

What kind of organizations can innovate?

ACADEMIA



BUSINESS



CAPITAL



GOVERNMENT



NOT-FOR-PROFIT



Here's to the crazy ones. The misfits. The rebels. The troublemakers. The round pegs in the square holes. The ones who see things differently. They're not fond of rules. And they have no respect for the status quo. You can quote them, disagree with them, glorify or vilify them. About the only thing you can't do is ignore them. Because they change things. They push the human race forward. And while some may see them as the crazy ones, we see genius. Because the people who are crazy enough to think they can change the world, are the ones who do.

- Steve Jobs, Apple CEO
1955-2011

Thinking differently.

Exquisite molecular portraits—
at an affordable price p. 354

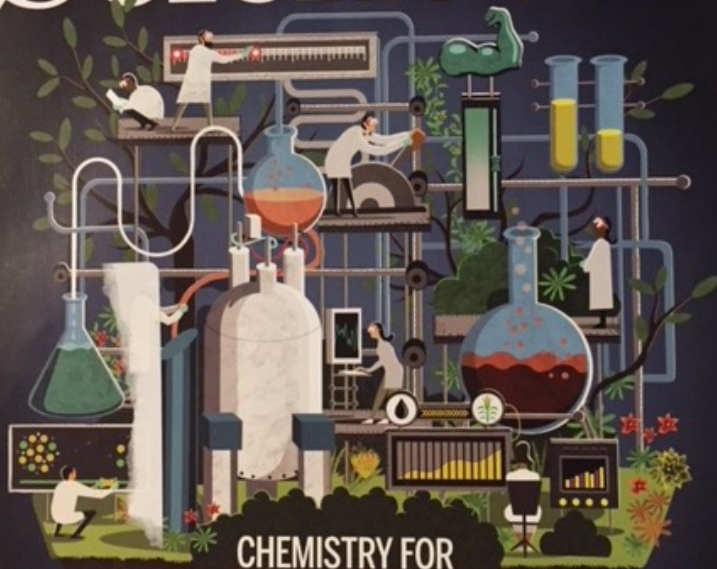
Suppression of movement
during sleep pp. 366 & 440

Probing surfaces with ultrafast
microscopy pp. 368 & 411

Science

\$15
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AAAS



CHEMISTRY FOR
**TOMORROW'S
EARTH**

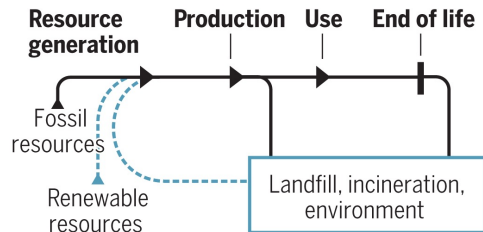
REVIEW

Designing for a green chemistry future

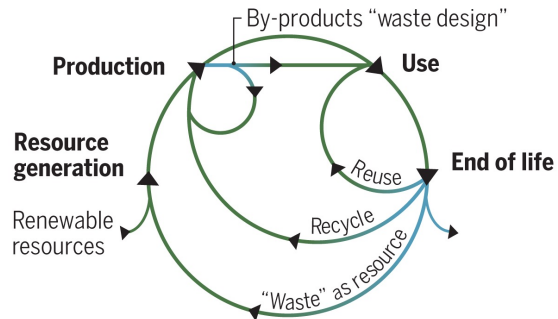
Julie B. Zimmerman^{1,2,3*}, Paul T. Anastas^{2,3,4}, Hanno C. Erythropel^{1,3}, Walter Leitner^{5,6}

The material basis of a sustainable society will depend on chemical products and processes that are designed following principles that make them conducive to life. Important inherent properties of molecules need to be considered from the earliest stage—the design stage—to address whether compounds and processes are depleting versus renewable, toxic versus benign, and persistent versus readily degradable. Products, feedstocks, and manufacturing processes will need to integrate the principles of green chemistry and green engineering under an expanded definition of performance that includes sustainability considerations. This transformation will require the best of the traditions of science and innovation coupled with new emerging systems thinking and systems design that begin at the molecular level and results in a positive impact on the global scale.

Today's chemical sector



Tomorrow's chemical sector



Mostly linear processes → Circular processes

Fossil feedstocks → Renewable feedstocks

Reactive, persistent, or toxic chemical reagents and products → Benign chemical reagents and products

Catalysis using rare metals → Catalysis using abundant metals, enzymes, photons, or electrons

Covalent bonds → Weak, noncovalent interactions

Conventional solvents → Low toxicity, recyclable, inert, abundant, easily separable green solvents or solventless

Material- and energy-consuming isolation and purification → Self-separating systems

Large "waste" volume → Atom-, step-, and solvent-economical processes

"Waste" treatment → "Waste" utilization

Design exclusively for use phase with reliance on circumstantial control → Intentional molecule design for full life cycle

Performance = maximize function → Performance = maximize function + minimize hazards

Maximum chemical production for increased profit → Maximum performance with minimal benign material use for increased profit

More Is Different

Broken symmetry and the nature of
the hierarchical structure of science.

P. W. Anderson

The reductionist hypothesis may still be a topic for controversy among philosophers, but among the great majority of active scientists I think it is accepted without question. The workings of our

planation of phenomena in terms of known fundamental laws. As always, distinctions of this kind are not unambiguous, but they are clear in most cases. Solid state physics, plasma physics, and perhaps also biology are extensive. High energy

less relevance they seem to have to the very real problems of the rest of science, much less to those of society.

The constructionist hypothesis breaks down when confronted with the twin difficulties of scale and complexity. The behavior of large and complex aggregates of elementary particles, it turns out, is not to be understood in terms of a simple extrapolation of the properties of a few particles. Instead, at each level of complexity entirely new properties appear, and the understanding of the new behaviors requires research which I think is as fundamental in its nature as any other. That is, it seems to me that one may array the sciences roughly linearly in a hierarchy, according to the idea: The elementary entities of science X obey the laws of science Y.

The main fallacy in this kind of thinking is that the reductionist hypothesis does not by any means imply a "constructionist" one: The ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe. In fact, the more the ele-

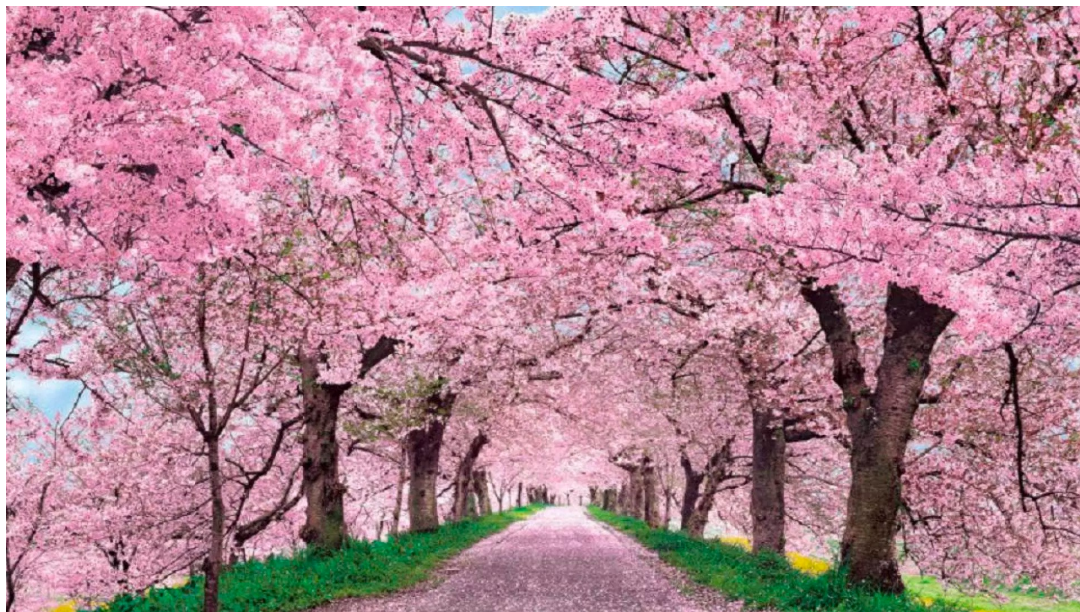
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1. Efficiency will help you do the thing you are doing, better. It will not help you do a better thing.
2. Efficiency is not the same as effective.





Short Music from www.mfiles.co.uk
Arranged for Piano Solo **Piano Concerto No.21 in C**
(2nd movement - as used in Elvira Madigan) Wolfgang Amadeus Mozart
arranged Jim Paterson

Andante
Tutti

pp

p

4

6

8

11

14

sf *p* *sf* *p*

Musical score for Piano Concerto No. 21 in C, 2nd movement. The score is arranged for piano solo and is in 3/4 time. It features a melodic line in the right hand and a rhythmic accompaniment in the left hand. The tempo is marked 'Andante' and the dynamics range from 'pp' to 'sf'. The score is divided into measures, with measure numbers 4, 6, 8, 11, and 14 indicated. The arrangement is by Jim Paterson.

Why is innovation at the heart of green chemistry,
(and at the heart of P2 Science)?

Green Chemistry

Cutting-edge research for a greener sustainable future
rsc.li/greenchem



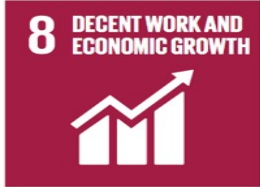
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CRITICAL REVIEW
Paul T. Anastas et al.
The Green ChemisTREE: 20 years after taking root with the 12 principles

The Green
ChemisTREE:
20 years after taking
root with the 12
principles.
Green Chemistry, 20(9),
1929-1961.

Sustainable Development Goals



The Periodic Table of the Elements of Green and Sustainable Chemistry

Humanitarian		Green Chemistry and Green Engineering										Enabling Systems Conditions					Noble Goals					
1 A Appropriate Technologies for the Developing World																		2 Ho Hippocratic Oath for Chemistry				
3 Cw Chemistry for Wellness	4 Dd No Molecular Design for Dependency																	10 P Design for Posterity				
11 Sw Access to Safe and Reliable Water	12 Fg Ensure access to Material Resources for Future Generations																					
19 Bf Chemistry for Benign Food Production and Nutrition	20 Tc Transparency for Chemical Communication	21 Wu Waste Material Utilization	22 Sa Molecular Self-Assembly	23 Ru Reduce Use of Hazardous Materials	24 Dg Design Guidelines	25 Aq Aqueous and Biobased Solvents	26 Ee Energy and Material Efficient Synthesis and Processing	27 Ib Integrated Biorefinery	28 E Enzymes	29 Bm Benign Metabolites	30 Sn Sensors	5 B Biomimicry	6 Cb Life Cycle Cost-Benefit Analysis	7 Ae Atom Economy	8 Pr Producer Responsibility	9 Ea Epidemiological Analysis and Ecosystem Health	13 Ce Circular Economy	14 Fc Full Cost Accounting	15 Ef E-Factor	16 Pb Property Based Regulation	17 Aa Alternatives Assessment	18 Lp Life-Compatible Products & Processes
37 J Ensure Environmental Justice, Security, and Equitable Opportunities	38 Cs Chemistry for Sustainable Building and Buildings	39 Op One-Pot Synthesis	40 Ip Integrated Processes	41 Gc In Situ Generation & Consumption of Hazardous Materials	42 Cm Computational Models	43 Il Ionic Liquids / Non-Volatile Solvents	44 R Renewable / Carbon-Free Energy Inputs	45 C Carbon Dioxide and other C1 Feedstocks	46 Ac Earth Abundant Metal Catalysis	47 Md Molecular Degradation Triggers	48 Co In Process Control and Optimization	31 Bd Benign by Design	32 Hc Harm Charge / Carbon Tax	33 Ff F-Factor	34 Ct Chemical Transparency	35 Lc Life Cycle Assessment	36 Z Zero Waste					
55 Pc Chemistry to Preserve Natural Carbon and Other Biogeochemical Cycles	56 Ic An Individual's Molecular Code Belongs to that Individual	57 Pi Process Intensification	58 As Additive Synthesis	59 Ch C-H Bond Functionalization	60 Ba Bioavailability / ADME	61 Sc Sub- and Super-Critical Fluids	62 Es Energy Storage / Transmission Materials	63 Sb Synthetic Biology	64 Ht Heterogeneous	65 Dp Degradable Polymers and Other Materials	66 Ex Exposome	49 Ie Industrial Ecology	50 Dc Depletion Charge	51 Ql Qualitative Metrics	52 Cl Chemical Leasing	53 So Solvent Selection Screens	54 Fi Chemistry is Equitable and Fully Inclusive					
73 Wo No Chemicals of War or Oppression	74 Nc Molecular Codes of Nature Belong to the World	75 Ss Self-Separation	76 W Non-Covalent Derivatives/ Weak Force Transformation	77 Is Inherent Safety and Security	78 Ts High Throughput Screening (Empirical) / In Vivo / In Vitro	79 S Smart Solvents (Obedient, Tunable)	80 V Waste Energy Utilization and Valorization	81 Bt Biologically-Enabled Transformation	82 Hm Homogeneous	83 Pd Prediction and Design Tools	84 Ga Green Analytical Chemistry	67 Tg Trans-Generational Design	68 Rf Sustained Research Funding	69 Qn Quantitative Metrics	70 Se Self-Enforcing Regulations	71 Cf Chemical Footprinting	72 De Benefits Distributed Equitably					
												85 Be Bio Based Economy	86 Ci Capital Investment	87 Bb Chemical Body Burden Measurement	88 I Innovation Ecosystem Translation from Lab to Commerce	89 Et Education in Toxicology	90 K Extraordinary Chemical Knowledge Comes With Extraordinary Responsibility					

This collection of science and technology is the manifestation of the Twelve Principles of Green Chemistry and the Twelve Principles of Green Engineering.

P2

Elegant Processes.

Sustainable Products.

To make the products

we use everyday

better.

Global human-made mass exceeds all living biomass

Elhacham, E. *et al.* Nature 2020

<https://doi.org/10.1038/s41586-020-3010-5>











Biorenewable.

Biocompatible.

Biodegradable.

Some observations

The test of a first-rate intelligence is the ability to hold two opposing ideas in mind at the same time and still retain the ability to function. One should, for example, be able to see that things are hopeless yet be determined to make them otherwise.

– *F Scott Fitzgerald*

The customer is always right.

The customer doesn't know what they want.

Innovation is all about big breakthroughs.

Innovation is all about execution.

It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of light, it was the season of darkness, it was the spring of hope, it was the winter of despair.

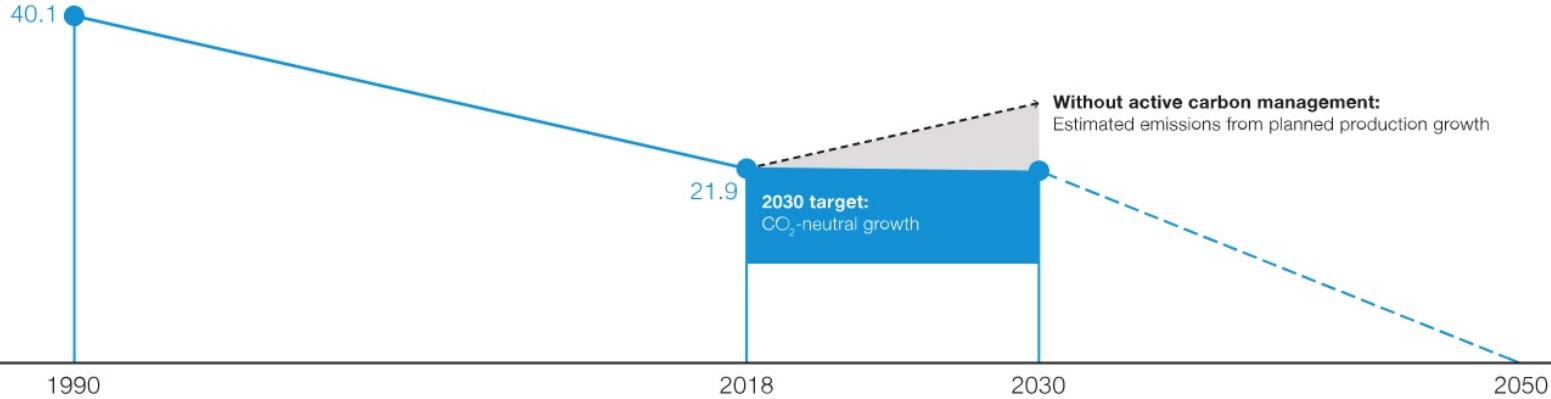
- *Charles Dickens*

**L'Oréal 2030: 95% Of Ingredients To Be Sustainable,
Renewables To Replace Petroleum-Derived Products**

**Unilever to eliminate fossil fuels in cleaning
products by 2030**

**Green Deal: Commission adopts new Chemicals Strategy
towards a toxic-free environment**

Million metric tons of CO₂ equivalents



1990 to 2018

Sales product volumes doubled and emissions almost halved through:

- Decomposition of nitrous oxide
- Increased process and energy efficiency

2018 to 2030

Expand production while keeping emissions at the 2018 level, primarily through:

- Higher process and energy efficiency
- Purchasing electricity from renewable sources

From 2030

Reduce emissions through:

- Fundamentally new technologies developed in the Carbon Management R&D Program

BASF

P2