

The role of chemists and chemical engineers in a sustainable world

David Cole-Hamilton

EaStCHEM,

University of St. Andrews

Past President. EuChemS



The Edinburgh and St Andrews
Research School of Chemistry



University
of
St Andrews

The Future of Chemistry?

Let's make our
country a chemical
free zone

All chemistry can
be done by
computers now.
Take your lab
coat off!

Chemistry is a
mature discipline;
there is nothing
else to do

Everything is
biotechnology
now; there is
nothing left for
chemistry

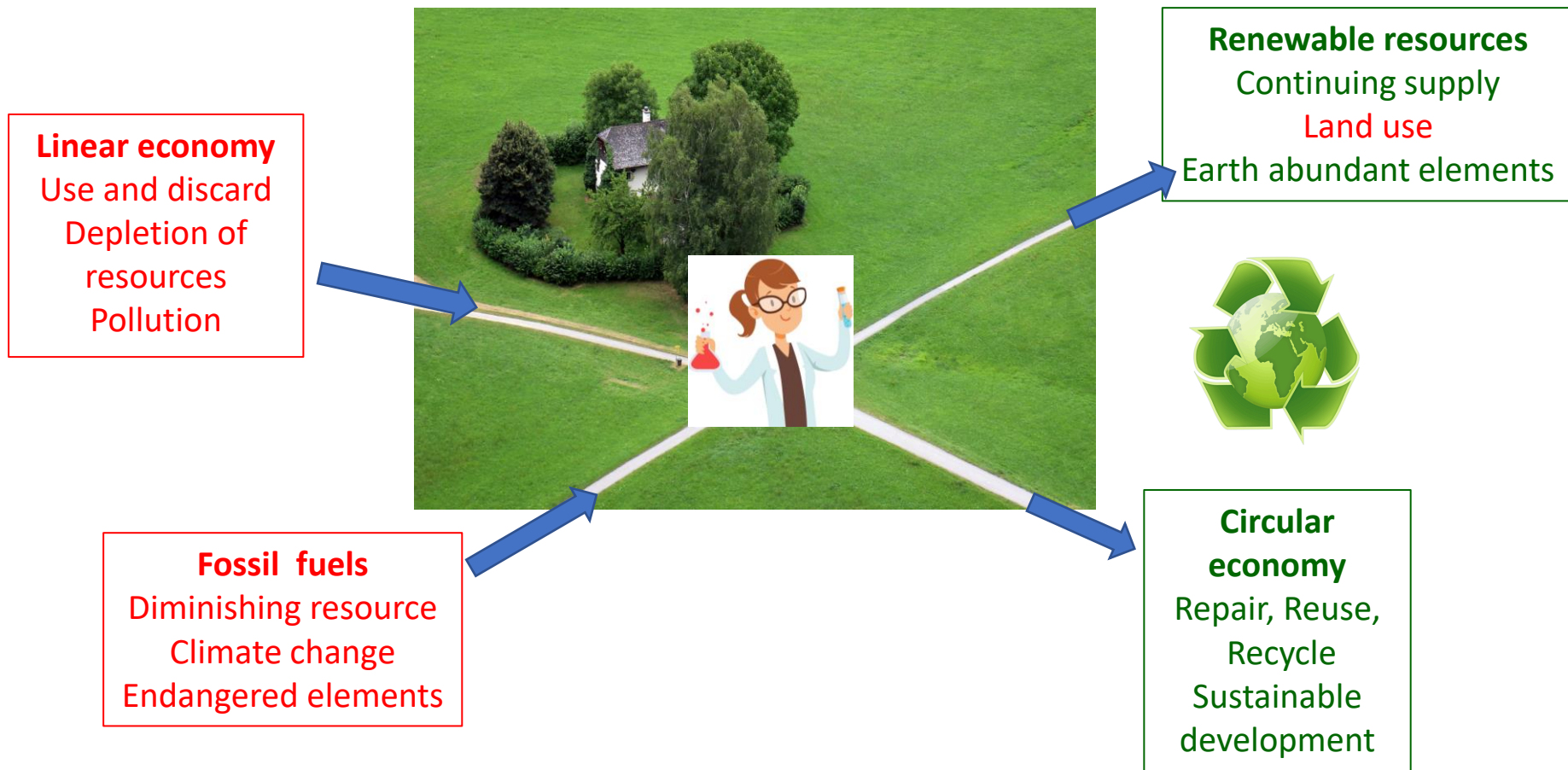
The Future of Chemistry?

Let's
country a
free zone

All chemistry can
be done by
computers now
Take your

Chemistry is a
discipline;
there is nothing
else to do

technology
now; there is
nothing left for
chemistry



UN 17 Sustainable development goals





Haber Bosch Process

Opportunity 1

Develop and / or commercialise new low energy routes to fertilisers



Efficient water electrolysis or photolysis

Low temperature catalyst; differential catalyst heating

For fertilisers

BASF

450 M tpa

80 % of N in body

+ Herbicides, insecticides,
High activity and specificity, low toxicity

Allows an extra 2 bn people to be fed

But uses 1.4 % of world energy supply

Equivalent to 100 M people



New diagnostics and medicines

Opportunity 2

Develop and / or commercialise new medicines

Anti-microbial resistance (EU Parliament, April, 2016 EuCheMS and EFMC)

Diseases of ageing

- Cancer
- Dementia
- Parkinson's disease (EU Parliament, 8th November, 2018, EuChemS, EFMC)



Lifestyle diseases

- Obesity
- Diabetes

Chemistry Nobel Prize 2018

Directed evolution of
proteins
60 % of new drugs



Frances
Arnold

George
Smith

Gregory
Winter





**Chemical
Education is
generally of
high quality**



Jan Mehlich

Pilot study finished
Available to all
from October 2019

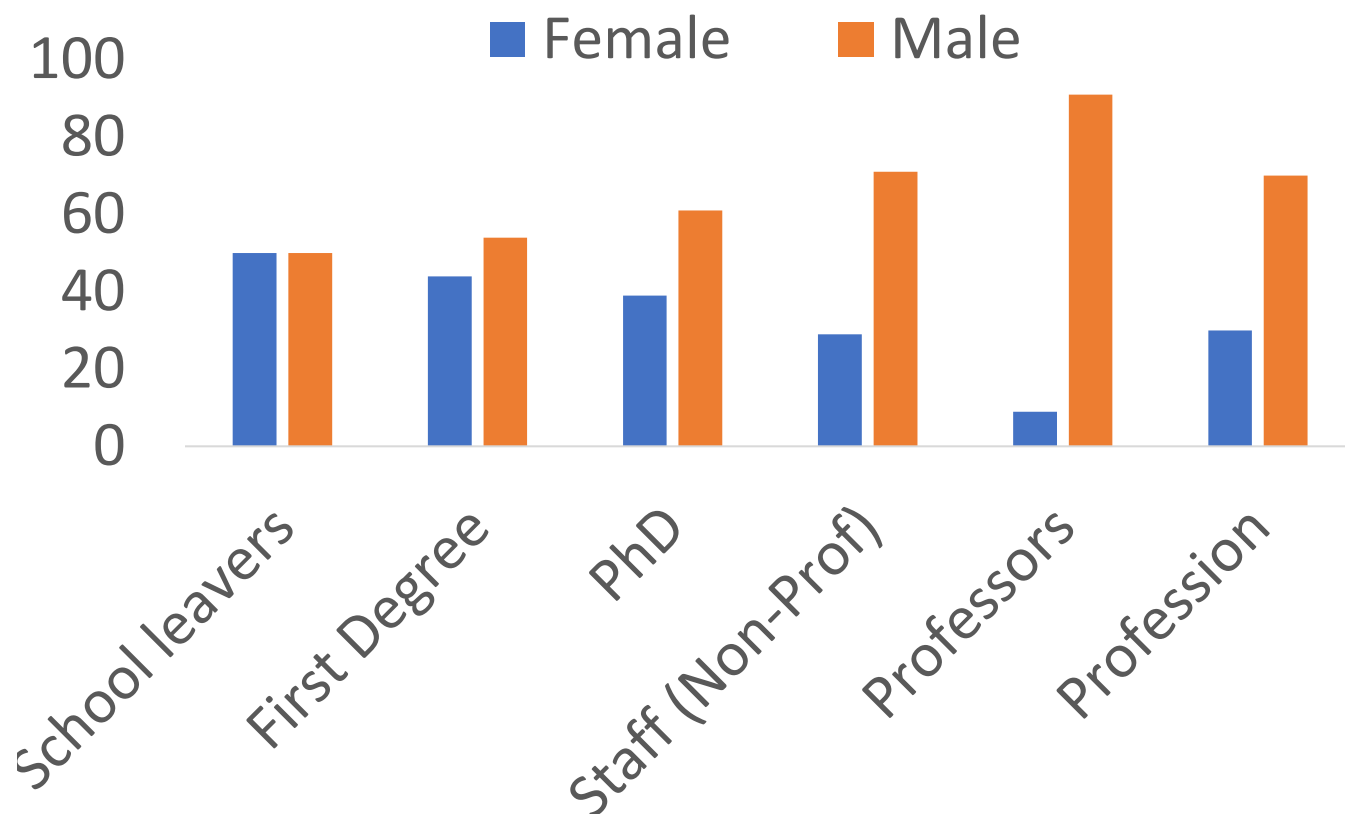
1	Introduction
2	Scientific Inquiry
3	The Scientific Method(s)
4	Scientific Practice
5	Scientific Misconduct
6	Scientific Publishing
7	Collaborations, Conflicts of Interest, Mentorship
8	Academic Freedom, Intellectual Property
9	Animal Experiments

Online Course on Ethics & Chemistry

10	Sustainability
11	Science and values
12	Responsibility
13	Risk, Uncertainty, Precaution
14	Science Governance, Technology Assessment
15	Science Communication
16	Example: Nanoscience



The leaky pipeline Chemistry UK



5 GENDER
EQUALITY



The leaky pipeline Chemistry UK



Frances Arnold
Nobel Prize
2018
Chemistry



Pilar Goya
President EuChemS



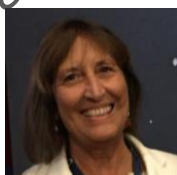
Nineta Hrastelj
General Secretary
EuChemS



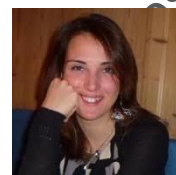
Alice Soldà
Past Chair EYCN



Roberta Sessoli
Discovered first molecular magnetic
RSC Centenary Award, 2019



Angela Agostiano
President SCI



Nausicaa
Orlandi
President FNCF



6 CLEAN WATER
AND SANITATION



Dual use of chemicals

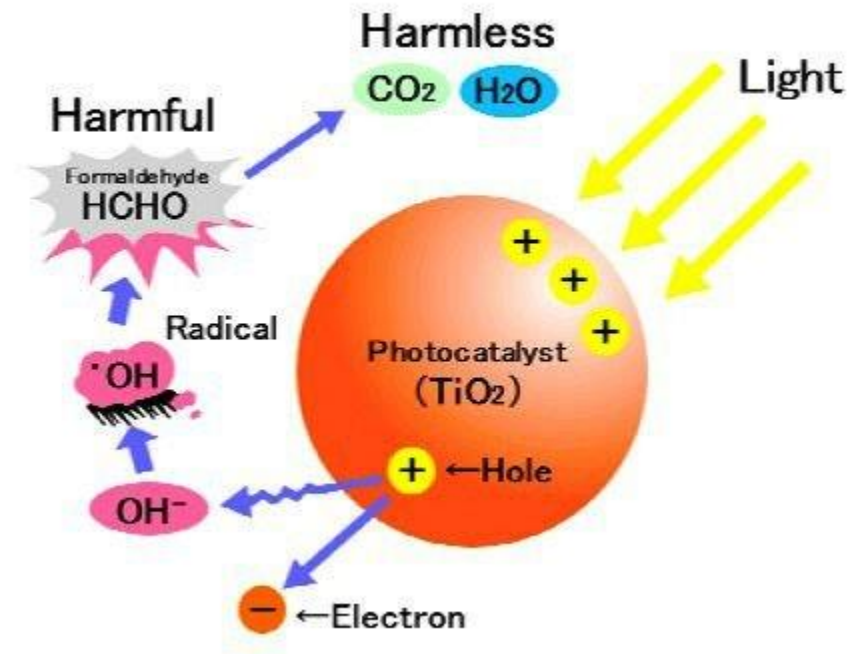
Opportunity 3
Develop and / or
commercialise new
benign water
purification
technologies

2000 children a day die because of contaminated water
Population of Rome in < 4 years



Works well

BUT



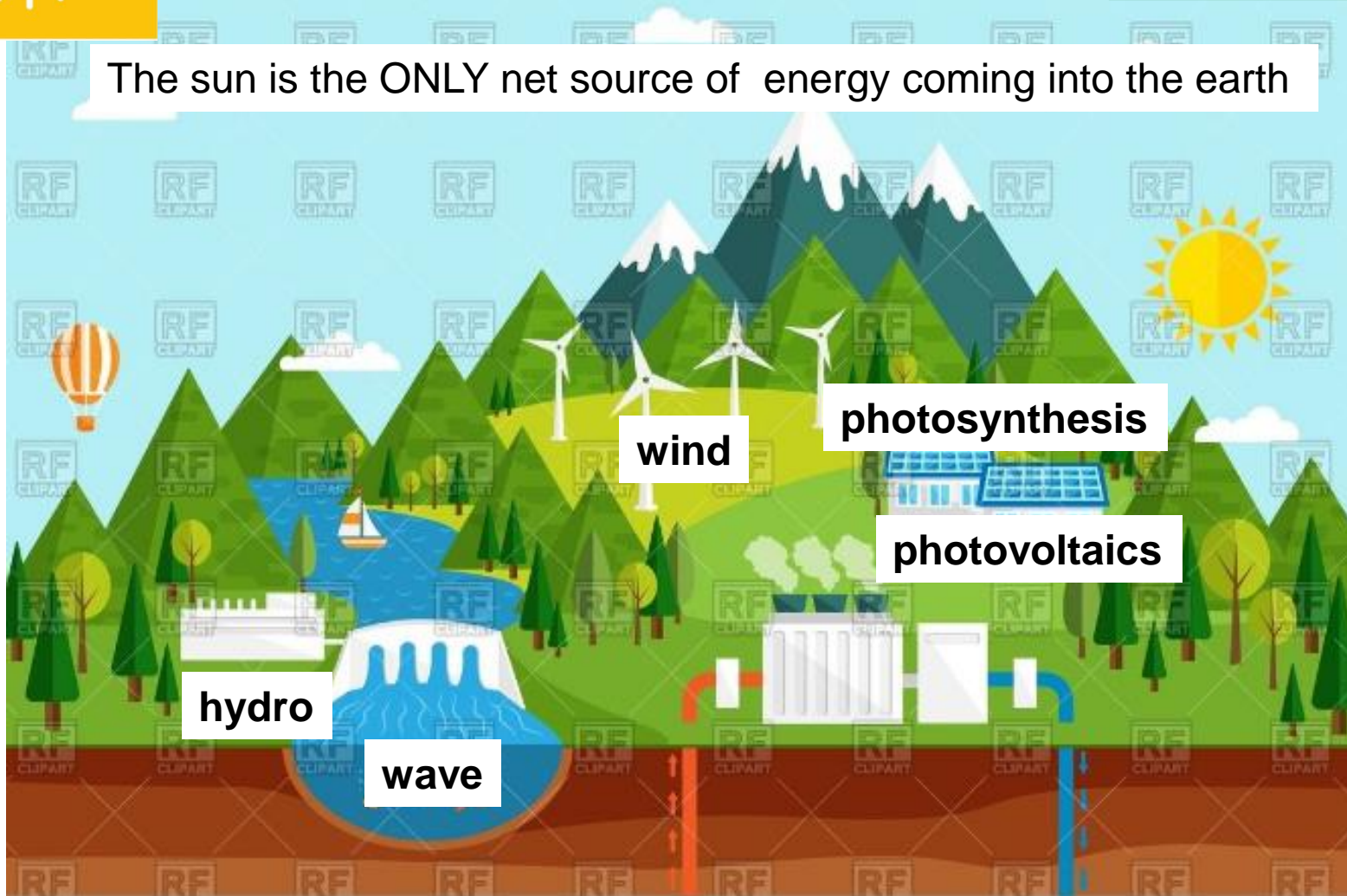
Can be used as a chemical weapon (Syria)



Renewable energy

Opportunity 4
Develop and / or
commercialise new
solar energy conversion

The sun is the ONLY net source of energy coming into the earth



All have a major contribution from chemistry

World Energy requirement

10 % solar energy conversion; whole world supplied from an area the size of Libya

Political Map of the World, September 2008



Conversion and storage are the (chemical) problem

Water splitting (7.9 % efficiency)

S. Y. Reece, J. A. Hamel, K. Sung, T. D. Jarvi, A. J. Esswein, J. J. H. Pijpers, D. G. Nocera, *Science*, 2011, **334**, 645



United Nations
Educational, Scientific and
Cultural Organization

9

INDUSTRY, INNOVATION
AND INFRASTRUCTURE



Special Thanks

Suzanne Issa
Print and Design
St. Andrews

11

Sustainable
Development



12

RESPONSIBLE
CONSUMPTION
AND PRODUCTION



The 90 natural elements that make up everything

How much is there? Is that enough?

18

Task Group

Saskia van der Vies, Christophe Coperet,
Nicola Armaroli, Jelena Lazic, Alex
Schiphorst, David Cole-Hamilton (Chair) -
assisted by Elena Lenci, Katarina
Josefowska,

Sub-group “IYPT2019-EuCheMS”

Jan Apotheker (Chair), Brigitte van
Tiggelen, Ilka Parchmann, Jacintha
Vermeer

Input from Jan Reedijk (IUPAC), Robert
Parker

Read Support Notes and play the Video Game (*Elemental Escapades! A Periodic Table Adventure*)
at <http://bit.ly/euchems-pt>



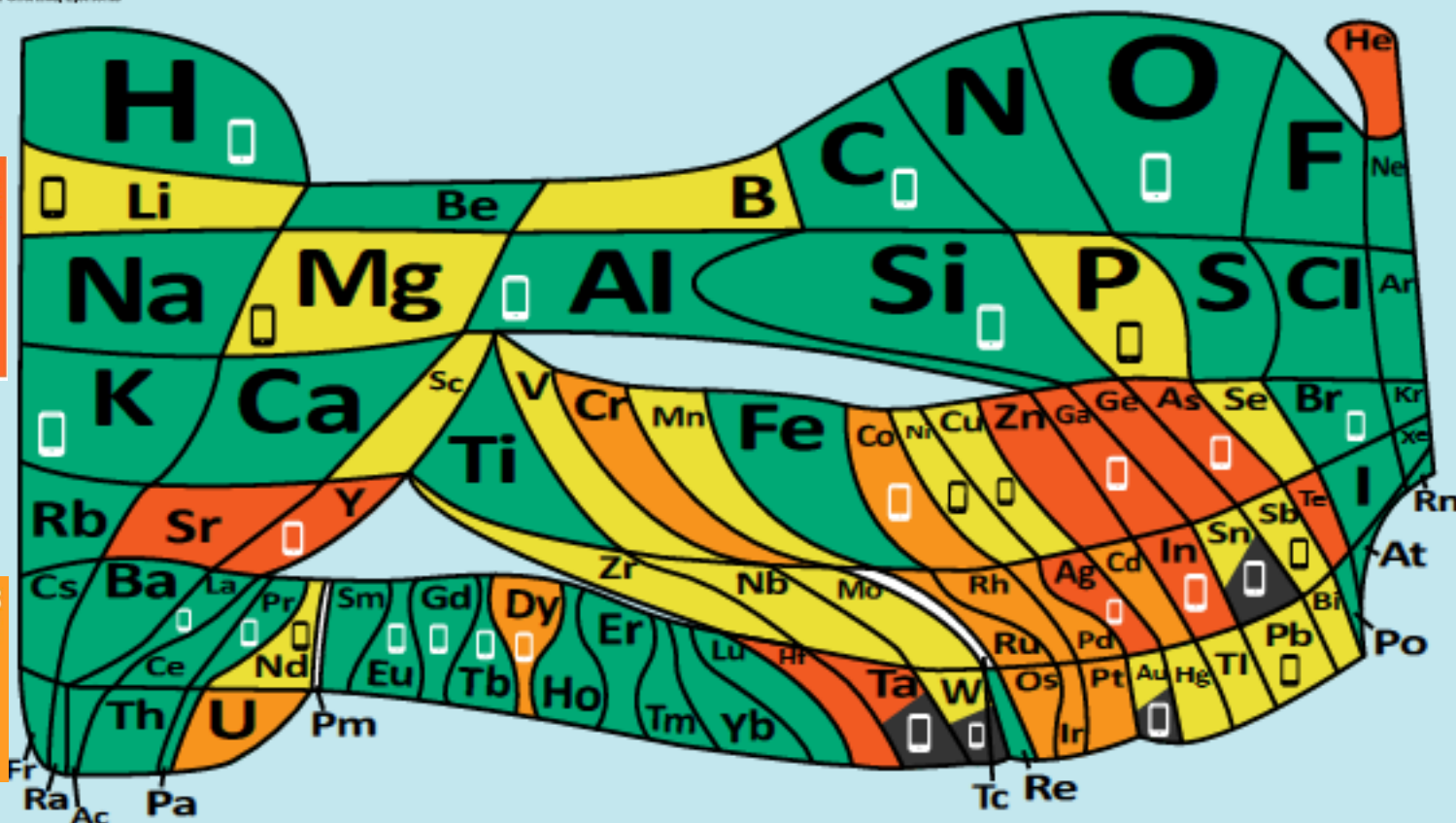
This work is licensed under the Creative Commons Attribution-NoDerivs CC-BY-ND

 **EuChemS**
European Chemical Society



The 90 natural elements that make up everything

How much is there? Is that enough?



- Serious threat in the next 100 years
- Rising threat from increased use
- Limited availability, future risk to supply
- Plentiful supply
- Synthetic
- From conflict minerals
- Elements used in a smart phone

Read Support Notes and play the Video Game (*Elemental Escapades! A Periodic Table Adventure*) at <http://bit.ly/euchems-pt>



This work is licensed under the Creative Commons Attribution-NoDerivs CC-BY-ND

EuChemS
European Chemical Society

>30 Languages

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE



11 SUSTAINABLE CITIES AND COMMUNITIES



12 RESPONSIBLE CONSUMPTION AND PRODUCTION





What should we do?

The Circular Economy



Reduce

Repair



Reuse/recycle

Replace (materials)



Smart phones

Use and discard

EU 10 M phone upgrades / month



Indium – 20 years **Tantalum** - < 50 years
Traceability

Many lie around at home
wasting valuable resources.
(50 % of UK homes have at
least one – RSC survey)

Others reused in developing
countries (Reuse) and then
trashed or mined for gold
under appalling conditions
often by children

Modular phones where parts
can be replaced are available
(Repair)

Can **YOU** justify changing
your phone every 2-3 years?
(Reduce)



Recycle, Replace, Reduce

Opportunity 5

Develop and / or commercialise alternative materials for touch screens and other components

Recycle

- Small amounts of ITO on every computer / phone screen
- We need companies that will do ethical recycling of elements in electrical goods
- We need incentives to hand in our electronic devices

Replace

- Must find equivalent materials using earth abundant metals (graphene, SbSnO_x , CaMoO_3)
- Requires huge research effort

Reduce

- **Change your phone and computer less often**



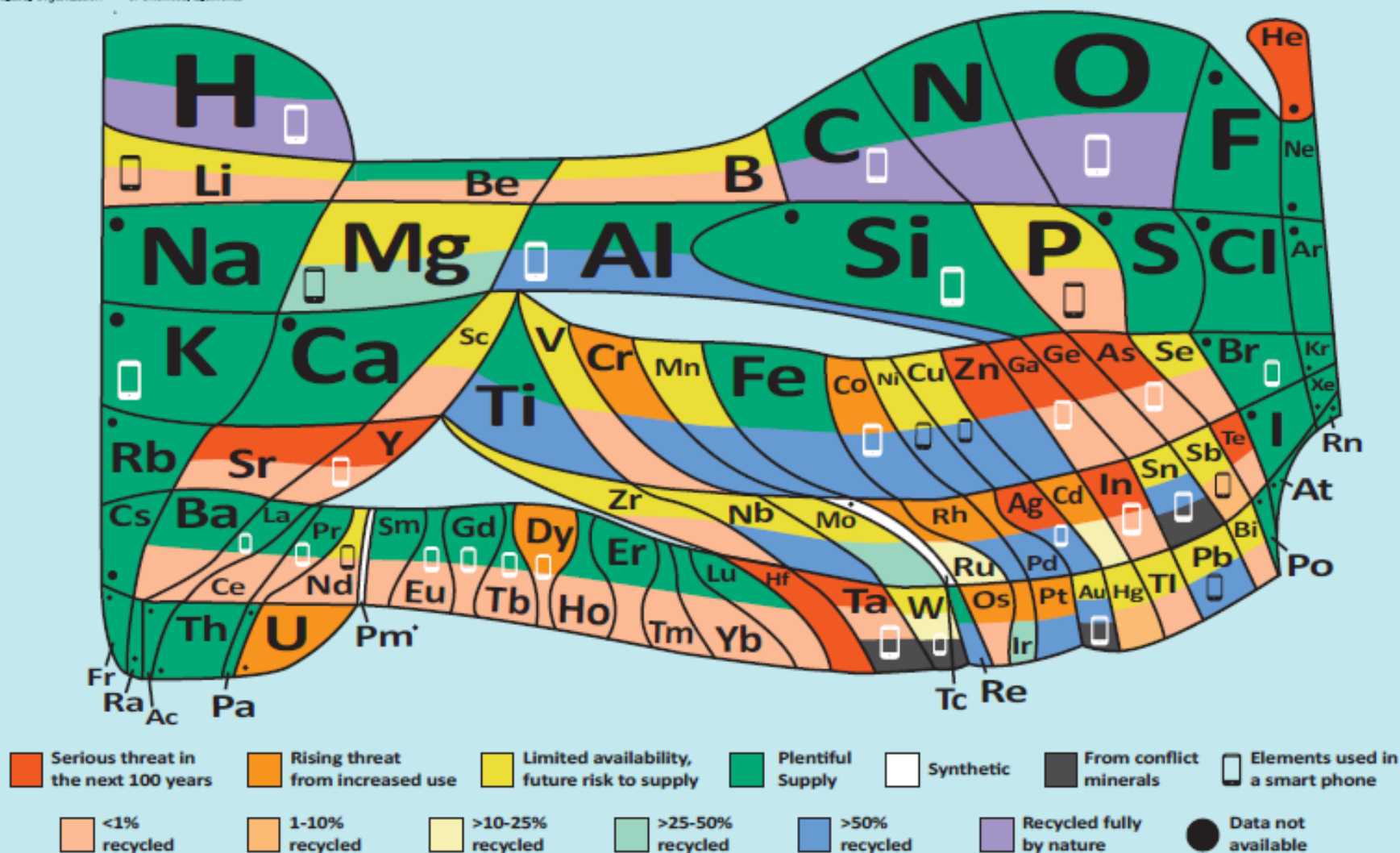
United Nations
Educational, Scientific and
Cultural Organization



2019
International Year
of the Periodic Table
of Chemical Elements

The 90 natural elements that make up everything

How much is there? Is that enough? What are we recycling?



This work is licensed under the Creative Commons Attribution-NoDerivs CC-BY-ND



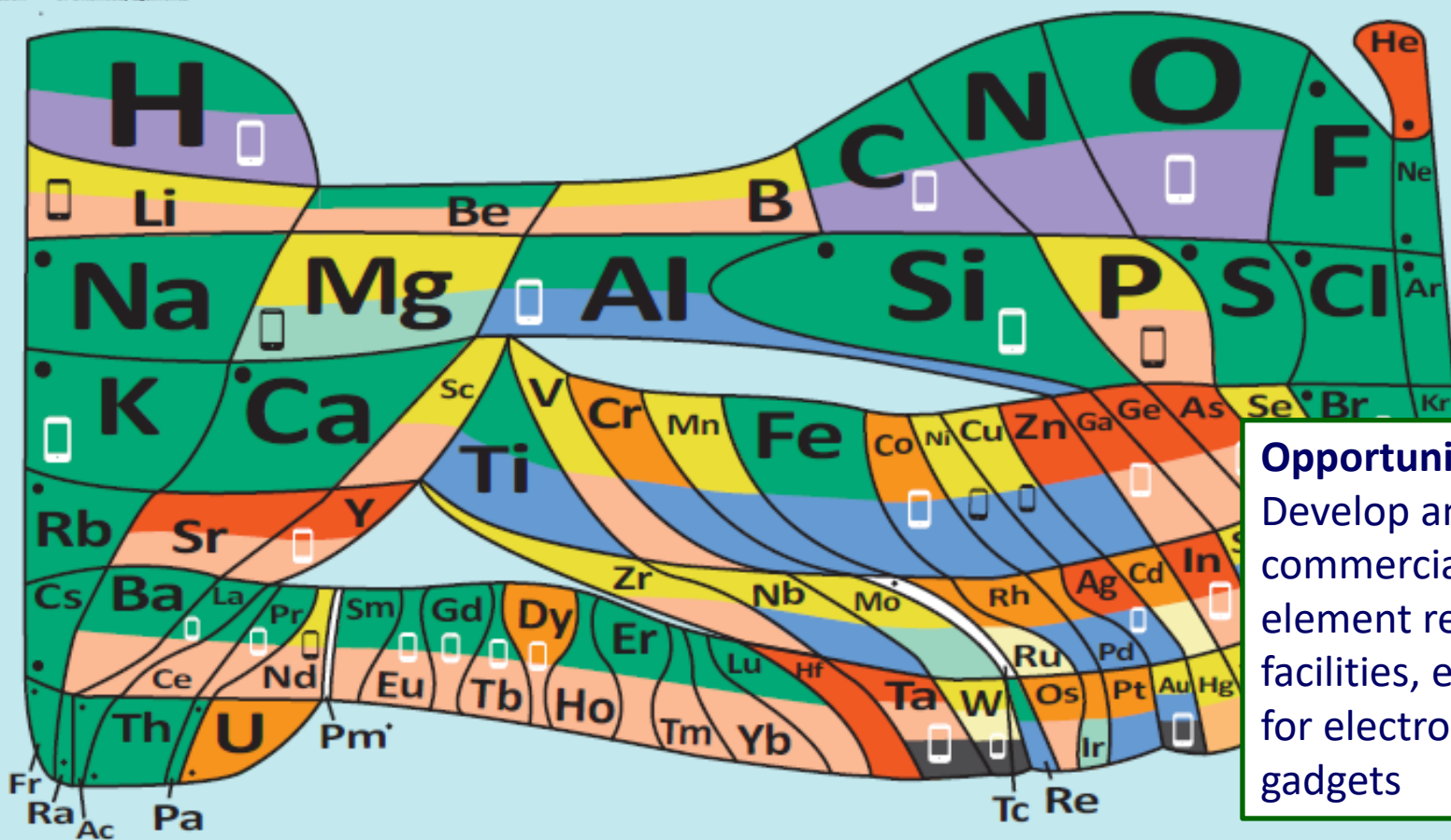
United Nations
Educational, Scientific and
Cultural Organization



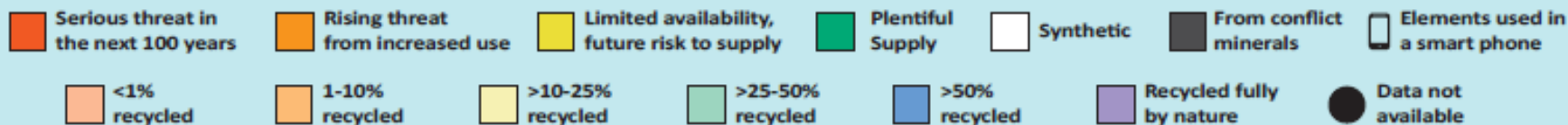
International Year
of the Periodic Table
of Chemical Elements

The 90 natural elements that make up everything

How much is there? Is that enough? What are we recycling?



Opportunity 6
Develop and / or
commercialise new
element recycling
facilities, especially
for electronic
gadgets



This work is licensed under the Creative Commons Attribution-NoDerivs CC-BY-ND

Helium

Deep sea diving

MRI Imaging



Liquid helium cooled



Helium/oxygen reduces "the Bends"

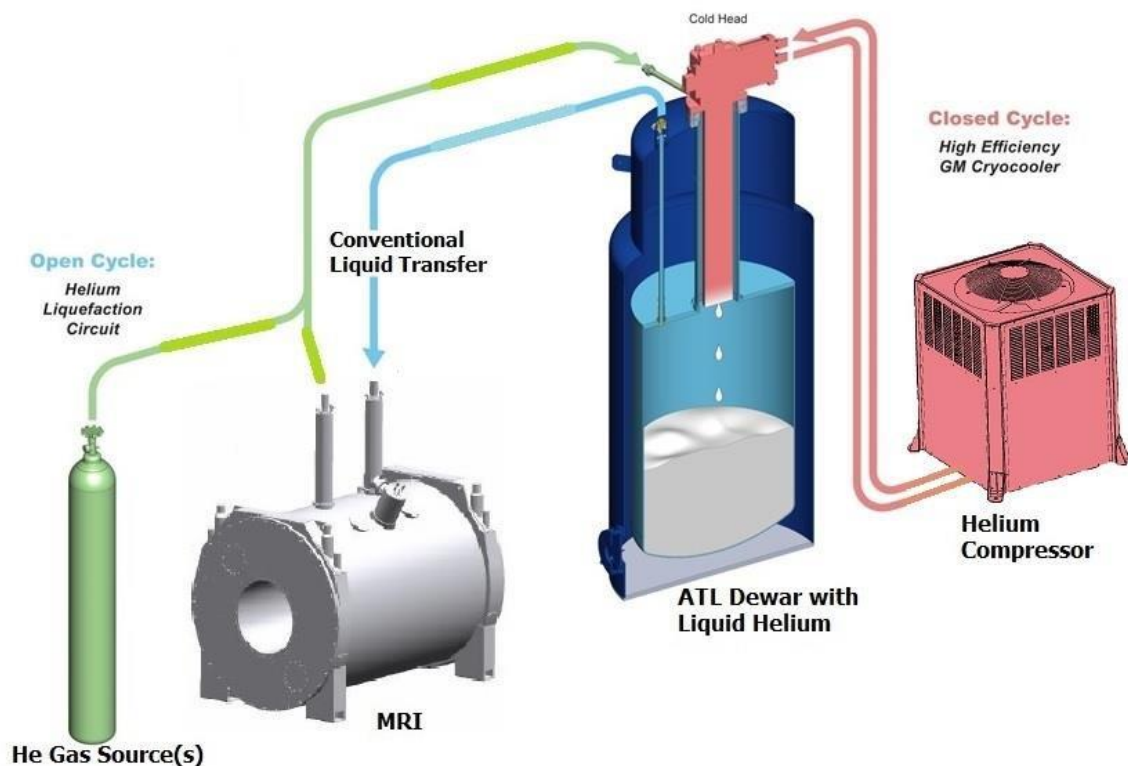
Helium
recycling



22

Once released into the atmosphere
helium can be lost into outer space forever

Helium



Main suppliers

Qatar – Closed

USA – Closing 2021

Tanzania – Opening 2020

Enough for 8-12 years



Can we really justify using helium celebration balloons when this precious resource will be lost forever?



BALLOON GAS



Best
Practice



EUROPEAN BALLOON
& PARTY COUNCIL

www.ebpc.org

Opportunity 7

Develop and / or commercialise new helium purification facilities

- “Tiny” amount (10 %) of helium is used in party balloons (47 % in Russia)
- “Dirty” helium recycled from MRI scanners, “cannot be used in science and academic applications”
- “Re-liquefying is currently considered uneconomical from the locations of where the filling application take place”
- Helium concentration is ~95 %; Tanzanian field <10 %)
- In ~ 80 years **ALL** the Tanzanian helium will be lost

Can we *really* justify using helium celebration balloons when this precious resource will be lost forever?

Trains delayed by balloons



Network Rail (UK): 619 balloon related incidents in last year - many dangerous.

Found on a beach in St Andrews

- Plastic can kill land and sea animals, birds
- Biodegradable in a few months
- Swallowed by creatures in a few seconds.



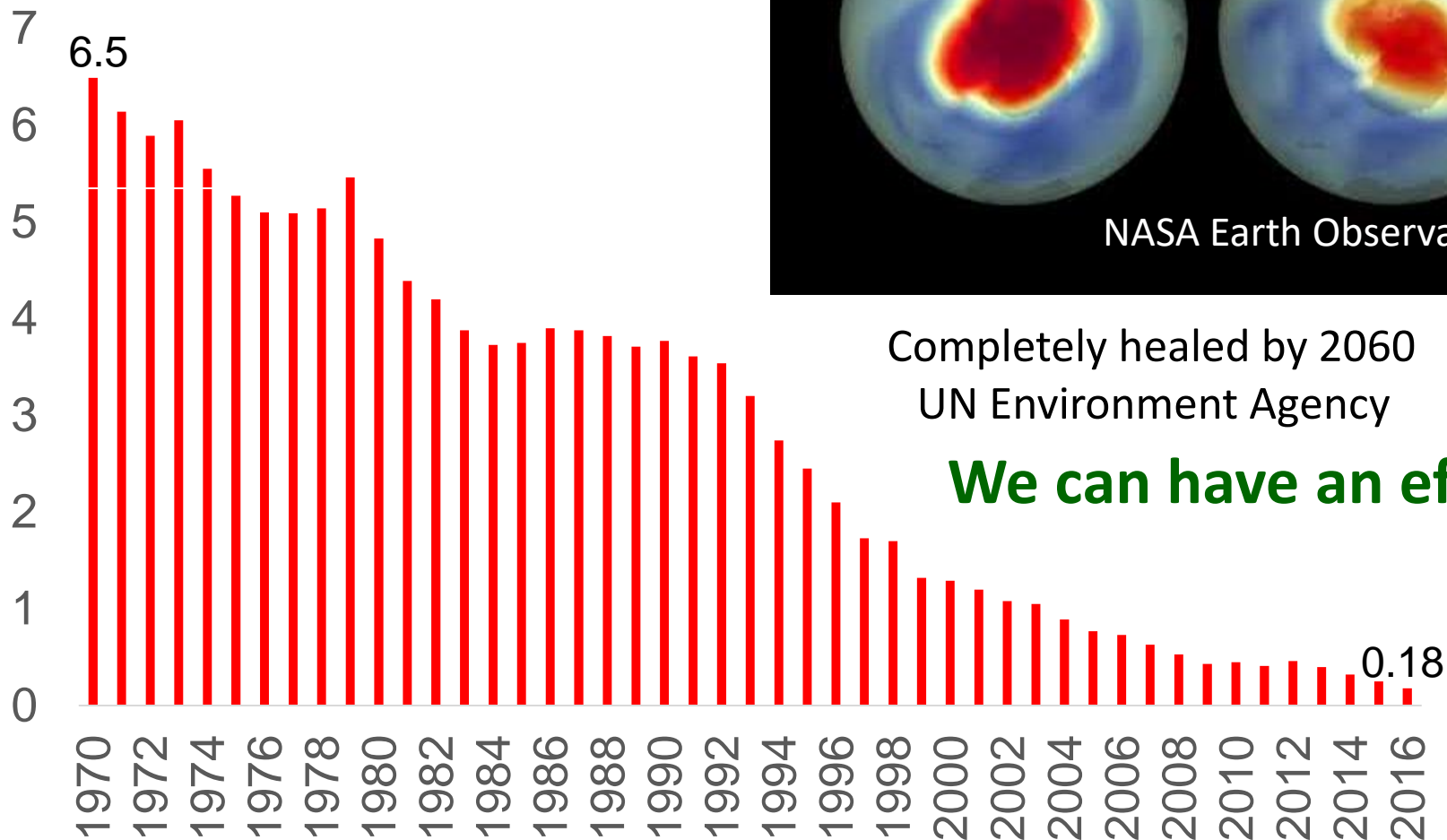
Gibraltar National Day





Waste

Reduce, Recycle

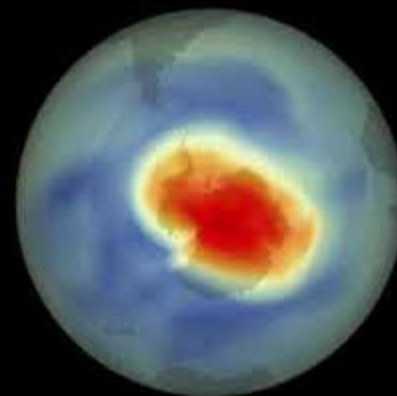
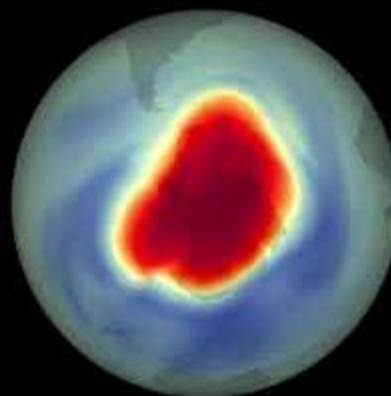


UK SO₂ emissions / megaton per year - Government statistics

Hole in the ozone layer

2000

2017



NASA Earth Observatory

Completely healed by 2060

UN Environment Agency

We can have an effect!



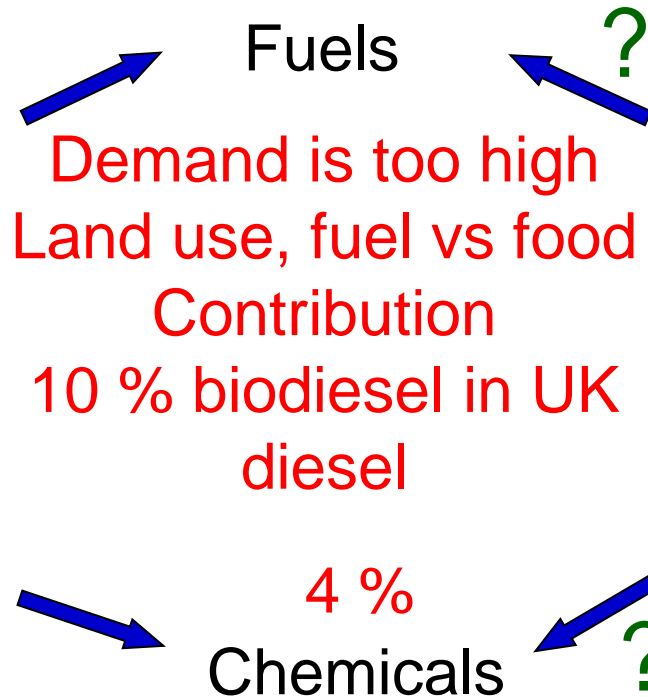
Green Chemistry



Develop chemistry that avoids waste

Alternative feedstocks

Opportunity 7
Develop and / or
commercialise new
products from lignin
and cellulose



Lignin

50 M tonnes per
year

Current usage is
1.1 M tonnes

Using waste streams is best

Cellulose

1.5×10^{12} tonnes
per year

World's most
abundant organic
polymer

Waste Oils

Tall Oil (paper)



Kraft
Process
→
NaOH
Na₂S



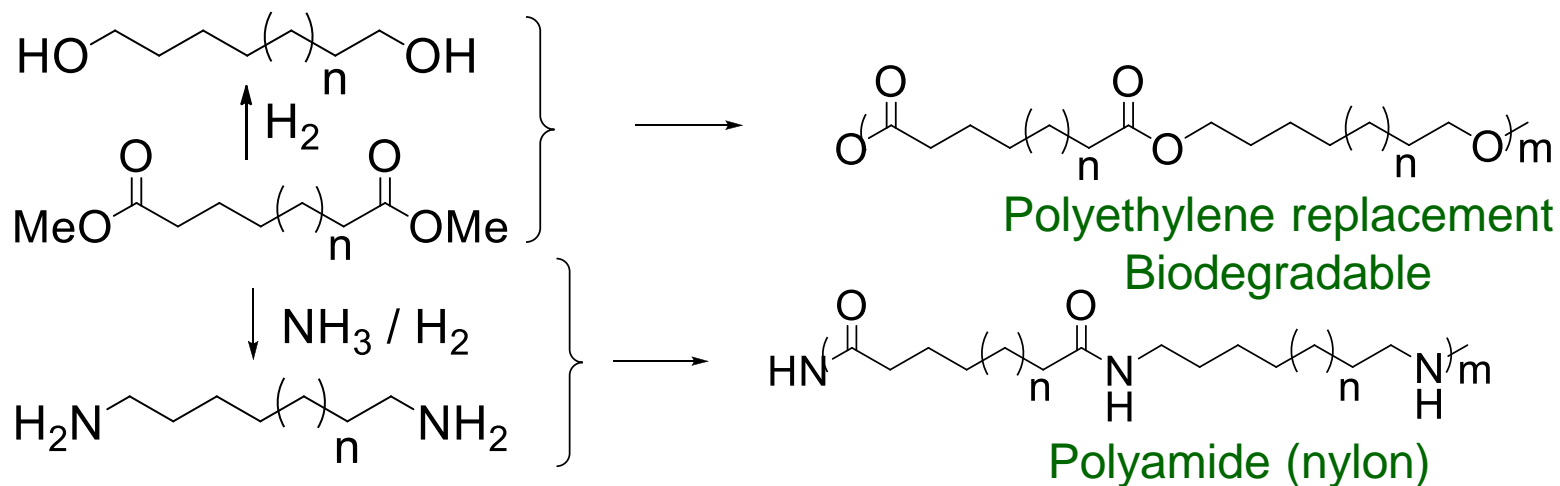
2 M tonnes per year

Cashew nut shell liquid (food)



300,000 tonnes per year

Uses of α,ω -difunctionalised compounds



Fibres
Thermoplastics
Coatings
Nylons (2 M tonnes per year).

Elastomers
Melt adhesives
Engineering plastics,

Overall 3 M tonnes per year

M. Kilner, D. V. Tyers, S. P. Crabtree and M. A. Wood, WO, 2003, 03/09328.

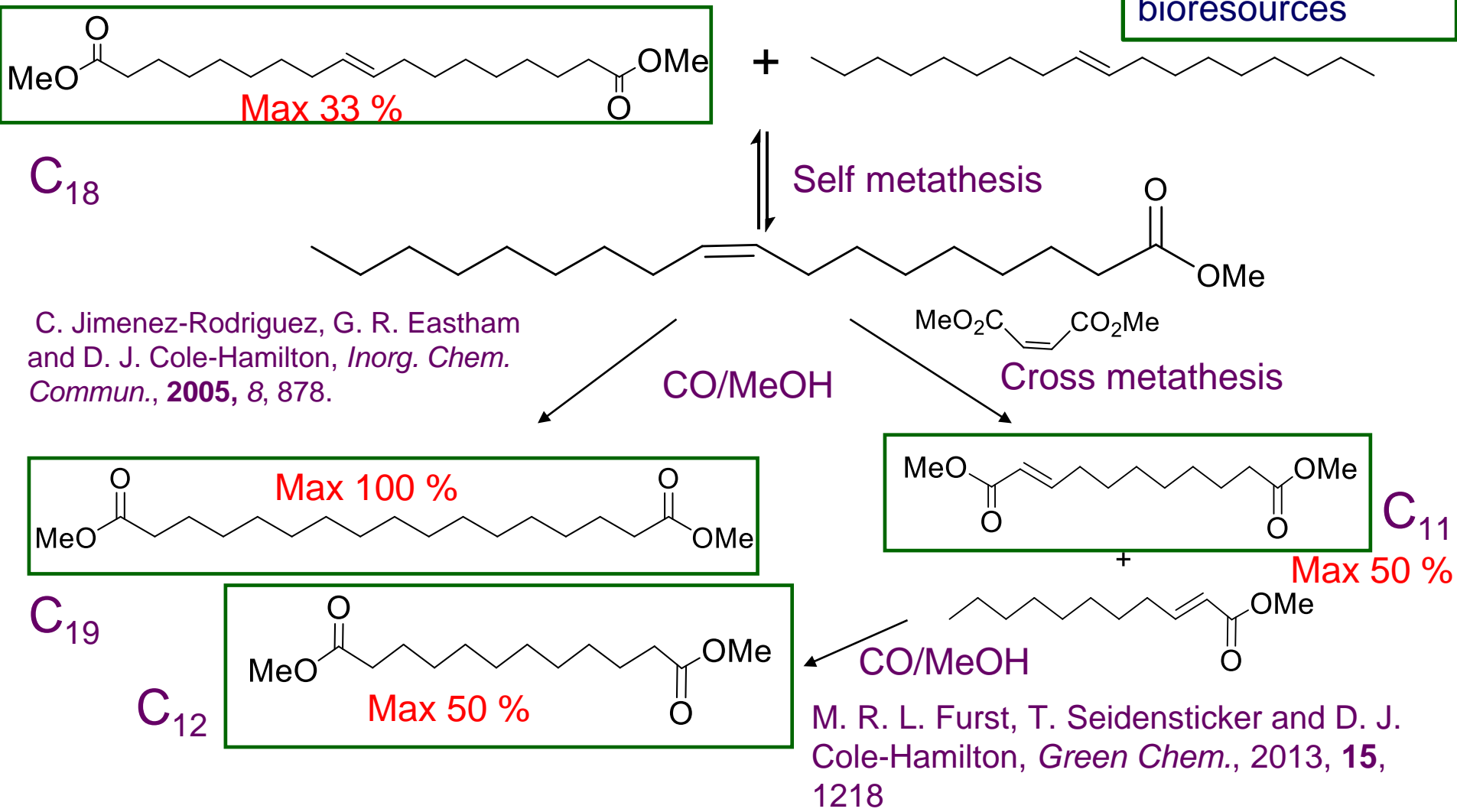
S. P. Crabtree, D. V. Tyers, M. Sharif, WO 2005, 05/051907A1

M. Wood, S. P. Crabtree, D. V Tyers, WO 2005, 05/051875

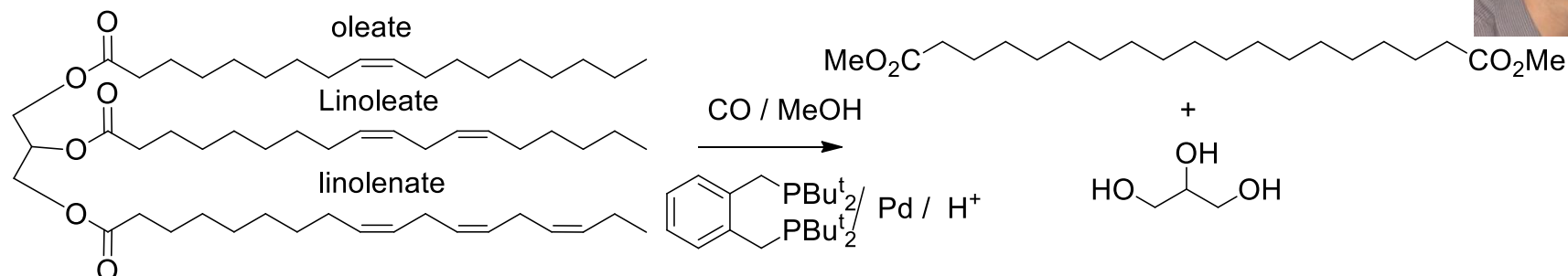
Difunctional materials from methyl oleate

Opportunity 8
Develop and / or commercialise new polyesters or polyamides derived from bioresources

Flow metathesis: R. Duque, E. Öschner, H. Clavier, F. Cajo, S. P. Nolan, M. Mauduit and D. J. Cole-Hamilton, *Green Chemistry*, 2011, **13**, 1187



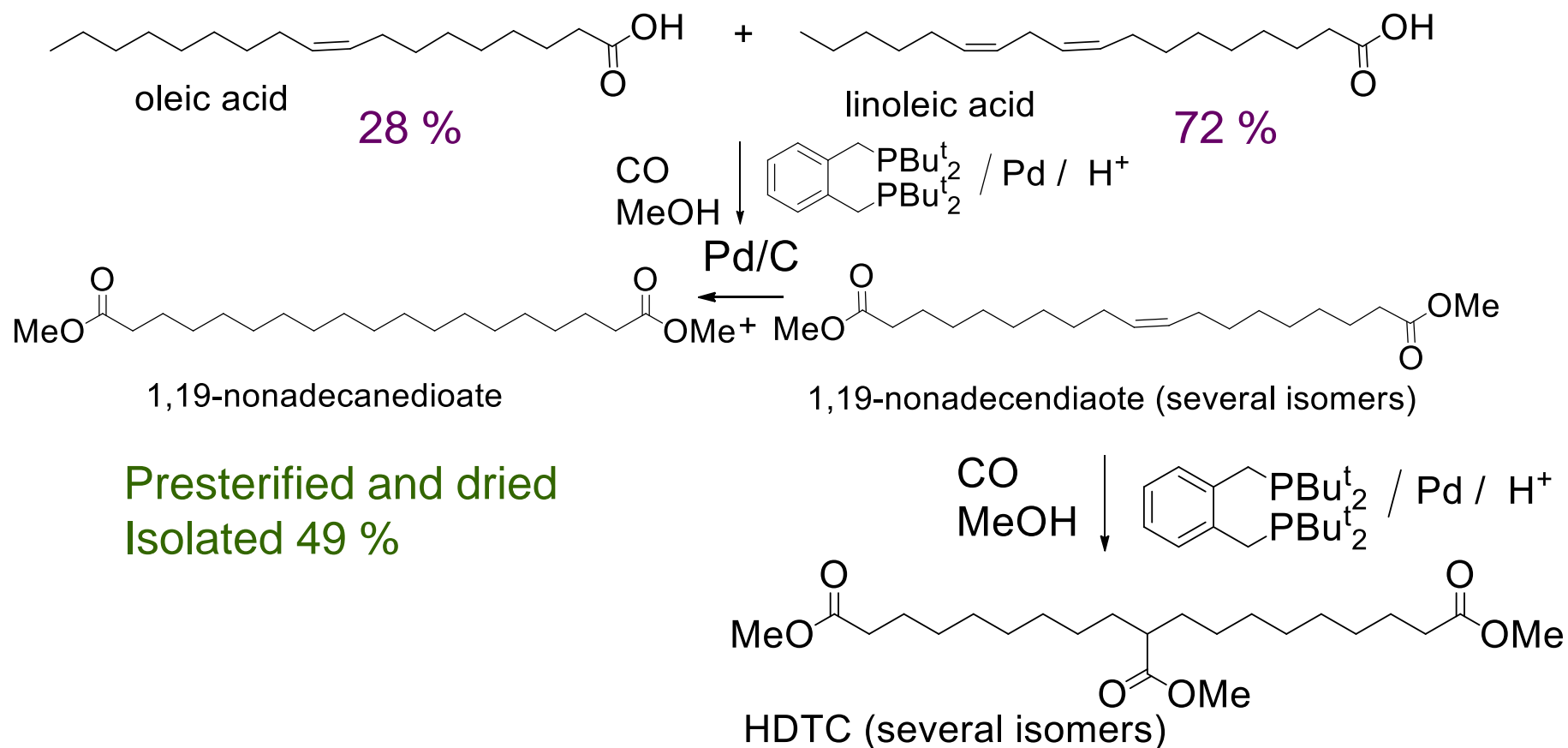
Methoxycarbonylation of natural oils



	Methyl oleate (Aldrich)	Olive (Tesco)	Rapeseed (Tesco)	Sunflower (Tesco)
Oleate / %	>90	73	64	38
Linoleate / %		2	19	50
Linolenate / %		3	10	2
Diester / g from 10 mL oil	9.0	6.9	6.4	3.4
Yield / % (from oleate)		74.7 102.3	69.3 108.3	36.8 96.8
Cost of diester / kg ⁻¹	\$ 6500 (>99 %) \$ 50 (70 %)			

Marc Furst

Tall Oil Fatty Acids (TOFA)

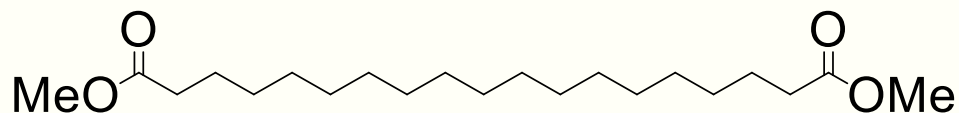
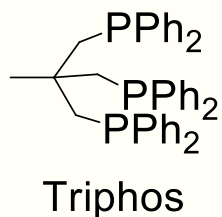


Diols and diamines

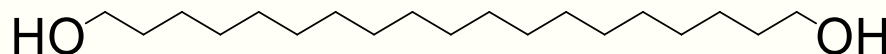
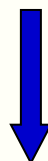


Yiping Shi

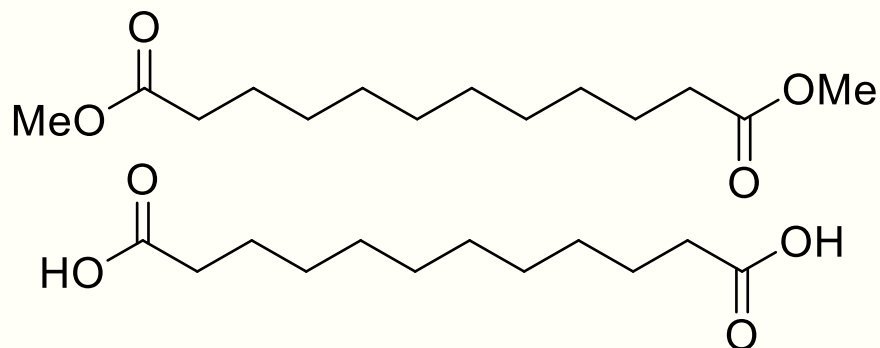
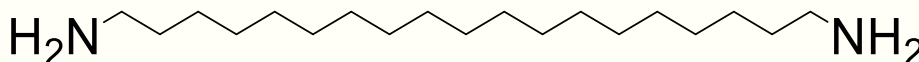
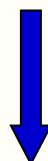
Ru (2 mol %)/triphos
/MSA, 1,4-dioxane
220 °C, 10 bar, 20 h



H_2 / H_2O



Decompress
Add NH_3 (aq)
Recompress



78 %

79 %

83 %

Isolated yields

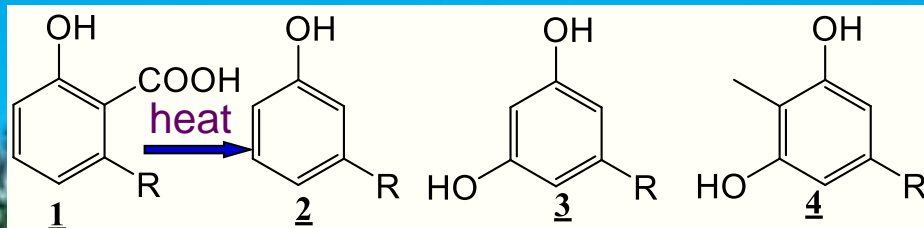
M. R. L. Furst, R. Le Goff,
D. Quinzler, S. Mecking, C.
H. Botting and D. J. Cole-
Hamilton, *Green Chem.*,
2012, **14**, 472

F.-E. Baumann, M. Ullrich,
M. Roos, P. Hannen, F.-M.
Petrat, H. Haeger, A.
Köckritz, G. Walther, J.
Deutsch, A. Martin,
US20120203033
Liquid ammonia .

Y. P. Shi, P. C. J. Kamer and D. J. Cole-Hamilton, *Green Chem.*, 2017, **19**, 5460

Chemicals from Cashew nut shell liquid

Royal Society, Leverhulme Trust



Solvent extraction

60

10

15

tr

Roasting

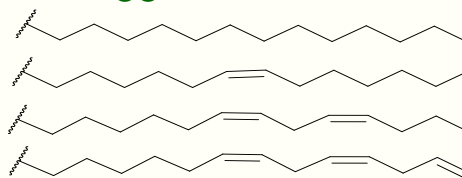
10

85

2

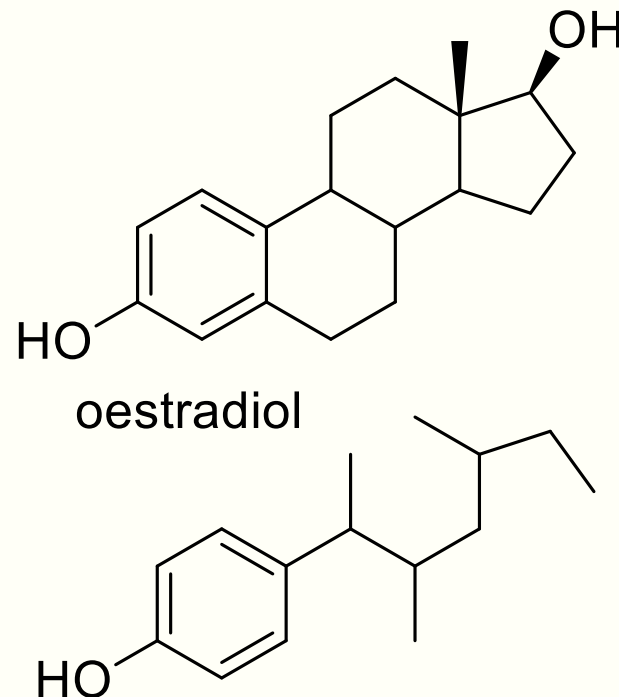
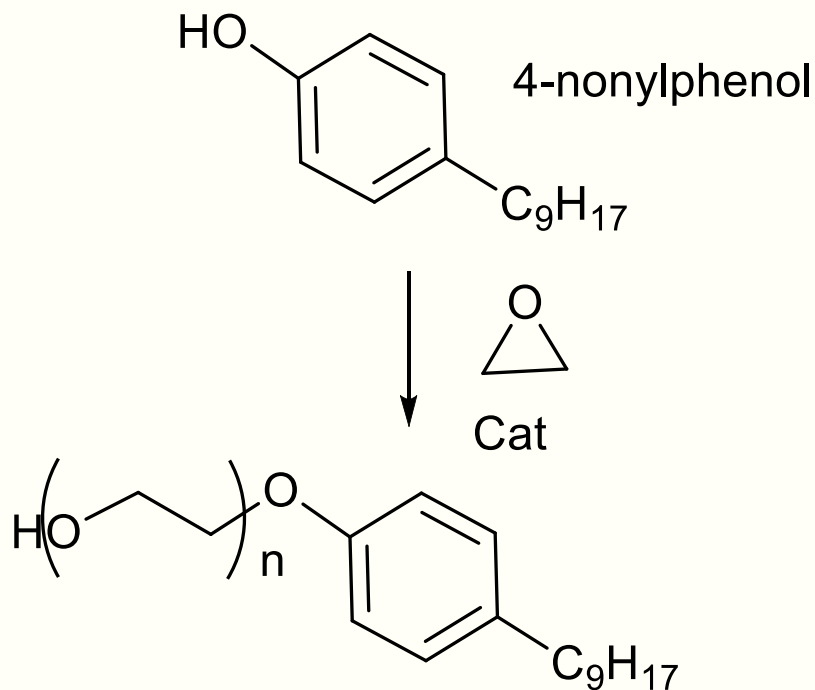
(10 % polymer)

R =



600,000 Tonnes per year

4-nonylphenol

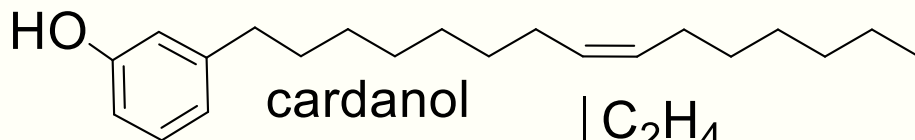


Large scale production as detergent (100 k tonnes per year)

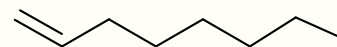
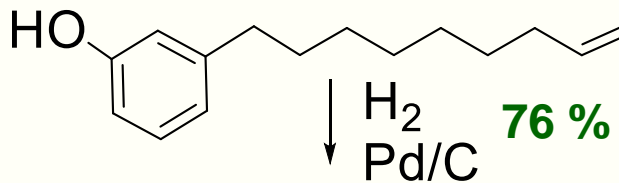
Endocrine disrupter – banned in Europe

Chemicals from cardanol

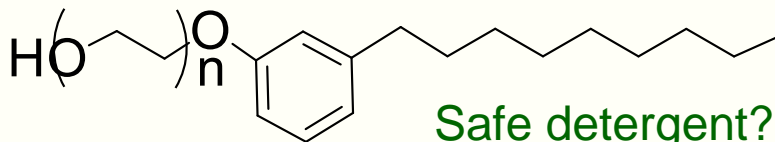
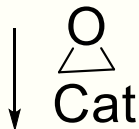
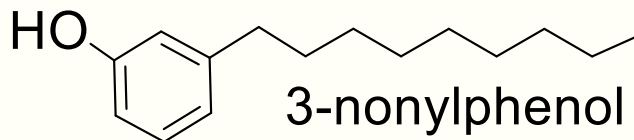
Juma Mmongoyo



↓ C₂H₄
↓ metathesis



85 %



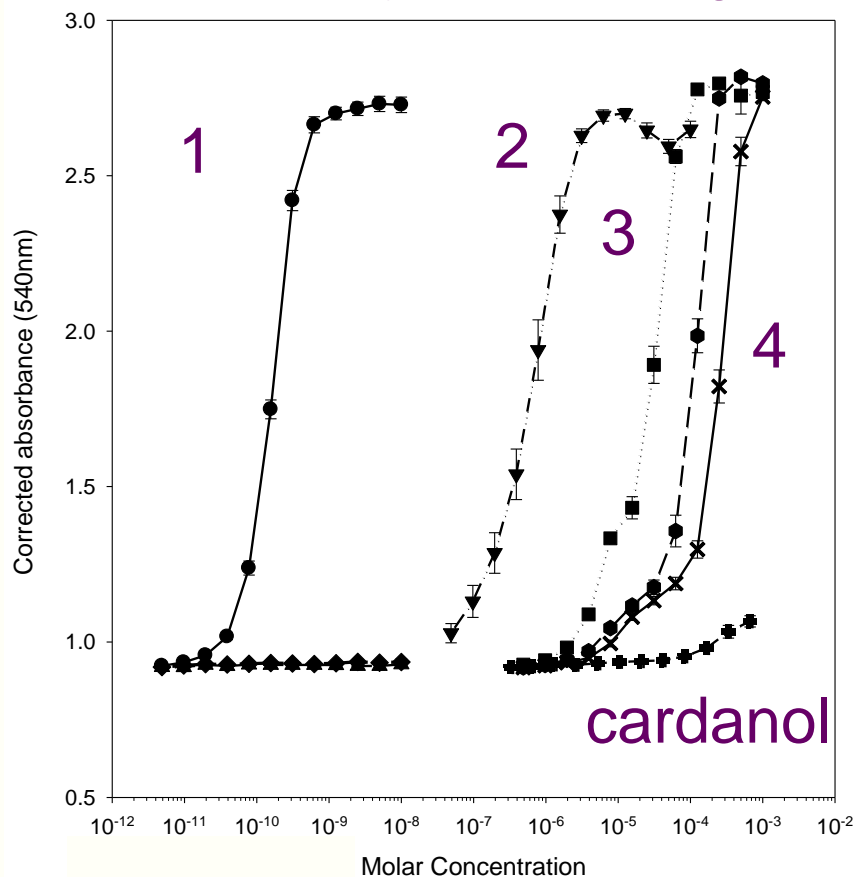
Safe detergent?
Less foaming

Triene	1.7
Diene	2.7
Monoene	87
Saturated	7.5

Bio-1-octene
Polyethylene
comonomer
600,000 tonnes
\$1.2 Bn per year

Endocrine Disruption?

Yeast assay for oestrogenicity



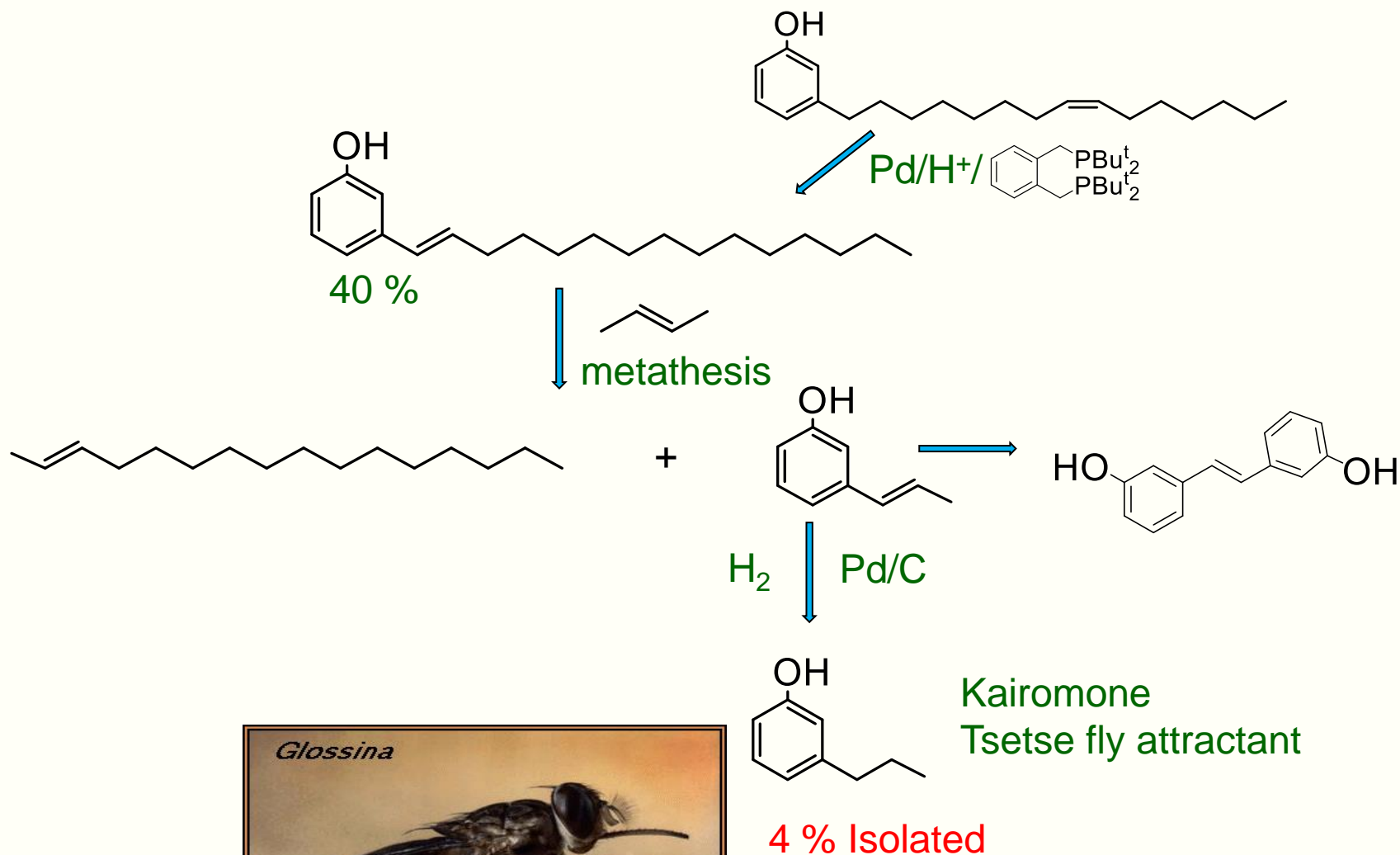
1	Oestradiol	2,000,000
2	4-nonylphenol	200
	(Mixed isomers)	
3	4-n-nonylphenol	10
4	3-n-nonylphenol	1

N. Beresford, E. Routledge

E. J. Routledge and J. P. Sumpter, *J. Biol. Chem.*, 1997, **272**, 3280

J. Julis, S. A. Bartlett, S. Baader, N. Beresford, E. J. Routledge, C. S. J. Cazin and D. J. Cole-Hamilton, *Green Chem.*, 2014, **16**, 2846

Tsetse fly attractant



Quintino Mgani
Juma Mmongoyo



Sabrina
Baader

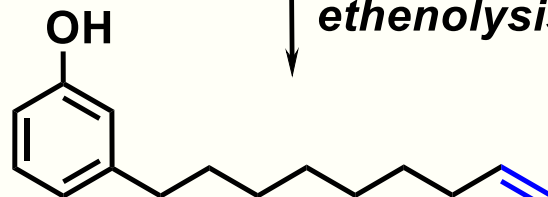
Isomerising ethenolysis / butenolysis

Opportunity 9

Develop and / or
commercialise
products from
bioresources

Cardanol

=
ethenolysis



3-nonenylphenol

+

1-octene

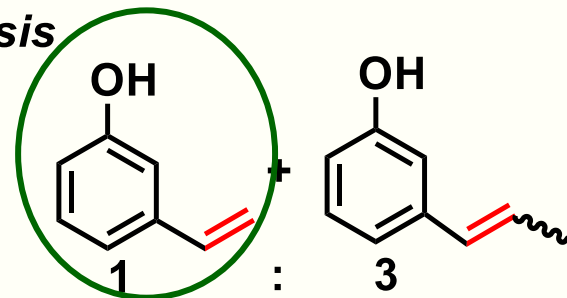
+



isomerising ethenolysis

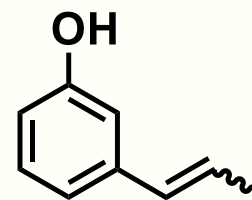
1.5 mol% Pd-cat.
1.5 mol% Ru-cat.

(2 bar) THF, 50 °C, 8 h



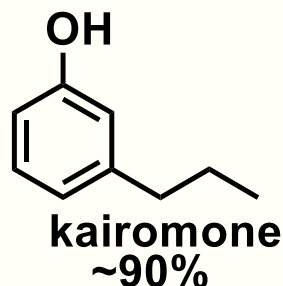
(50 equiv.)

16 h, 50 °C



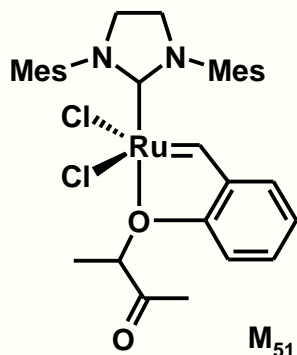
H₂ (2 bar)

MeOH, 1 h, 50 °C



kairomone
~90%

Isomerisation



M₅₁

Metathesis

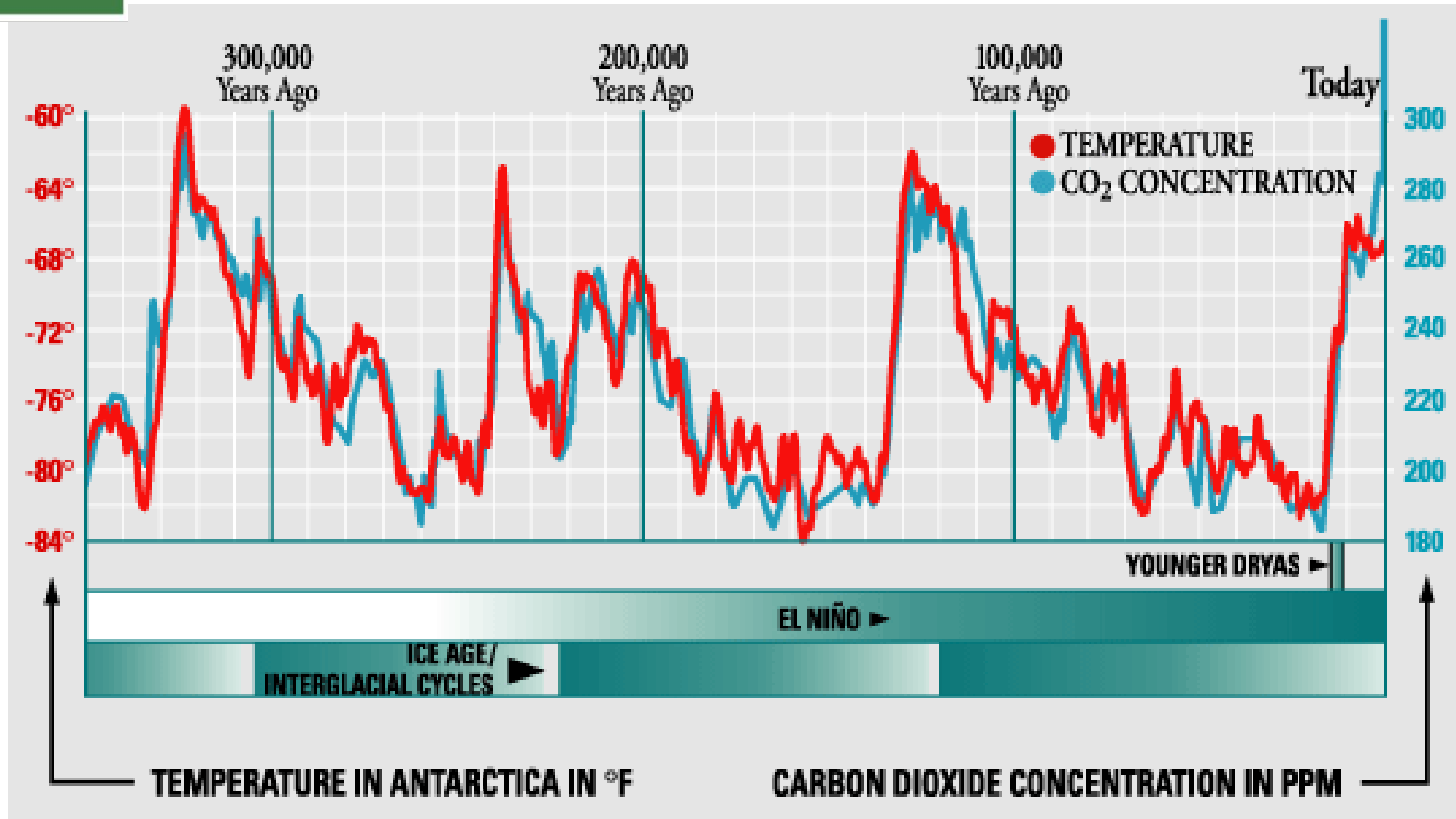
No other catalyst added
1 pot

S. Baader, P. E. Podsiadly, D. J. Cole-Hamilton and L. J. Goossen,
Green Chem., 2014, **16**, 4885



Is climate change real?

Analysis of ice cores in Greenland

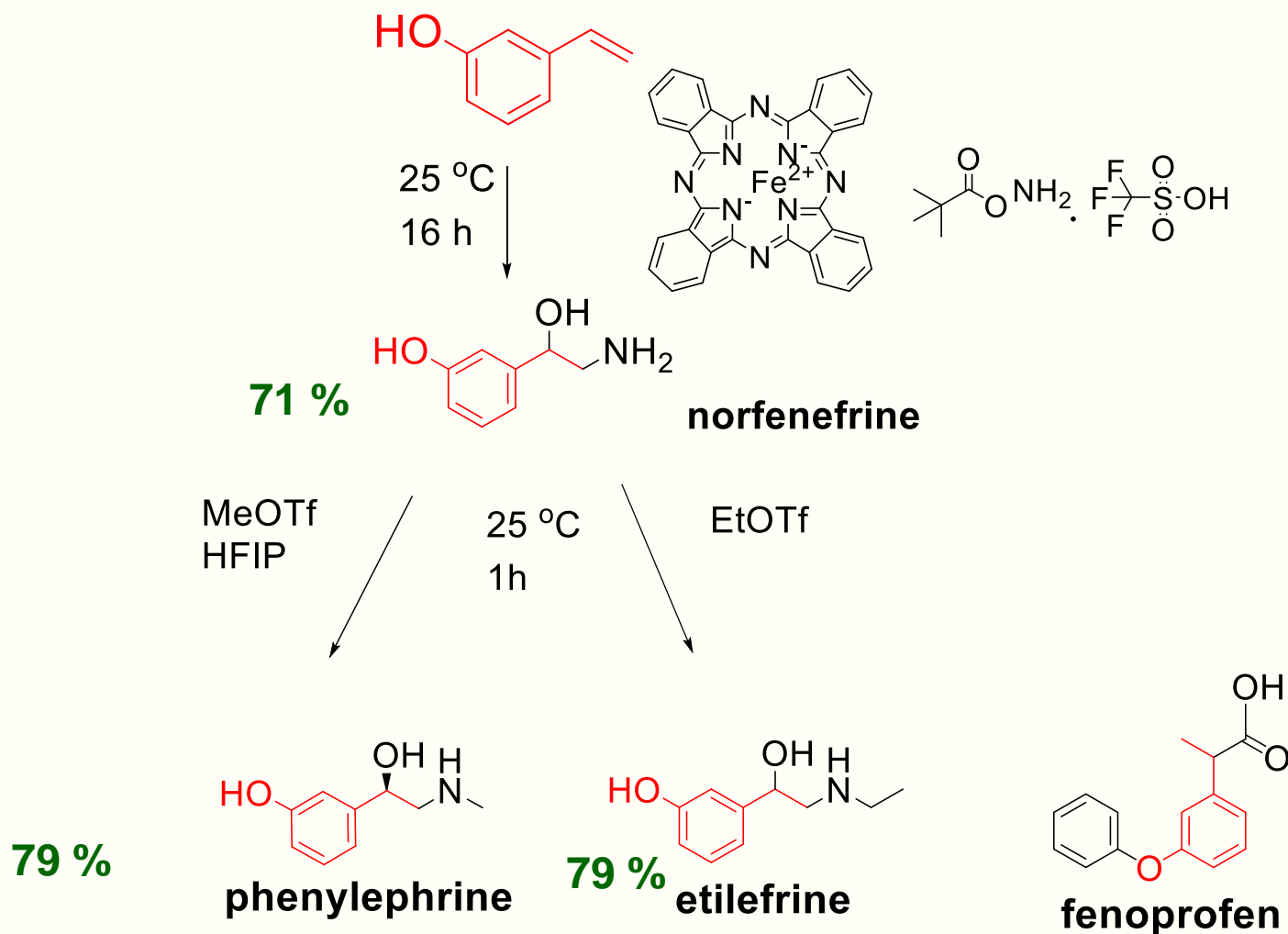


CO₂ rises **follow** rises in temperature, so do not cause the rises in temperature
 Changes caused by tilts of the earth's axis, rotation and distance from sun
 Milankovitch cycles

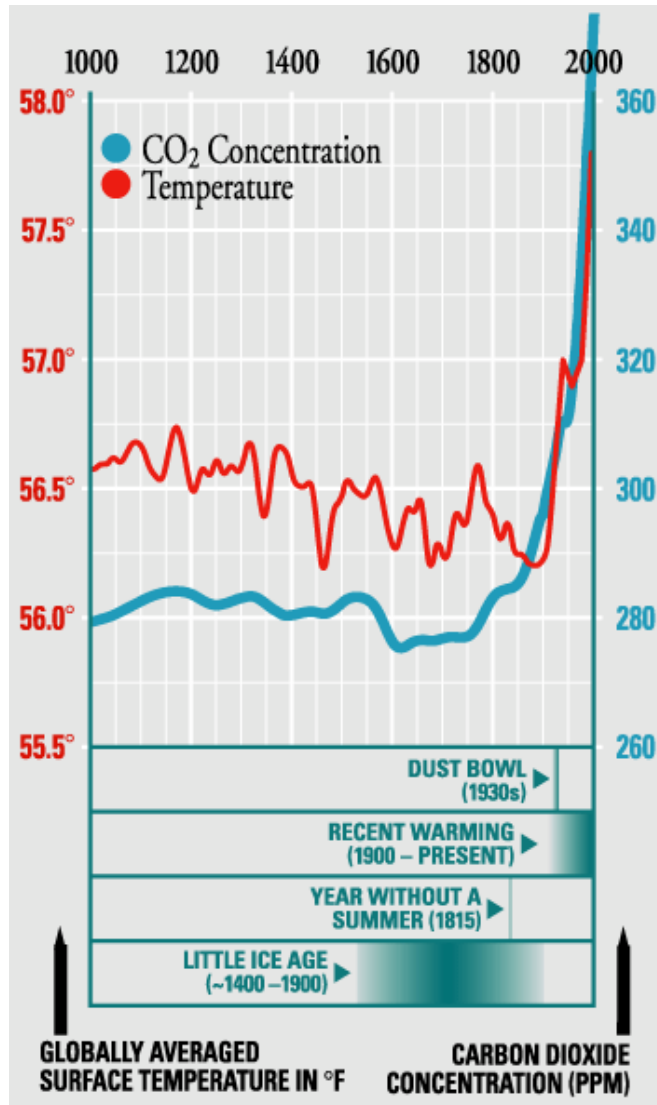
Pharmaceuticals from Cashew Nut Shell Liquid



Yiping Shi
Paul Kamer



Recent rises in CO₂ and temperature



Temperature rise occurred **after** rise in CO₂ levels

Almost all scientists now believe that increased global warming is caused by the actions of mankind

We must reduce CO₂ emissions **AND** remove CO₂ from the atmosphere



Reduce, reuse, recycle

Opportunity 11

Develop and / or commercialise new alternatives to single use plastics

Reduce single use plastics

Reuse containers

Replace plastic bags with paper

Use more natural materials

- Paper straws
- Wood q-tips

Develop biodegradable plastics





Reduce, reuse, recycle

Opportunity 11

Develop and / or commercialise new alternatives to single use plastics

Reduce single use plastics

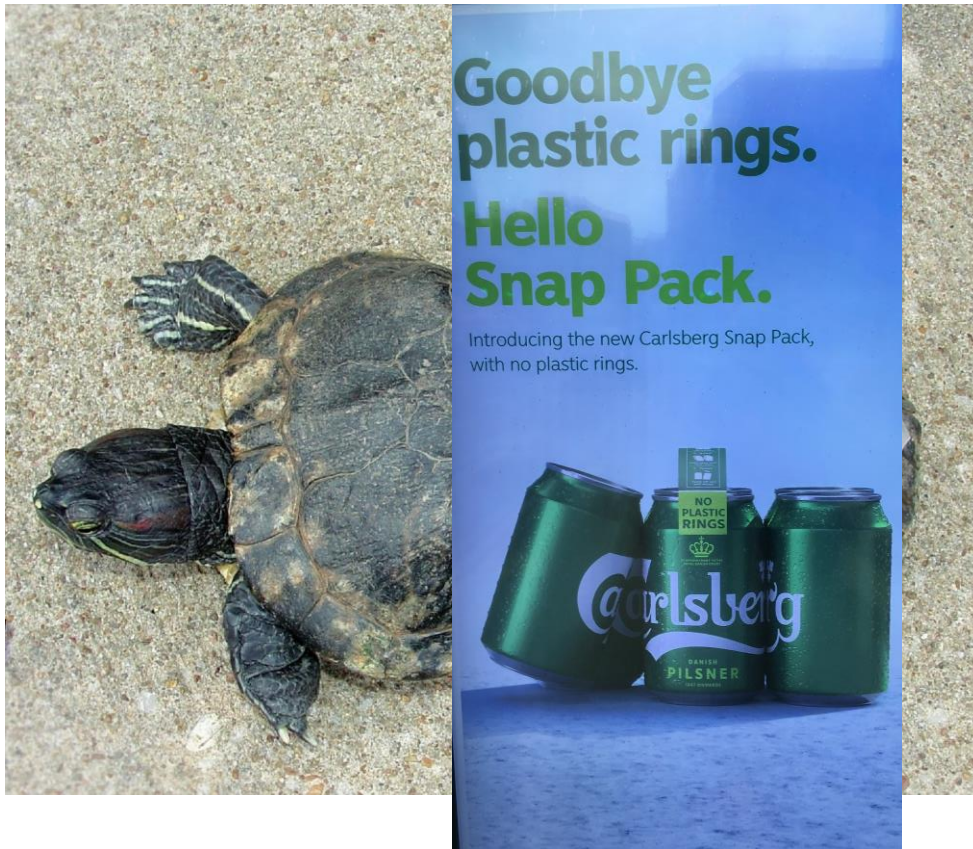
Reuse containers

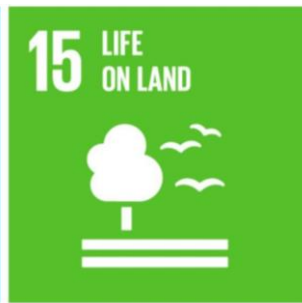
Replace plastic bags with paper

Use more natural materials

- Paper straws
- Wood q-tips

Develop biodegradable plastics





Reduce, reuse, recycle

Opportunity 11

Develop and / or commercialise new alternatives to single use plastics

Reduce single use plastics

Reuse containers

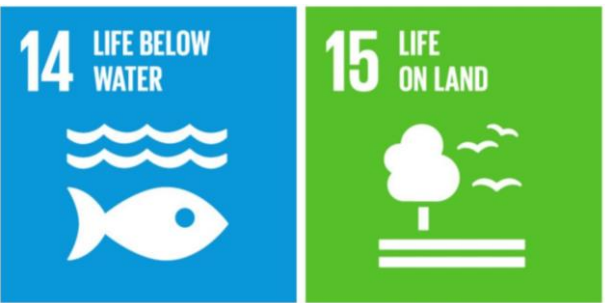
Replace plastic bags with paper

Use more natural materials

- Paper straws
- Wood q-tips

Develop biodegradable plastics





- Desirable



Manila Harbour

Oilprice.com

Biodegradable?

- Undesirable



Gas pipeline
(HDPE 50 % of all polyethylene)

What about the rest?

1 NO POVERTY



8 DECENT WORK AND
ECONOMIC GROWTH



10 REDUCED
INEQUALITIES



THE GLOBAL GOALS
For Sustainable Development

17 PARTNERSHIPS
FOR THE GOALS



If Chemistry has solved all the other problems, these will naturally fall into place

1 NO POVERTY



What about the

The Future is bright!
The future lies with
Chemistry and Chemical
Engineering

If Chemical Engineering solved all the other
problems, all the other problems naturally fall into place

17 PARTNERSHIPS
FOR THE GOALS

