

Sustaining 'CHNOPS', but Phosphorus first!

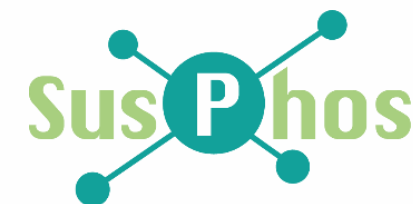


Chris Slootweg



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Acknowledgements



Rijksdienst voor Ondernemend
Nederland



Alexander von Humboldt
Stiftung/Foundation



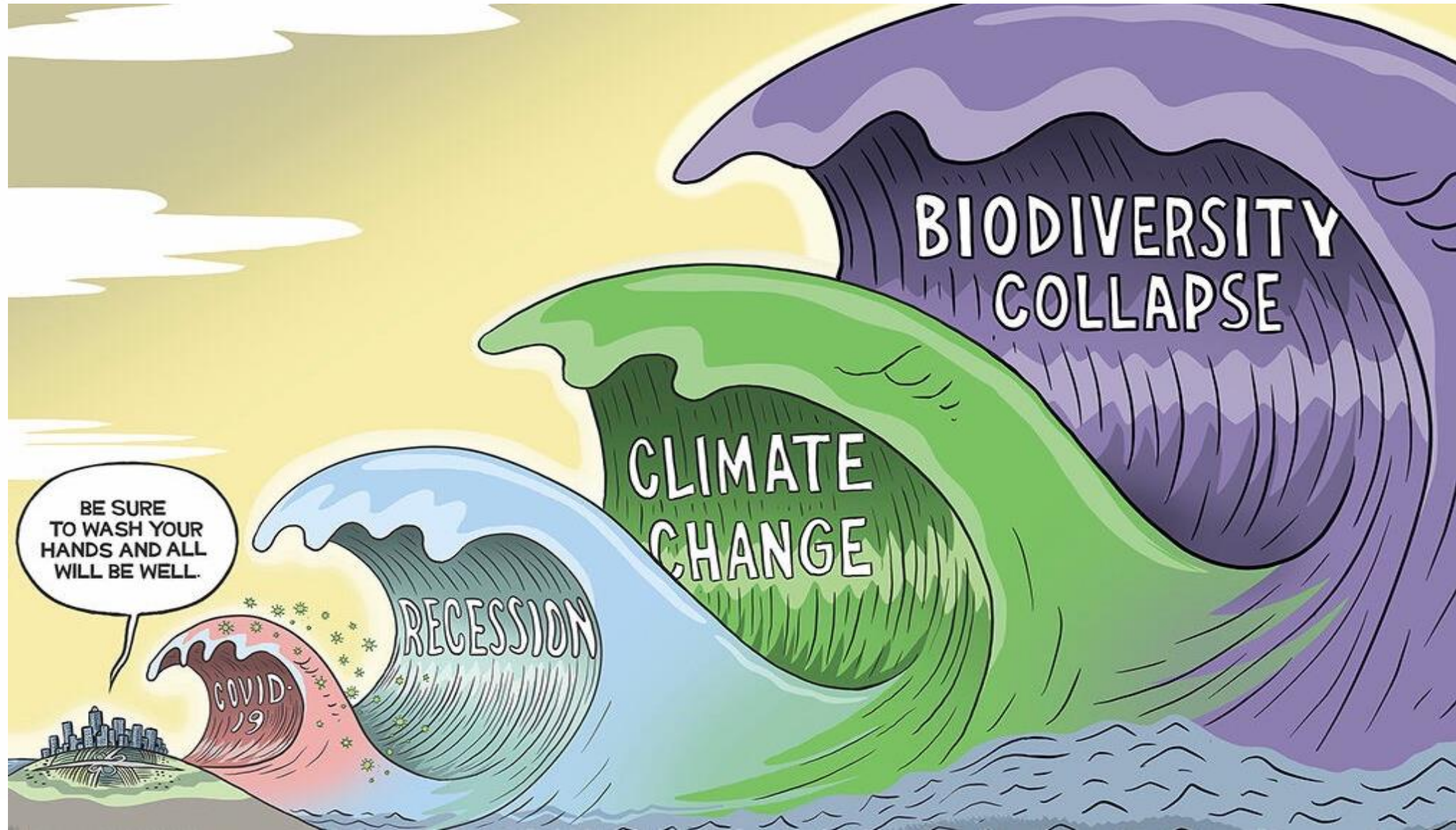
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'CHNOPS': the origin of life...

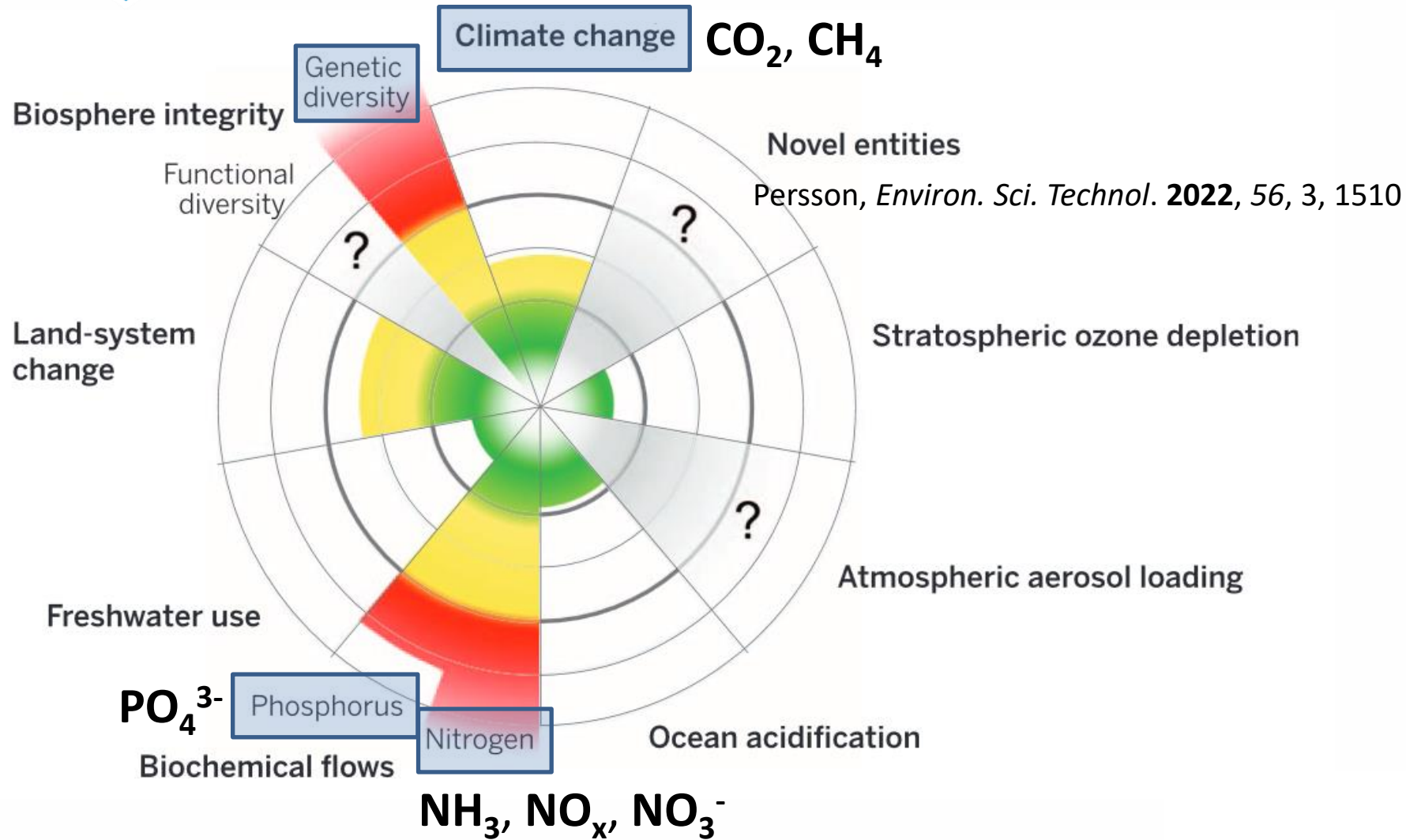


Benjamin
Gunn

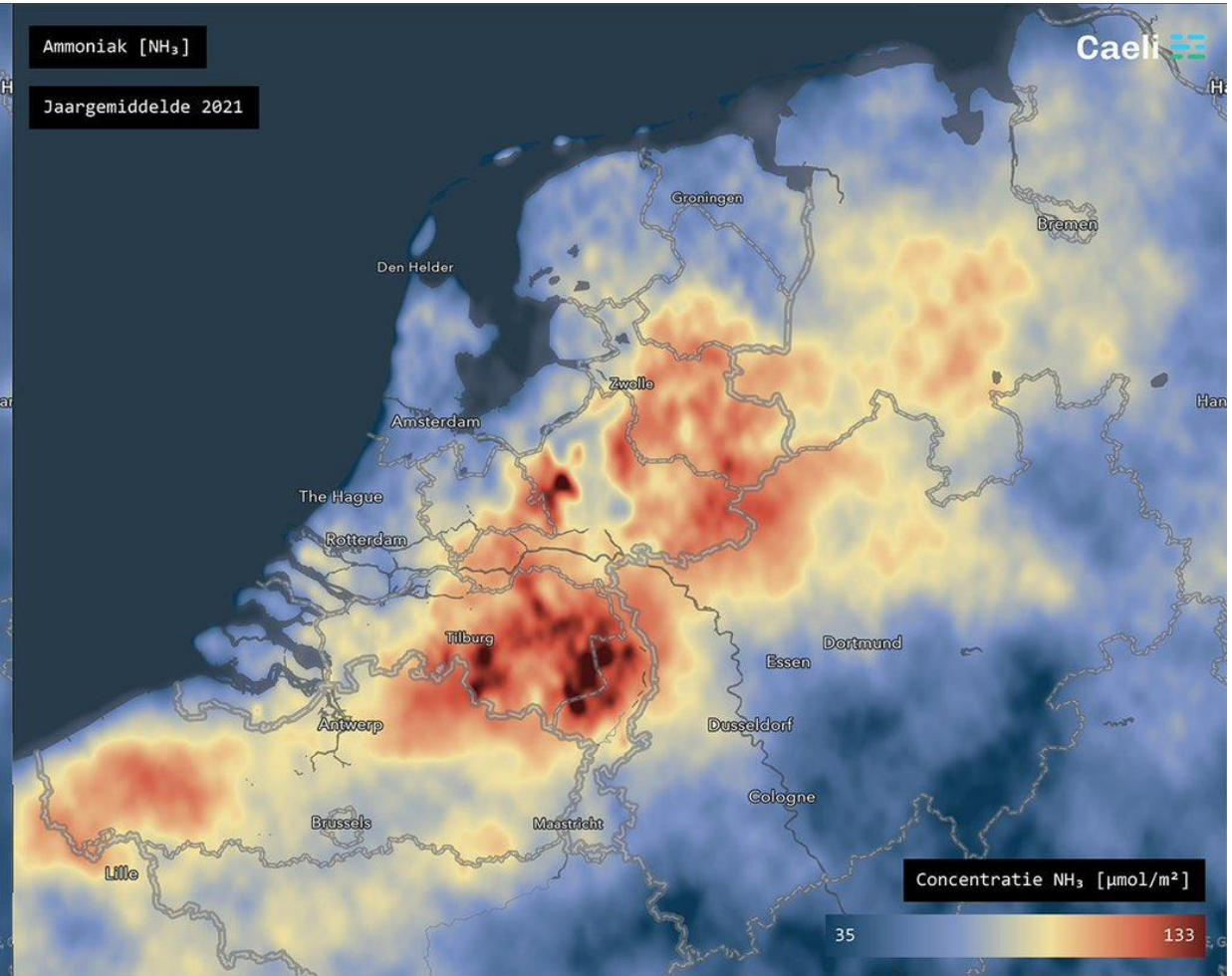
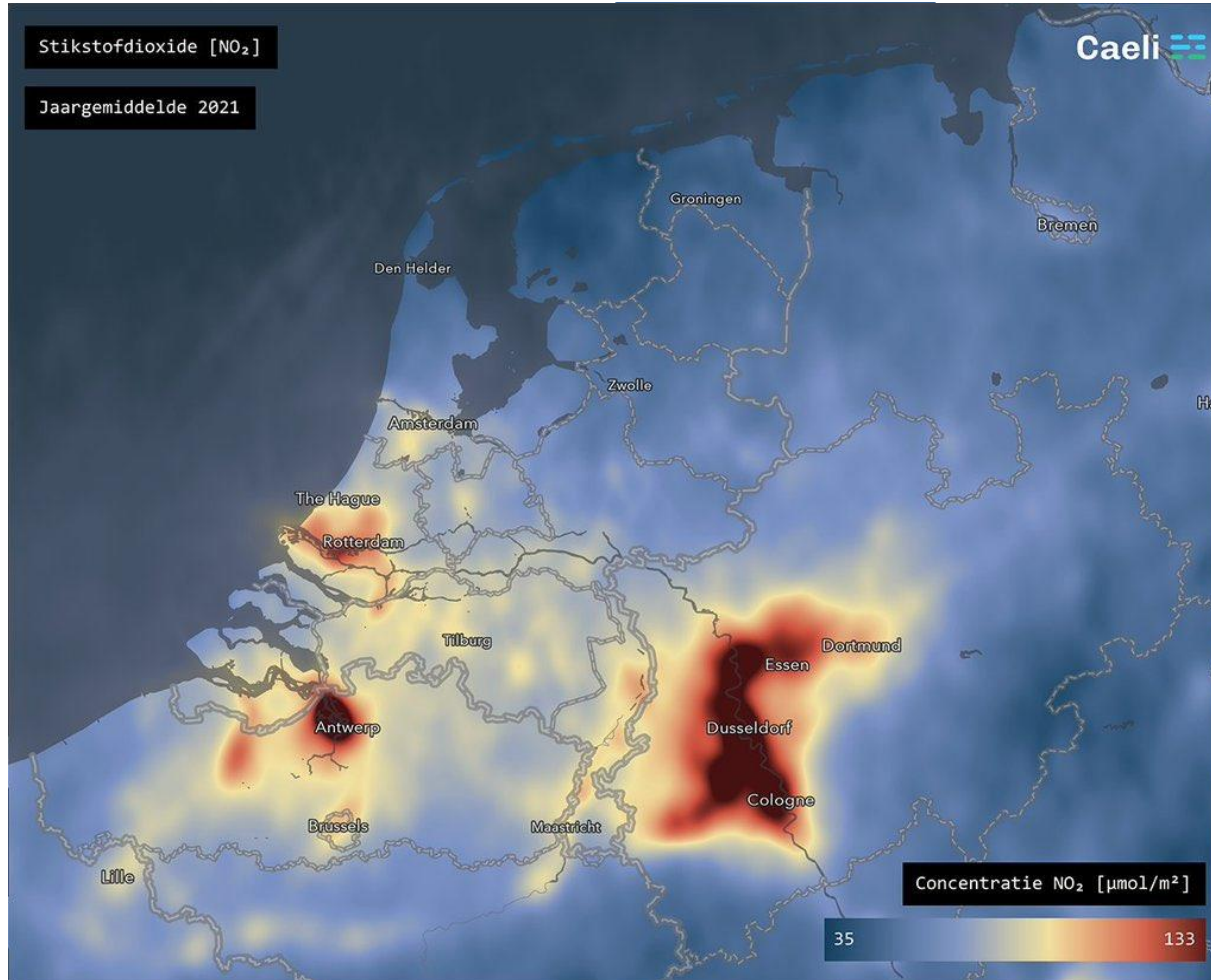
'CHNOPS': the origin of waste...



'CHNOPS': the origin of waste...



'CHNOPS': the origin of waste...



NH₃, NO_x, NO₃⁻

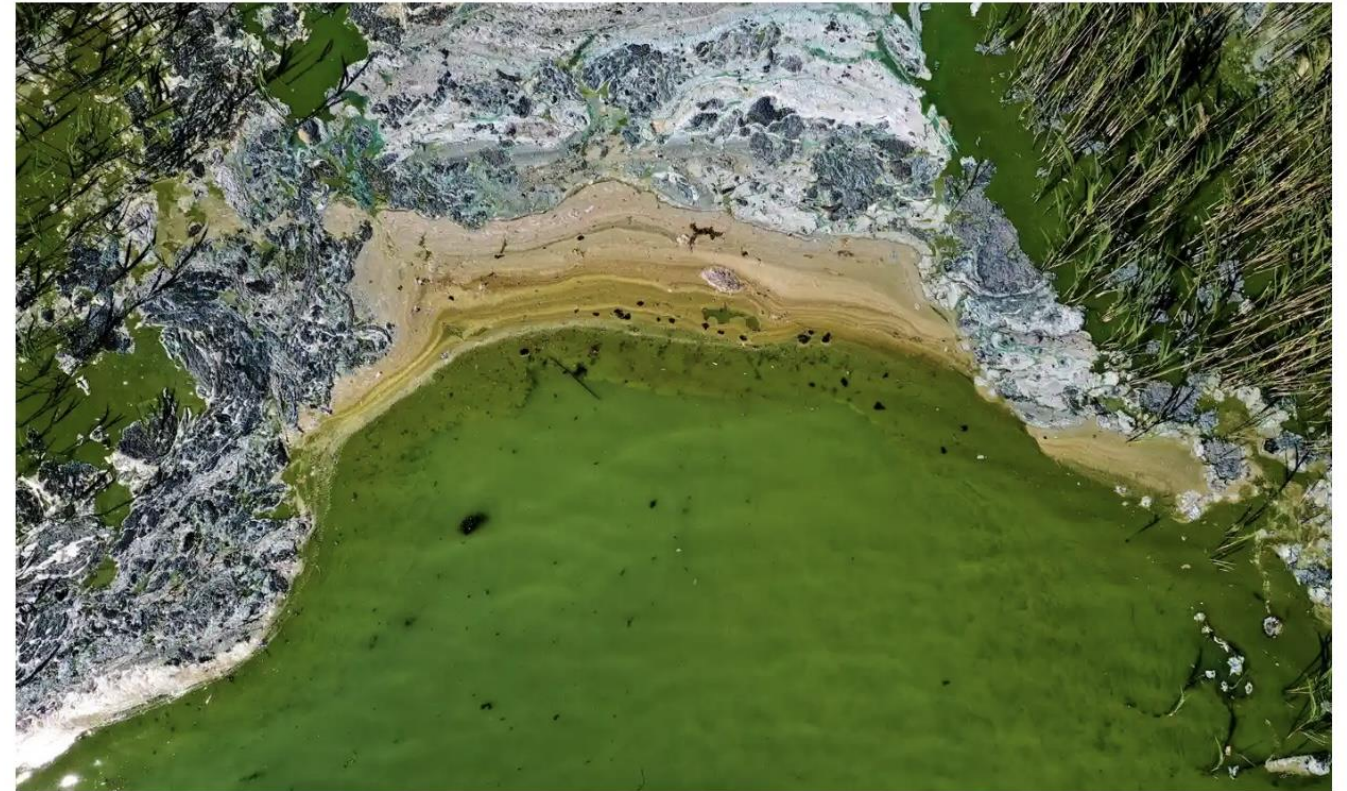
Steffen, Rockström et al., *Science* 2015, 347, 736

'CHNOPS': the origin of wa

The Observer Pollution

Scientists warn of 'phosphogeddon' as critical fertiliser shortages loom

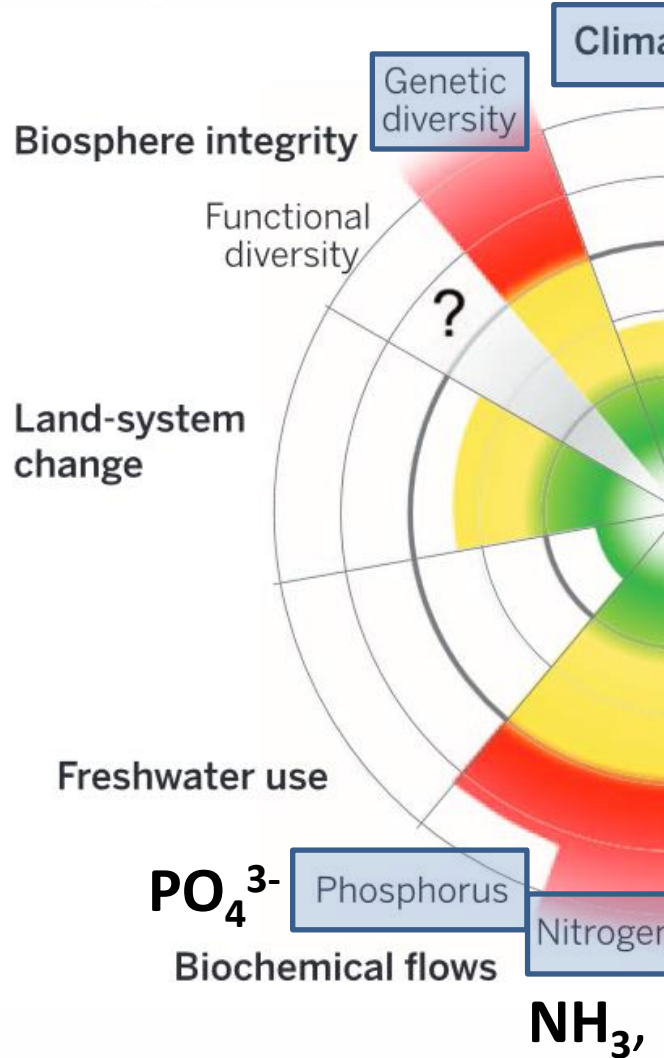
Excessive use of phosphorus is depleting reserves vital to global food production, while also adding to the climate crisis



📷 The overuse of phosphorus is creating algal blooms such as the one in the Baltic Sea near Stockholm in Sweden. Photograph: TT News Agency/Reuters

Robin McKie, *Science editor*

Sun 12 Mar 2023 09:00 GMT



Steffen, Rockström et al., *Science* 2015, 34

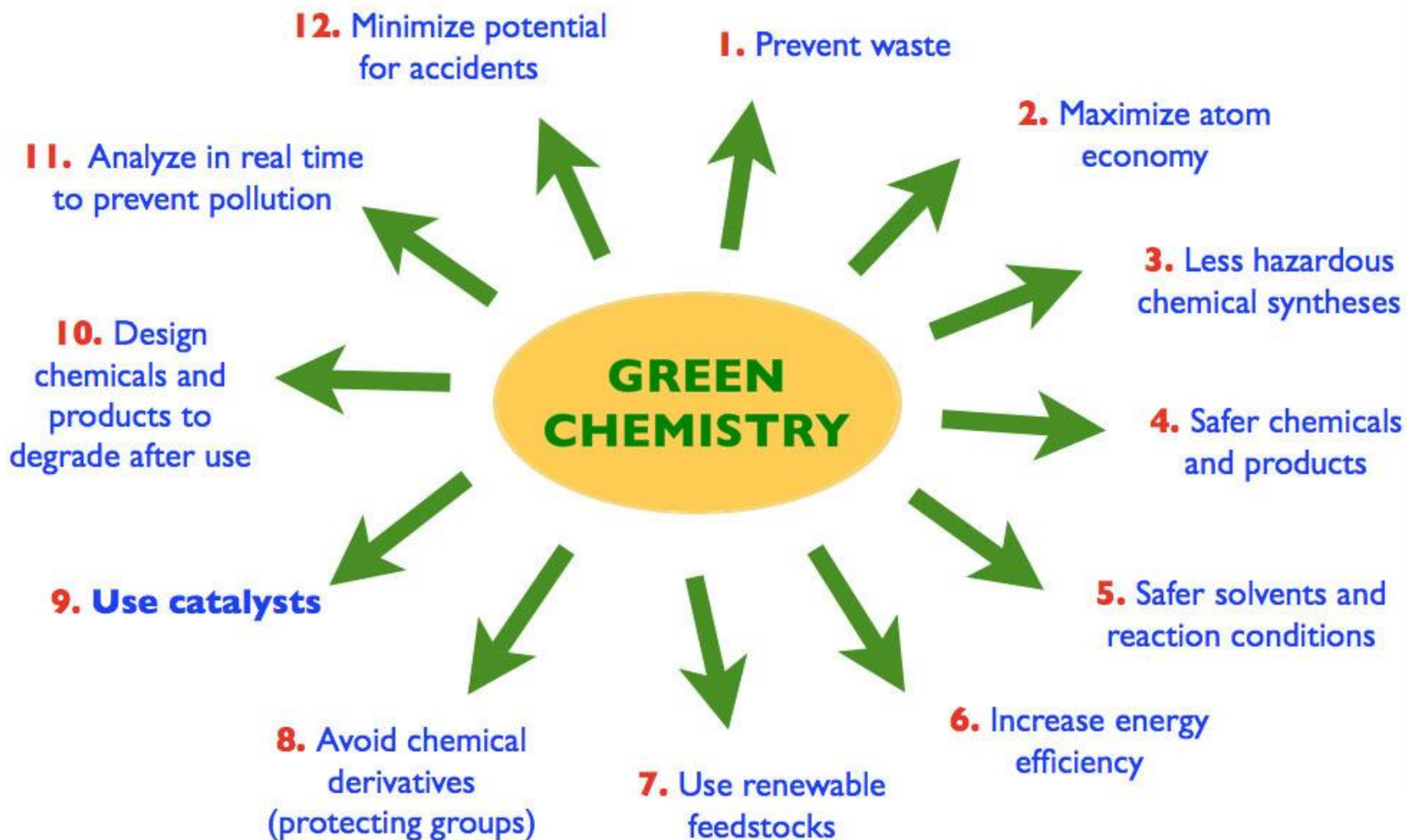
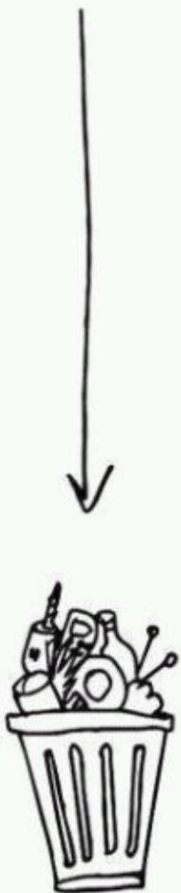
Radical Change is needed..

“We cannot solve our problems with the same thinking we used when we created them.”

– Albert Einstein

12 Guiding Principles to optimise linear processes

LINEAR ECONOMY



Anastas and Warner (1998)

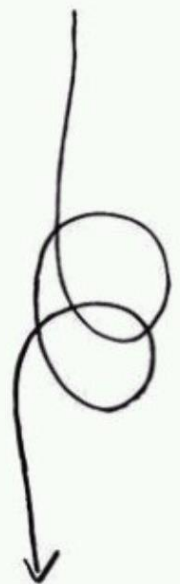
Circular technologies are urgently needed

LINEAR ECONOMY

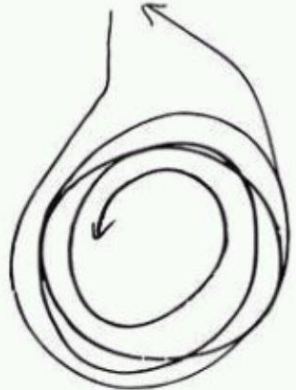


Waste = Resource

RECYCLING ECONOMY



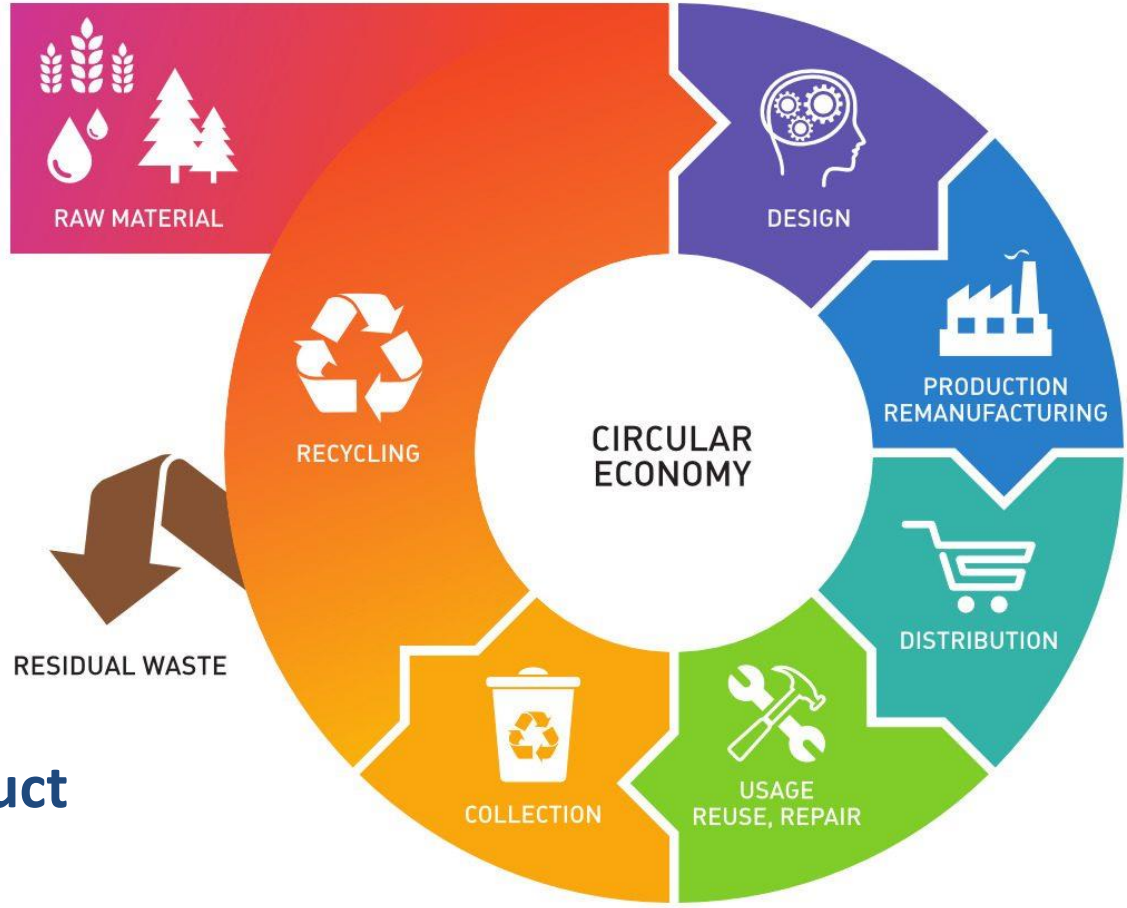
CIRCULAR ECONOMY



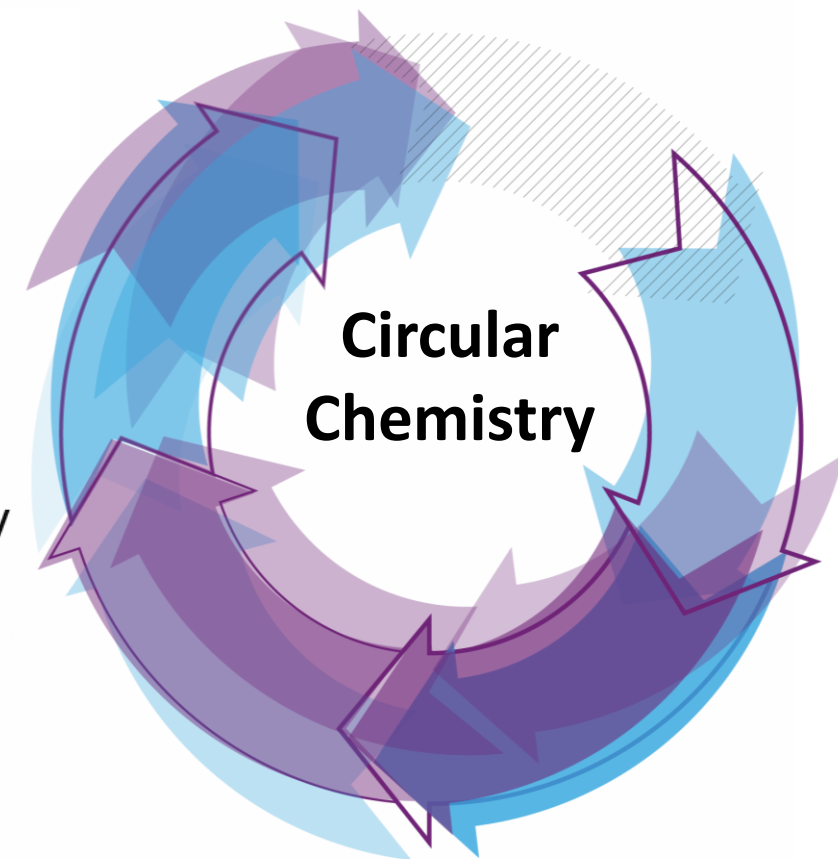
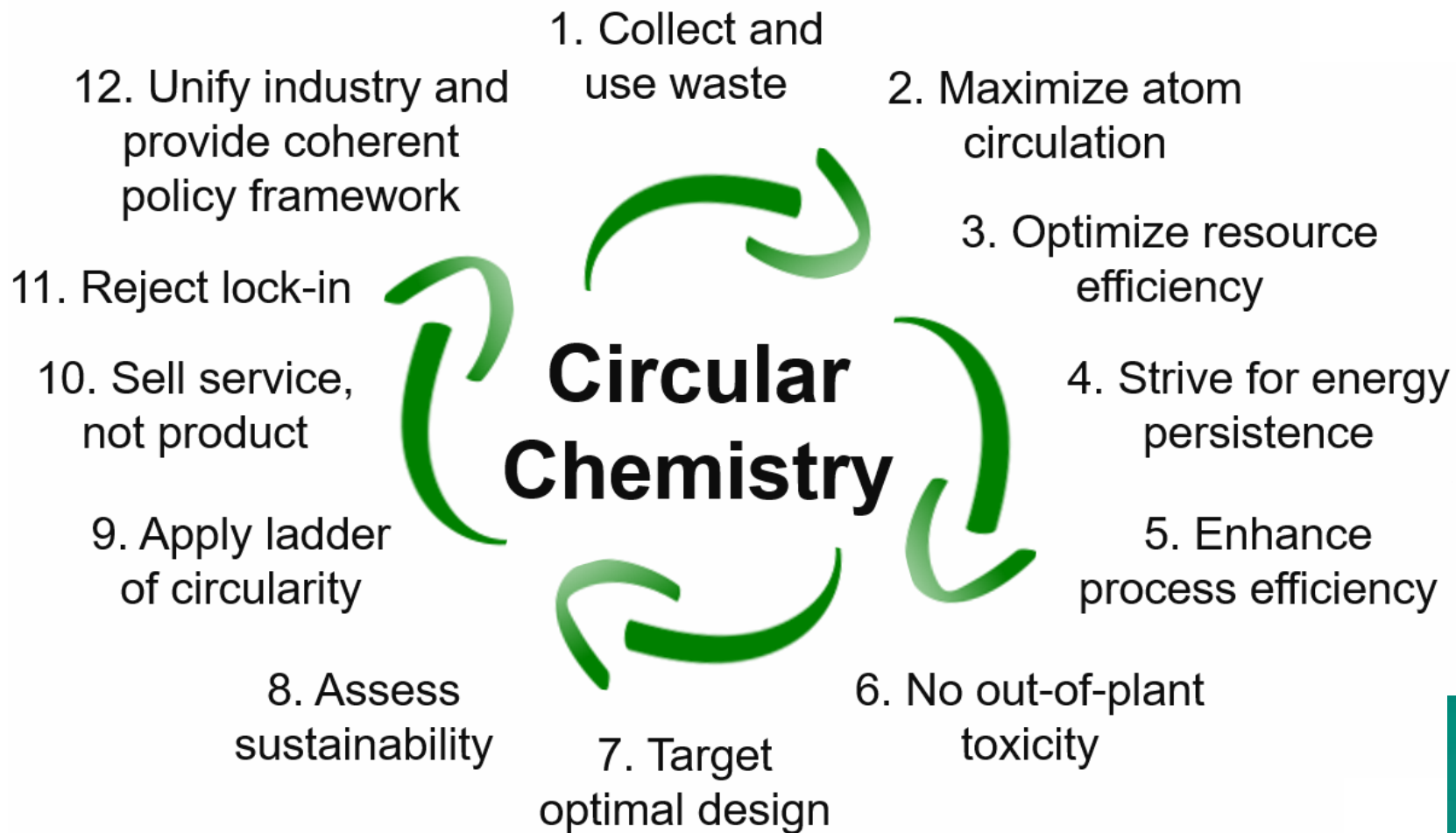
closed-loop, waste-free



Product = Resource = Renewable



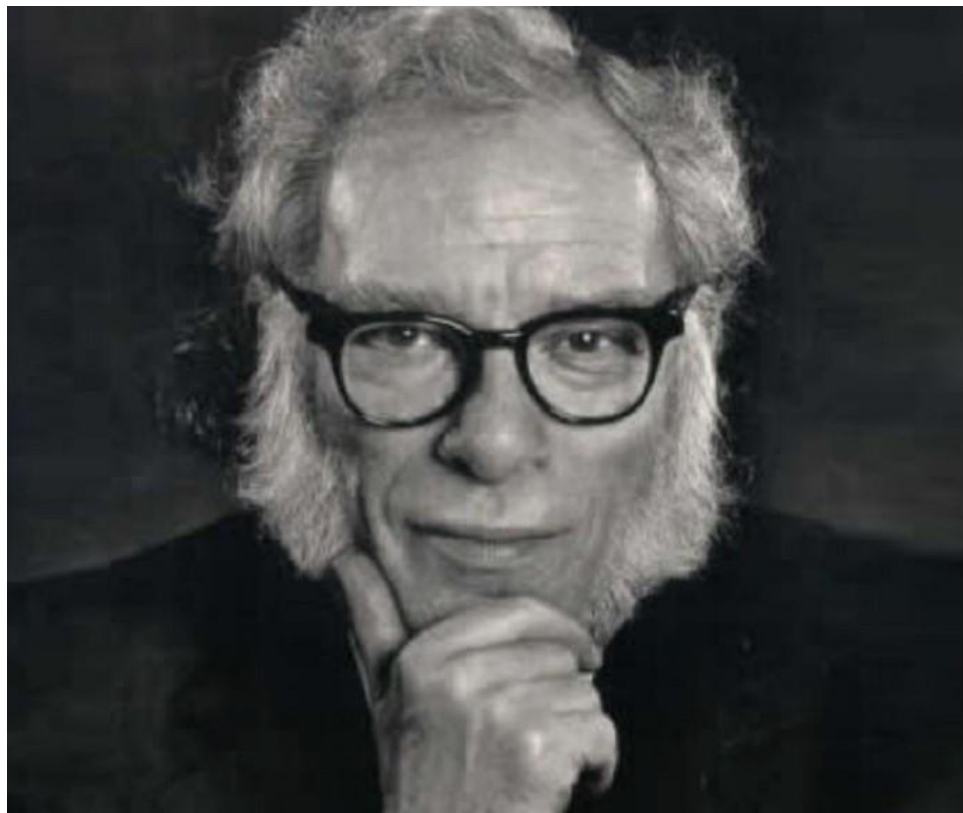
Circular technologies are urgently needed



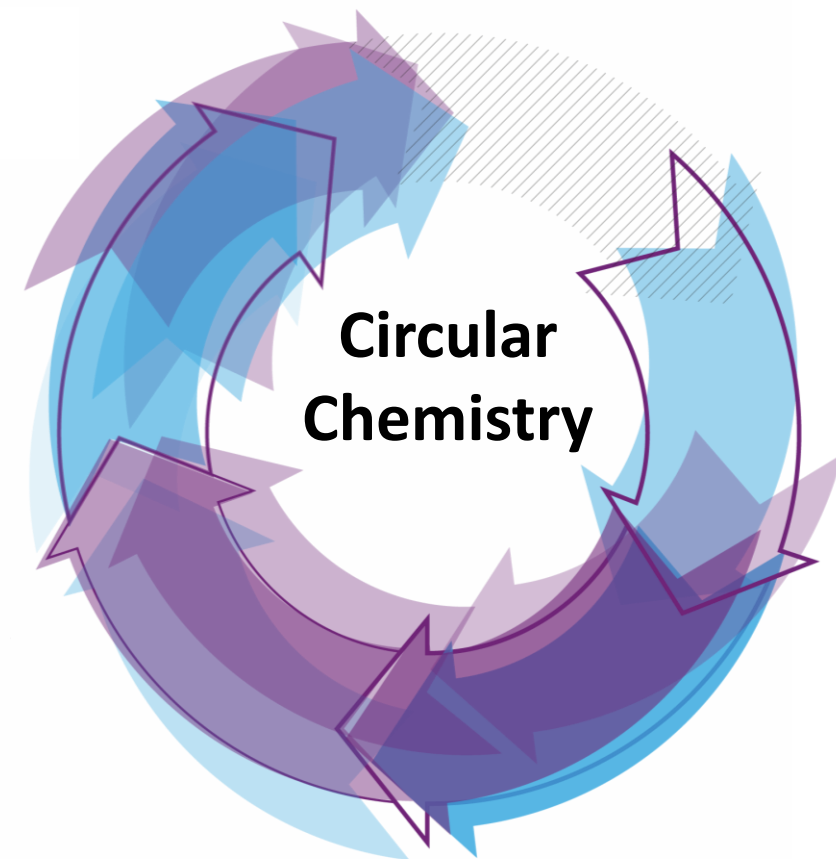
SUSTAINABILITY
Green chemistry comes full circle

'CHNOPS': Phosphorus **first**, as it is life's bottleneck

“for phosphorus there is neither substitute nor replacement”

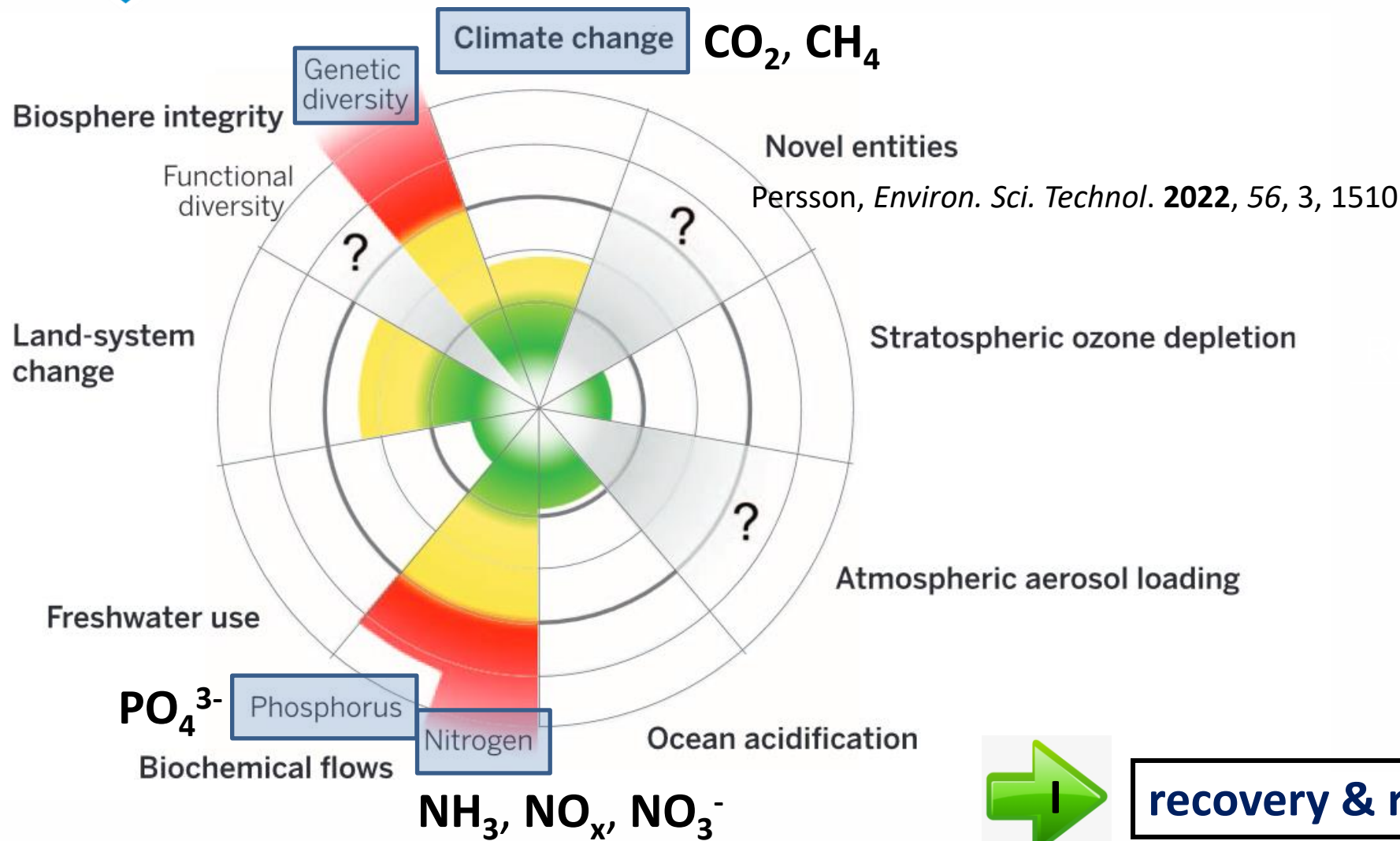


Isaac Asimov

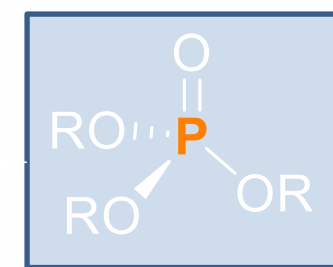


SUSTAINABILITY
Green chemistry comes full circle

'CHNOPS': circular technologies are urgently needed



Safe by Design



recovery & recycling of nutrients!






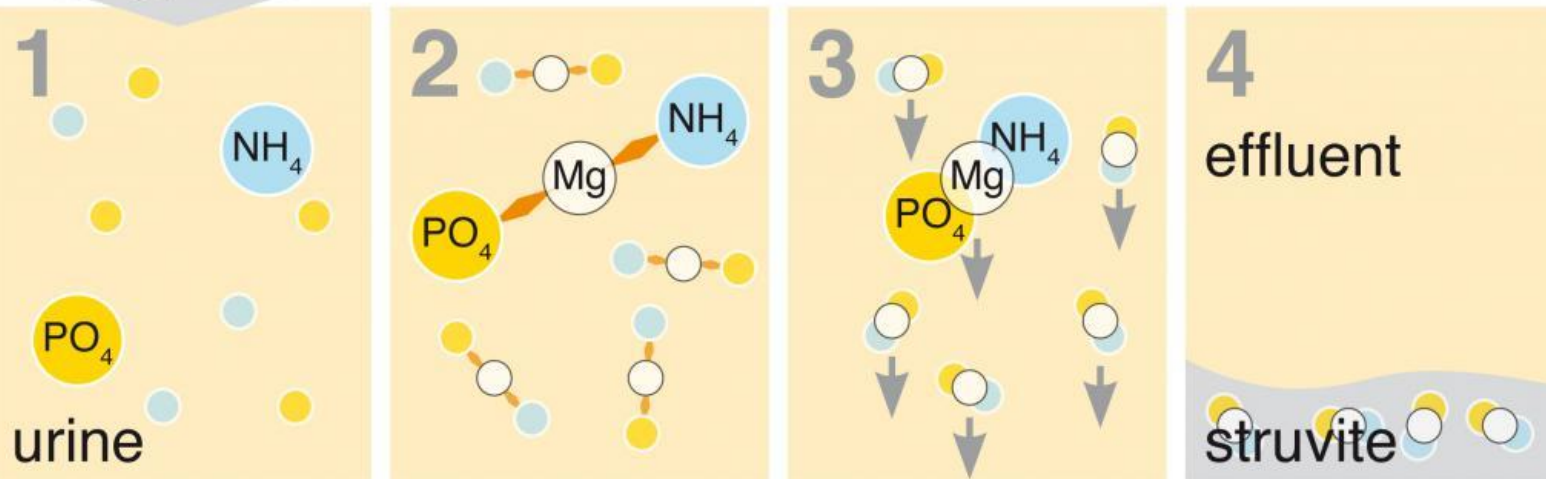
P-resource efficient?



Circular Chemistry: waste = resource!

- phosphate *and* ammonia

magnesium





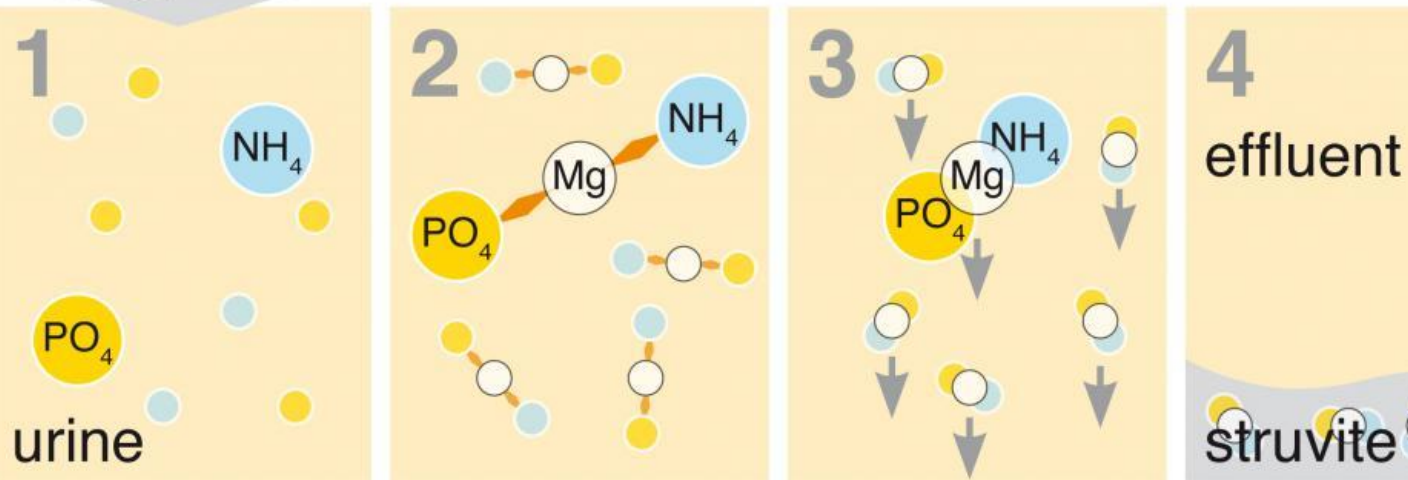
Recovery



Circular Chemistry: waste = resource!

- phosphate *and* ammonia

magnesium




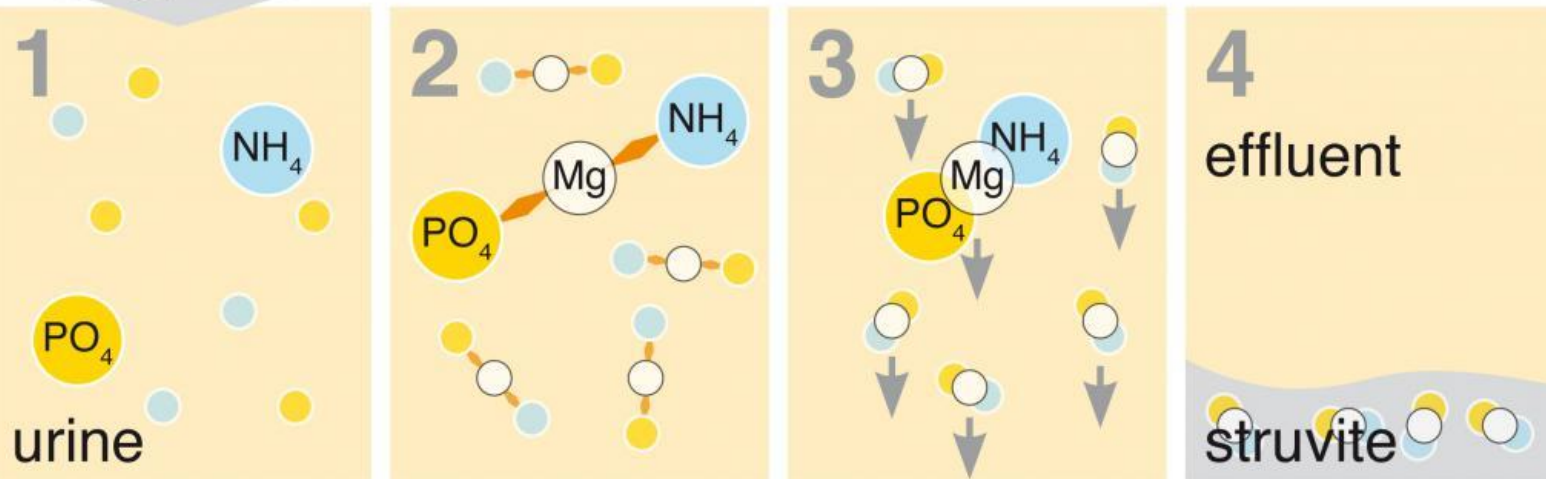
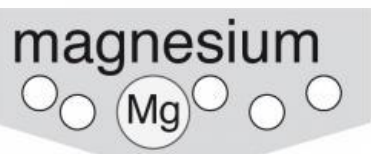
Recovery



pure gold?

Circular Chemistry: waste = resource!

- phosphate *and* ammonia



Recovery



SusP_{hos}



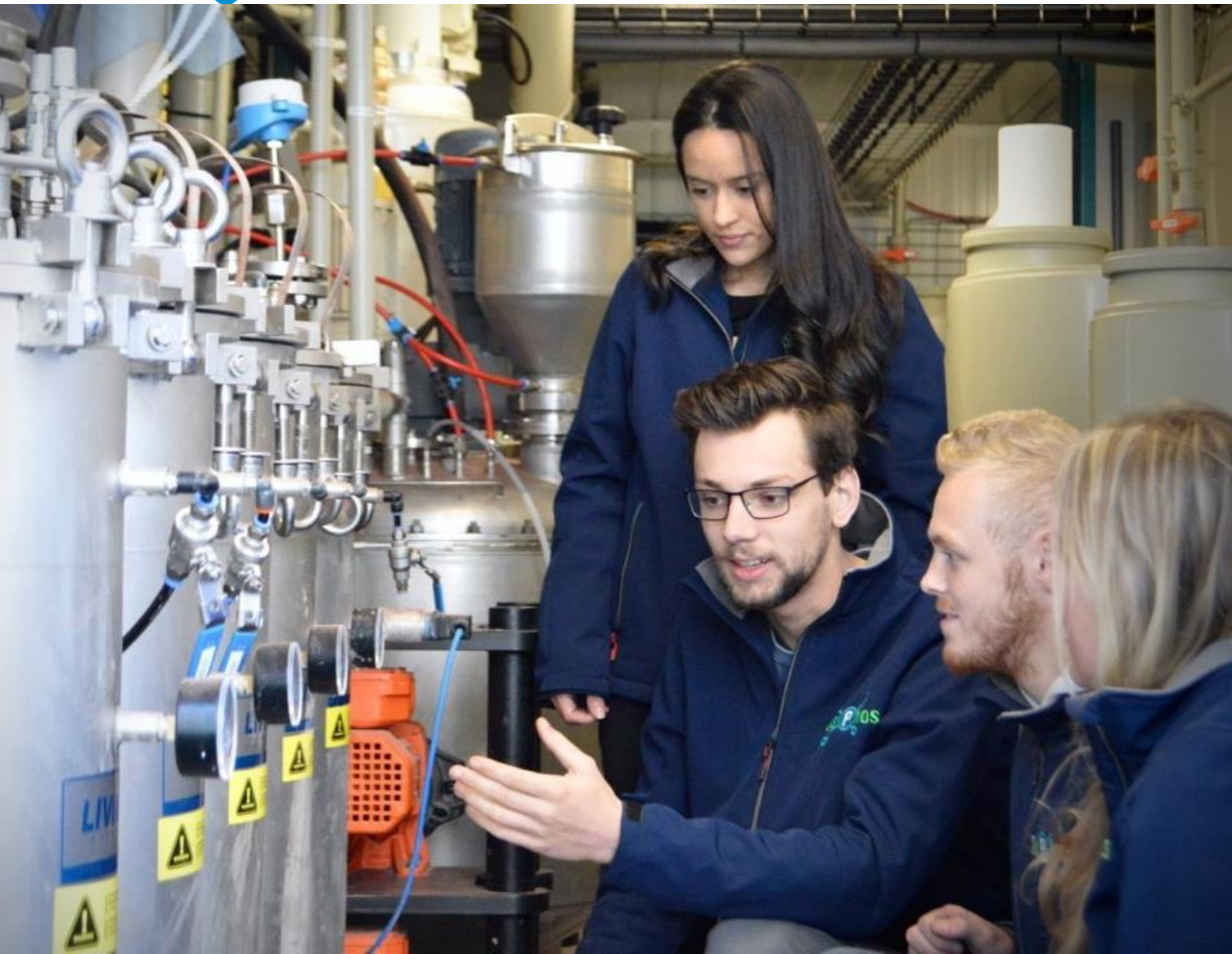
Recycling



monoammonium phosphate

WO2020/169708

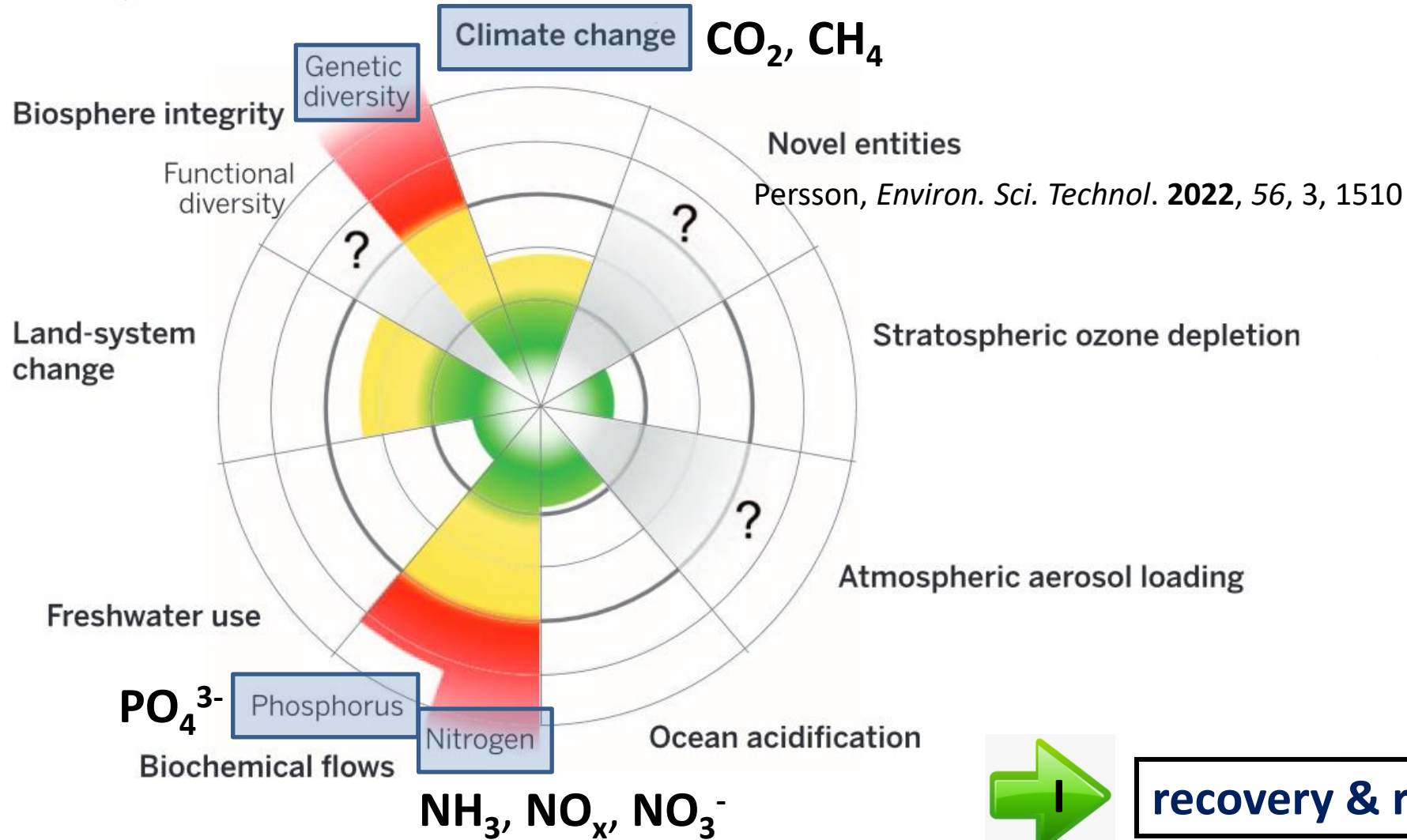
Pilot plant SusPhos, 2021



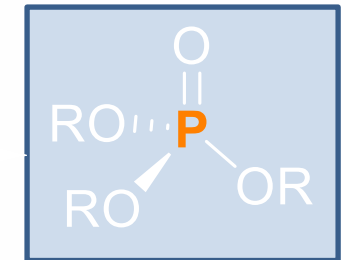
Towards a Circular Phosphate Economy



'CHNOPS': circular technologies are urgently needed



Safe by Design



recovery & recycling of nutrients!

Safe and Sustainable by Design

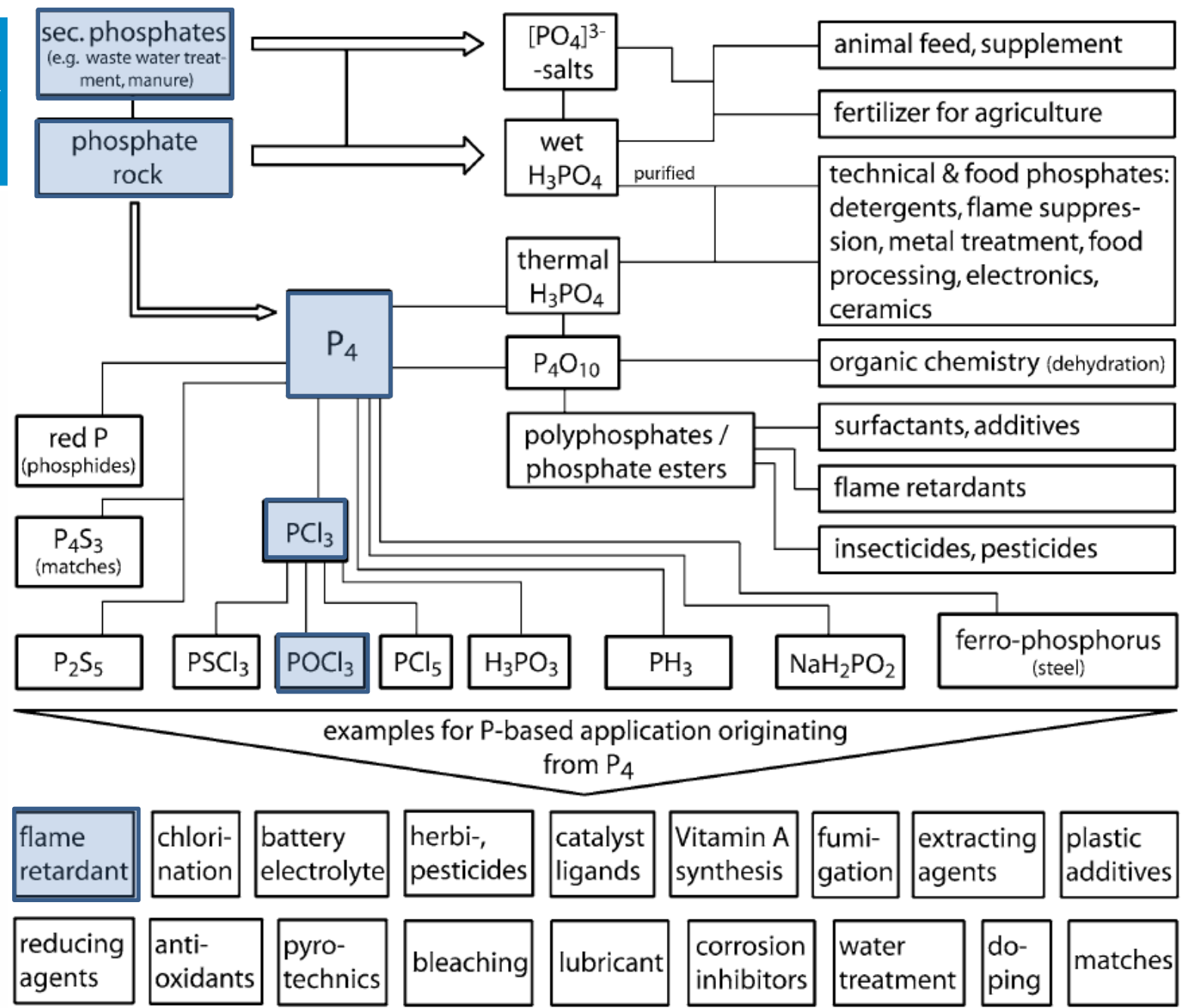
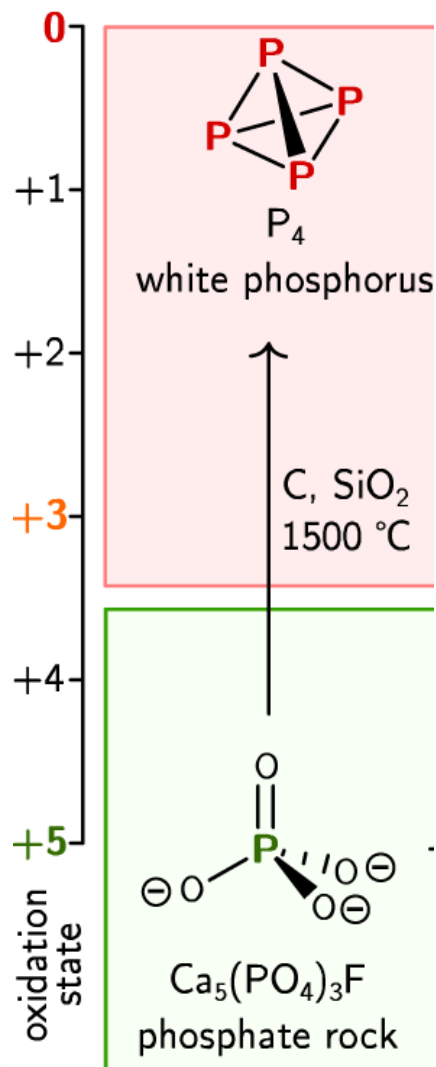
SAFE AND SUSTAINABLE- BY-DESIGN: BOOSTING INNOVATION AND GROWTH WITHIN THE EUROPEAN CHEMICAL INDUSTRY

OCTOBER 2021

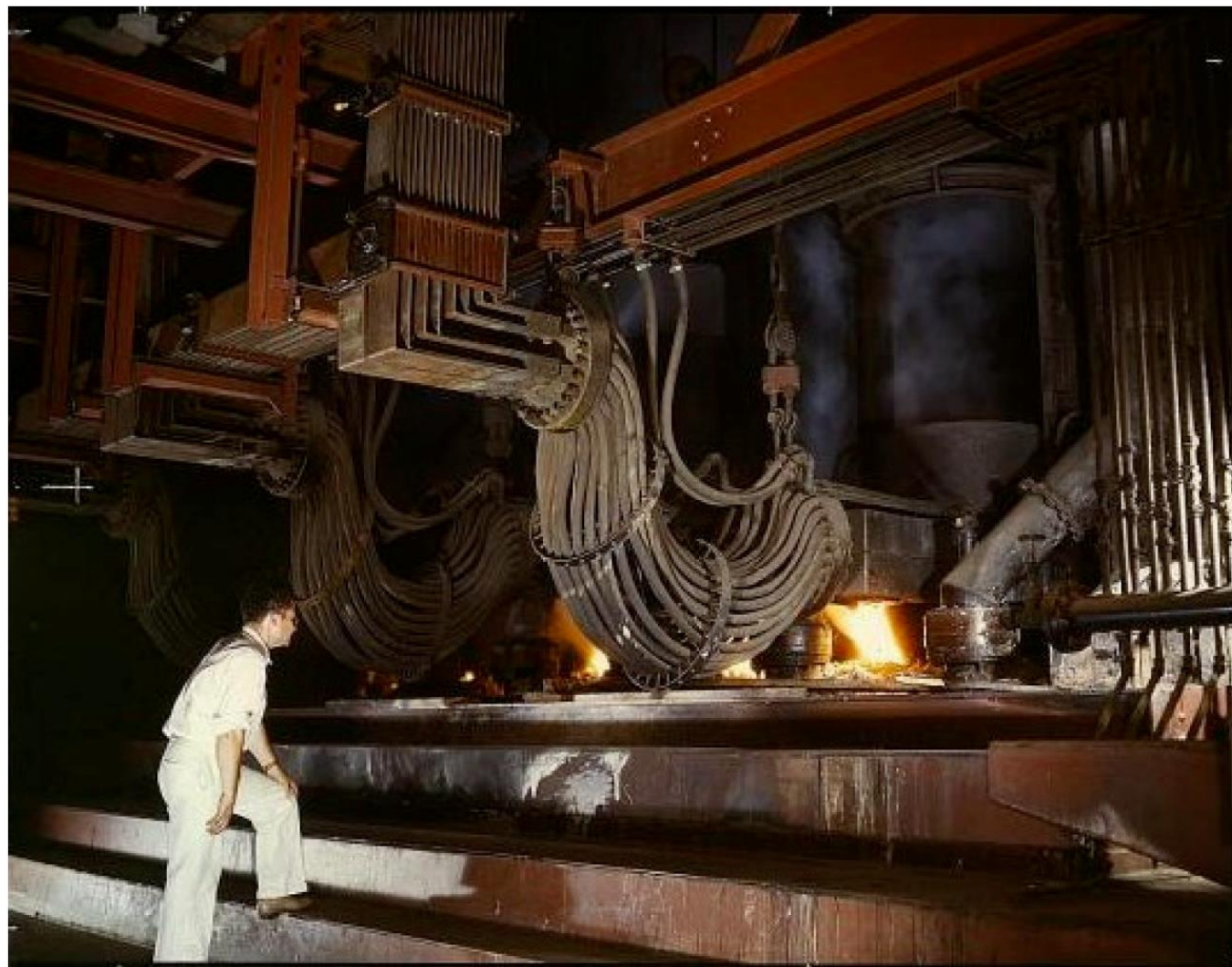
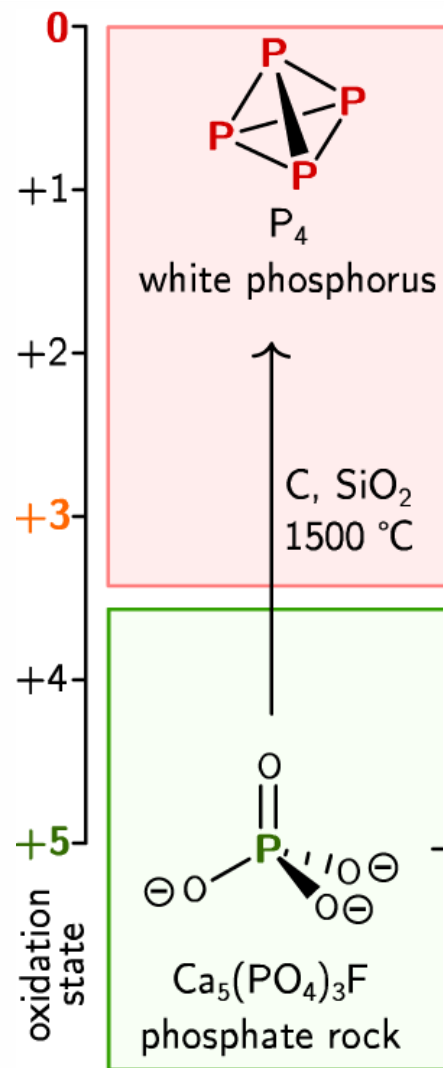
Hannah Flerlage, Steven Beijer, Anna Chernysheva



Sustaining P Chemistry



Redox Inefficient Phosphorus Chemistry



'CHNOPS': the origin of life...



Organophosphate Flame Retardants

- frequently detected in the environment
- many show toxic effects

ENVIRONMENTAL
Science & Technology

pubs.acs.org/est

Article

Glacial Melt Inputs of Organophosphate Ester Flame Retardants to the Largest High Arctic Lake

Yuxin Sun, Amila O. De Silva,* Kyra A. St Pierre, Derek C. G. Muir, Christine Spencer, Igor Lehnherr, and John J. MacInnis

ENVIRONMENTAL
Science & Technology **LETTERS**

Organophosphate Ester Flame Retardants: Are They a Regrettable Substitution for Polybrominated Diphenyl Ethers?

Arlene Blum,^{†,‡} Mamta Behl,[§] Linda S. Birnbaum,^{||} Miriam L. Diamond,[⊥] Allison Phillips,[•] Veena Singla,[#] Nisha S. Sipes,[§] Heather M. Stapleton,[@] and Marta Venier^{*,▽}

Societal Impact

SUSTAINABLE-BY-DESIGN

Societal empowerment
(e.g. better public engagement, consumer acceptance)



Regulatory preparedness
(e.g. adaptive regulation, standards)

**Advanced properties
Functional
Efficient process
design**

Industrial relevance
(e.g. more cost effective, faster to market)

REUSE

RECOVER

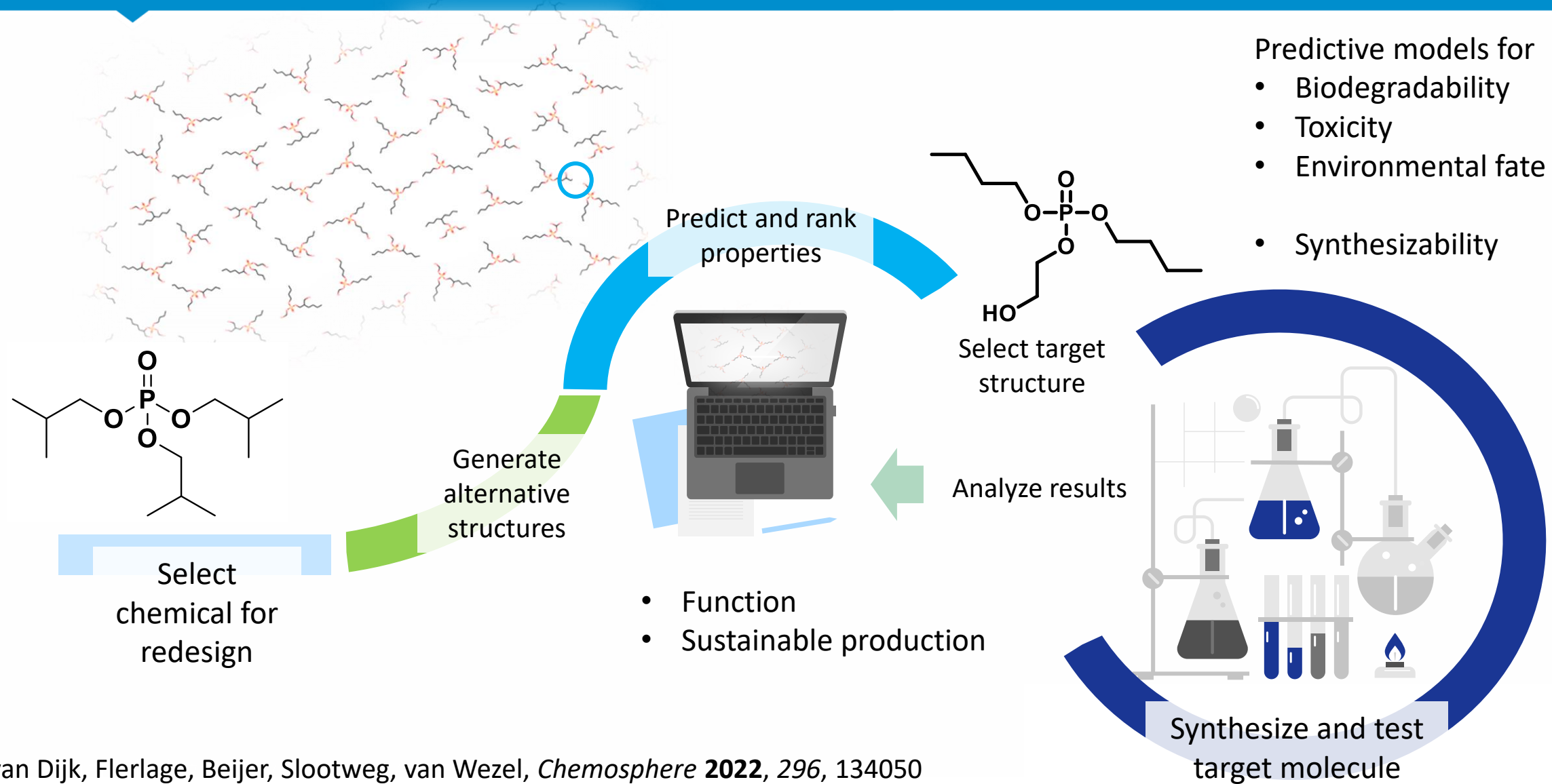
REPAIR

RECYCLE

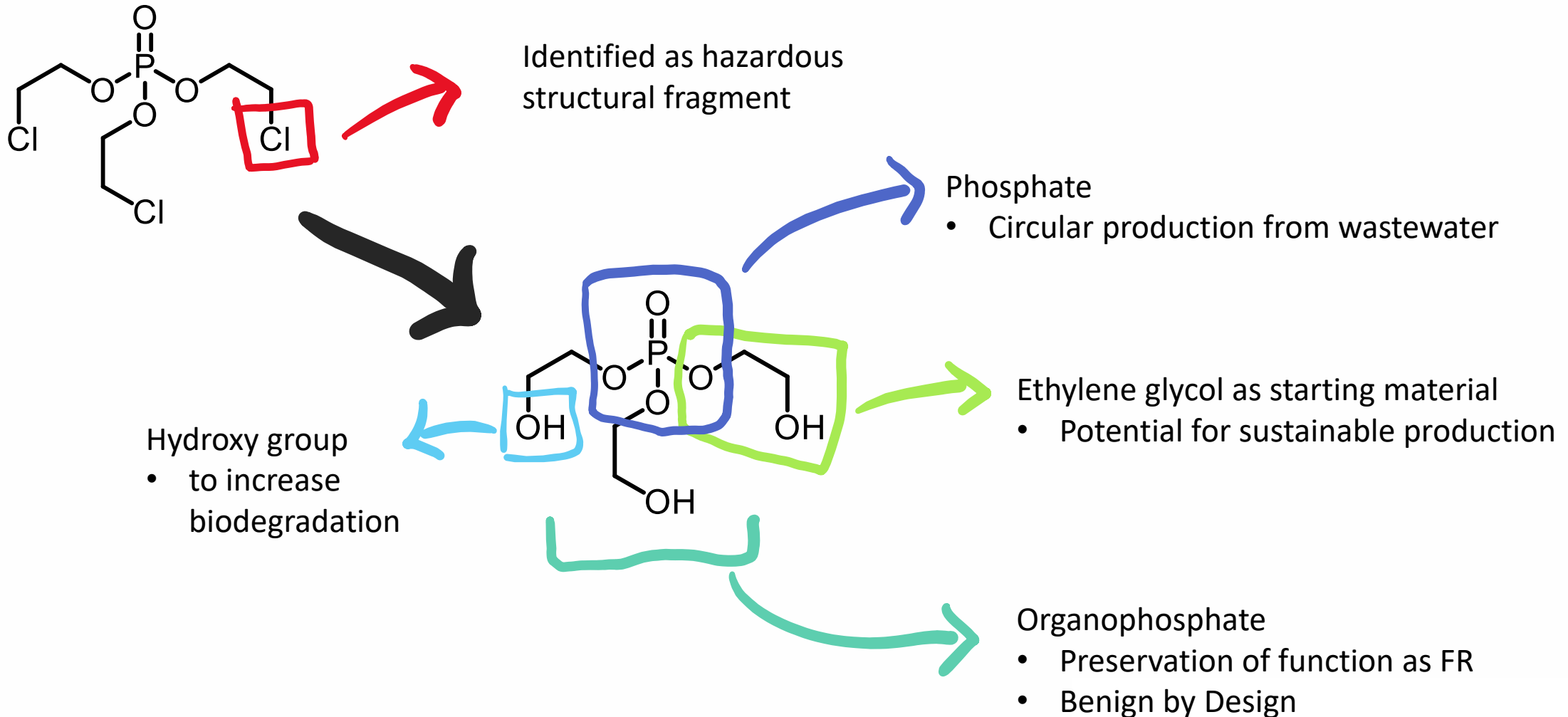
combine **Synthesis, Design & Environmental Impact**

LIFE CYCLE ASSESSMENT

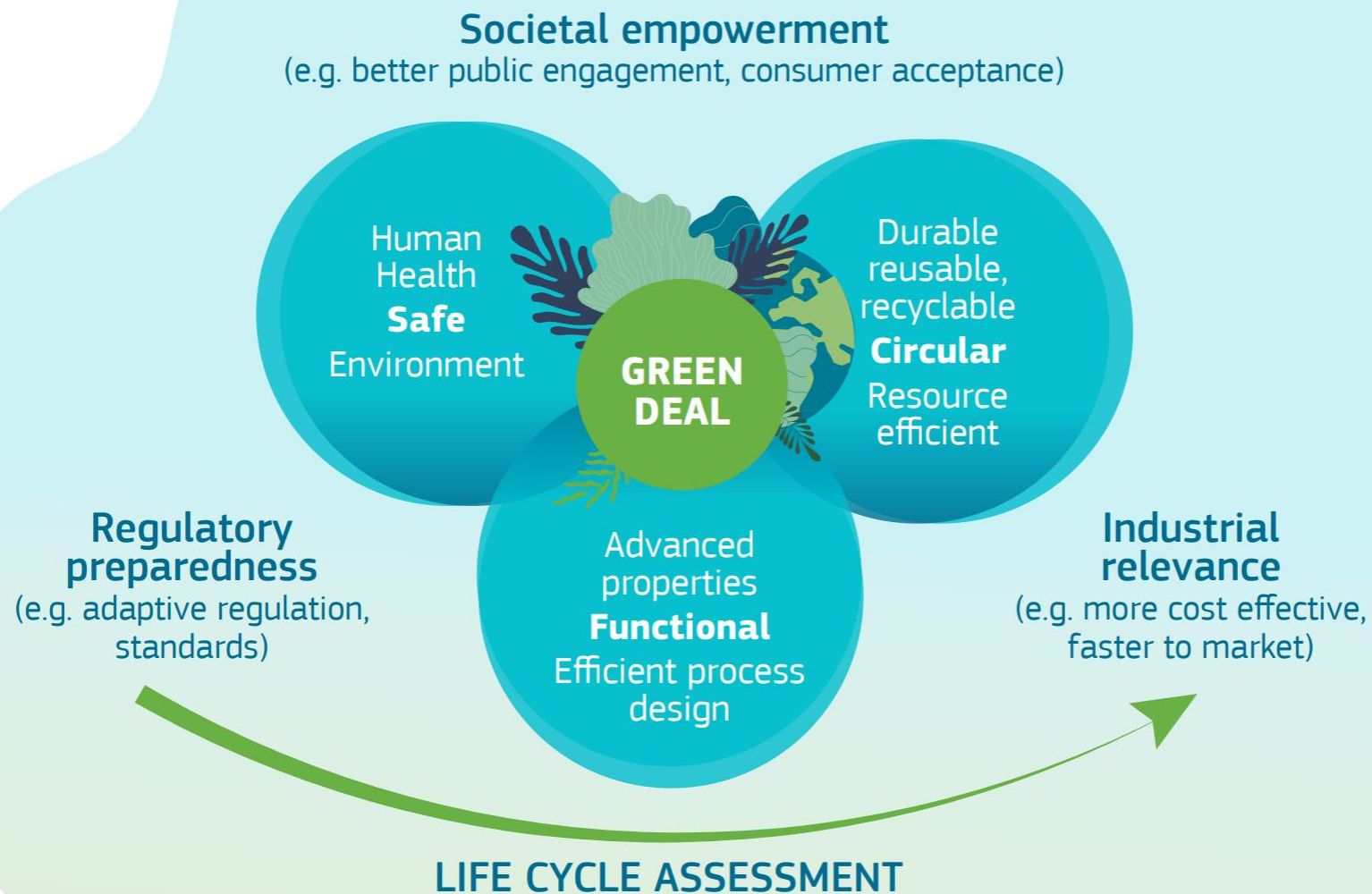
Computer-aided redesign framework



Current design: Substitute Cl with OH



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