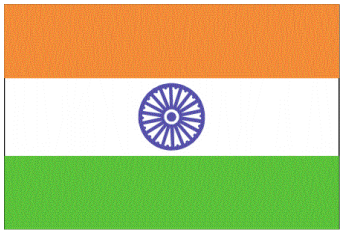
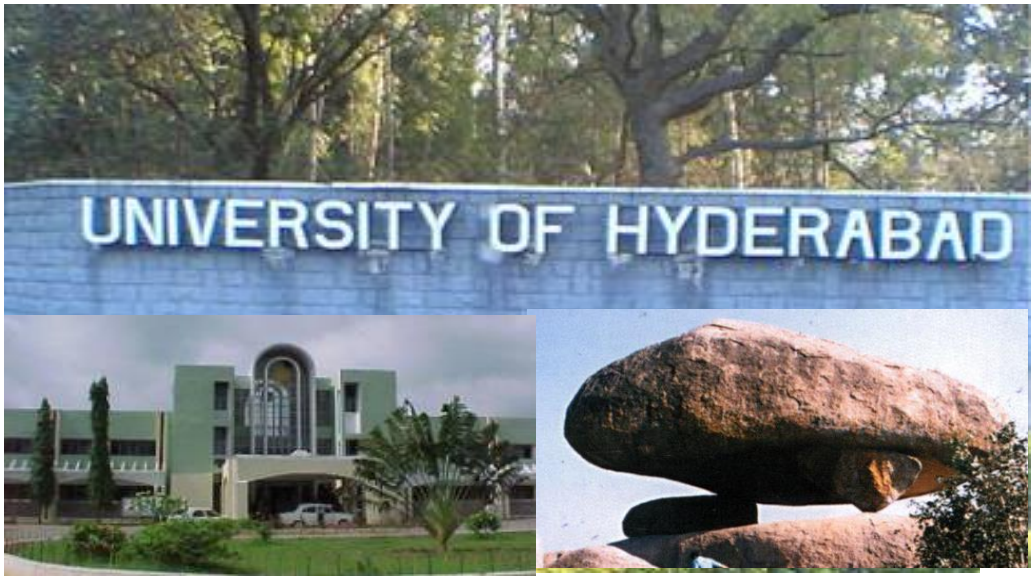
Goverdhan Mehta

Chemistry - A 21st Century Science for Global Sustainability: Is it future ready?





A ‘selfie’ with the chemical world……

National Geophysical Research Institute, CSIR Foundation Day, Sept. 27, 2019

Introducing Chemistry through the Lens of Earth's Systems: What Role Can Systems Thinking Play in Developing Chemically and Environmentally Literate Citizens?

J. Kornfeld, S. Stokoe. *J. Chemical Education* **2019**, *96*, 2910-2917

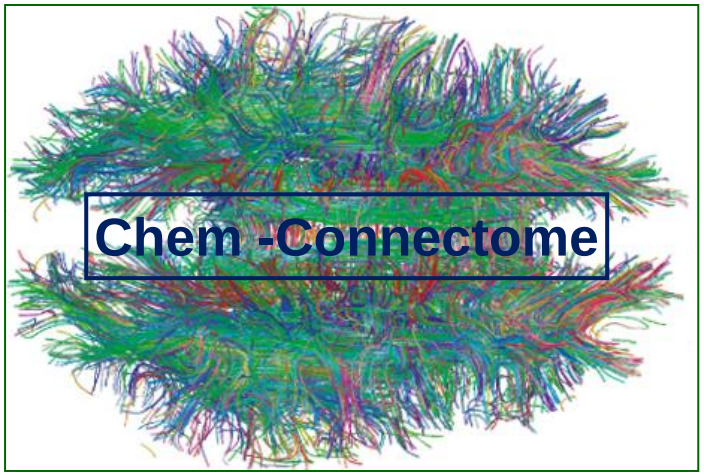
A bouquet of ‘matters’ that matter

Un mélange de beaucoup de choses

"Chemistry ought not to be for chemists alone"

- Miguel de Unamuno

'…Life, Universe and Everything'



Chemistry – a source of happiness….

'...I feel sorry for people who don't know anything about chemistry. They are missing an important source of happiness....' - Linus Pauling

1901-1994

S.A. Matlin, G. Mehta, H. Hopf. *Chemistry Embraced by All. Science* **2015**, *347*, 1179

Chemistry is in everything and everything is in it, it is the basis of life, without it we wouldn't exist.

Chemistry is ubiquitous/omnipresent

Chemistry – Tracing the roots and to the present

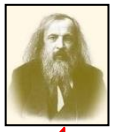
BCE

Art & craft of mixing substances

A giant knowledge leap

Alchemy to modern science

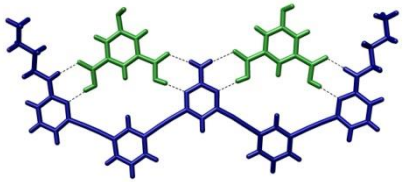
Evidence based science

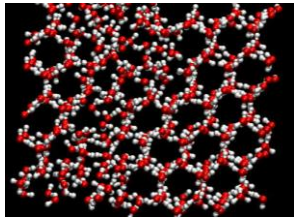


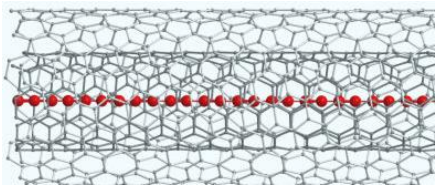
Discipline in a Table - systematization

Mendeleev's Periodic Law

'Molecularization' of chemical matter







20th Century

A century of evolutionary march of chemistry

20h Century

Value added products from almost anything and everything

"Utility science"

Molecular understanding of life processes and chemical matter

"Core Science"

Interdisciplinarity in forefront

"Integrative Science"

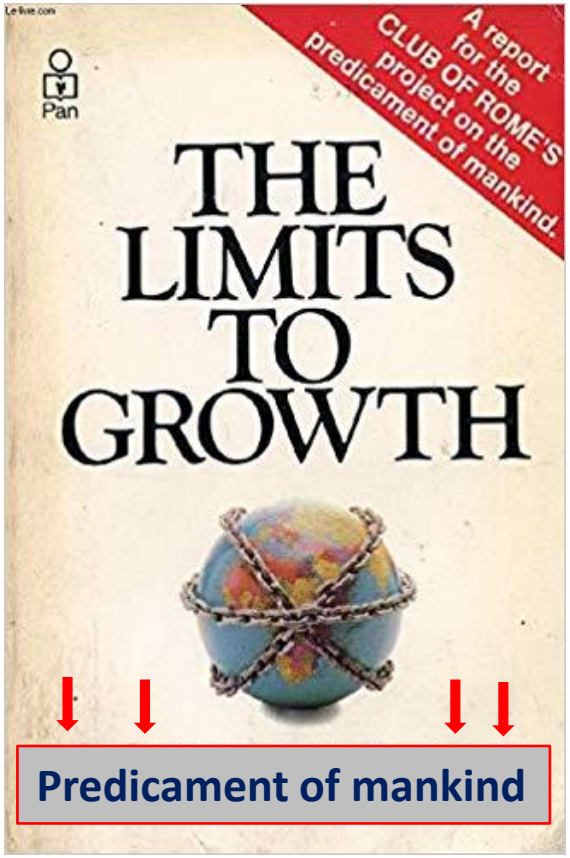
Resource stressed planet

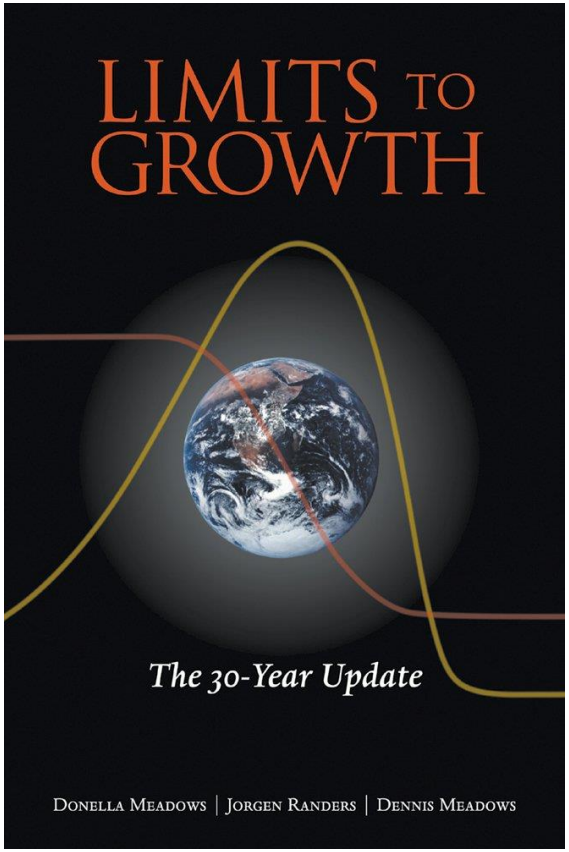
"Sustainability Science"

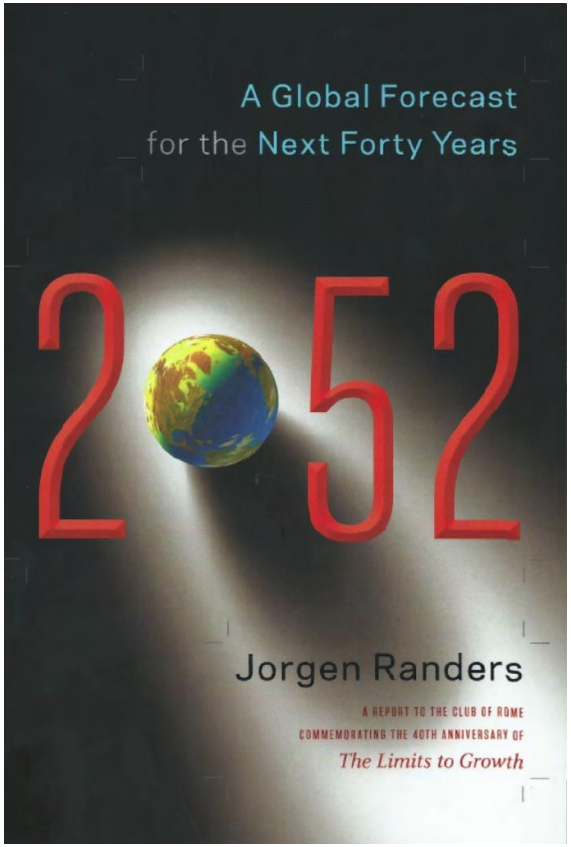
21st Century

S. A. Matlin, G. Mehta, H. Hopf, A. Krief. *Nature Chemistry* **2015**, *7(12)*, 941-943

A 'foresight' analysis of our world (1972- 2052)





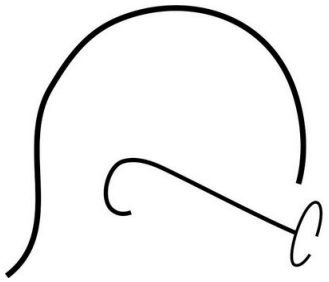


- Gain insights into the limits of our world system and the constraints it puts on human numbers and activity.
- Identify and study the dominant elements, and their interactions, that influence the long-term behavior of world systems.

A Foresight analysis of our world (1972- 2052)

Understanding of planetary boundaries….

Late lessons from early warnings – decades lost!



"……The *world* has *enough* for *everyone's need*, but not *enough* for *everyone's* greed." **- Gandhi**

A Foresight analysis of our world (1972- 2052)

Understanding of planetary boundaries….

Late lessons from early warnings – decades lost!

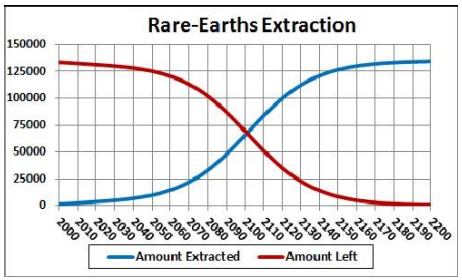
Silver lining!

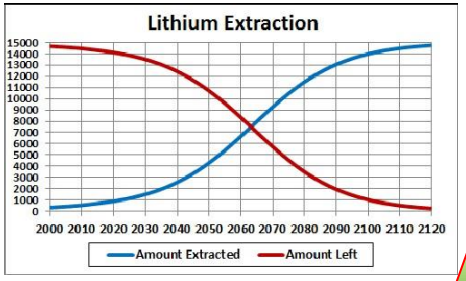
United Nations Sustainable Development Goals, 2015-30

Six of the 17 goals map into chemical sciences

New world realities – A pivotal role for chemistry

20th Century





All material used on our planet is chemically processed

>1000….BnT p.a.; producing >100…BnT of waste!

THIS IS UNSUSTAINABLE????

Chemistry can pave the way: greener, leaner and efficient processing, recycling.

Rapid depletion of lithium (White Gold) and rare earths

CO_2 <415 ppm

Resource stressed planet

"Sustainability Science"

21st Century

S. A. Matlin, G. Mehta, H. Hopf, A. Krief. *Nature Chemistry* **2015**, *7(12)*, 941-943

H. Hopf, A. Krief, G. Mehta and S. A. Matlin, SciDev. Net. 2019 (Appeared on April 22, World Earth Day)

New world realities – A pivotal role for chemistry

20th Century

The Mauna Loa Observatory, took a reading of 415.26ppm on 11 May – thought to be the highest since humans evolved.

21st Century

S. A. Matlin, G. Mehta, H. Hopf, A. Krief. *Nature Chemistry* **2015**, *7(12)*, 941-943

H. Hopf, A. Krief, G. Mehta and S. A. Matlin, SciDev. Net. 2019 (Appeared on April 22, World Earth Day)

A transformative perception of chemistry

More from less

Resource prudence

Liebigs Law

Justus von Liebig
(1803-1873)

'..Growth is controlled not by the total amount of resources available, but by the scarcest resource..'

Liebig's barrel

A world of [illegible] now passé

'Waste' does not exist : Chemical matter only changes 'form', so waste is actually material awaiting further use.

Circular Chemistry

S. A. Matlin, G. Mehta, H. Hopf, A. Krief. *Nature Chemistry* **2015**, *7(12)*, 941-943

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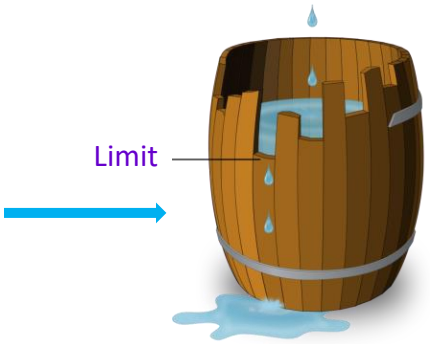

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Circular Chemistry

S. A. Matlin, G. Mehta, H. Hopf, A. Krief. *Nature Chemistry* **2015**, *7(12)*, 941-943

Chemistry: living prophecies


Antoine Lavoisier
1743-1794


Humphry Davy
1778-1829


Jacob Berzelius
1779-1848


Michael Faraday
1791-1867


Friedrich Wohler
1800-1882


Justus von Liebig
1803-1873


Marcellin Berthelot
1827-1907

'Nothing is lost, nothing is created, everything is transformed'

- Antoine Lavoisier

'die chemie ist also die Lehre von den stofflichen metamorhosen der materie'

- Kekulé

Wohler
1827

'Ammonium cyanate is **urea**'

100% atom economy;
No reagent, no solvent

'Green' is in the DNA of Chemistry

But, there are some worrisome mutations ?

'Study the past, if you would define the future' - Confucius


Augustus Kekule
1829-1886

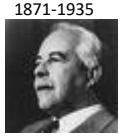

Dmitri Mendeleev
1834-1907


Alfred Werner
1866-1919

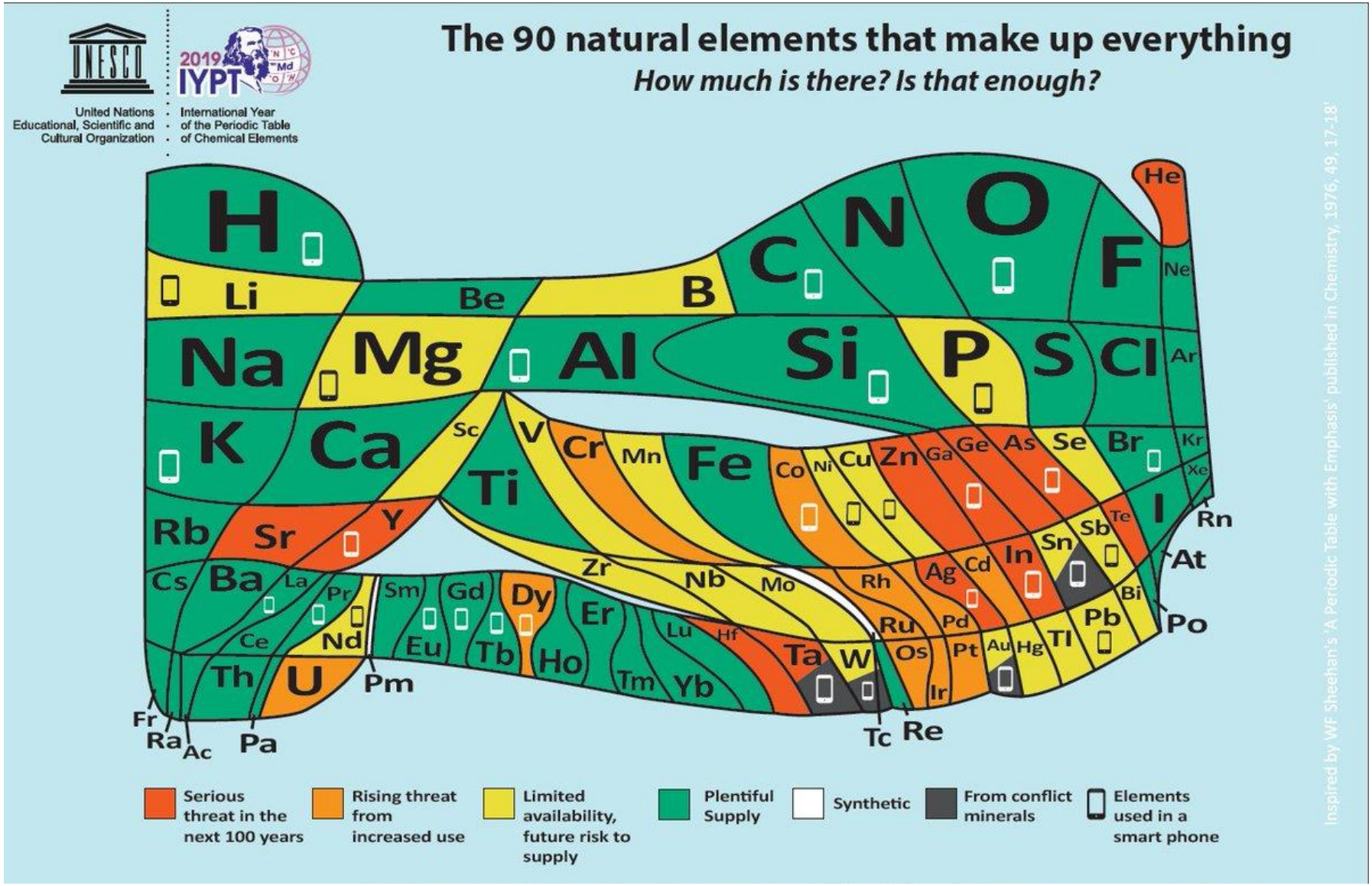

Adolf von Baeyer
1835-1917


Wllhelm Oswald
1853-1932


Victor Grignard
1871-1935

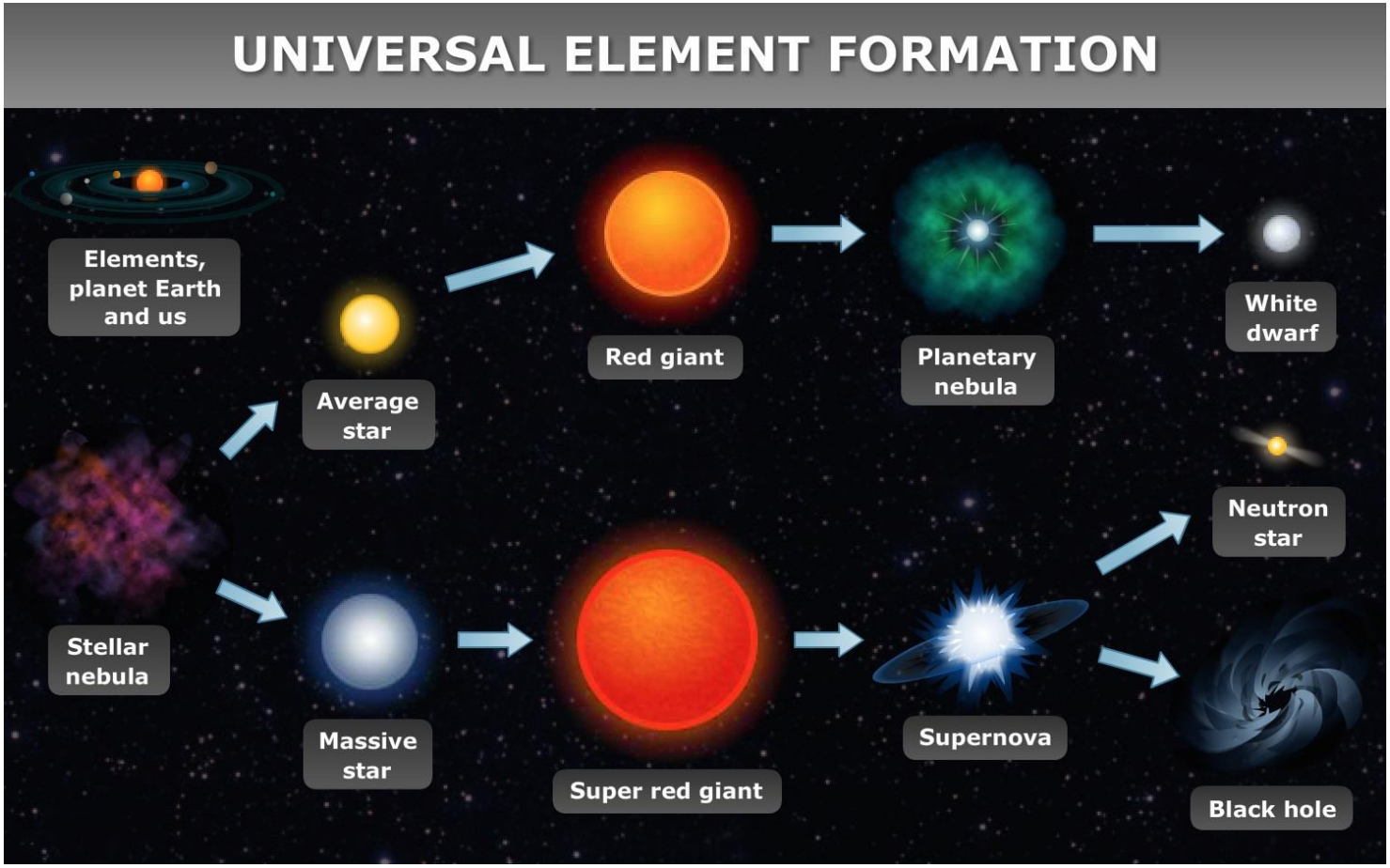

G. N. Lewis
1875-1946

INTERNATIONAL YEAR OF THE PERIODIC TABLE -2019



INTERNATIONAL YEAR OF THE PERIODIC TABLE -2019

Elemental (Geological) resources (~14 Bn years old) on our planet are ***finite and irreplaceable.***

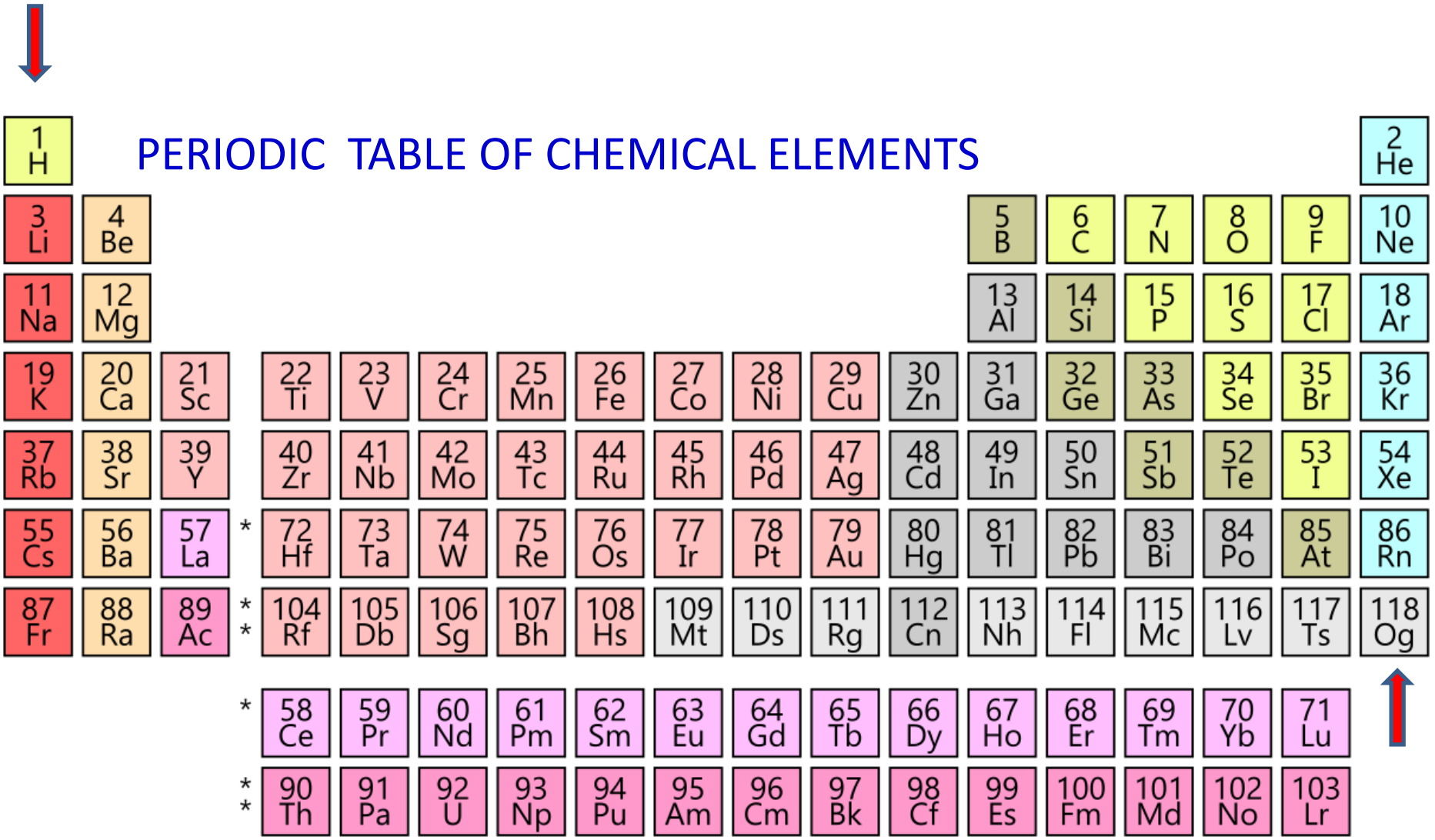


100 second after the 'Big Bang', the universe expanded and reached the temperature of one billion Kelvin (10^9 K).

S. A. Matlin, H. Hopf, A. Krief , G. Mehta, Current Science **2019,** *116*, 7. (**Editorial**)

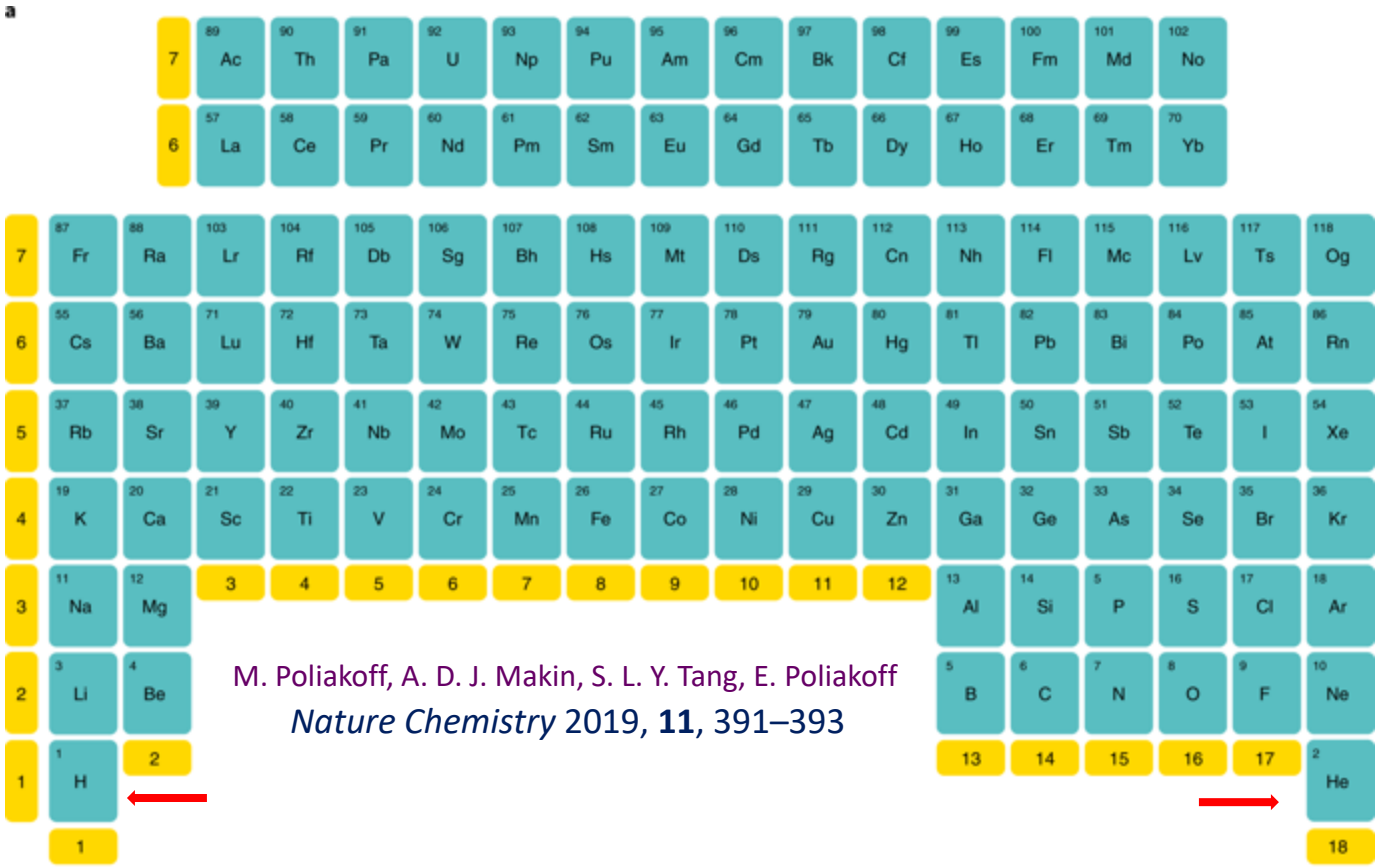
S. A. Matlin, G. Mehta, H. Hopf, A. Krief, *Eur. J. Inorg. Chem.* https://doi.org/10.1002/ejic.201801409

PERIODIC TABLE OF CHEMICAL ELEMENTS



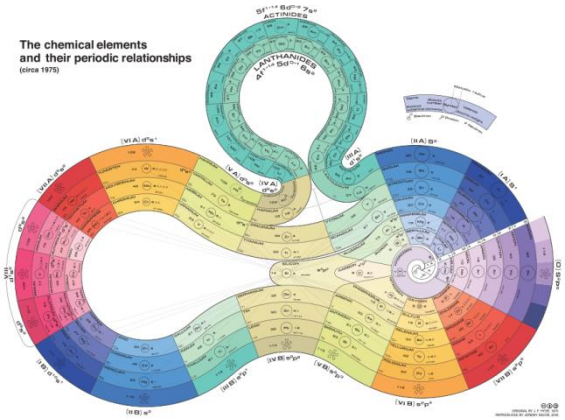
A new (crazy?) wave of Periodic Tables

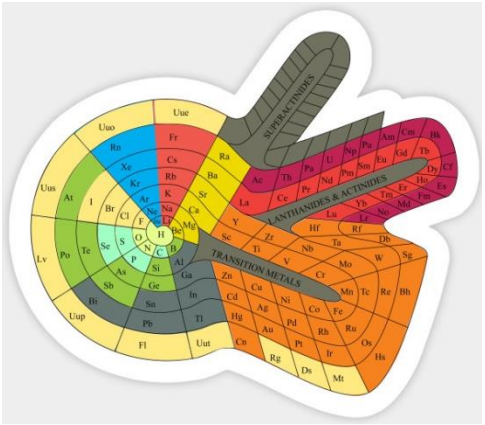
Inverted Periodic Table

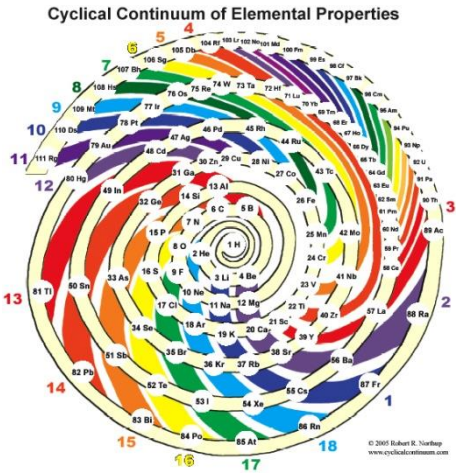


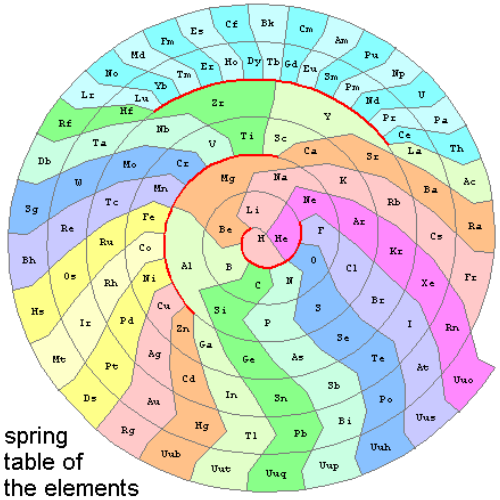
M. Poliakoff, A. D. J. Makin, S. L. Y. Tang, E. Poliakoff
Nature Chemistry 2019, **11**, 391–393

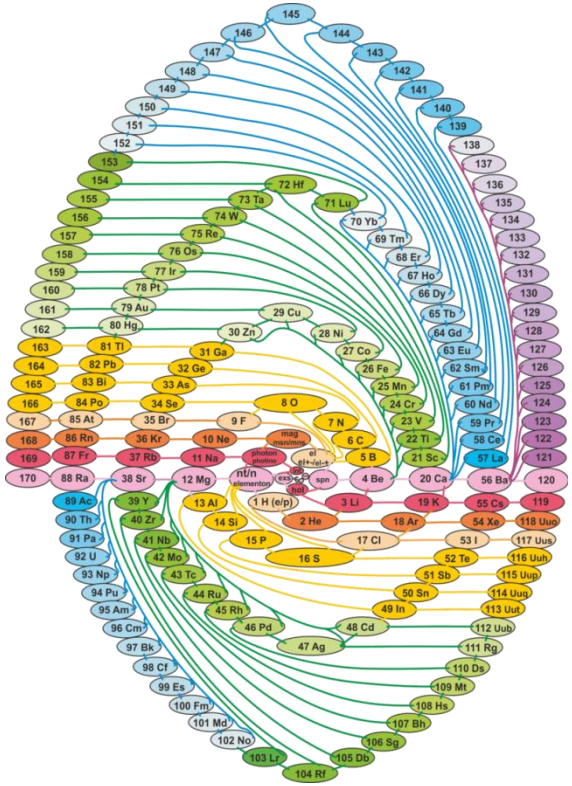
In the digital age over 100 periodic Tables proposed !!!

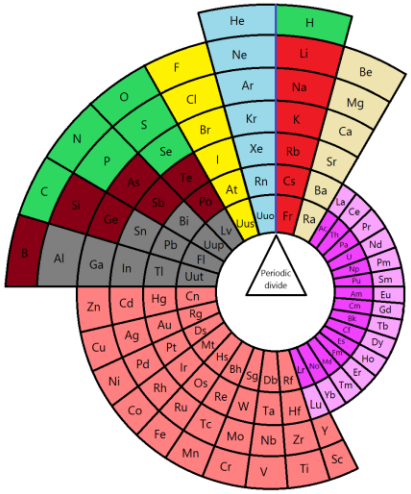




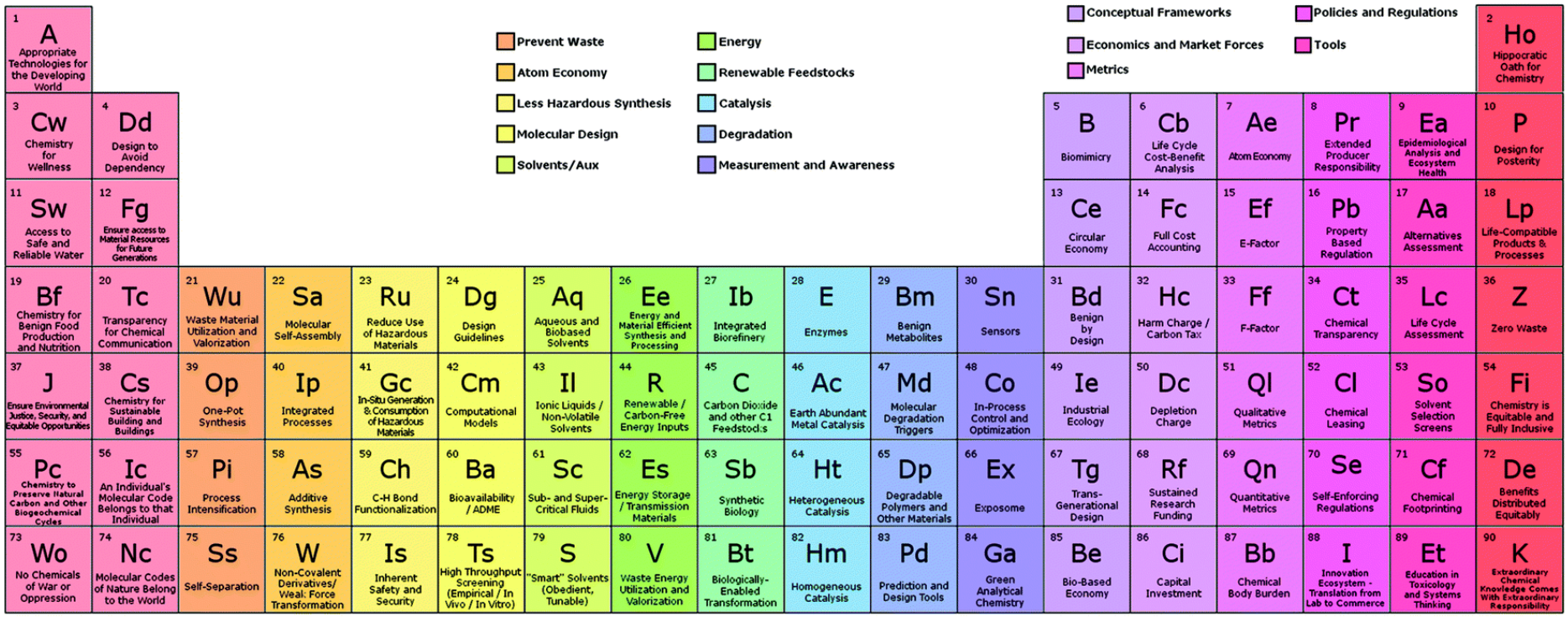






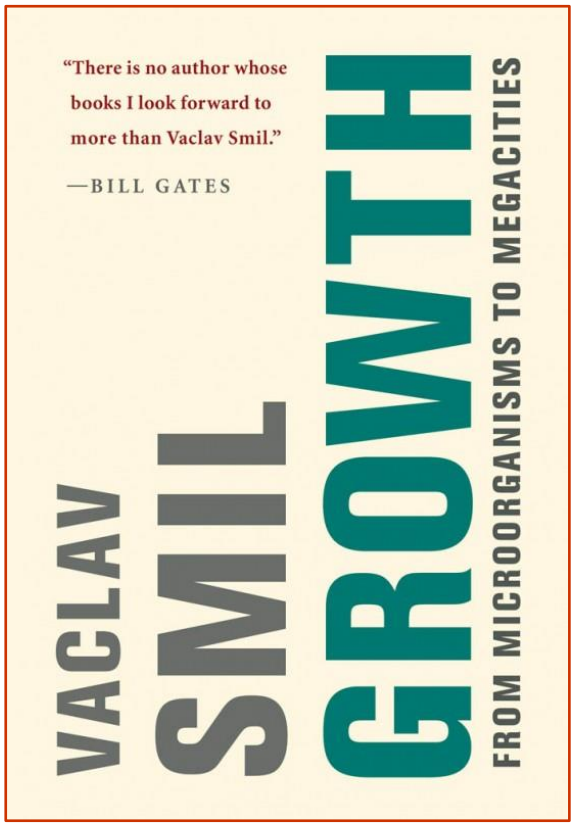


The periodic table of the elements of green and sustainable chemistry



P. Anastas and J. Zimmerman, *Green Chemistry*, **2019** DOI: 10.1039/c9gc01293a

Resources – Resources - Resources



"Human history is a story of innovation and increased efficiency, but also of relentless depletion of Earth's resources."

- Václav Smil

Listen to the Scientists…

- Greta Thunberg –Testimony before US Congress

…..How dare you?

"…all you can talk about is money and fairy tales of eternal economic growth. How dare you?"

- Greta Thunberg

Why are chemical resources basic to the sustainability of our planet?

From ‘Circular Economy’ to ‘Circular Chemistry’

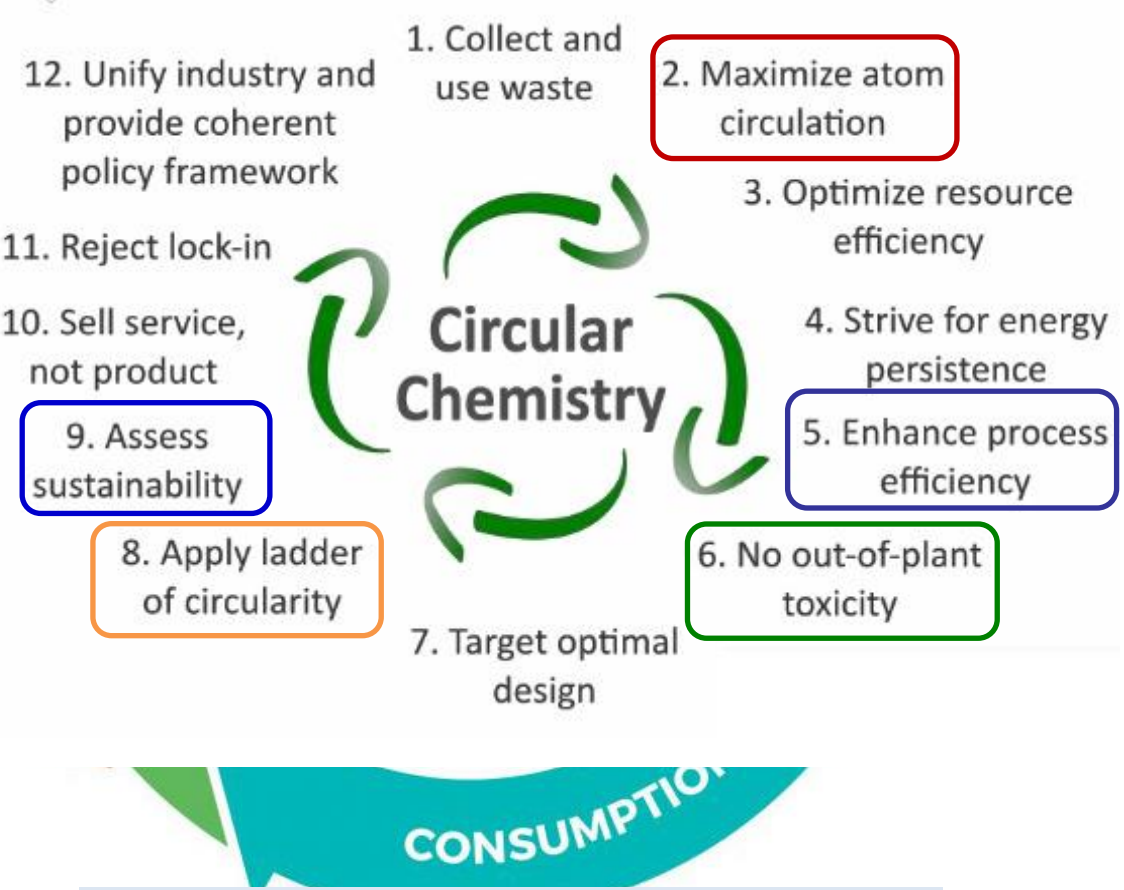
CHEMISTRY

R³

Resources

Reduce
Reuse
Recycle
R….R¹¹

Waste



…not merely Green Chemistry 2.0

Geng, Sarkis, Bleischwitz, *Nature,* **2019**, *565*, 153- 55

Keize, Bakker, Slootweg, *Nature Chemistry*, **2019**, 11, 190

Chemistry: Securing a Sustainable Future

Recognise the end of - make, use, dispose era;

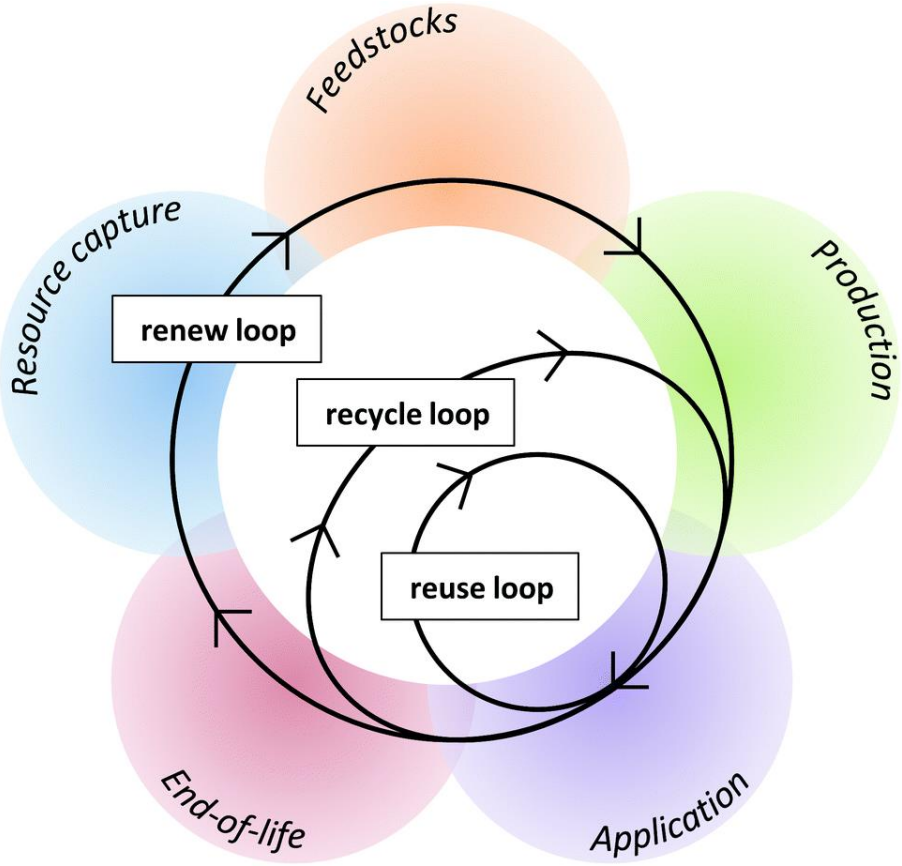
onset of - reuse, refurbish, re- and upcycle era

Cradle to Cradle 'C2C' chemical design

… design concepts in which …products are created according to the principles of an ideal circular economy, beyond the conventional recycling, inspired by eco-efficiency and sustainability .

"There is no such thing as 'away'. When we throw anything away it must go somewhere."

Need innovative approaches in chemistry



Some good practices and home truths

Chemical and material design for zero waste

A product is also a resource equal to a raw material

End-to-end , systems based approach

One ‘Green’ step in a process is inadequate

Digital processing/manufacturing

Shared platform between bench & process chemist

Seamless synergy between Chem. Eng. and chemists

K. Rossen, Greening organic chemistry with process chemistry, *J. Org. Chem*. **2019**, *84*, 4580-4582
James H. Clark *et al. Green Chemistry*, **2016**, *18*, 3914-3934

Material use in perpetuity

Possible scenarios…….

- Fixed allocation of material to every individual
- Material purpose defined
- Digitalization, AI and robotics, 3D-printing …….
- Real-time chemical transformation and delivery

Utopian ??????


Break for reflection

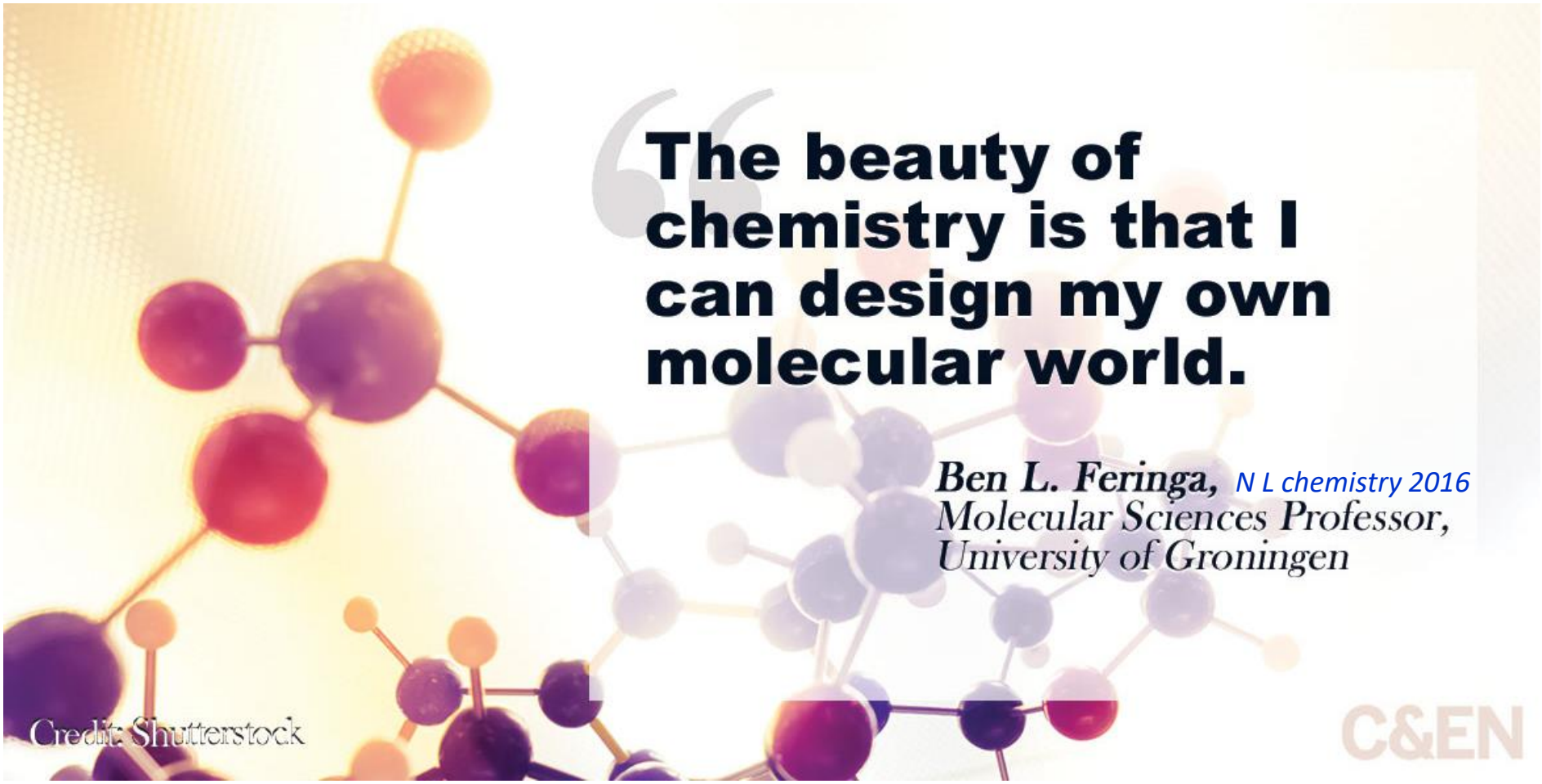
Molecular level view of everything and molecular creation is central to chemistry

Molecular machines ……molecular gastronomy….molecular condoms*!

*PNAS, May 2017

"Chemistry has become today the science of bodies that do not exist"

- Auguste Laurent - 1854



..Chemistry creates its subject. This creative ability, similar to that of arts, essentially distinguishes chemistry among the natural and historical sciences.

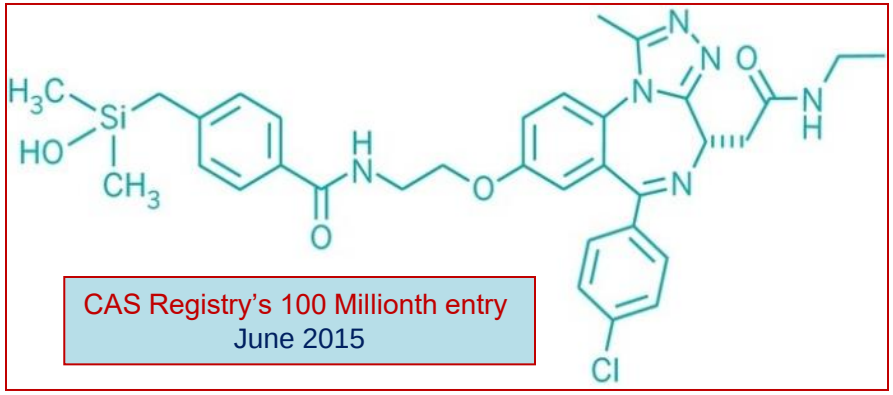
- M. Berthelot - 19th century

Sizing the molecular cosmos

10^{80} to 10^{200} unique chemical structures possible

That is not far from infinity; impractical?

…and there is not enough mass in the Universe !



CAS Registry's 100 Millionth entry
June 2015

A galloping pace..
145 M in CA Registry, 2018;
many millions buried in patents;
best estimate ~ 0.5 billion NME's
Only a fraction is useful!

Chemistry is also the science of the possible

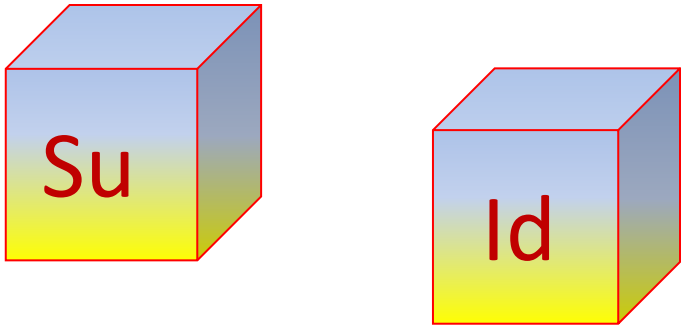
Just about any chemical can be accessed today but …..should we ?

Mantra to remember…

Resource only what is needed for human advancement and well-being;

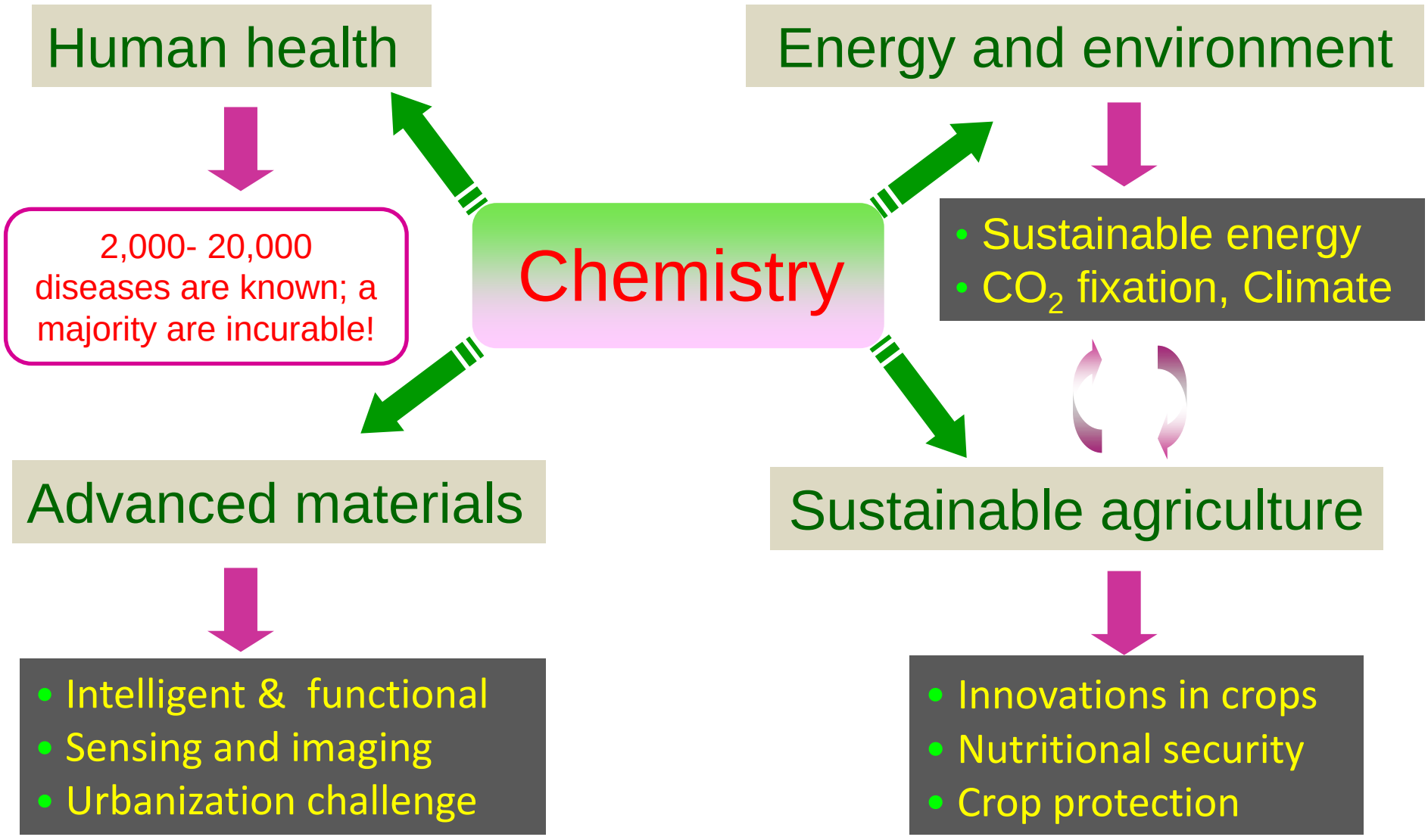
in risk free, non-hazardous way with minimal environmental footprint.

Adopt new symbols – Beyond the Periodic Table



* S. A. Matlin, G. Mehta, H. Hopf and A. Krief, *Nature Chemistry*, **2016**, *8*, 393

Pivotal role……on the path to sustainability



New opportunities, challenges and promises to keep;

Chemistry can!

Sustainability Science

A few take home messages & urgings

Chemistry's future as an ethical science

- ACS has created a Global Code of Ethics (GCCE) for chemists based on the Hague Ethical Guidelines[1];
- Ethical concerns must encompass responsible practice of chemistry and make a strong pitch for environment and sustainability;
- Adherence to method and values of science – embrace scientific temper ;
- Ethical concerns to expand beyond the traditional issues about research practices and transparency; personal conduct & practice of collegiality;

Value diversity[2]

- Ingrain ethical values as an integral part of chemistry education.

1 https://www.acs.org/content/dam/acsorg/global/international/scifreedom/global-chemists-code-of-ethics.pdf

2 G. Mehta, V. W.Yam, A.Krief, H.Hopf, S. A. Matlin, *Angew. Chem. Int. Ed.* **2018**, *57,* 14690-14698

Inculcate cultural competencies

GDCh Guest Editorial Angewandte International Edition Chemie

International Edition: DOI: 10.1002/anie.201900057
German Edition: DOI: 10.1002/ange.201900057

The Need for Cultural Competence in Science: A Practical Approach to Enhancing Equality, Diversity, and Inclusion

Stephen A. Matlin, Vivian W. W. Yam,* Goverdhan Mehta, Alain Krief, and Henning Hopf* *Angewandte Chemie, Intl. Ed*. 2019, 58(10), 2912.

Research integrity is more about culture than compliance

- Embed integrity in research culture.
- CC is the best antidote against ‘Fake-philia’ & ‘Dichotomania’

In shaping success – a scientist's persona matters……

A tale of two great chemists.

I. Langmuir
1881-1954

Langmuir won a Nobel Prize for surface chemistry and hobnobbed with the likes of Albert Einstein and Niels Bohr. He was very interactive, appeared on the cover of magazines and made millions of dollars for and from a company like General Electric.

Harmonize your persona with creative instincts?

G. N. Lewis
1875-1946

Lewis built the UC Berkeley, chemistry into the best in the world but lacking a Nobel Prize, became a bitter hermit. One afternoon in 1946, panicked graduate students discovered Lewis lying in a laboratory that smelled like almonds– HCN?. Dead!

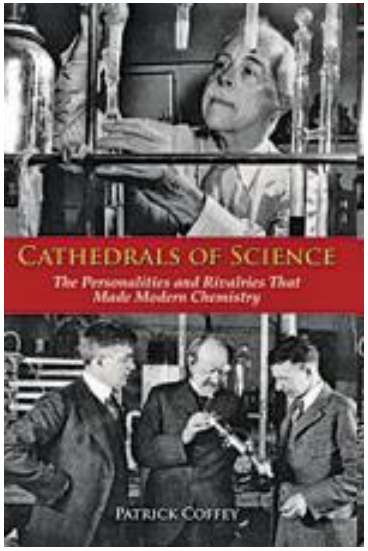
"If there was a manual on how not to win a Nobel Prize, Lewis could have written it."

Ref: Cathedrals of Science: The Personalities and Rivalries That Made Modern Chemistry, *Patrick Coffey, Oxford University Press, 2008*

The ugly terrain of scientific ambition……

Chemist's are no exception

Chemists are human: Also afflicted by avoidable rivalries



Lewis and Langmuir

Svente Arrhenius
1859-1927
N.L 1903

Walther Nernst
1864-1941
N.L 1920

"…His legacy secure, Arrhenius, as chair of the Nobel Institute for Physical Chemistry, in Stockholm, spent his life blocking the prize nominations of rivals like Nernst, who in turn blocked Lewis…."

Respect and accommodate the scientific contributions and creativity of peers and competitors

But, there is a better way……inspiring colleagues

- Letter from Derek Barton (NL 1969) to R. B. Woodward (NL 1965) on 16 Dec 1969

"Greetings from Stockholm….. This seems also a good moment to thank you for the remarkable inspiration you gave me in 1949–1950. **You transported me at that time from one world of chemistry to another which I had not imagined to exist."**

D. H. R. Barton
1918 -1998

R. B. Woodward
1917 -1979

Ref: Working with Sir Derek. H. R. Barton – "Chemistry, through chemistry and for chemistry"

J.I. Seeman. *Tetrahedron* 2019, 75, 57-69, https://doi.org/10.1016/j.tet.2018.11.004

A strong pitch for humility

Marie Sklodowska Curie
1867-1934

A legacy of passion and humility…

Albert Einstein is reported to have remarked that Mme.Curie was probably the only person who was **not corrupted by the fame that she had won.**

Acharya P. C. Ray
1861-1944

Father of chemistry and chemical industry in India

One who could integrate ideas with idealism;
A venerable legacy of humility and patriotism

Daniel Schechtman
1941-

" A good scientist is a humble scientist!“
- Dan Shechtman , Nobel Leaurate 2011

Board the 'Outlook' express

- Always look around - treat chemistry knowledge and learning as holistic
- Great to be focused but not a 'frog in the well' or 'ostrich-like'!
- Surf the horizon – develop the instinct to grasp the big picture
- Be mindful of the gap between visioning/dreaming and realizing
- Think chemistry as a science for the benefit of all – from ideas to products

"I have always tried to avoid following the flock. I have worked in many fields, but as soon as these fields became popular, I have moved on. I have made the joke of saying that if you cannot remember all the published papers in the field you are working in, then it is time to move on."

- D. H. R Barton, N.L Chemistry 1969

Thank you for your kind attention

A big thank you to Eli-Lilly, Jubilant Bhartia Foundation and Dr. Reddy's Research Laboratory for research support.

A crystal of aspirin

Chemistry is stunningly beautiful!

Thank you for your kind attention

Chemistry promotion with Professors Henning Hopf, Stephen Matlin and Alain Krief - **(C4S)**

supported by IOCD, **Syngenta, Royal Society of Chemistry (RSC), GDCh, DRILS and IICT**

A crystal of aspirin

Chemistry is stunningly beautiful!