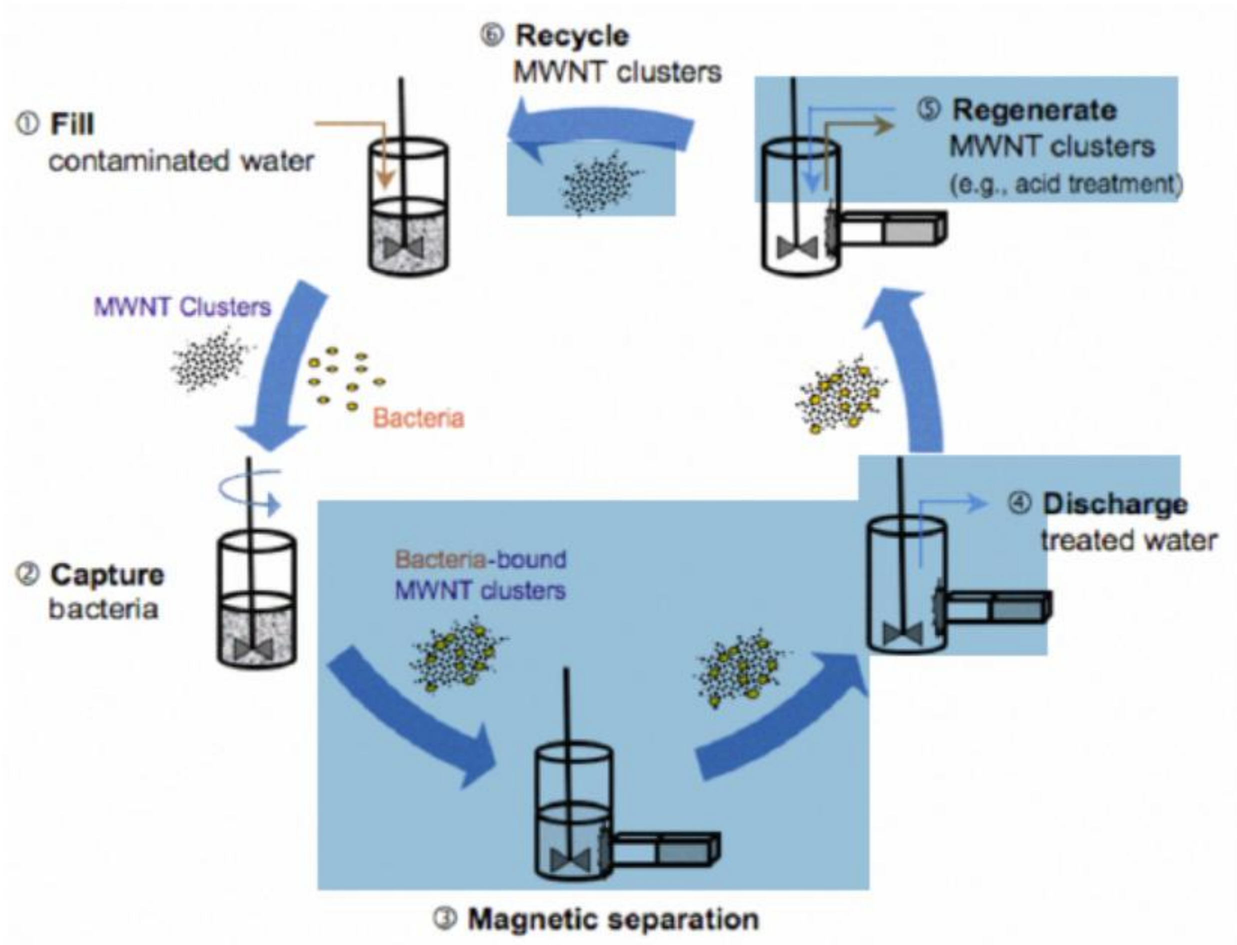


Figure 1. Schematic of overall process of the MWNT cluster-based microbial removal process.

Jin-Woo Kim, Hyung-Mo Moon, Steve Tung, and Hyun-Ho Lee

Proceedings of the 2009 4th IEEE International Conference on Nano/micro Engineered and Molecular Systems

January 5-8, 2009, Shenzhen, China

NEWater解決水荒的希望　甘魯生

淡水的短缺是世界性的，但有些地區這個問題甚至嚴重到威脅國家的安全及經濟發展，我們的近鄰新加坡就是其中之一。新加坡四百四十萬人口每年需1.36兆公升水，但新加坡沒有水源，水是從鄰國馬來西亞以三根大水管從運來。雖然有長期條約保障，內容是馬來西亞不能斷水而且水費便宜，每一千加侖 (一加侖等於3.8 公升) 不到美金一分錢。不過這些條約有的將在今 (2011) 年到期 (另外有些則到2061年)，新的水價可能是現在的20 至30 倍是可預期的，所以尋求水源是新加坡政府長期苦惱的問題。自1998年開始解決方法之一是挖水塘來儲雨水，如今全國有一半地方是水塘，但是還不夠。其二是淡化海水，目前大約可生產10%的用水，最後一個是所謂的NEWater．就是廢水再潔淨再利用。
NEWater 來自用過的水 (used water)，不用污水 (sewage) 這名詞是降低心理厭惡的因素。用過的水經過微過濾(microfiltration)及逆滲透之後再以紫外線處理得到潔淨的水，將這種水注入自來水廠儲水池中，和天然水一起經過處理而得到食用水，原理和方法都不複雜，其實這方法在美國已實行之有年，早在1978 年美國維吉尼亞州北部就上述的方法，得到的淨水也是注入水廠儲水槽，再以一般自來水方式處理。加州橘郡也以用同樣的方法回收水，不過是把得到的水注入地下之後才再利用。新加坡的貢獻是將這程序大規模化，新加坡現有四座淨水廠，第五座正在建造中。大量的生產使得價格降低，生產每一立方米 (或一噸) NEWater 需美金0.3 元，遠比淡化海水便宜(一立方米水要美金2.2元)，目前NEWater 提供了15%的用水量，第五座淨水廠完成後可望提高到30%，終極的目標是70%。

但這並不是沒有代價，新加坡政府在過去五年投入35 億美金，未來五年將同樣數字將投入。但淨水廠愈蓋愈大，不但增加就業機會，讓水能再利用的成本降低，不但解決了本身的水荒，也明顯指出一條解決淨水短缺的路。

大同大學生物工程學系 綠能及綠色化學電子月刊 2011 3月號
http://www.bioeng.ttu.edu.tw/issues/issuesindex.html

即時新聞 》降依賴 星國建第5座新生水廠
Breaking news

【中央社／新加坡21日專電】 2013.12.21 01:27 pm

新加坡將興建第5座新生水廠，預計在2016年啟用，為新加坡提供更多新生水，逐步達到供水自給自足的目標。

新加坡公用事業局昨天宣布第5座新生水廠展開招標，預計在2016年啟用後，每天可以處理5000萬加侖的水量，也就是說屆時5座新生水廠每天共可處理1億1200萬加侖的水量。

這座新生水廠將位於樟宜，採用公用事業局開發的先進薄膜技術處理，製成新生水，主要用於工商業用途，以及季節乾燥時可將新生水灌入蓄水池。目前其他4座新生水廠位於勿洛、克蘭芝、烏魯班丹和樟宜。

水資源在新加坡非常珍貴，前總理李光耀曾說，「在活命水面前，其他政策都得下跪」，新加坡現在約50%的水從馬來西亞進口，其餘來源包括雨水、海水淡化和再生水。

新加坡和馬來西亞的合約將在2061年到期，新加坡希望藉由發展新技術，以及建造水壩和蓄水池提高蓄水量，逐步降低依賴，最終達到供水自給自足的目標，至少在2060年可以達到80%的用水自給自足。

聯合報

未來方向

學生:　　要自動自發學習綠色/永續化學

工程師:　要有綠色/永續化學素養

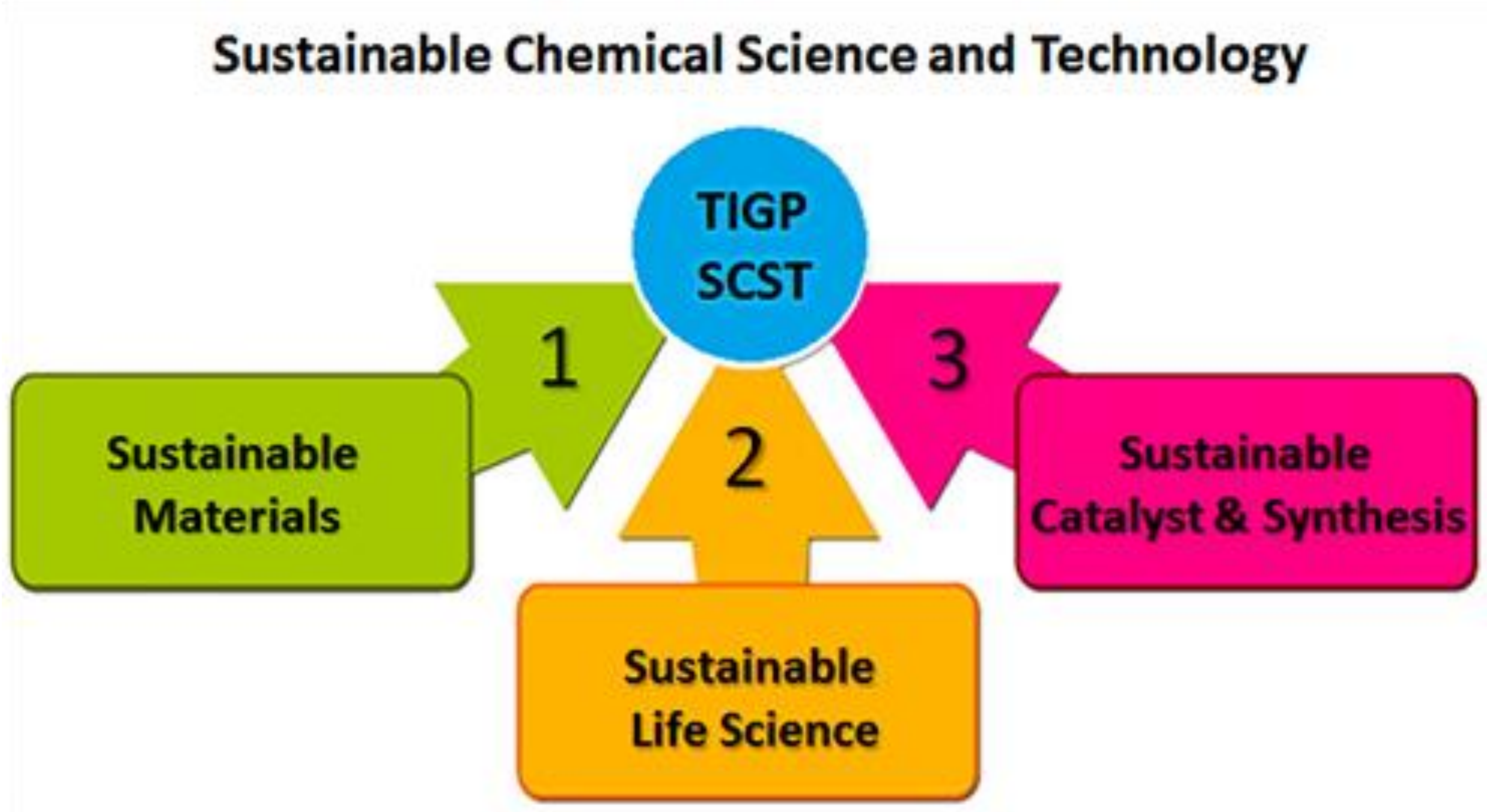
化學教授:要積極發現及學習綠色/永續化學新方法
並融入研究及教學中

研發人員: 要影響管理階層綠色/永續化學是有報酬
及利潤的

創新及研究:要以落實於應用為終極目標

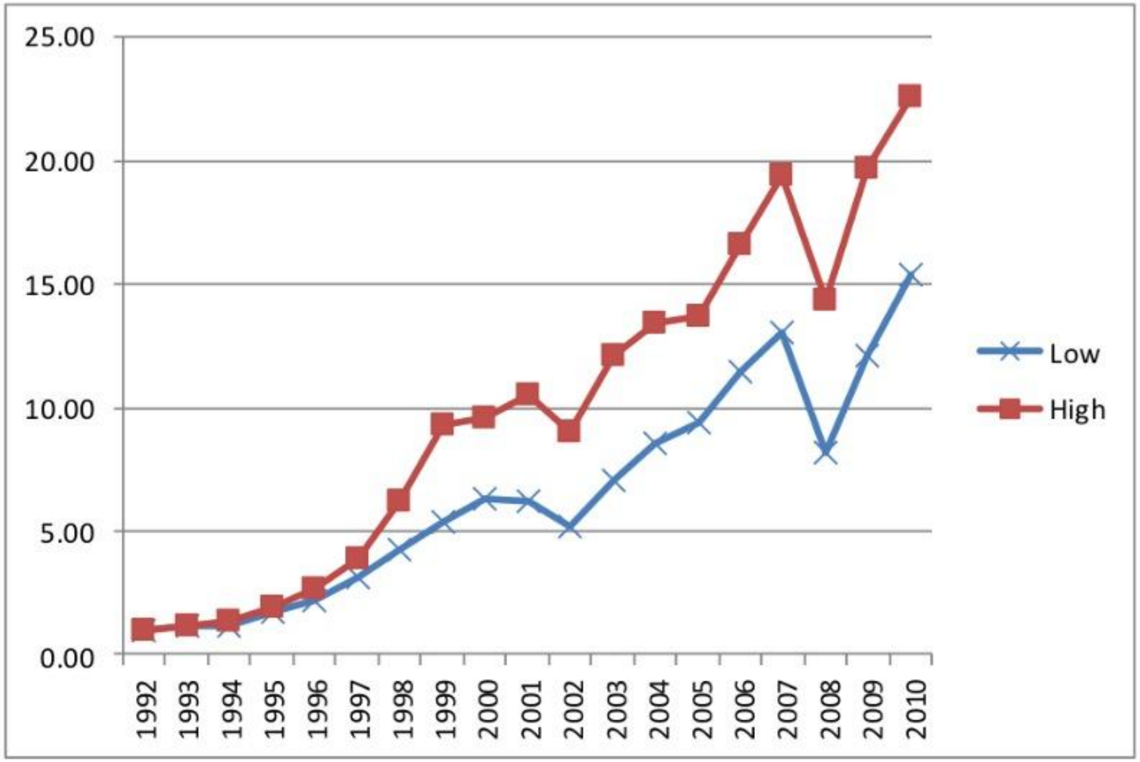
唯有永續化學才能使化學永續 (劉廣定老師)
人類　　(甘魯生)

化學所/交大應化系 TIGP 永續化學科技學程



A 2012 survey by Independent Chemical Information Services (ICIS) shows 54% of 700+ respondents say their company has a sustainability strategy and /or policy already in place, and a further 17% indicate a policy is currently in development and 17% that initiatives are likely within the next 2-3 years. Only 12% reported that there is little interest. http://img.en25.com/Web/ICIS/FC0126_Chem_201301.pdf

Evolution of $1 invested in the stock market in value-weighted portfolios



Paul Anastas: "We can, I believe we will, because we must."

http://www.hbs.edu/faculty/Publication%20Files/12-035_a3c1f5d8-452d-4b48-9a49-812424424cc2.pdf

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