

# Chemie van de toekomst: Groen én Circulair



Chris Slootweg



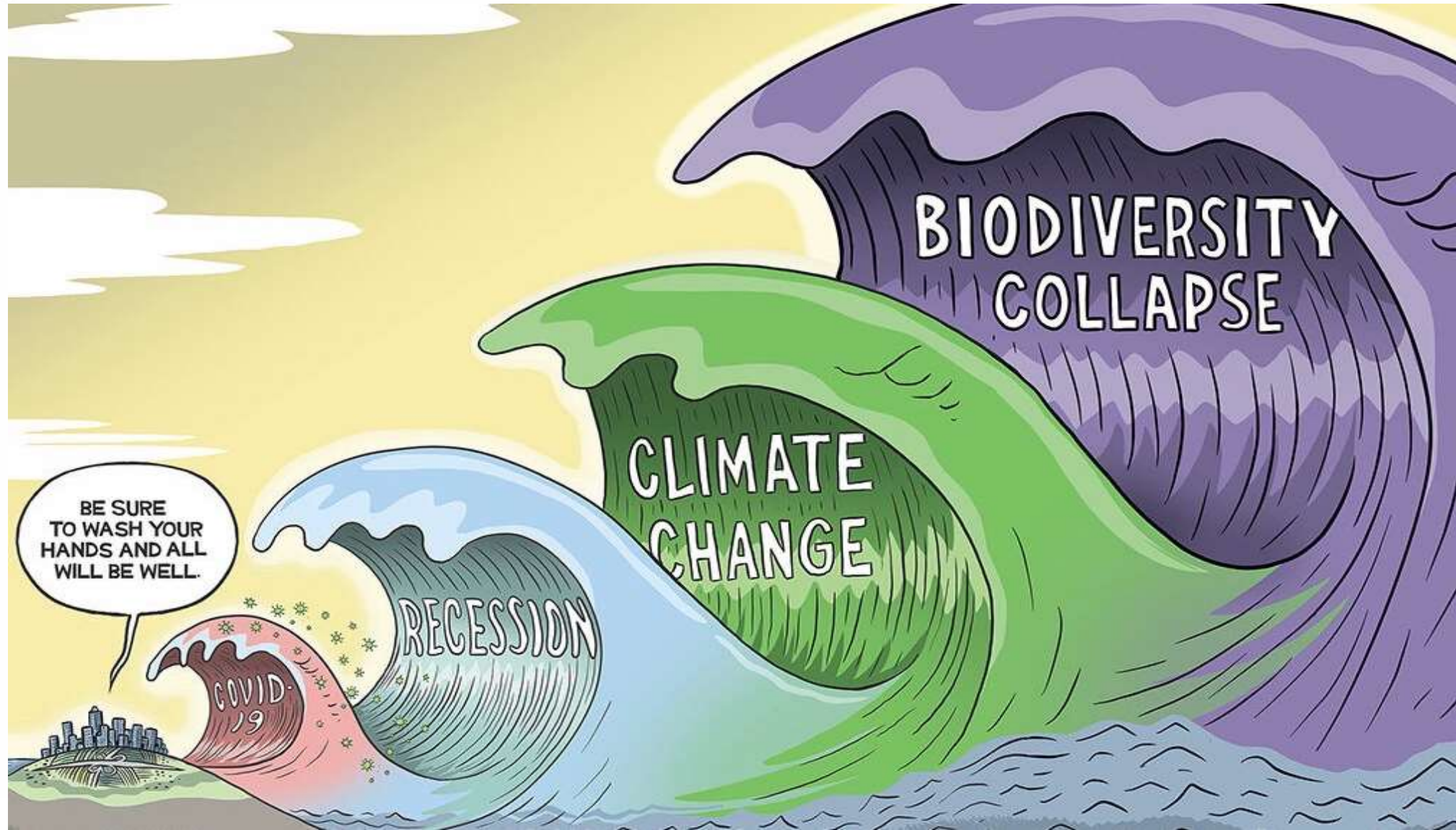
UNIVERSITEIT VAN AMSTERDAM

# 'CHNOPS': the origin of life...

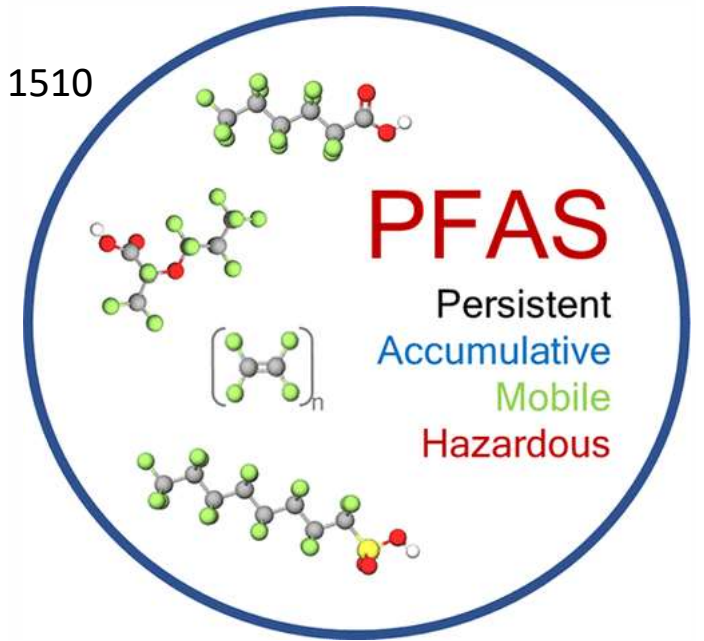
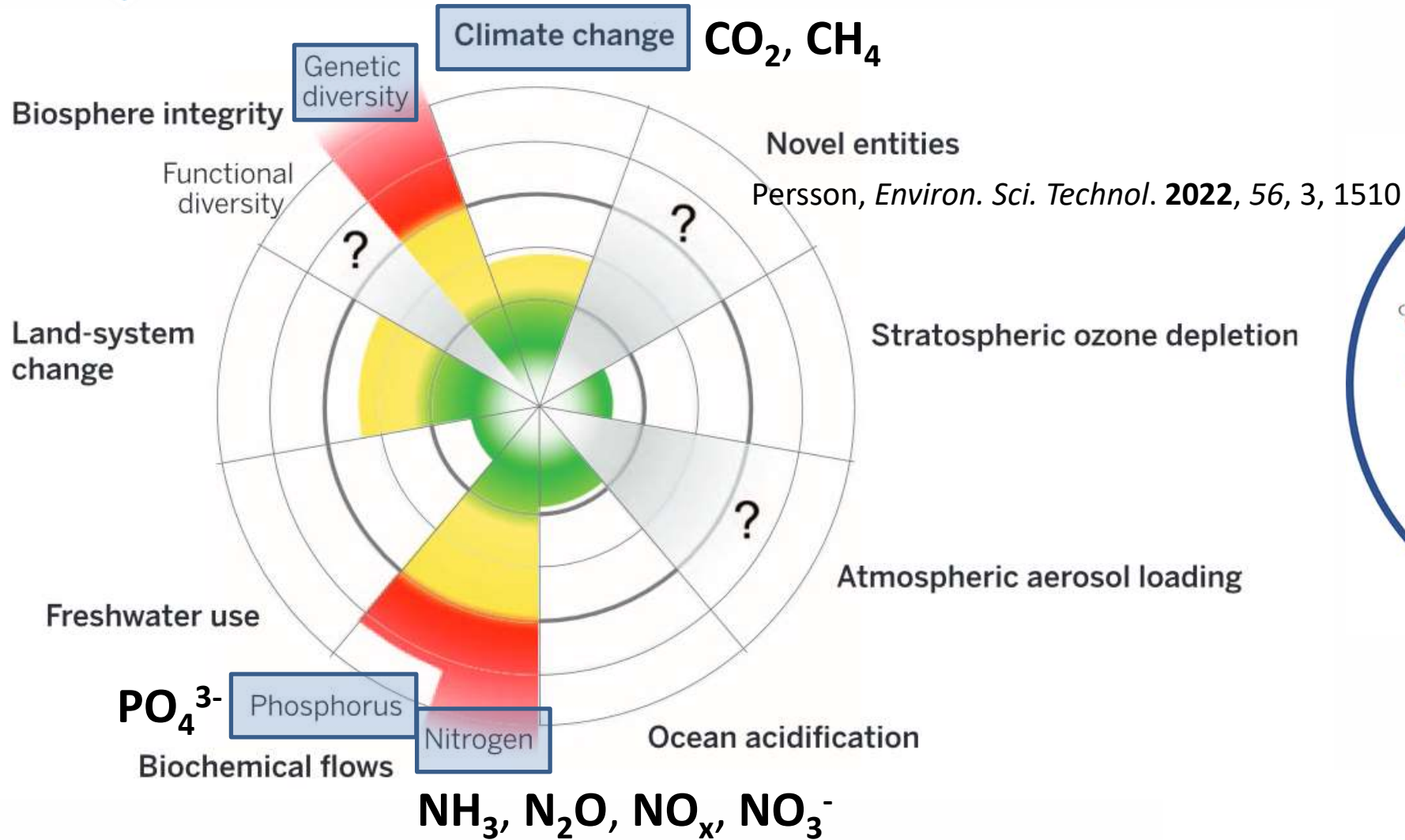


Benjamin  
Gunn

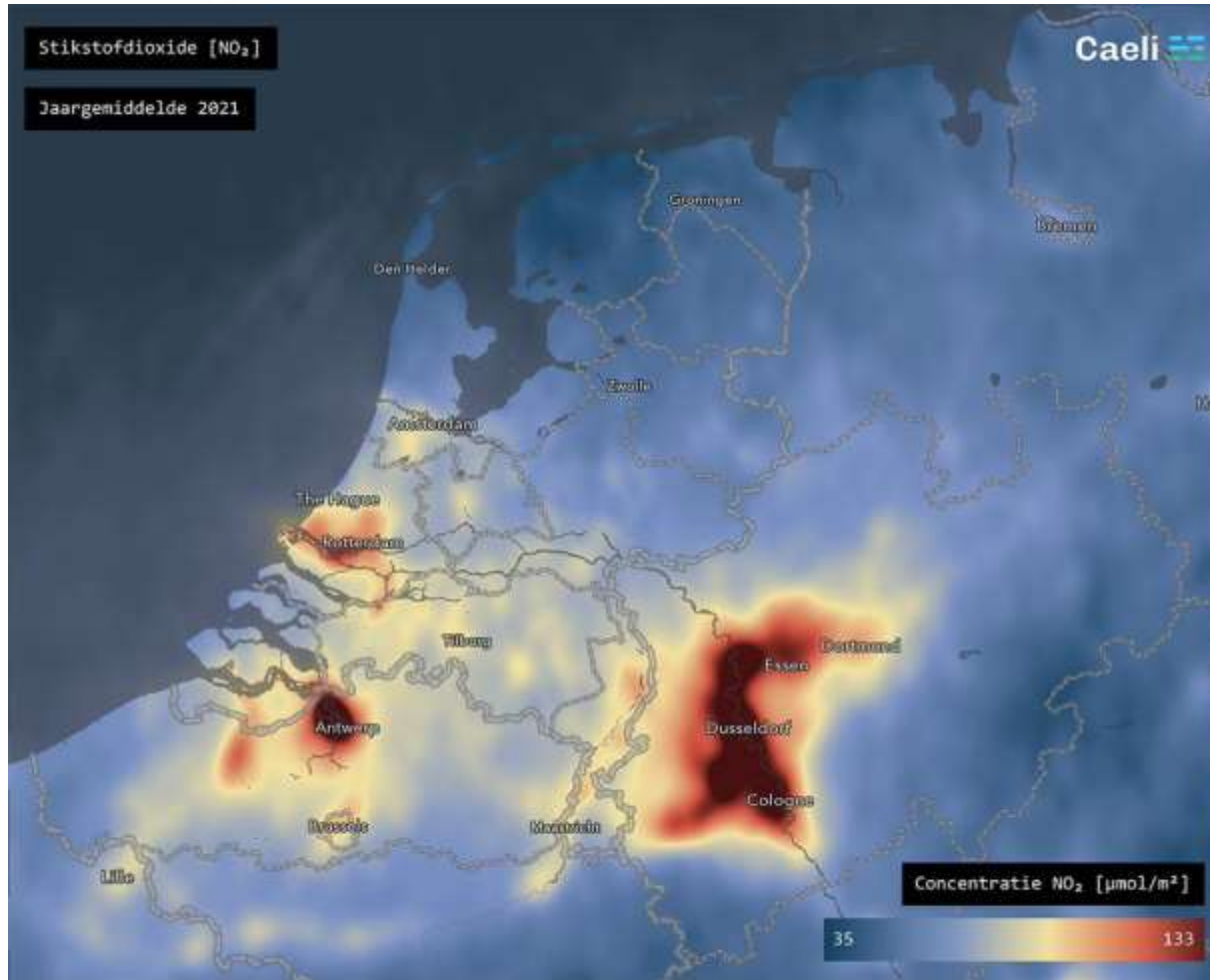
# 'CHNOPS': the origin of waste...



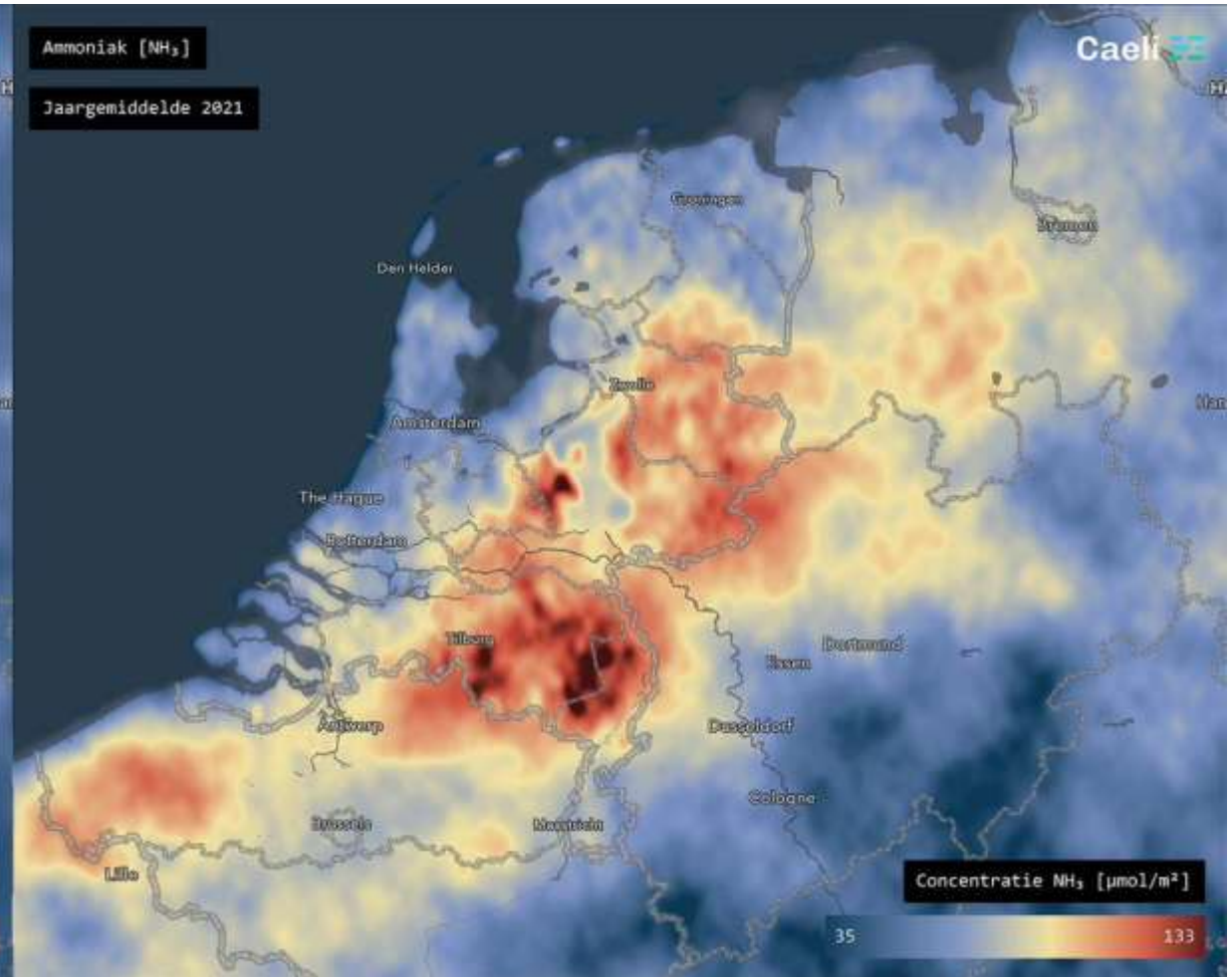
# 'CHNOPS': the origin of waste...



# 'CHNOPS': the origin of waste...



NH<sub>3</sub>, N<sub>2</sub>O, NO<sub>x</sub>, NO<sub>3</sub><sup>-</sup>



NH<sub>3</sub>

'CHNOPS': the origin of wa

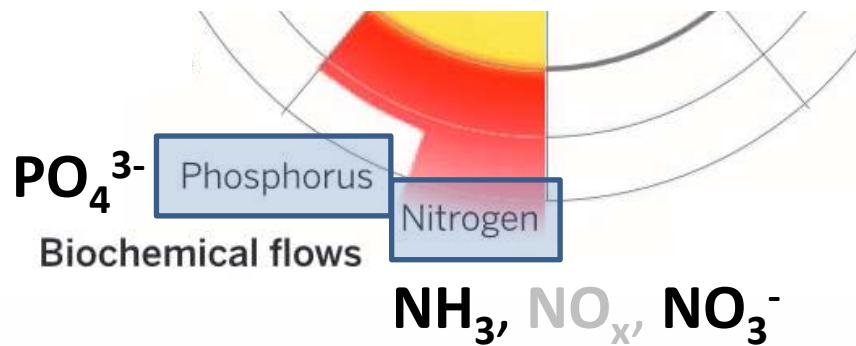
The Observer Pollution

# 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



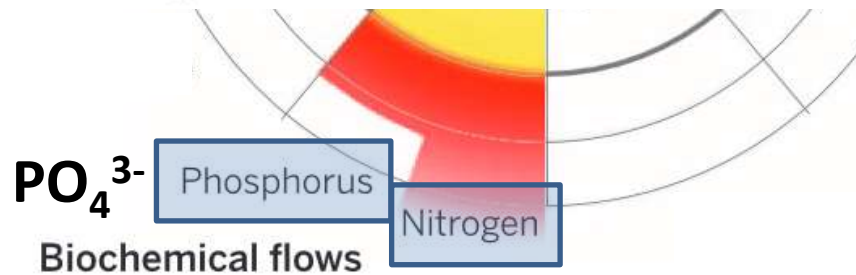
Robin McKie, Science editor

Sun 12 Mar 2023 09:00 GMT

# 'CHNOPS': the origin of wa

## The Phosphorus Cycle in Nature

FOR his presidential address to the Geological Section of the Congress of the South Eastern Union of Scientific Societies, held on October 14, Dr. K. P. Oakley took as his subject "Man and the Migrations of Phosphorus". For some time after the earth's formation, the phosphorus cycle in the sea was simple, the phosphate ions being built up into the earliest forms of organic life and released again at their death, the only loss occurring through the precipitation of phosphate ions accumulated at the lower levels, with the formation of sedimentary rock phosphate beds. Following the emergence of life from the sea and the



*Nature* 1944, 154, 762–763

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

blur MODERN LIFE IS RUBBISH

CHEMISTRY



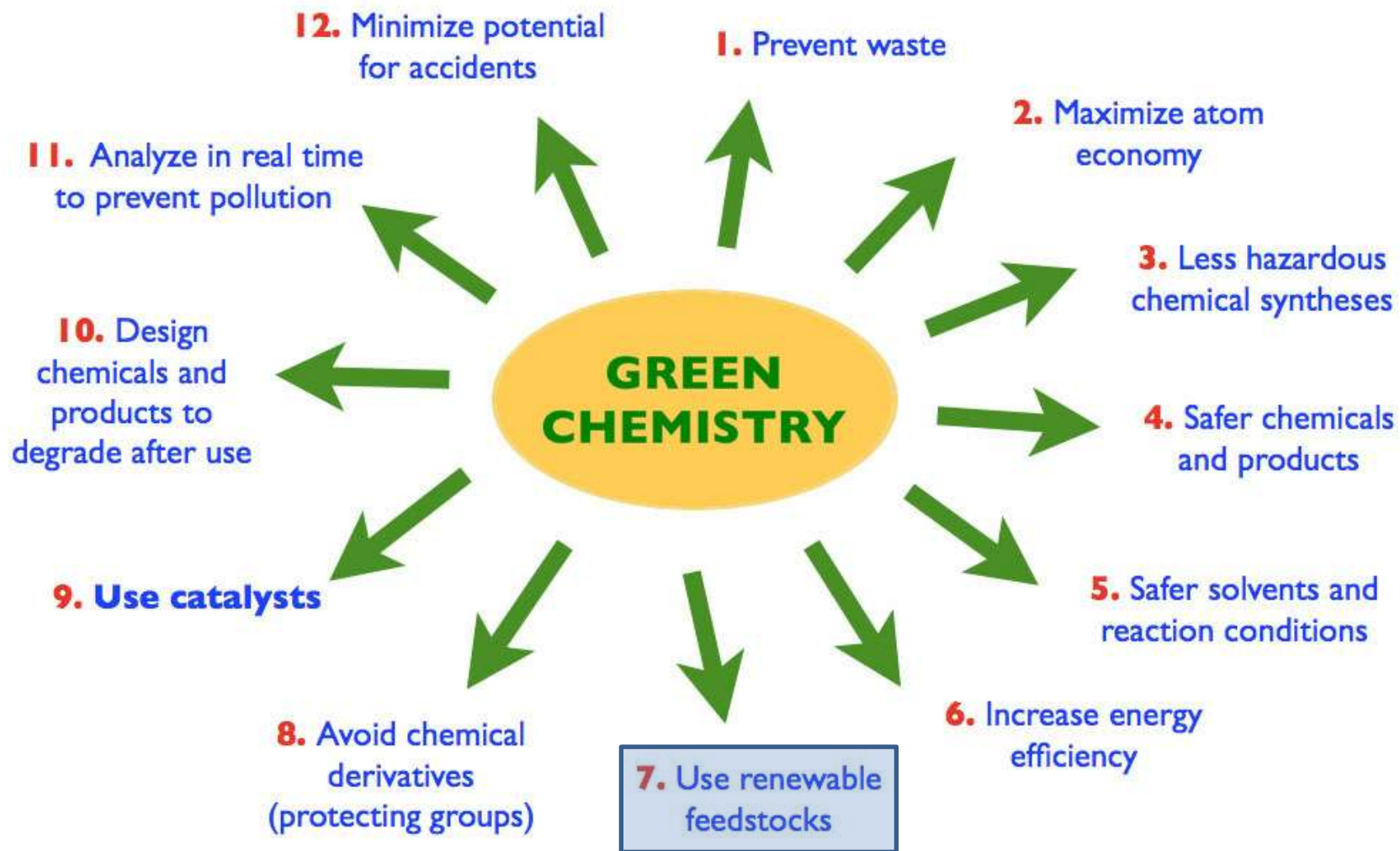


Radical Change is needed..

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

*– Albert Einstein*

# 12 Guiding Principles?



Just a Different Feedstock...

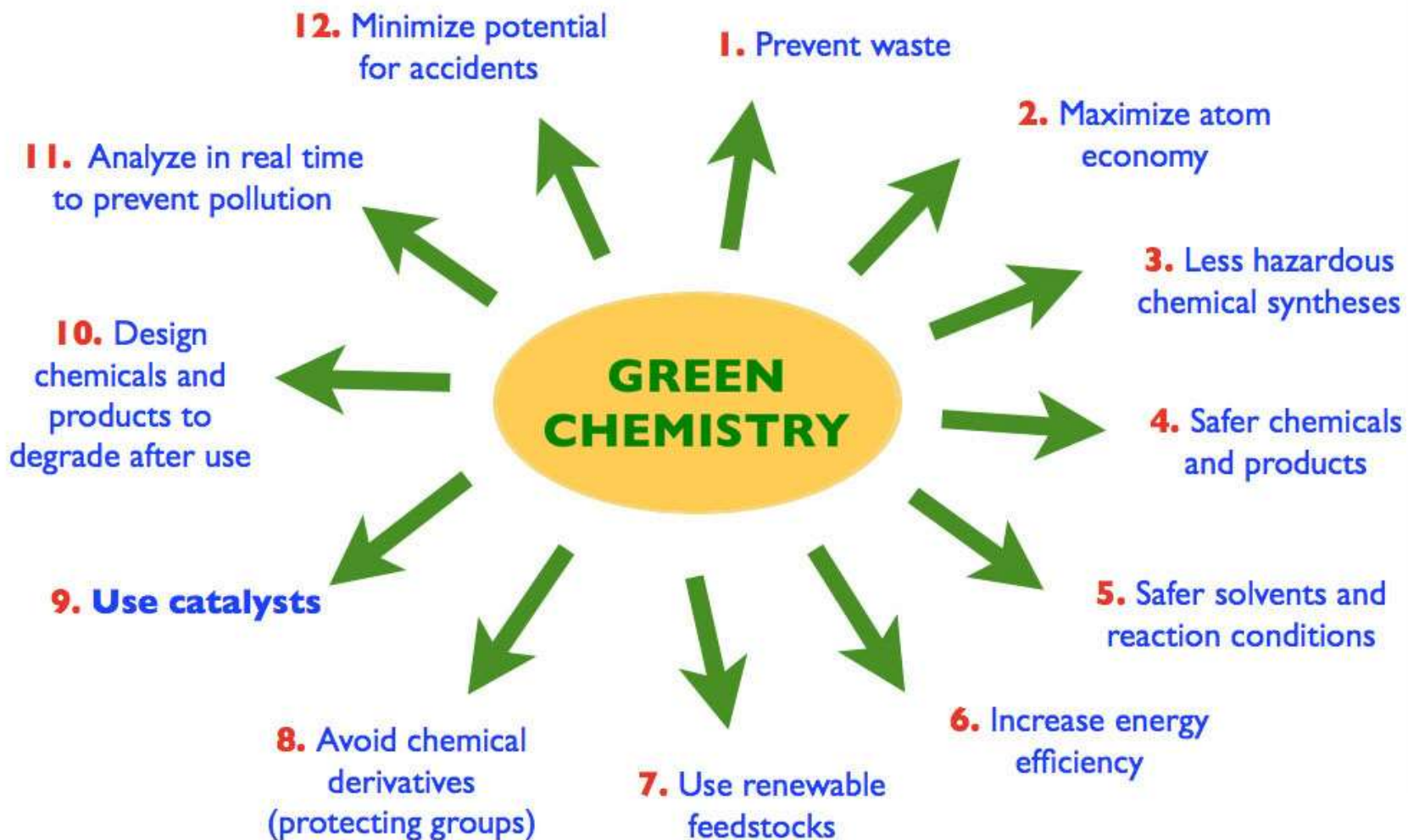
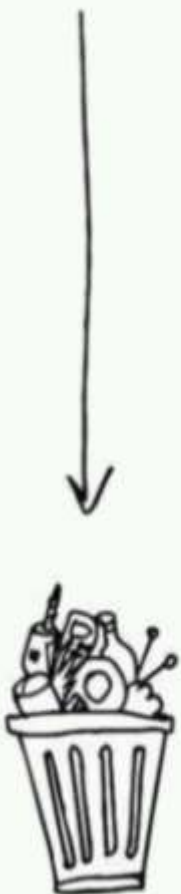


# Bio-based Plastic Soup?



# 12 Guiding Principles to optimise linear processes

LINEAR ECONOMY



Anastas and Warner (1998)

# Circular technologies are urgently needed

LINEAR ECONOMY

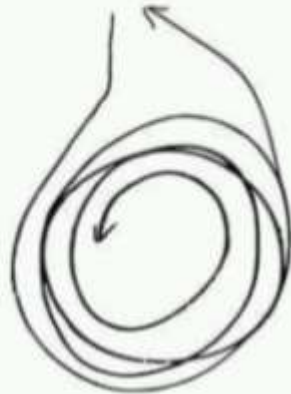


Waste  
=  
Resource

RECYCLING ECONOMY



CIRCULAR ECONOMY



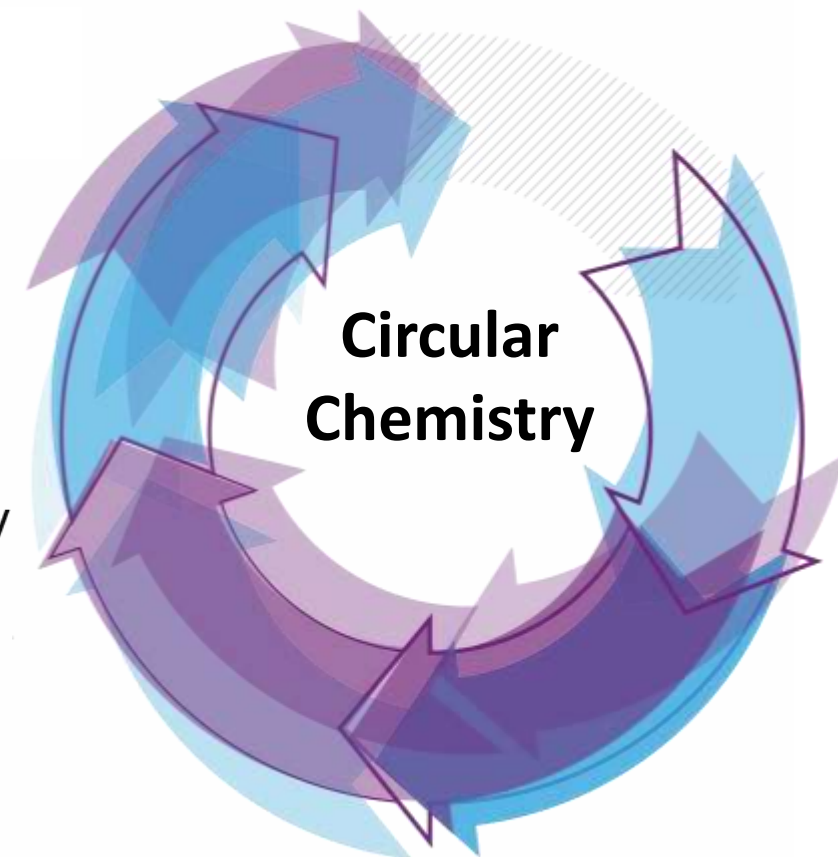
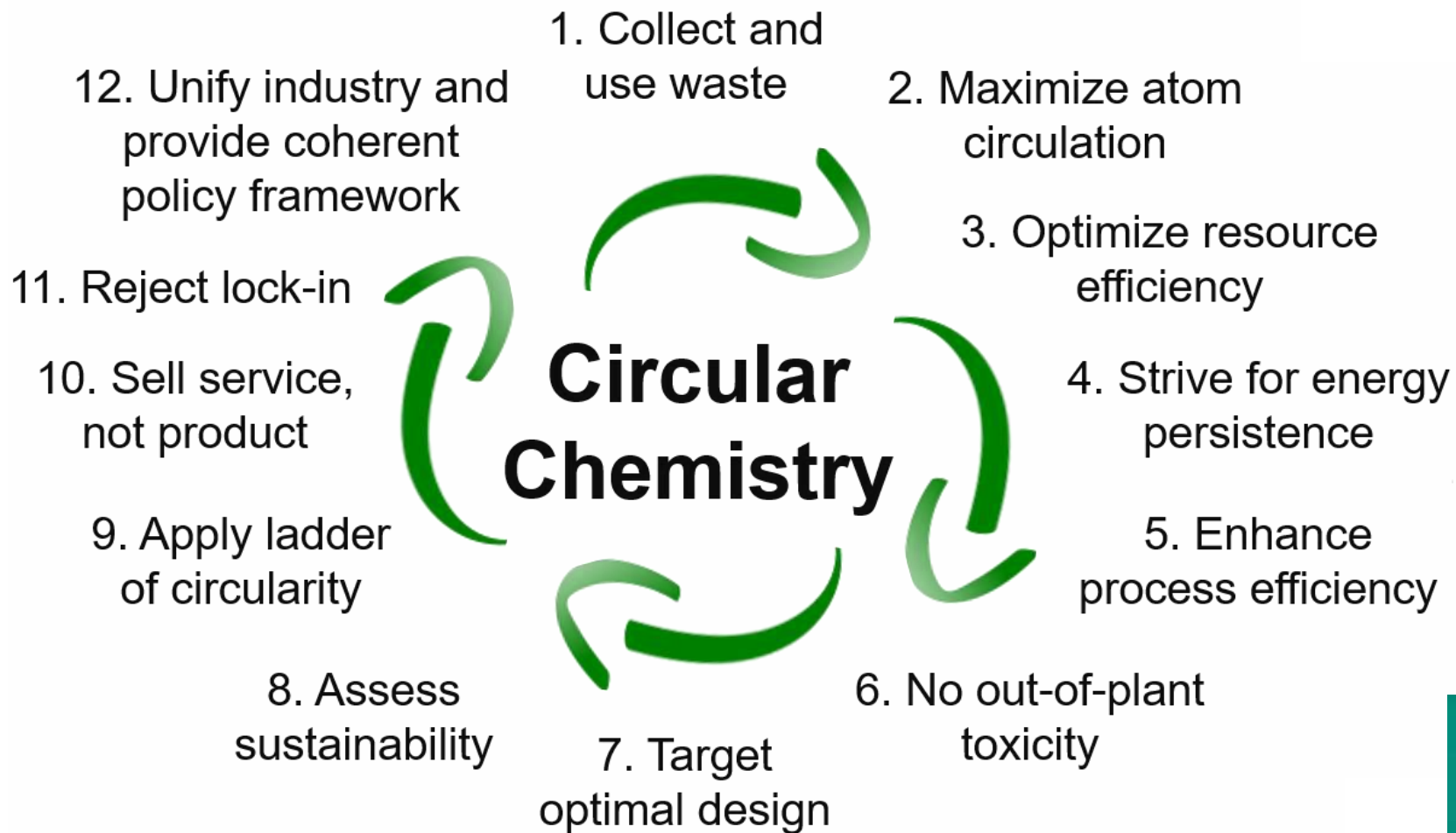
closed-loop,  
waste-free



Product  
=  
Resource  
=  
Renewable

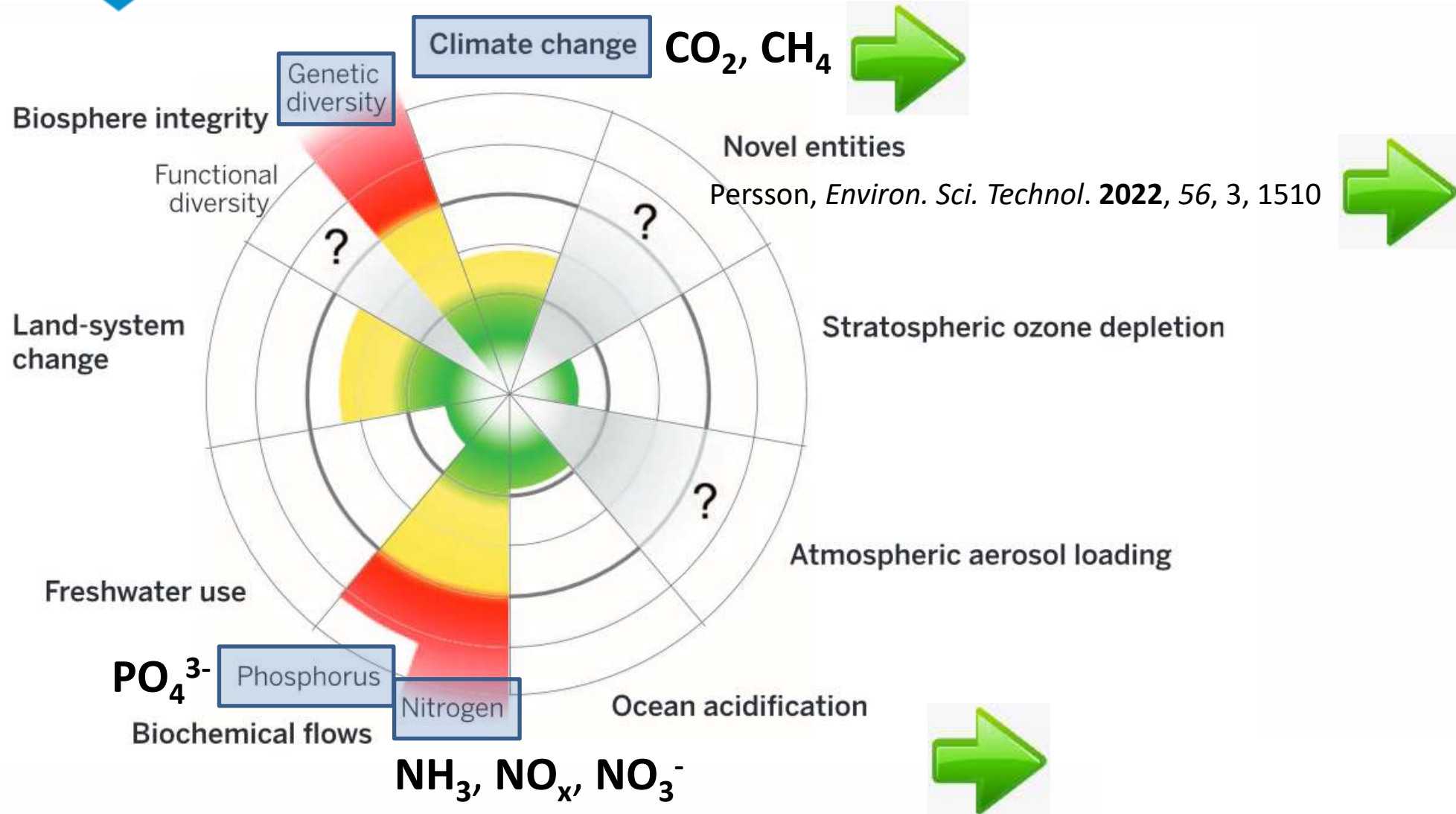


# Circular technologies are urgently needed



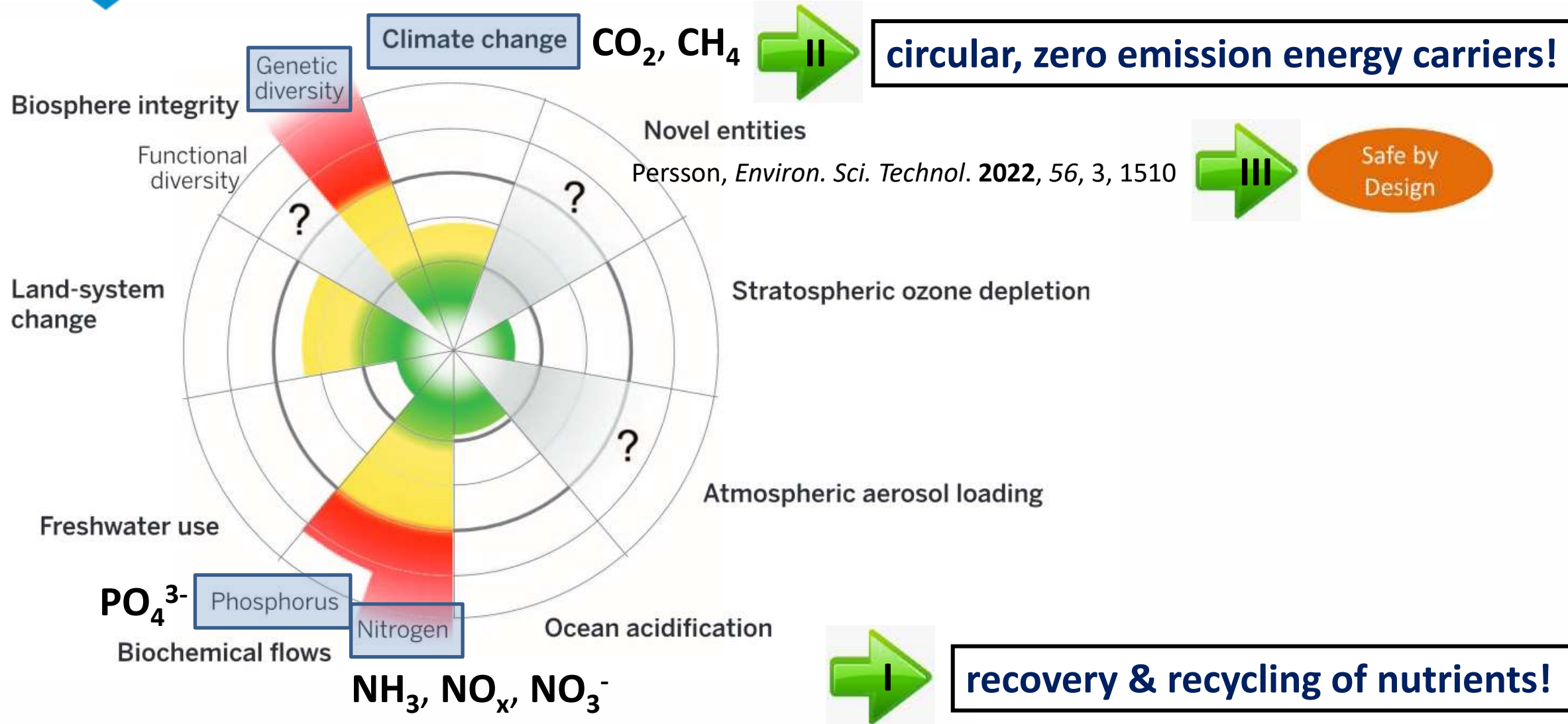
**SUSTAINABILITY**  
Green chemistry comes full circle

# 'CHNOPS': circular technologies are urgently needed





# 'CHNOPS': circular technologies are urgently needed





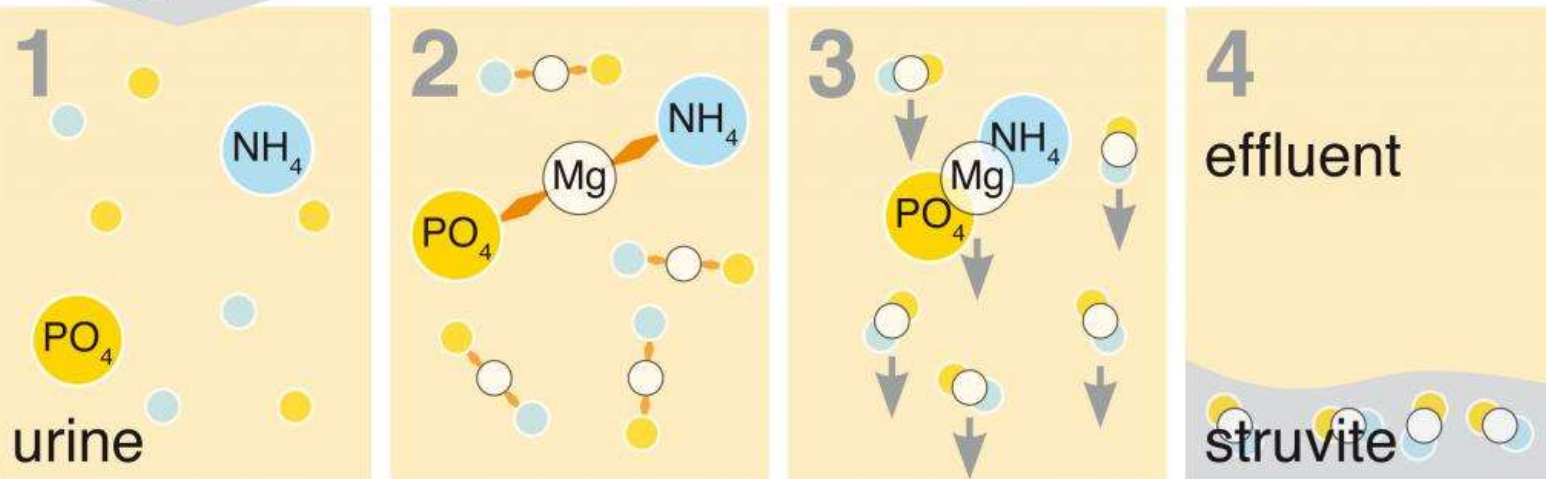
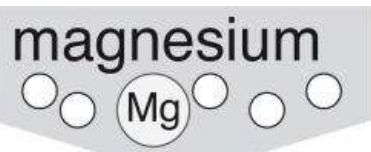


P-resource efficient?



# Circular Chemistry: waste = resource!

- phosphate *and* ammonia

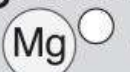


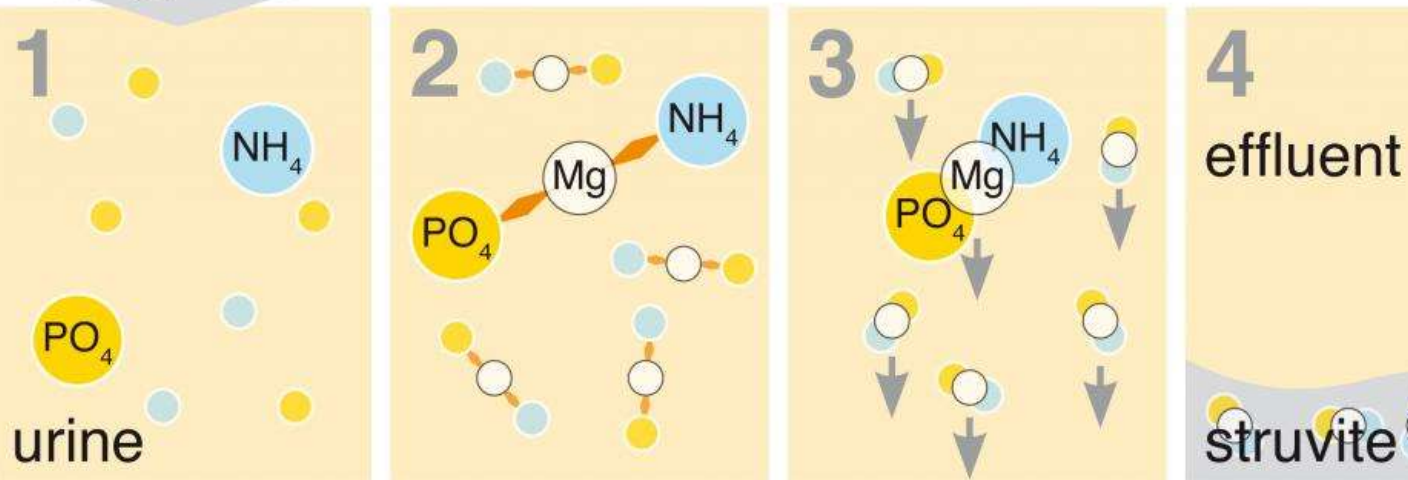
Recovery



# Circular Chemistry: waste = resource!

- phosphate *and* ammonia

magnesium  




Recovery

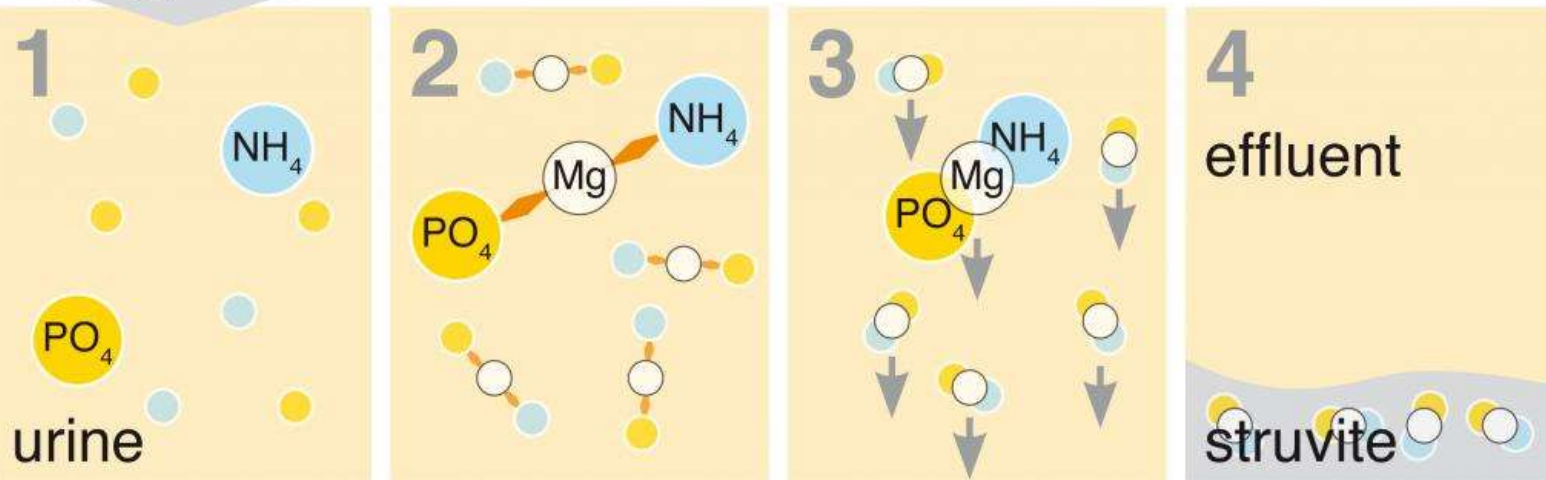
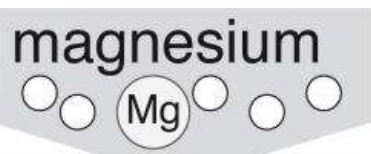


pure gold?



# Circular Chemistry: waste = resource!

- phosphate *and* ammonia



Recovery



Recycling



monoammonium phosphate

WO2020/169708

# Circular Chemistry: practicum bij jou in de klas?

- Pilot vanaf februari: testklassen gezocht
- Opgeven bij de stand van Bètapartners op de infomarkt



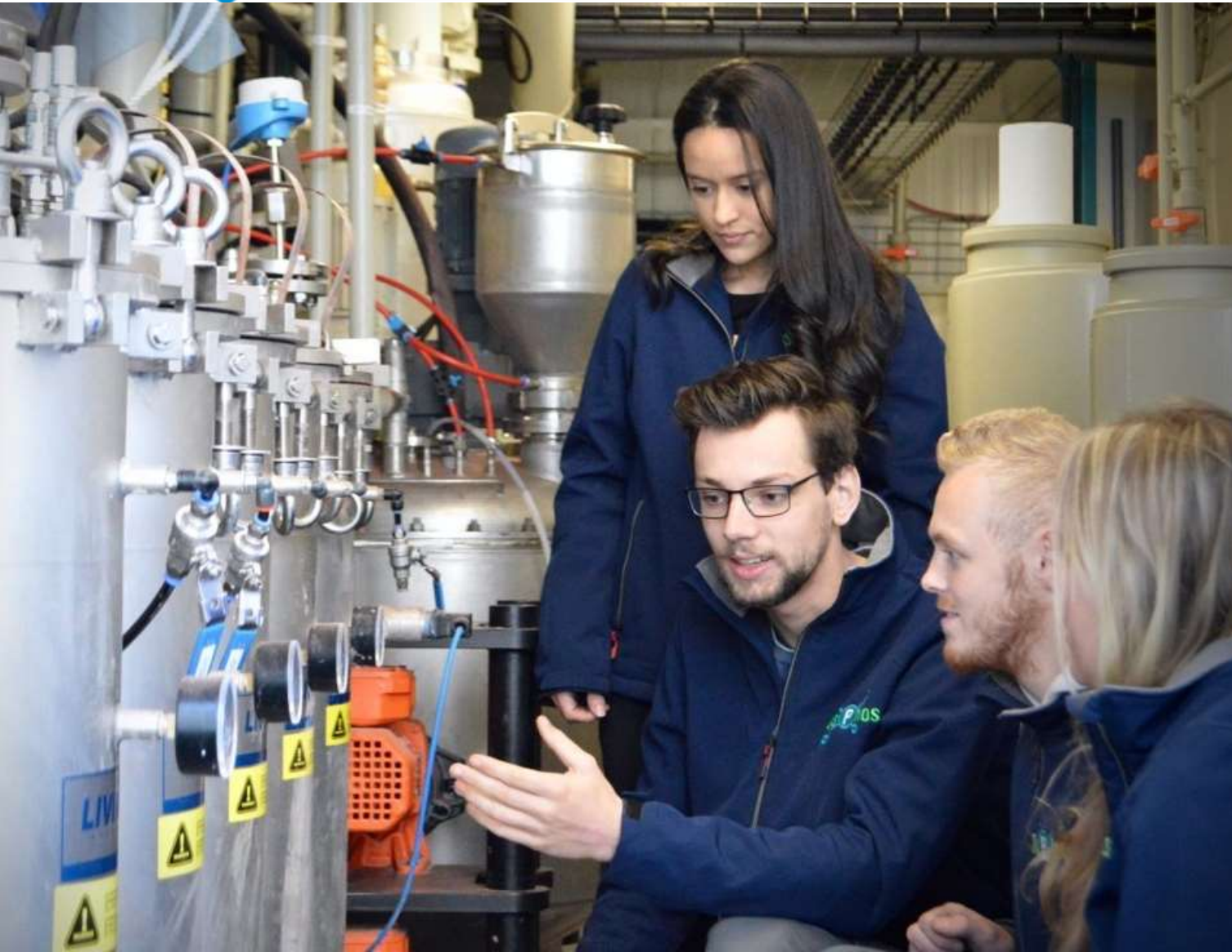
- Onderbouw activiteit
- Te boeken via bètapartners



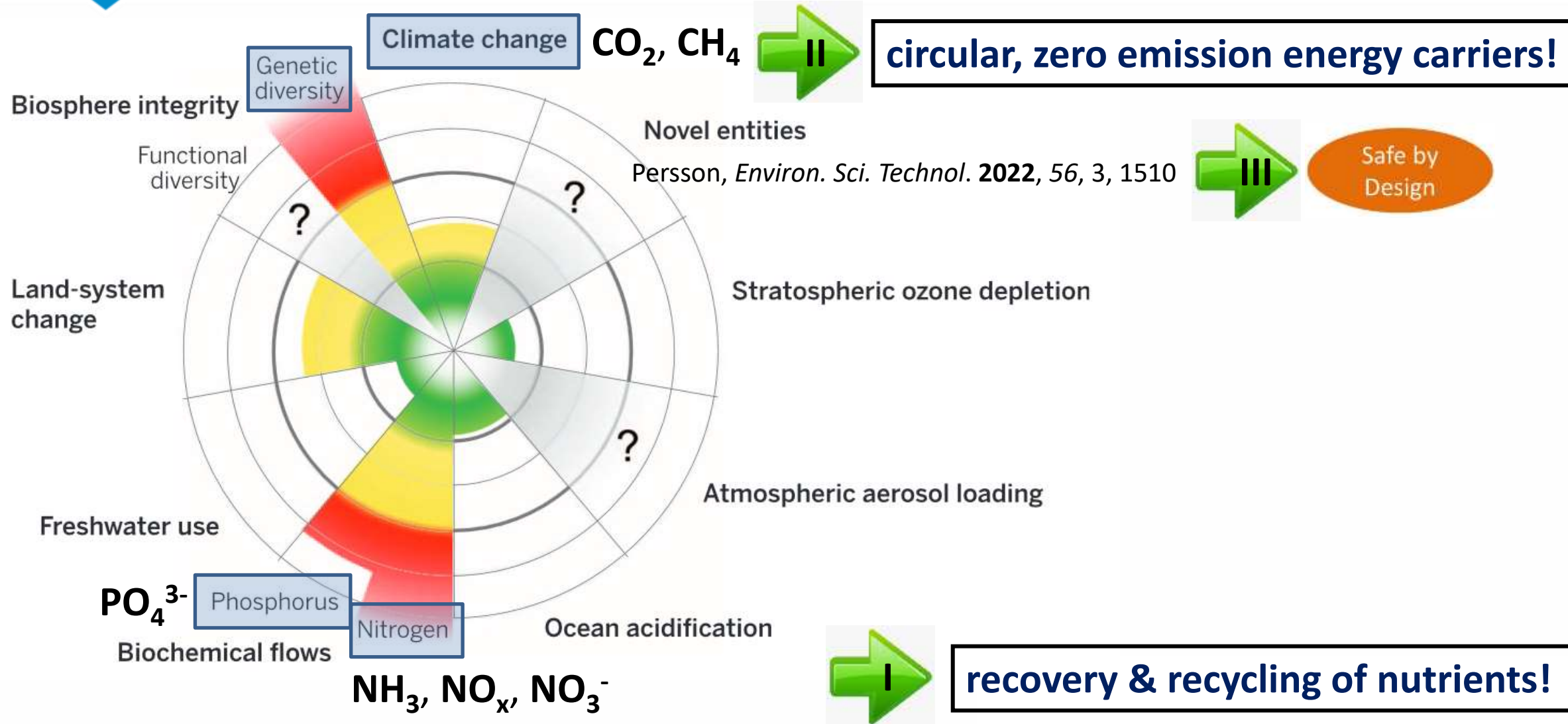
monoammonium phosphate



# Pilot plant SusPhos; Towards a Circular Nutrient Economy



# 'CHNOPS': circular technologies are urgently needed

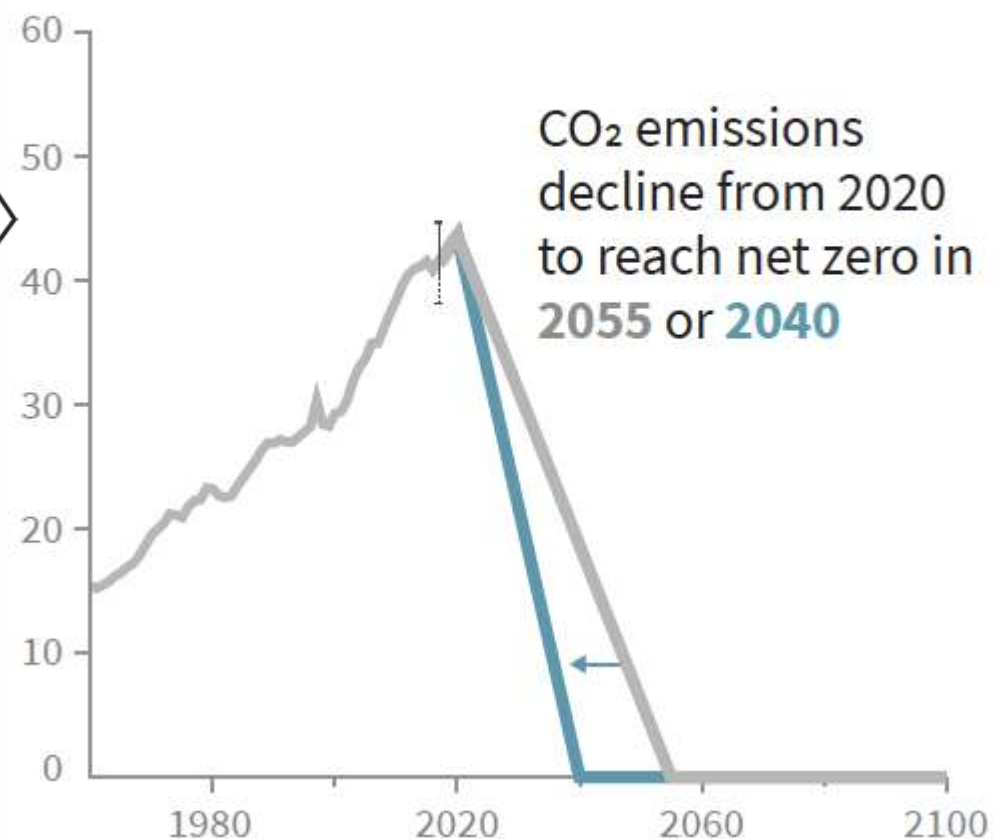


# The Paris Agreement

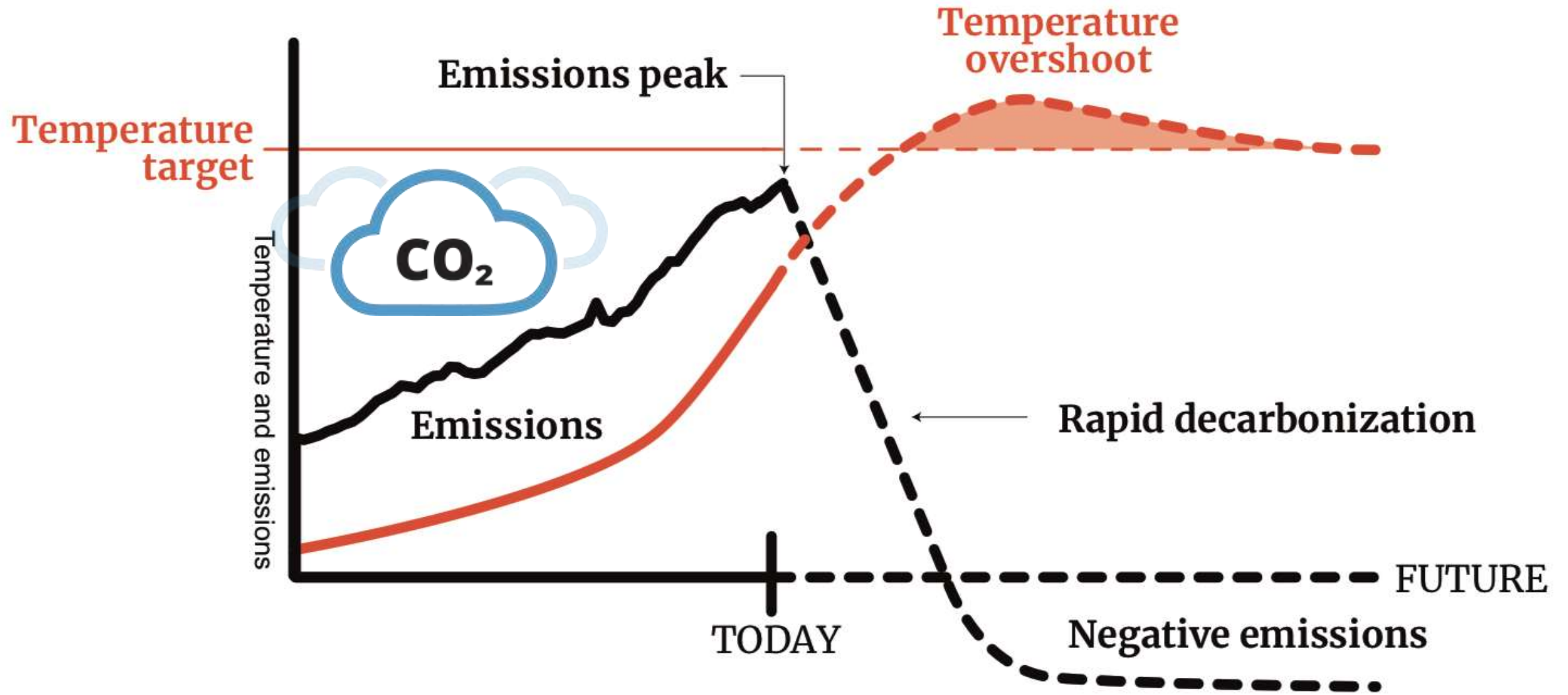
UNITED NATIONS  
**PARIS CLIMATE  
AGREEMENT**  
SIGNING CEREMONY  
— 22 APRIL 2016 —



b) Stylized net global CO<sub>2</sub> emission pathways  
Billion tonnes CO<sub>2</sub> per year (GtCO<sub>2</sub>/yr)



# Decarbonize our Energy System



# Clean Electricity Production/Storage – H<sub>2</sub> Production/Storage



# The Hydrogen Ladder

Unavoidable

Key: No real alternative



**NH<sub>3</sub>: 500 MT/yr of CO<sub>2</sub> (1.8% GCE)**

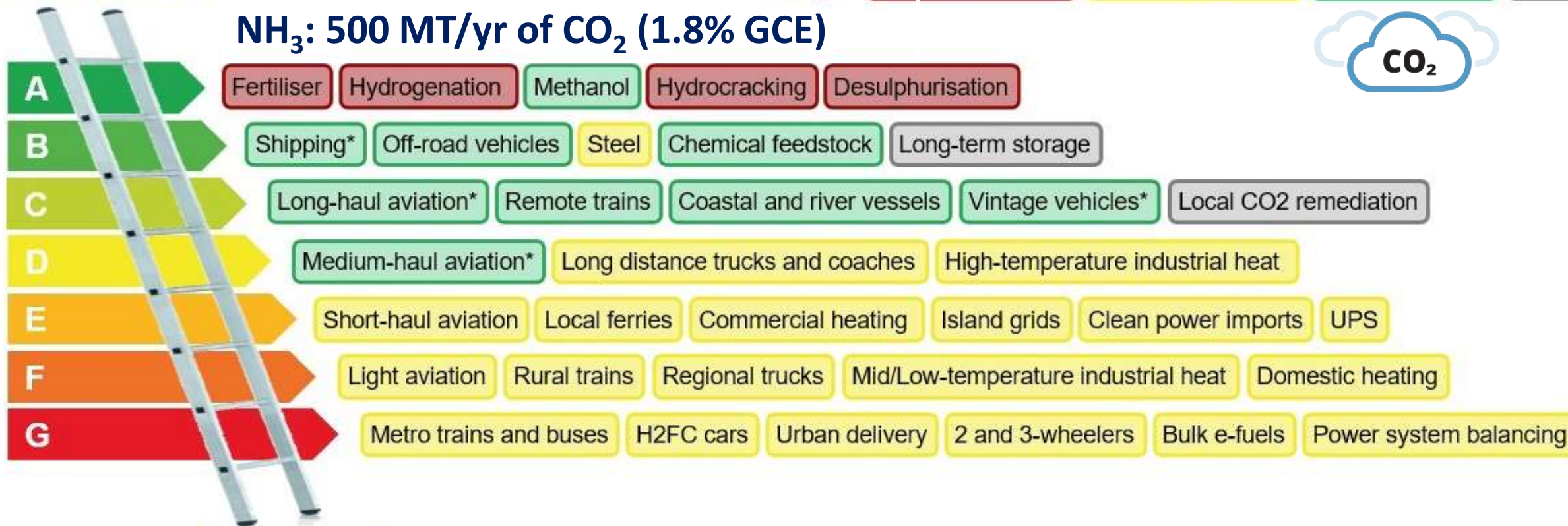
- Fertiliser
- Hydrogenation
- Methanol
- Hydrocracking
- Desulphurisation

# The Hydrogen Ladder (not a silver bullet)

Unavoidable

Key: No real alternative Electricity/batteries Biomass/biogas Other

**NH<sub>3</sub>: 500 MT/yr of CO<sub>2</sub> (1.8% GCE)**



Uncompetitive

# Clean H<sub>2</sub> demand



Existing industry use



New industry feedstock



Building and industry heat

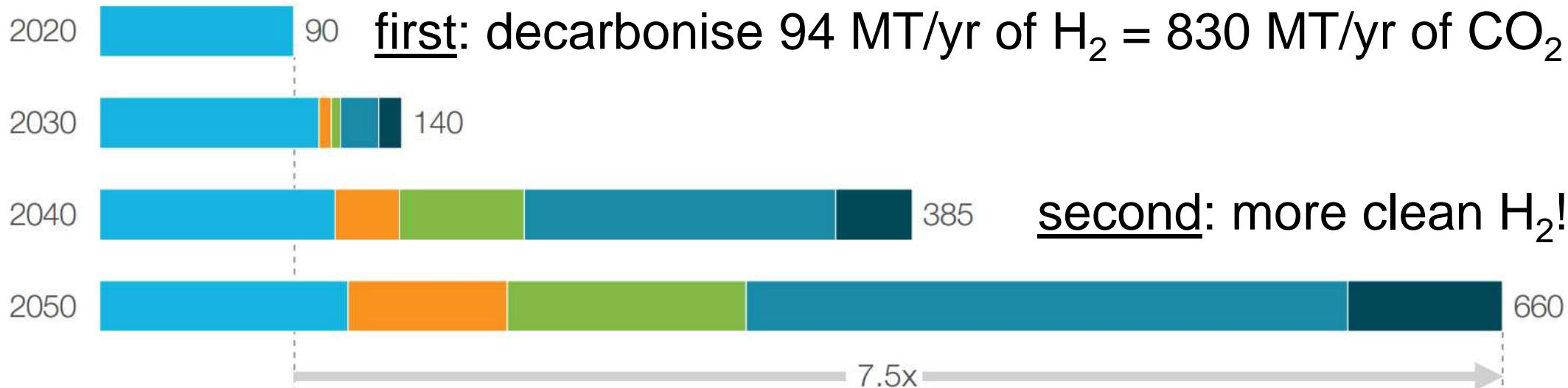


Transport



Power generation

Hydrogen demand, million tons

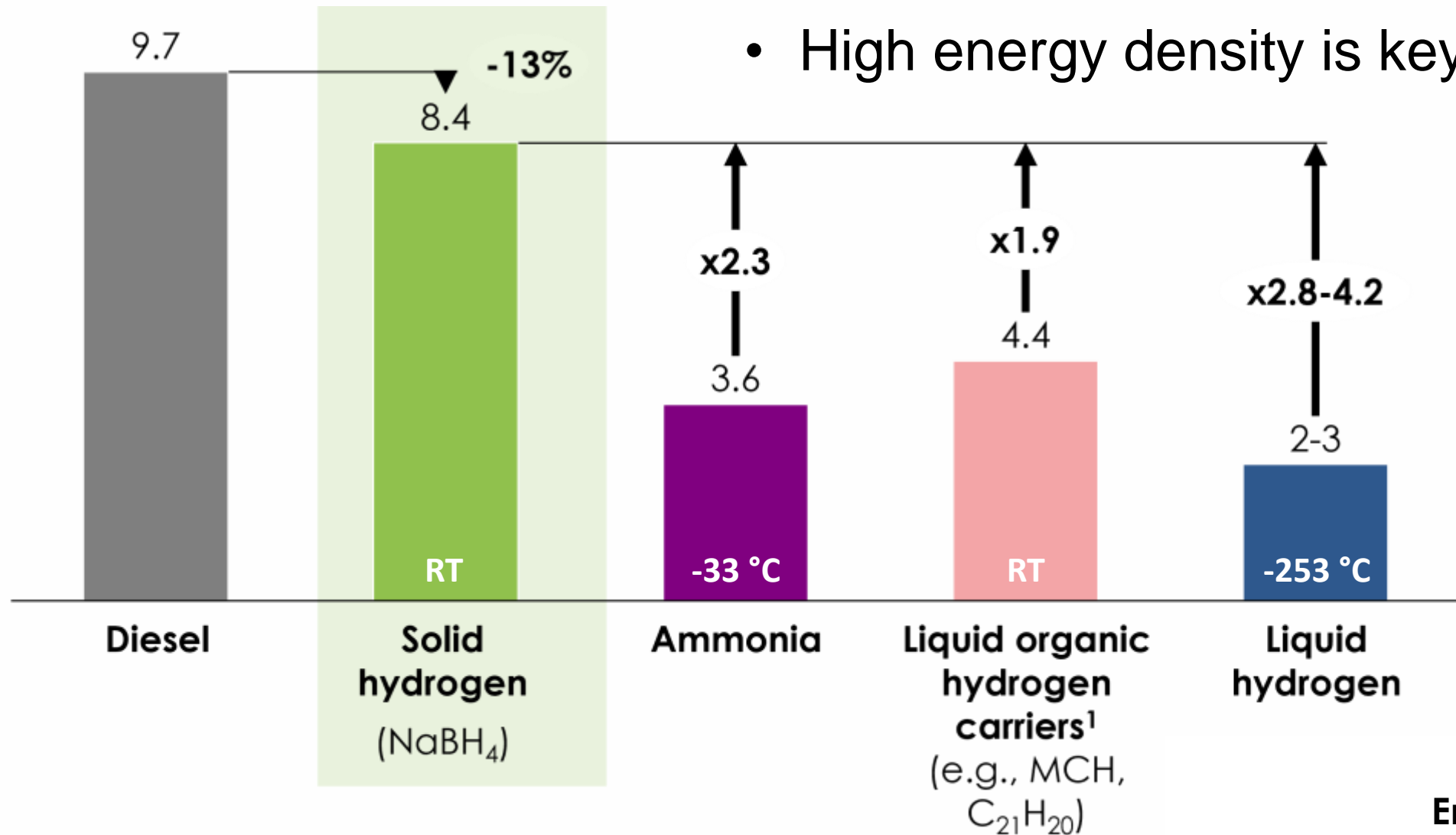




# Port of Amsterdam – from coal to 1 million tons of green H<sub>2</sub>

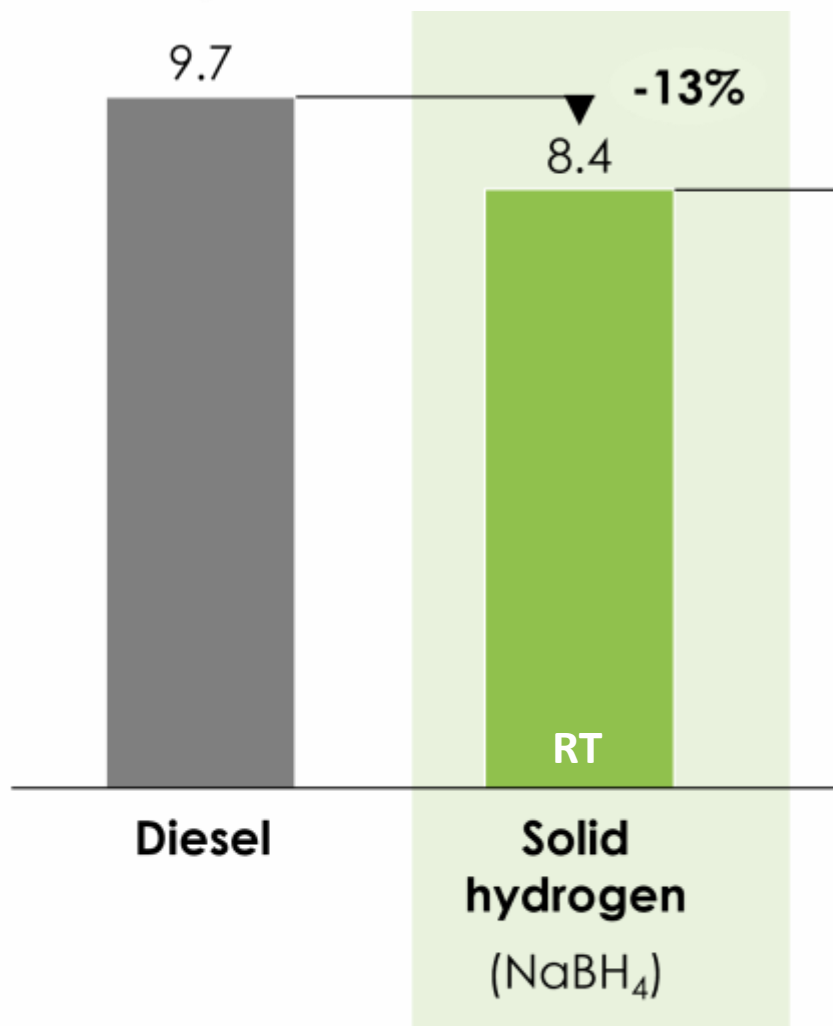


# Safe and Circular H<sub>2</sub> carriers



Energy density, kWh/L

# Safe and Circular H<sub>2</sub> carriers

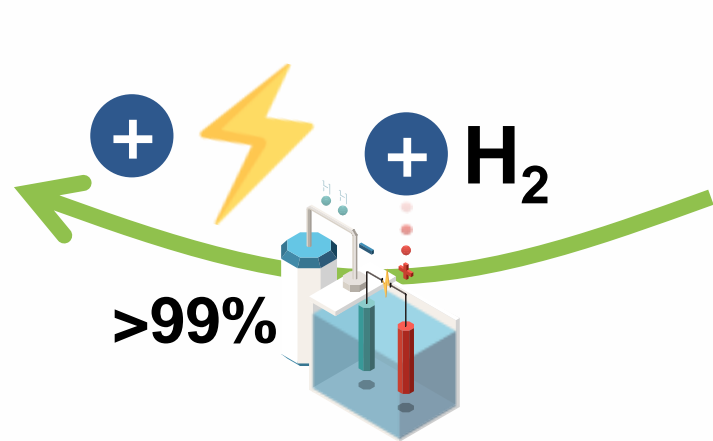
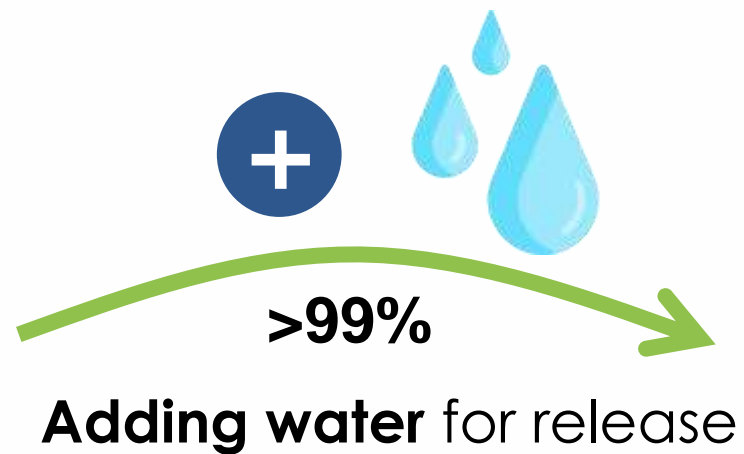


not flammable, corrosive nor toxic

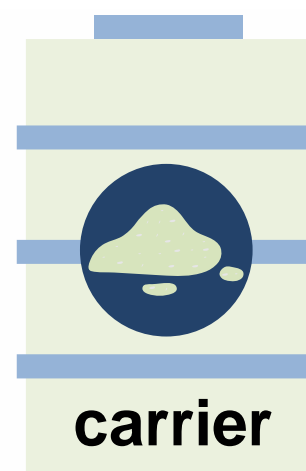
# H2Fuel-UvA Breakthrough Technology



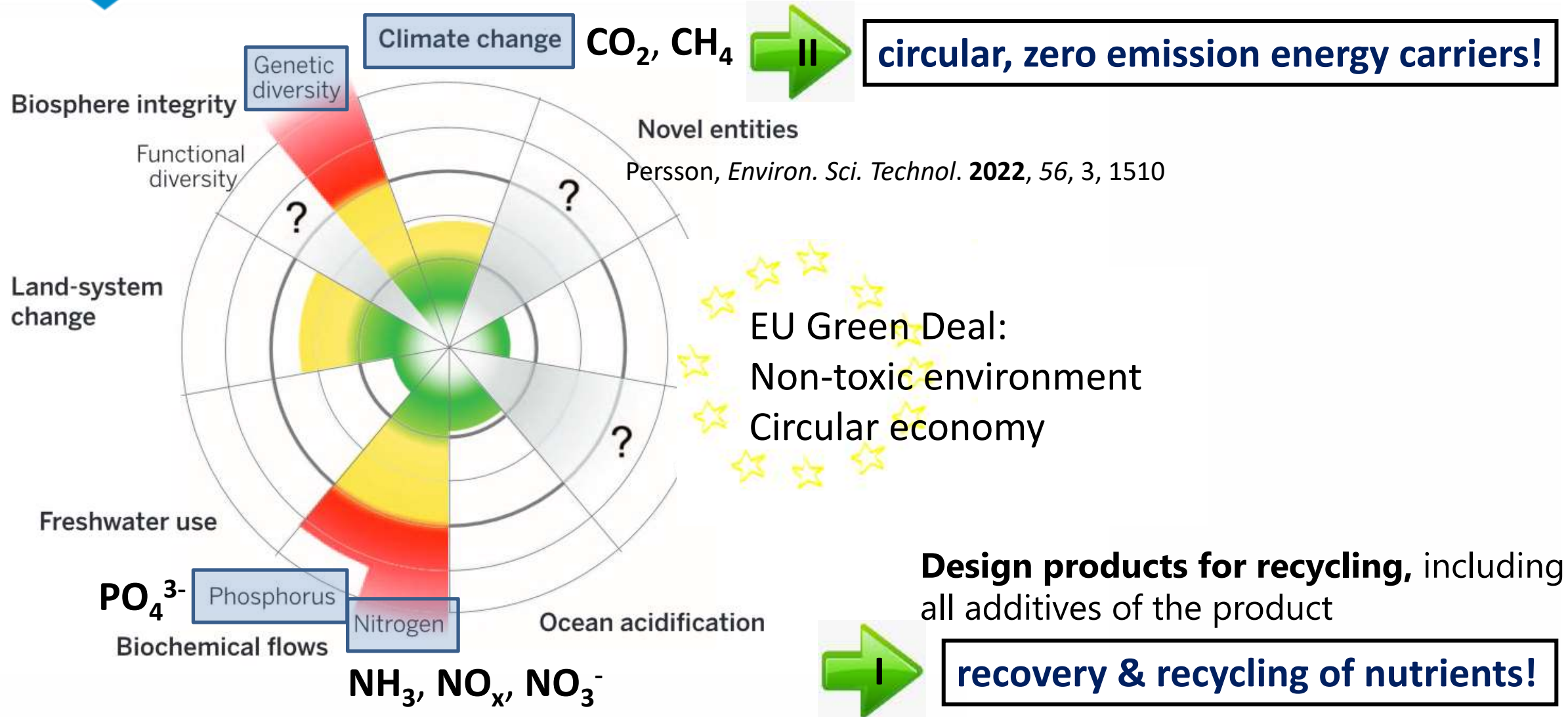
**H2FUEL**   
Making Hydrogen work



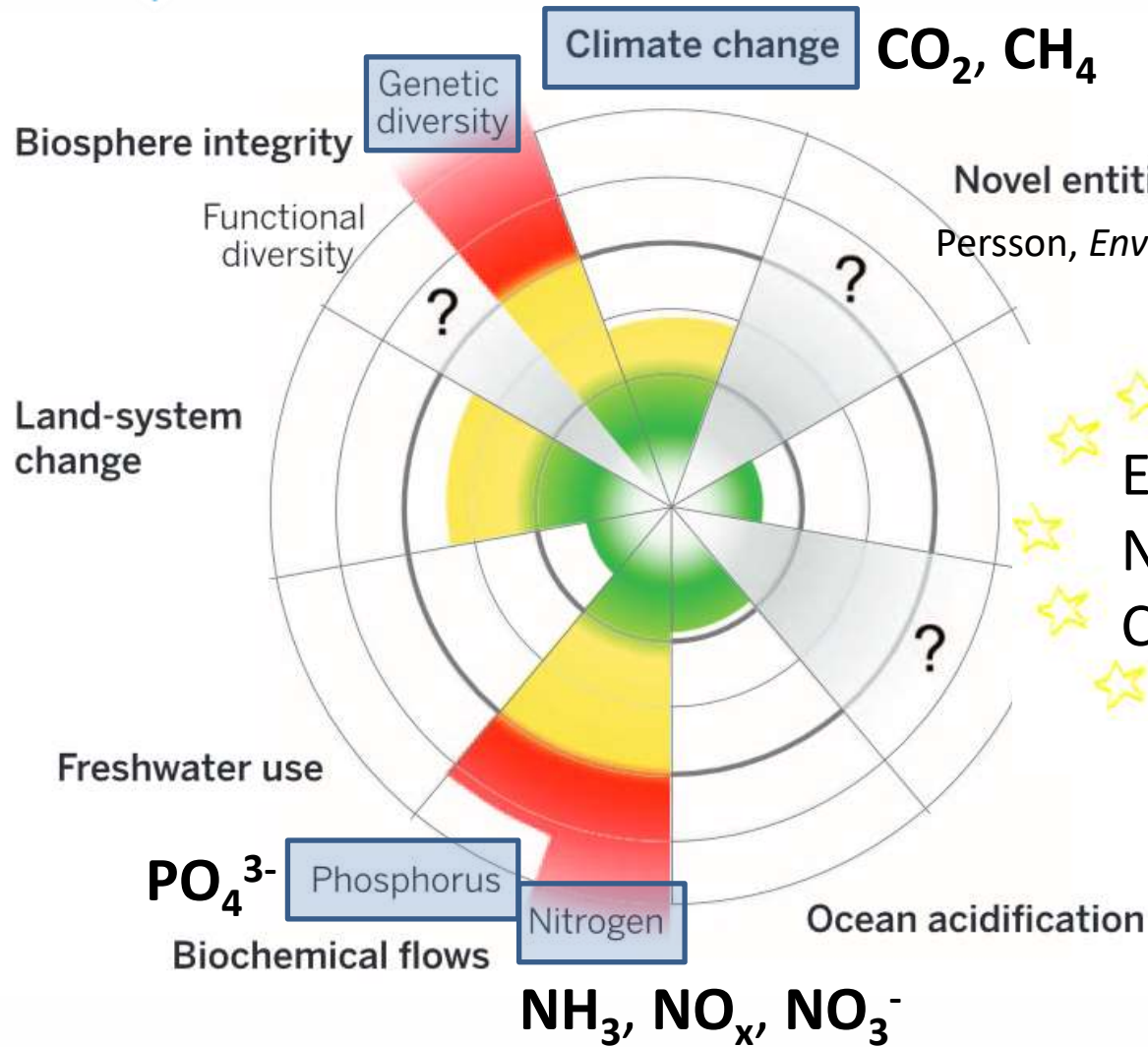
**&**



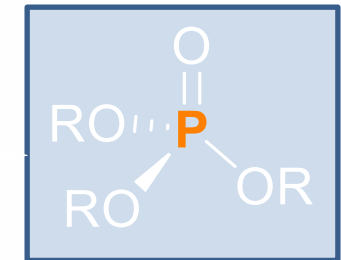
# 'CHNOPS': circular technologies are urgently needed



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**Design products** not suitable for capture and recycling **for complete fast mineralization** at the end of their lives

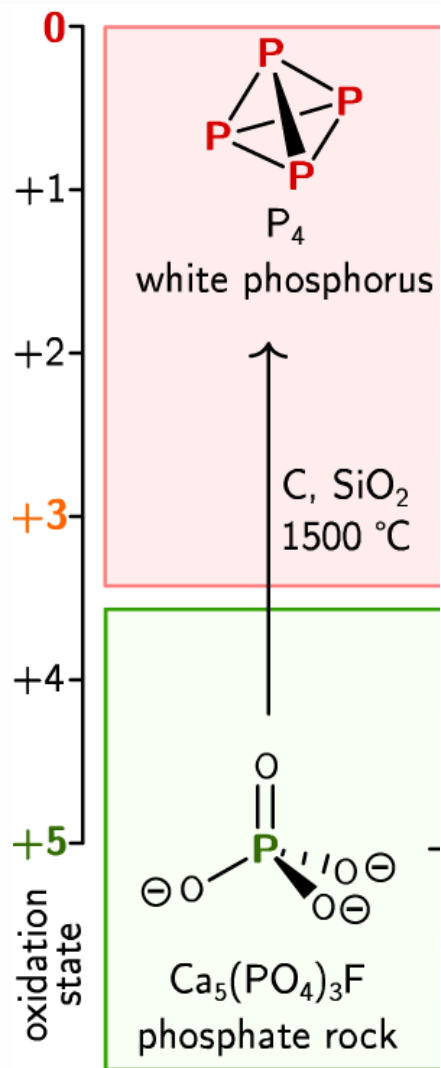


EU Green Deal:  
Non-toxic environment  
Circular economy

**Design products for recycling**, including all additives of the product

**recovery & recycling of nutrients!**

# Redox Inefficient Phosphorus Chemistry



# 'CHNOPS': the origin of life...





# Organophosphate Flame Retardants

- frequently detected in the environment
- many show toxic effects

**ENVIRONMENTAL**  
Science & Technology

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Article

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

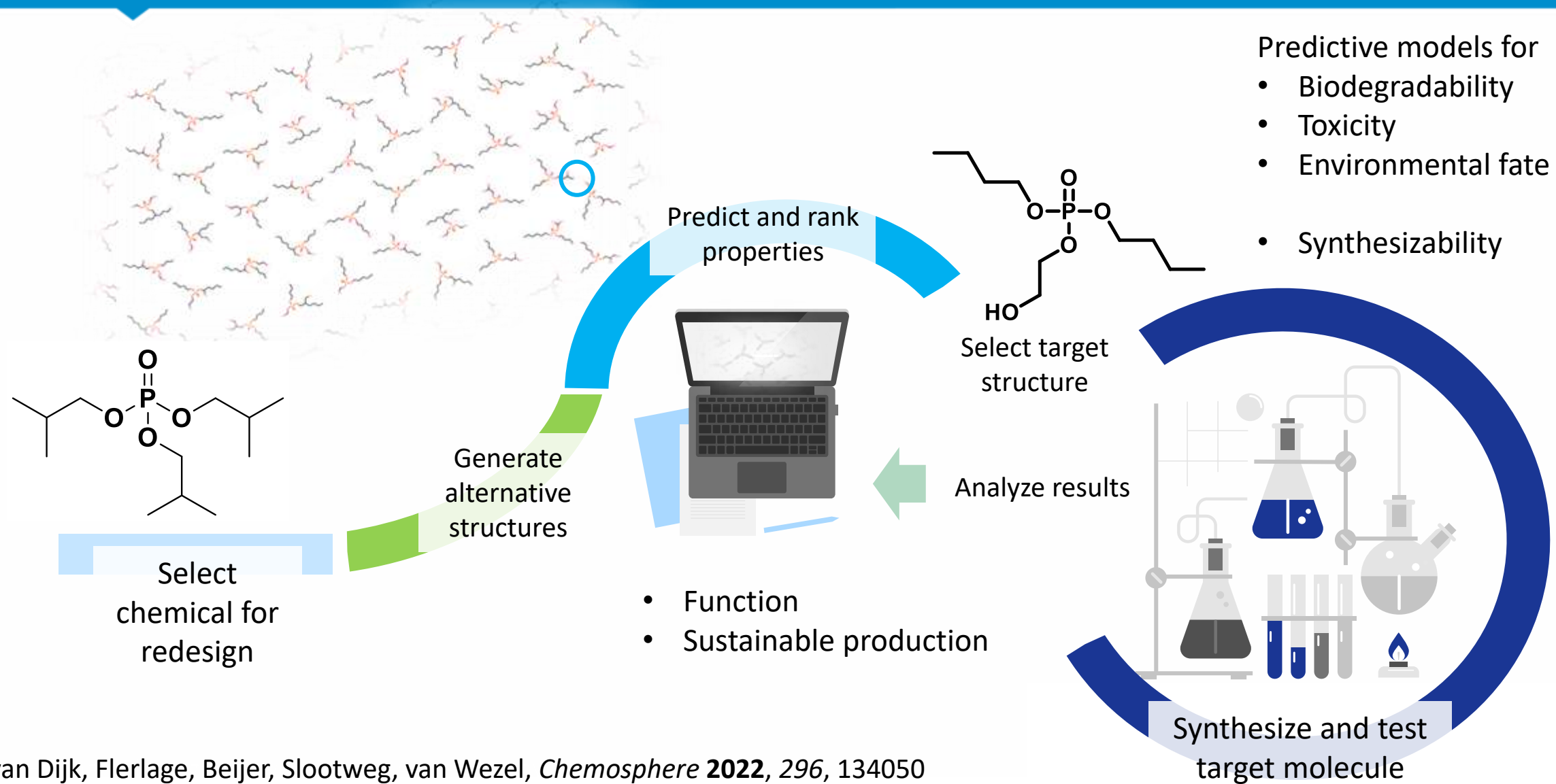
Yuxin Sun, Amila O. De Silva,\* Kyra A. St Pierre, Derek C. G. Muir, Christine Spencer, Igor Lehnherr, and John J. MacInnis

**ENVIRONMENTAL**  
Science & Technology **LETTERS**

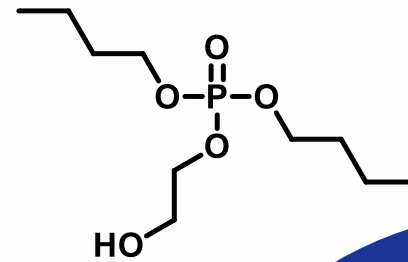
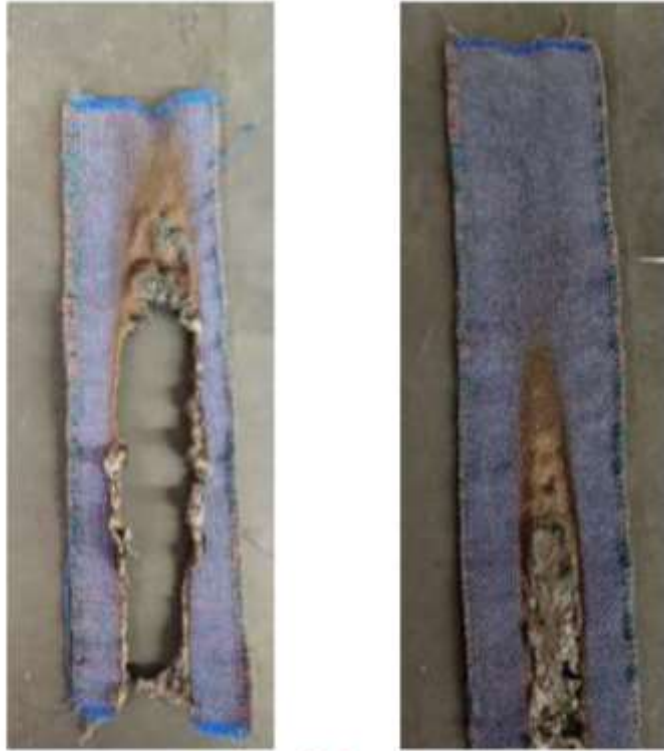
## Organophosphate Ester Flame Retardants: Are They a Regrettable Substitution for Polybrominated Diphenyl Ethers?

Arlene Blum,<sup>†,‡</sup> Mamta Behl,<sup>§</sup> Linda S. Birnbaum,<sup>||</sup> Miriam L. Diamond,<sup>⊥</sup> Allison Phillips,<sup>•</sup> Veena Singla,<sup>#</sup> Nisha S. Sipes,<sup>§</sup> Heather M. Stapleton,<sup>@</sup> and Marta Venier<sup>\*,∇</sup>

# Computer-aided redesign framework

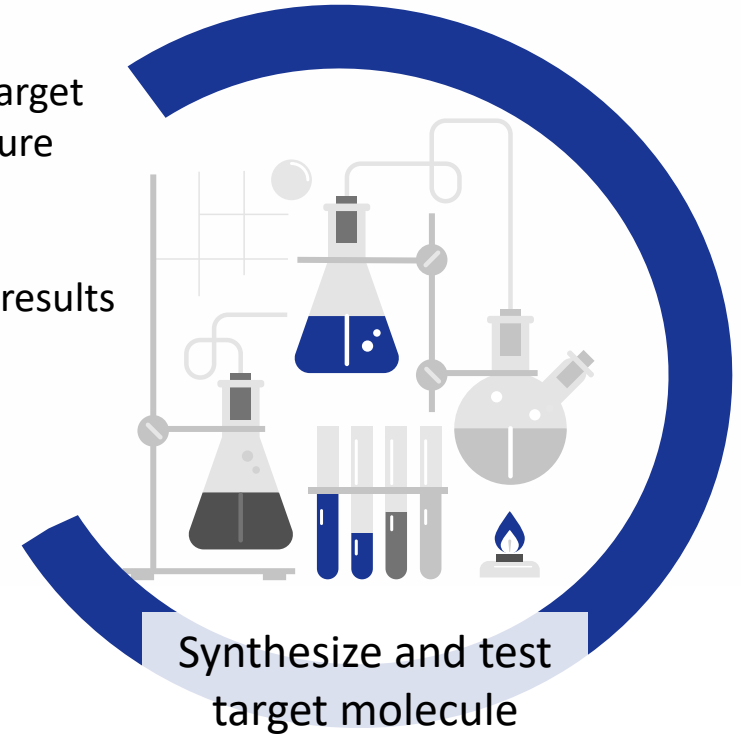


# Flame Retardancy Tests on Wool-PA blend fabrics

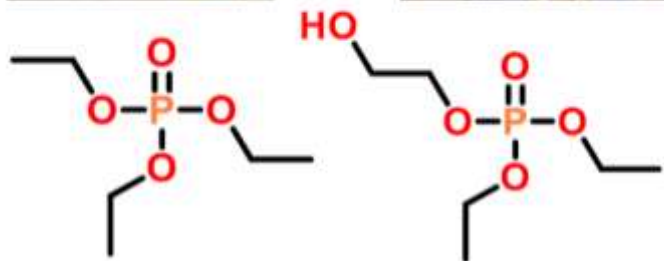


Select target structure

Analyze results

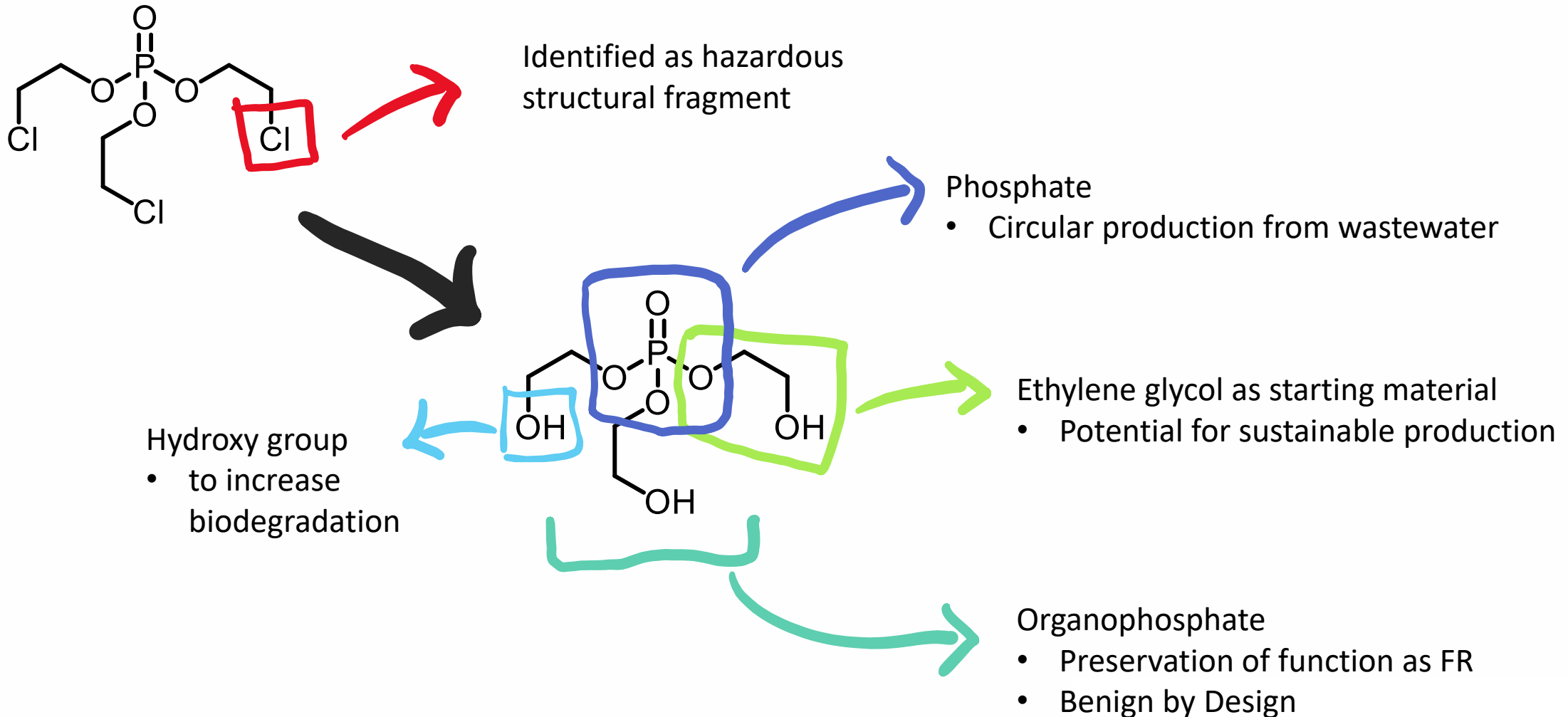


- Predictive models for
- Biodegradability
  - Toxicity
  - Environmental fate
  
  - Synthesizability



- Function
- Sustainable production

# Current design: Substitute Cl with OH



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