Twin challenges of the energy transition and circular economy



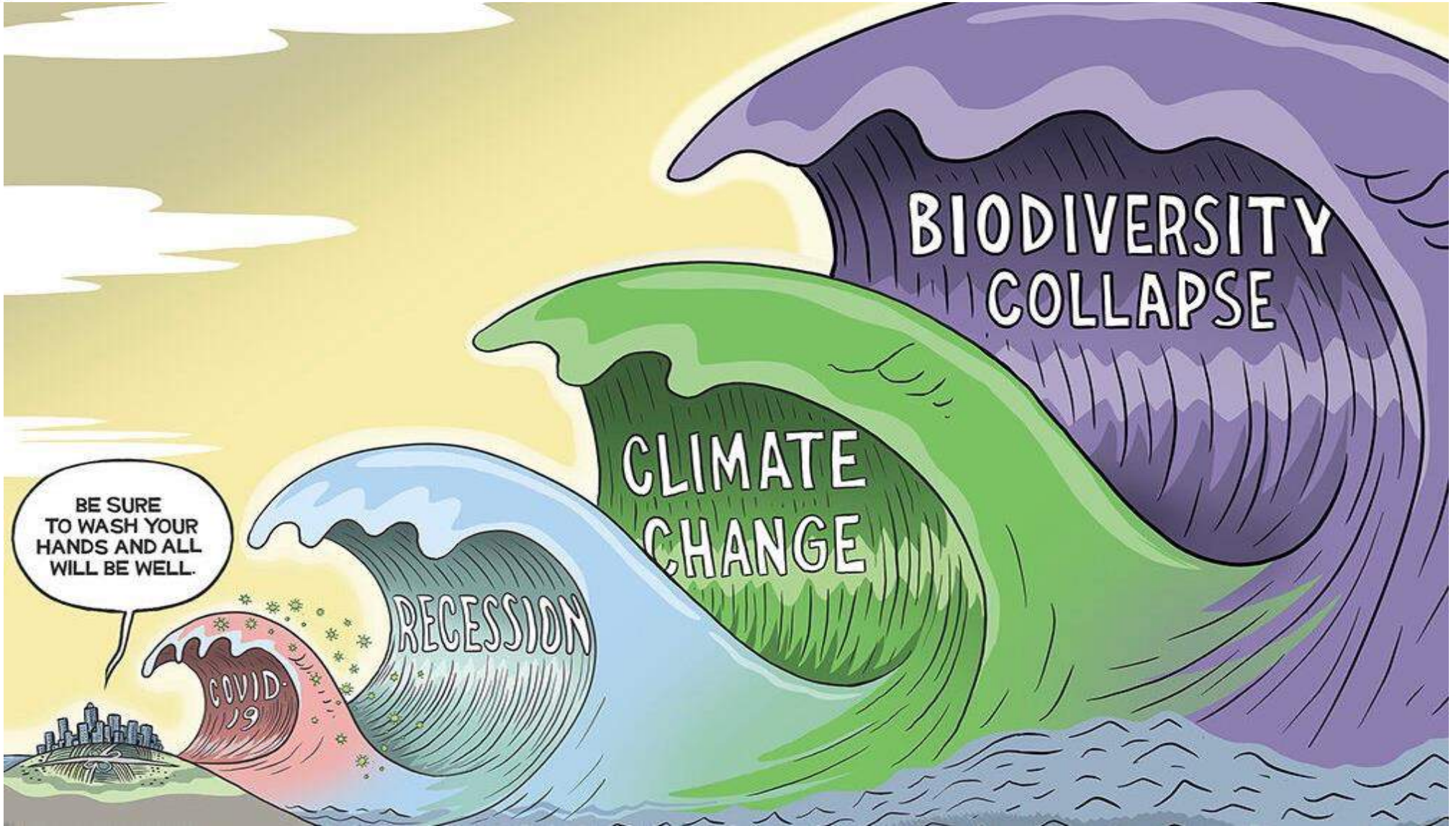
Chris Slootweg

UNIVERSITEIT VAN AMSTERDAM

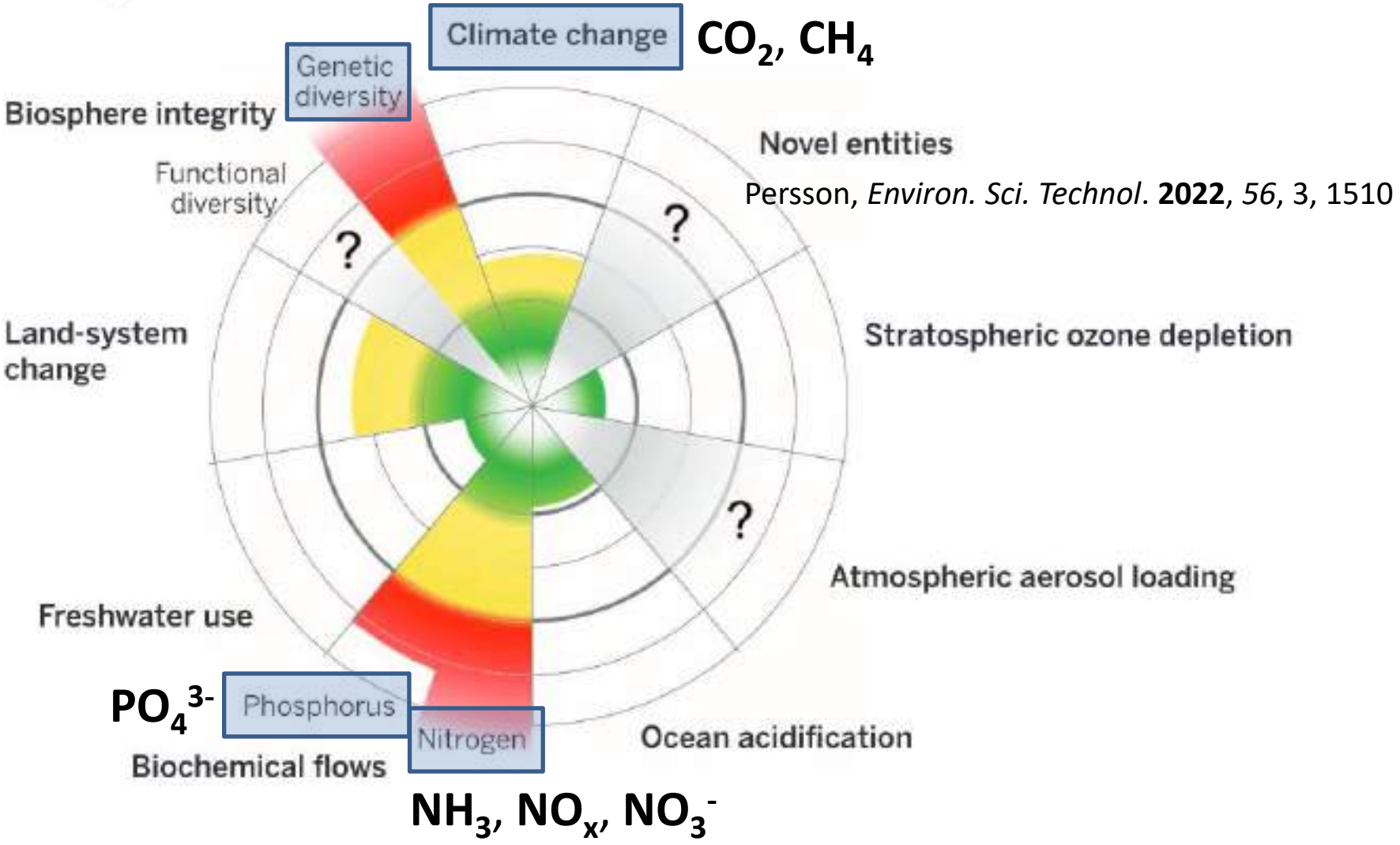
‘CHNOPS’: the origin of life…



‘CHNOPS’: the origin of waste…



‘CHNOPS’: the origin of waste…



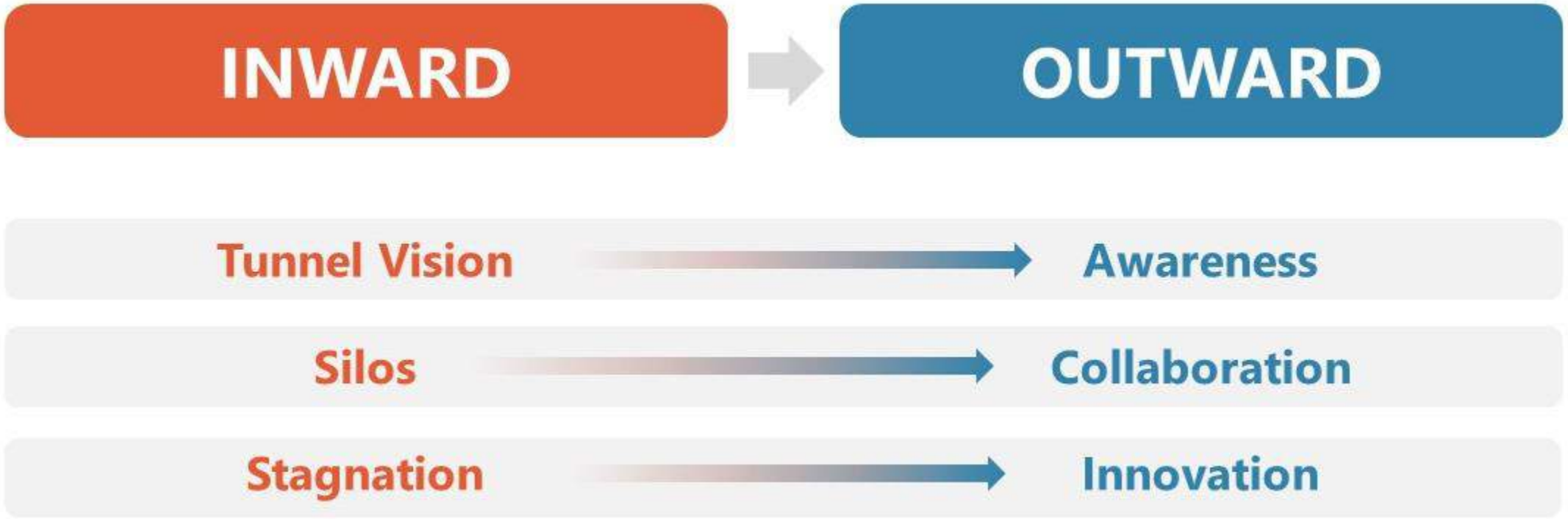
Persson, *Environ. Sci. Technol*. **2022**, *56*, 3, 1510

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

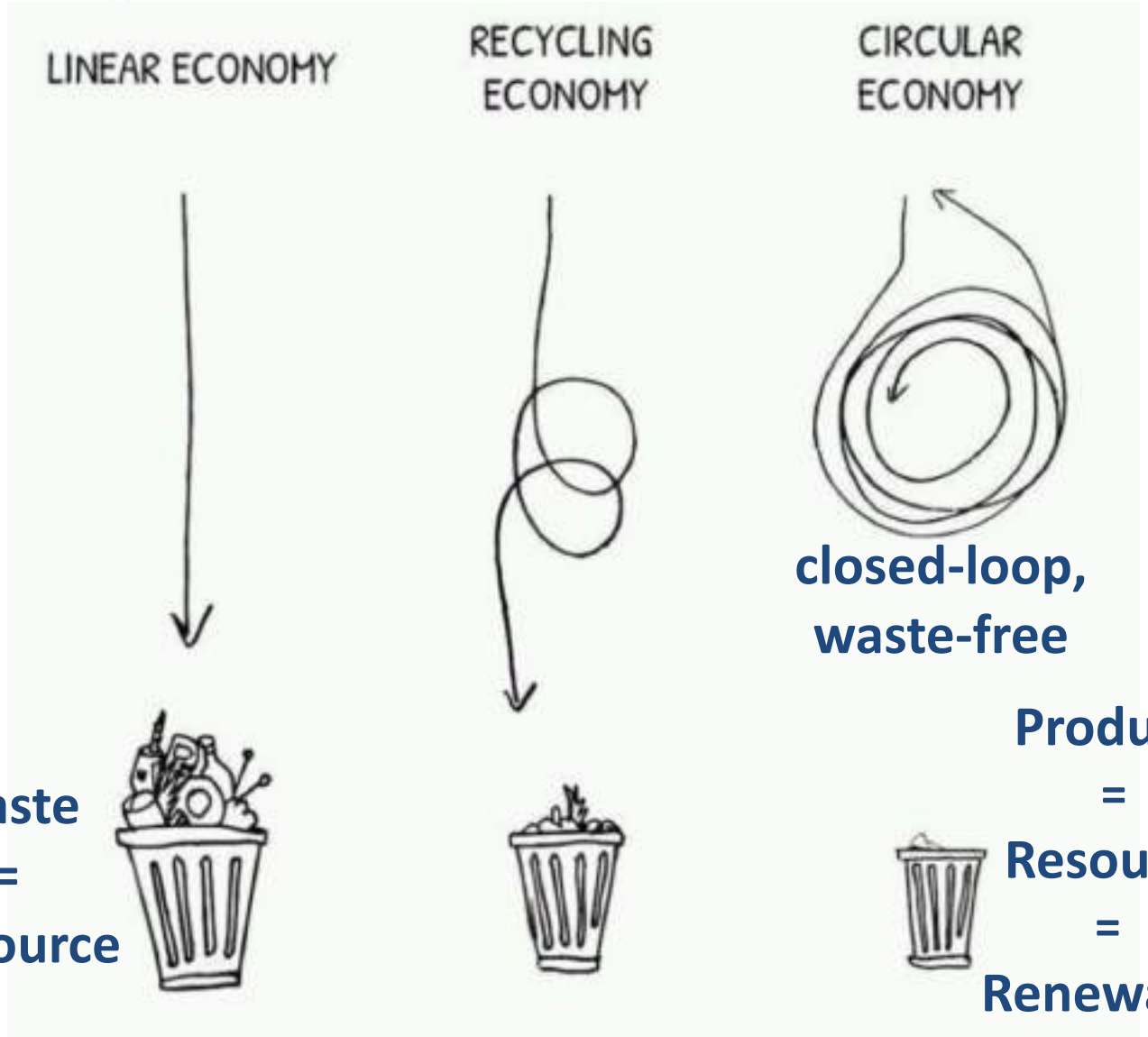
Radical Change is needed..

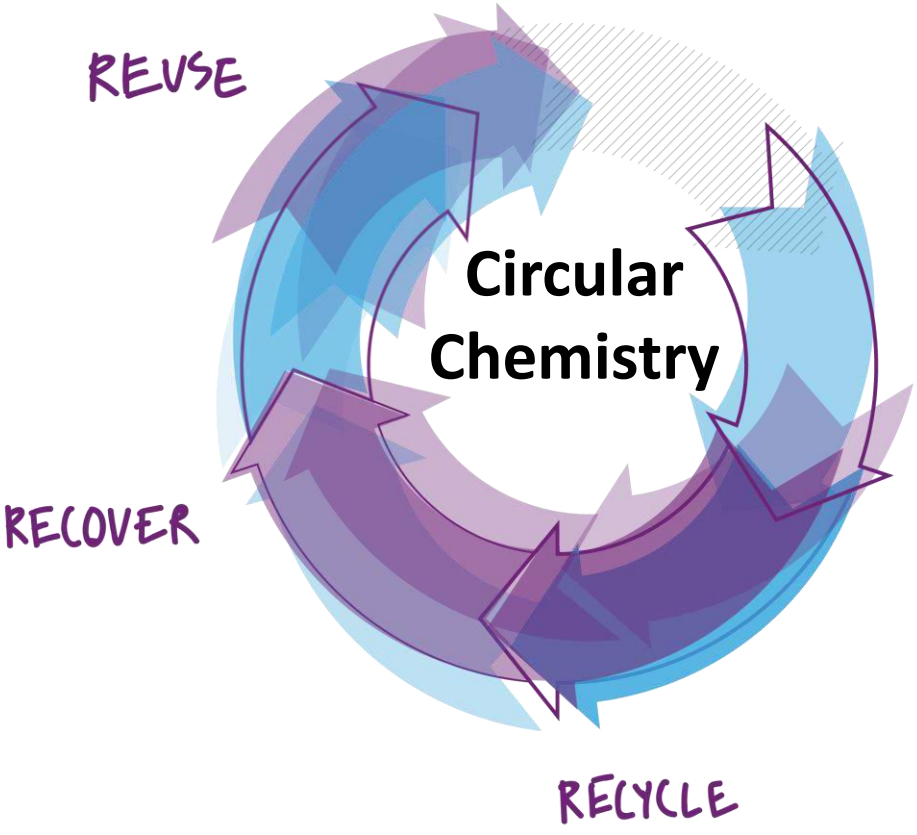
"We cannot solve our problems with the same thinking we used when we created them."

– Albert Einstein



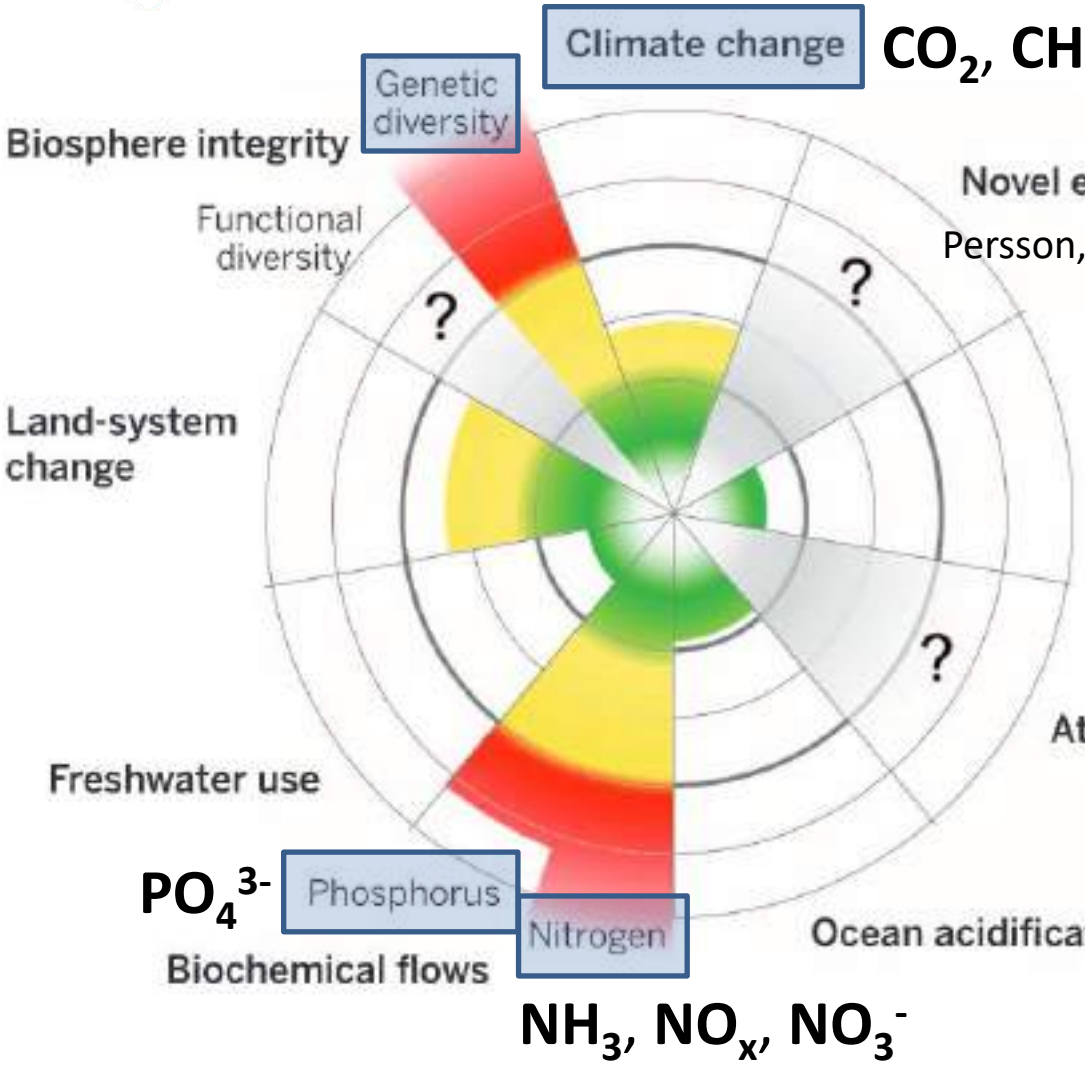
‘CHNOPS’: circular technologies are urgently needed





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

‘CHNOPS’: circular technologies are urgently needed



CO_2, CH_4

circular, zero emission energy carriers!

Persson, *Environ. Sci. Technol*. **2022**, *56*, 3, 1510

Safe by Design



PO_4^{3-}

NH_3, NO_x, NO_3^-

recovery & recycling of nutrients!

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




OCP

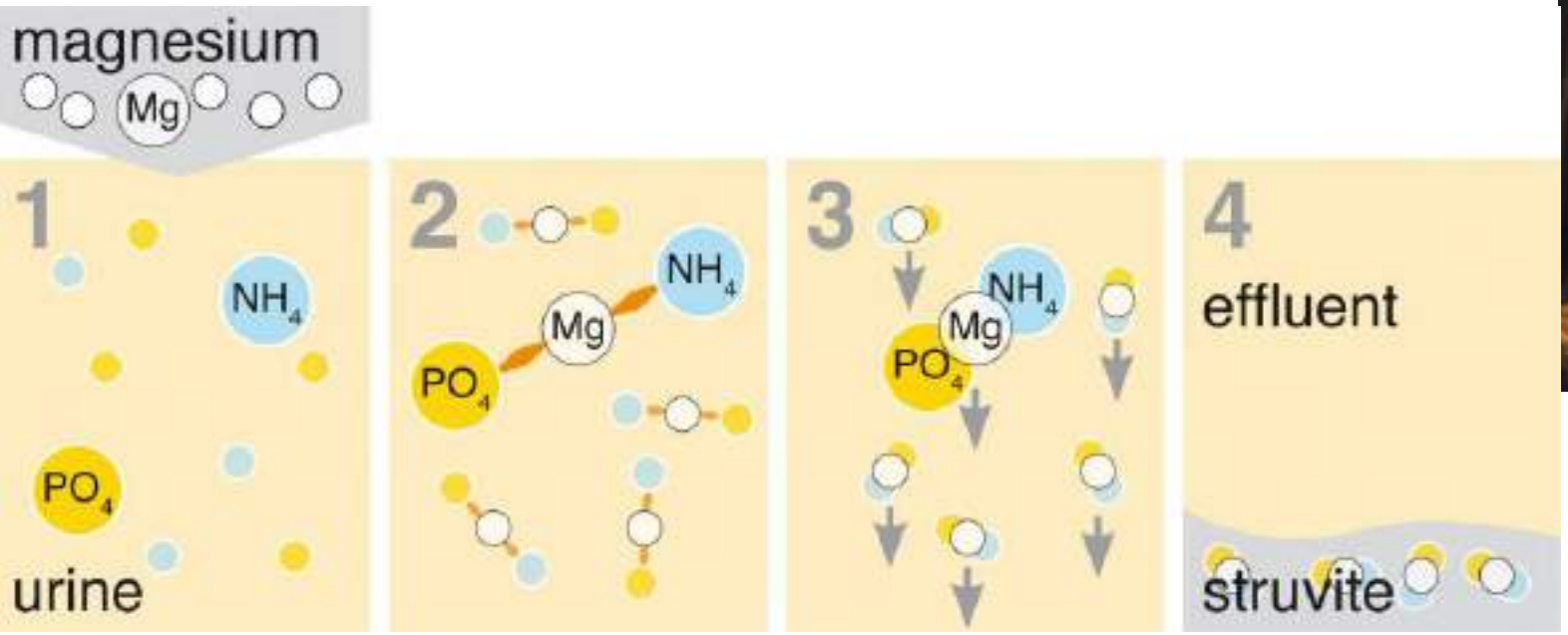
P-resource efficient?



P Recovery and Recycling, *Chem Soc. Rev*. **2021**, *50*, 87

Circular Chemistry: waste = resource!

- phosphate *and* ammonia





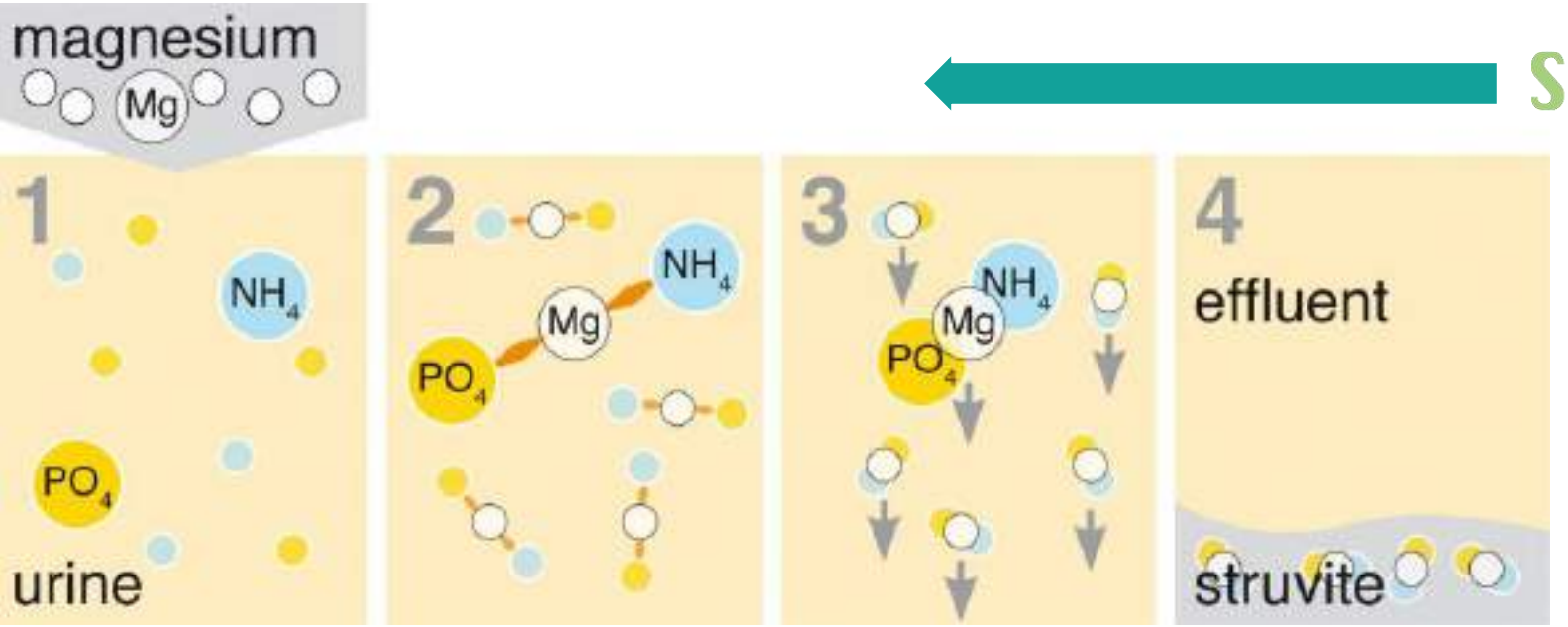
Recovery



P Recovery and Recycling, *Chem Soc. Rev*. **2021**, *50*, 87

Circular Chemistry: waste = resource!

- phosphate *and* ammonia



SusPhos

Recovery



Recycling



monoammonium phosphate

WO2020/169708

Circular Chemistry!





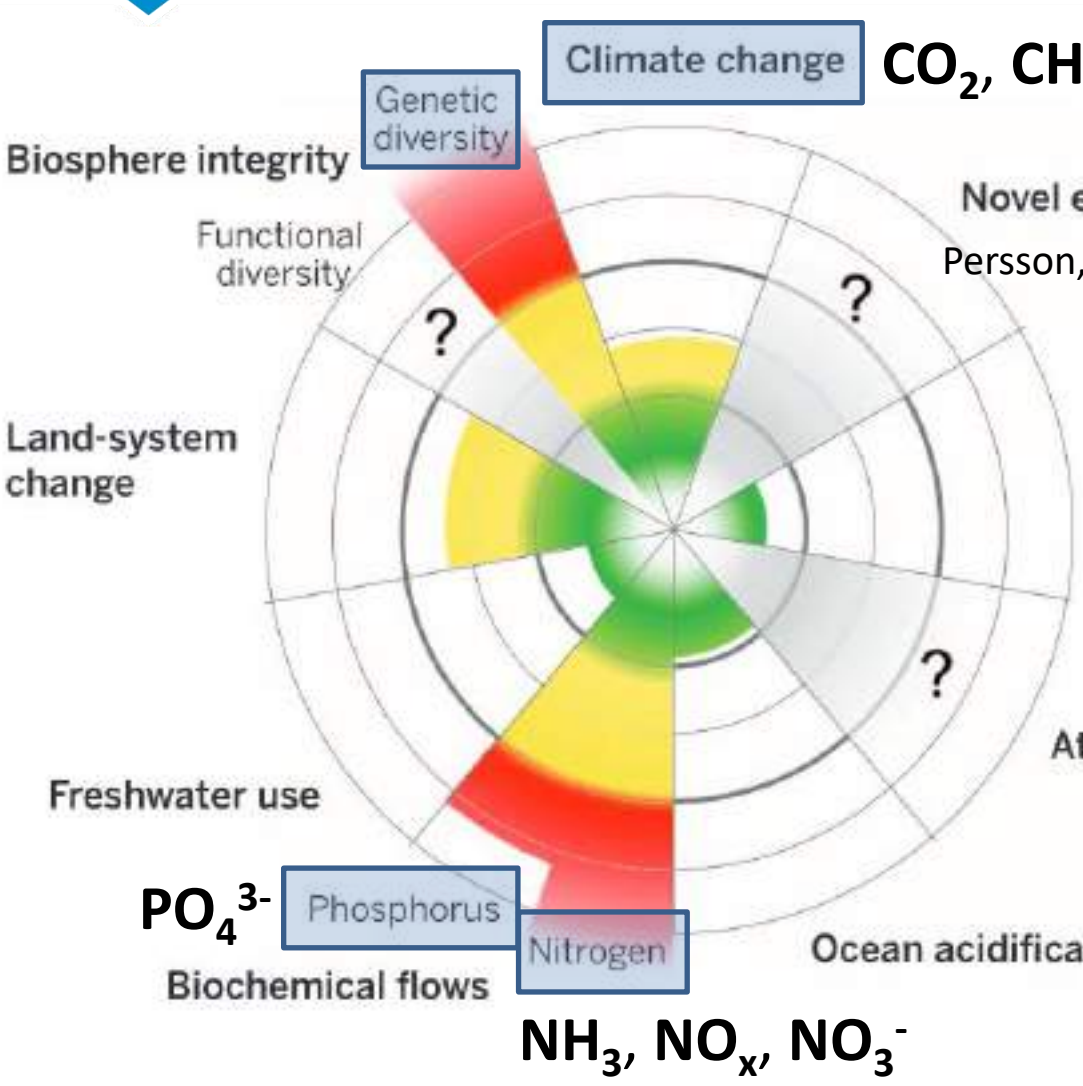
Environ. Sci. Technol. **2018**, *52*, 14564;
Angew. Chem. Int. Ed. **2018**, *57*, 6386

Pilot plant SusPhos, 2021





‘CHNOPS’: circular technologies are urgently needed



CO_2, CH_4

circular, zero emission energy carriers!

Persson, *Environ. Sci. Technol*. **2022**, *56*, 3, 1510

Safe by Design

PO_4^{3-}

NH_3, NO_x, NO_3^-

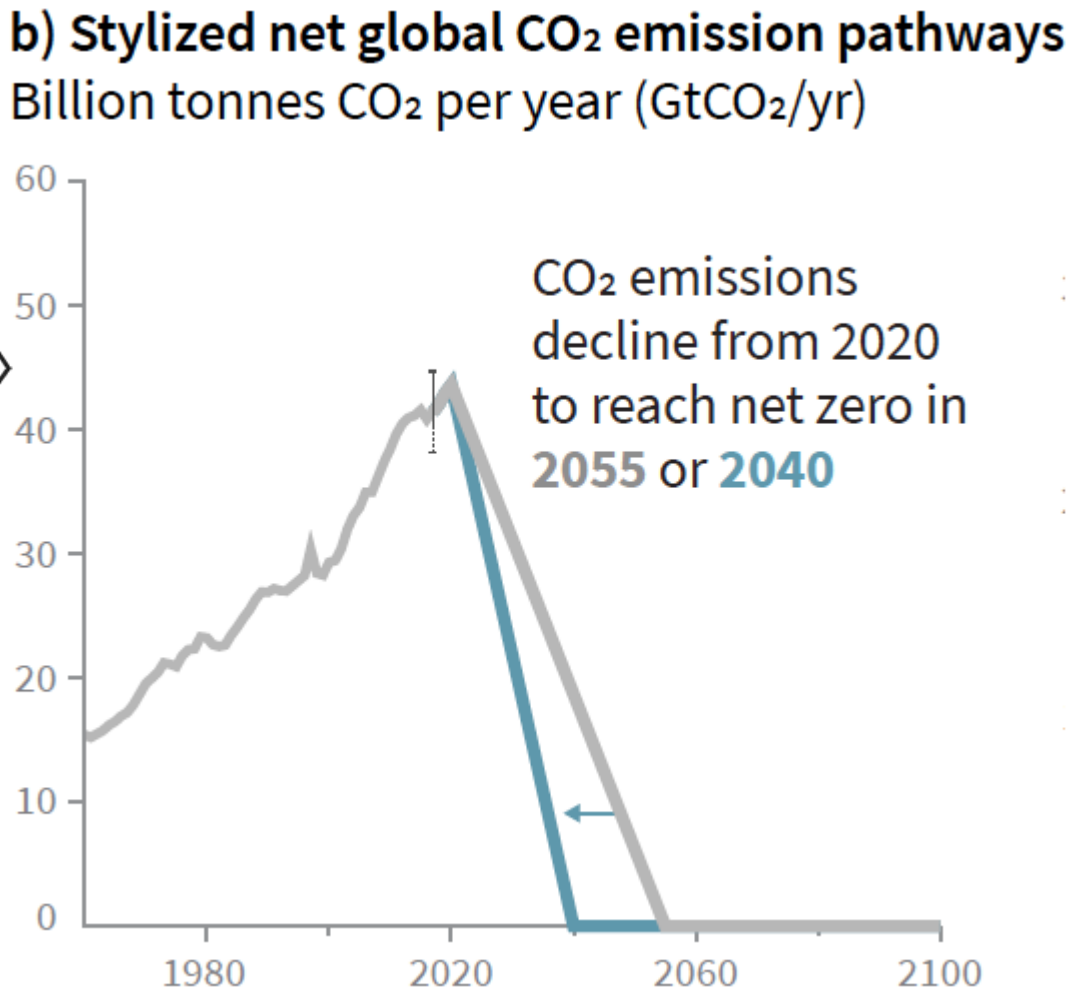
recovery & recycling of nutrients!

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

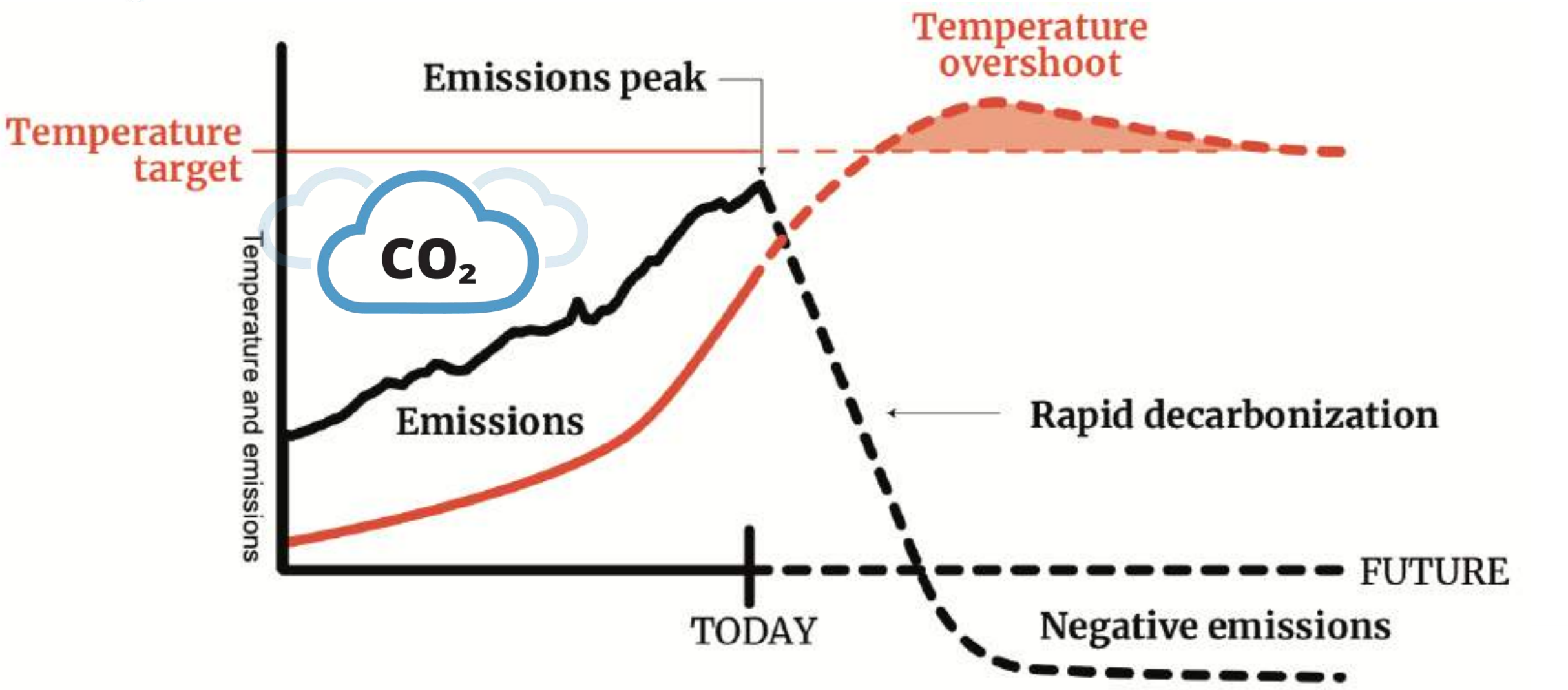
The Paris Agreement

UNITED NATIONS
PARIS CLIMATE AGREEMENT
SIGNING CEREMONY
22 APRIL 2016





Decarbonize our Energy System



Green Energy – H_2 Production – H_2 Storage

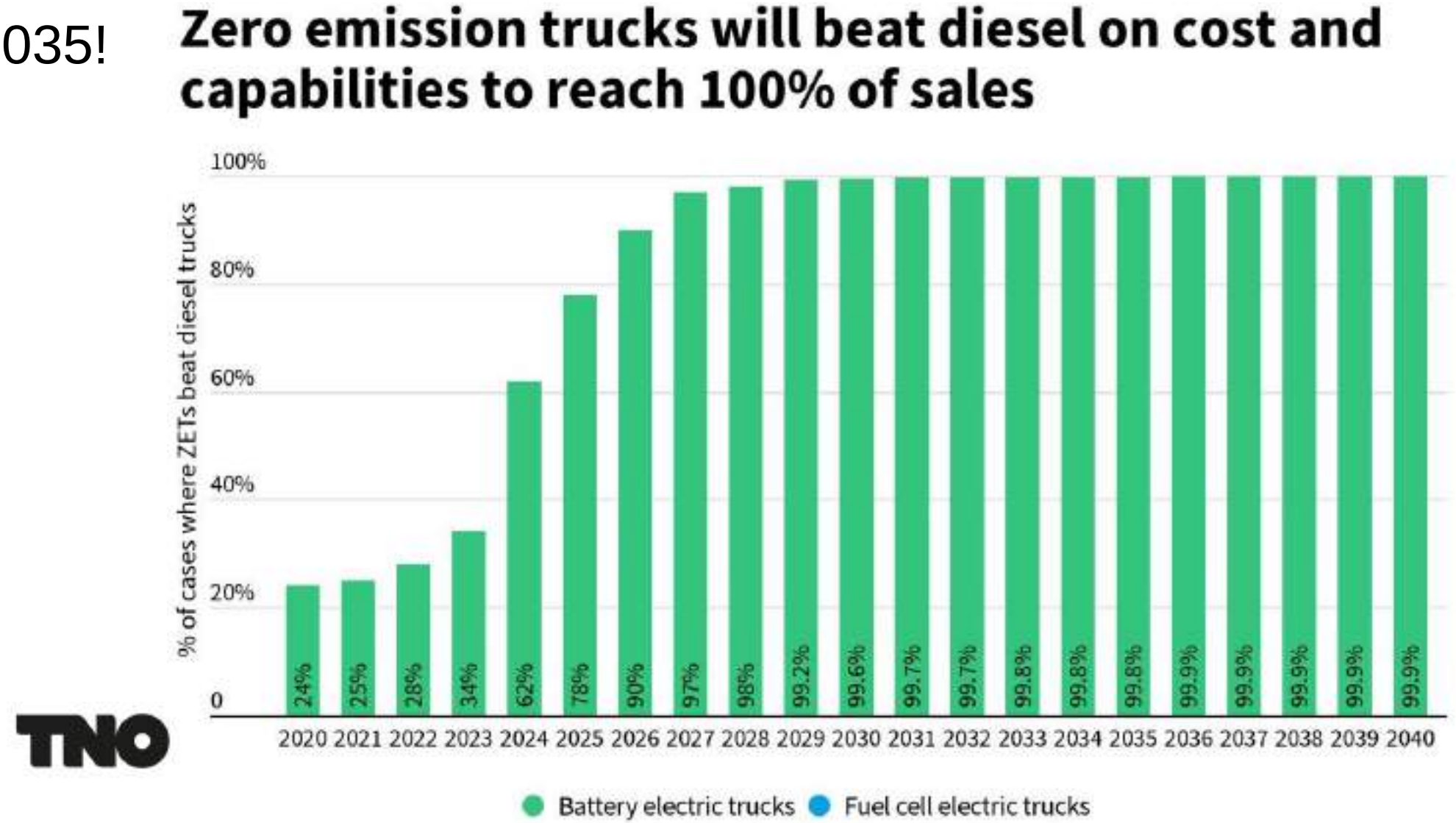


Don’t hydrogenise what will be electric…



Don’t hydrogenise what will be electric…

- from 2035!



The Hydrogen Ladder

Unavoidable

Key: No real alternative

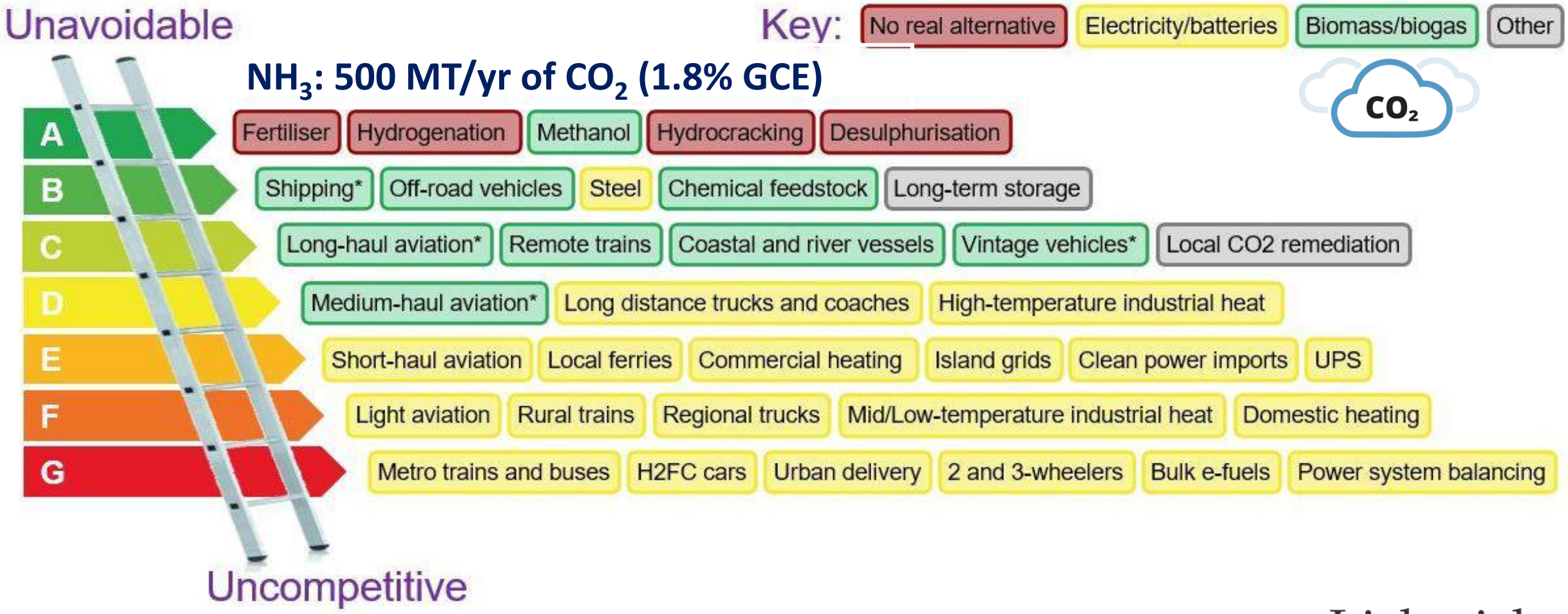


NH_3: 500 MT/yr of CO_2 (1.8% GCE)

Fertiliser | Hydrogenation | Methanol | Hydrocracking | Desulphurisation

Liebreich Associates

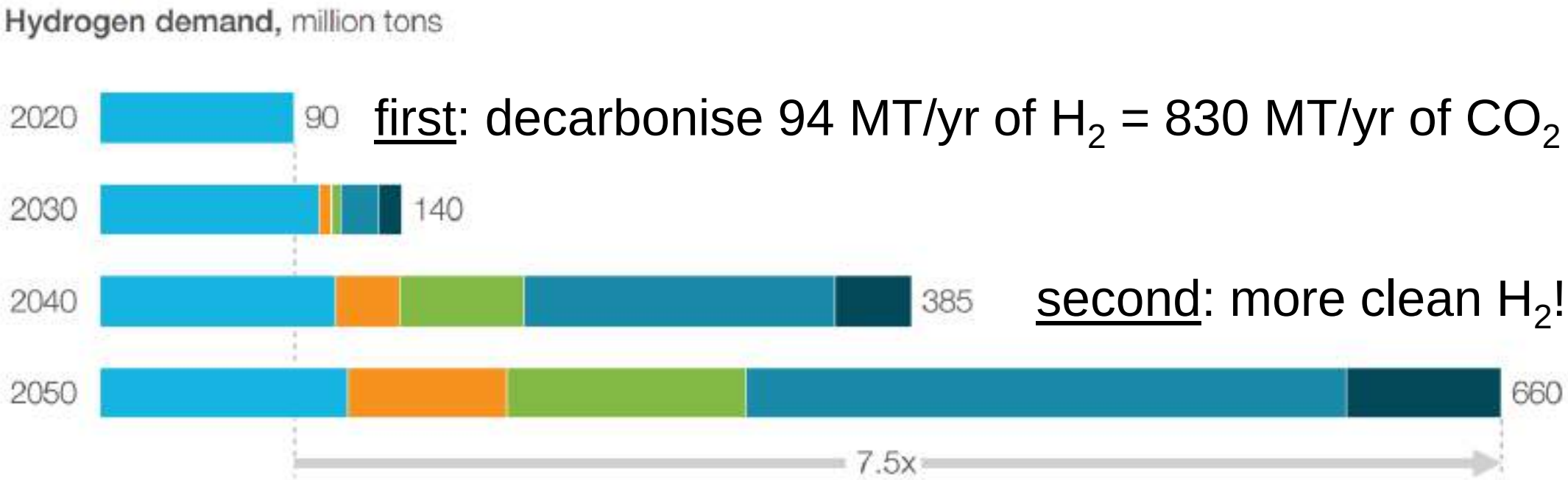
The Hydrogen Ladder (not a silver bullet)



Liebreich Associates

Clean H_2 demand

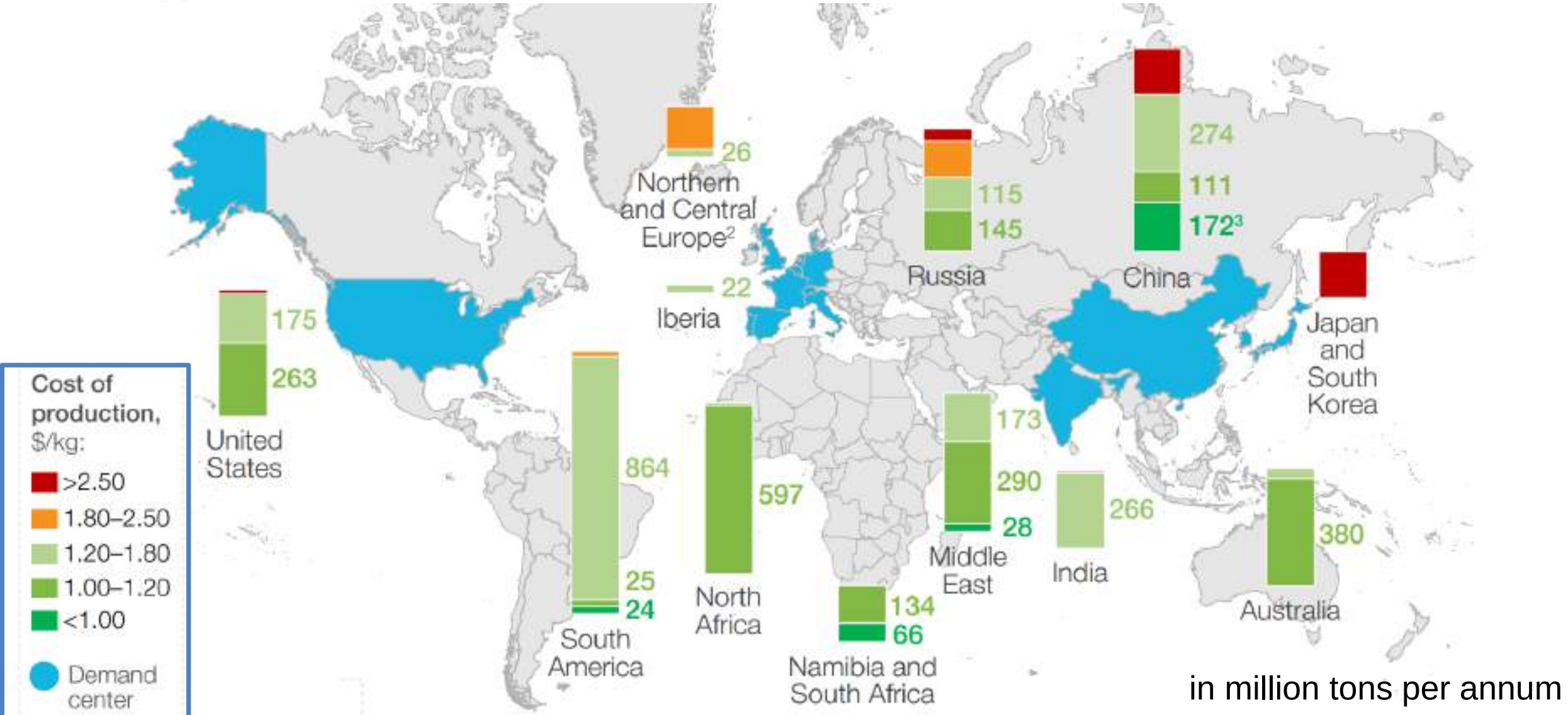




first: decarbonise 94 MT/yr of H_2 = 830 MT/yr of CO_2

second: more clean H_2!

Hydrogen Production and Demand in 2050 (mismatch)



in million tons per annum

60% of clean H_2 will be transported over long distances in 2050



Port of Amsterdam – from coal to 1 million tons of green H_2



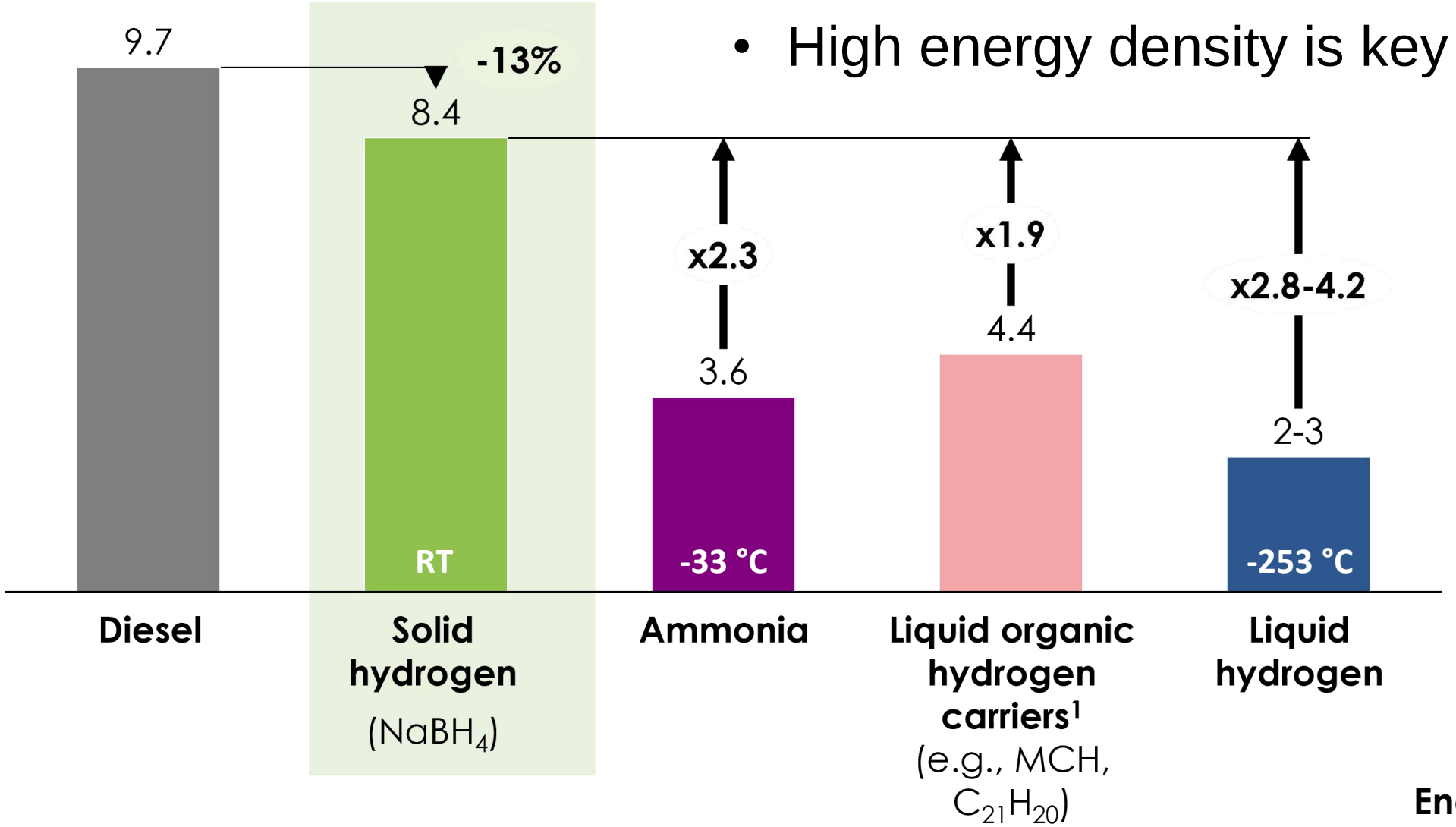
60% of clean H_2 will be transported over long distances in 2050



- Europe-wide H_2 pipelines not before 2035
- Clean hydrogen production ($1/kg)
- Safe transport (high H_2 content)

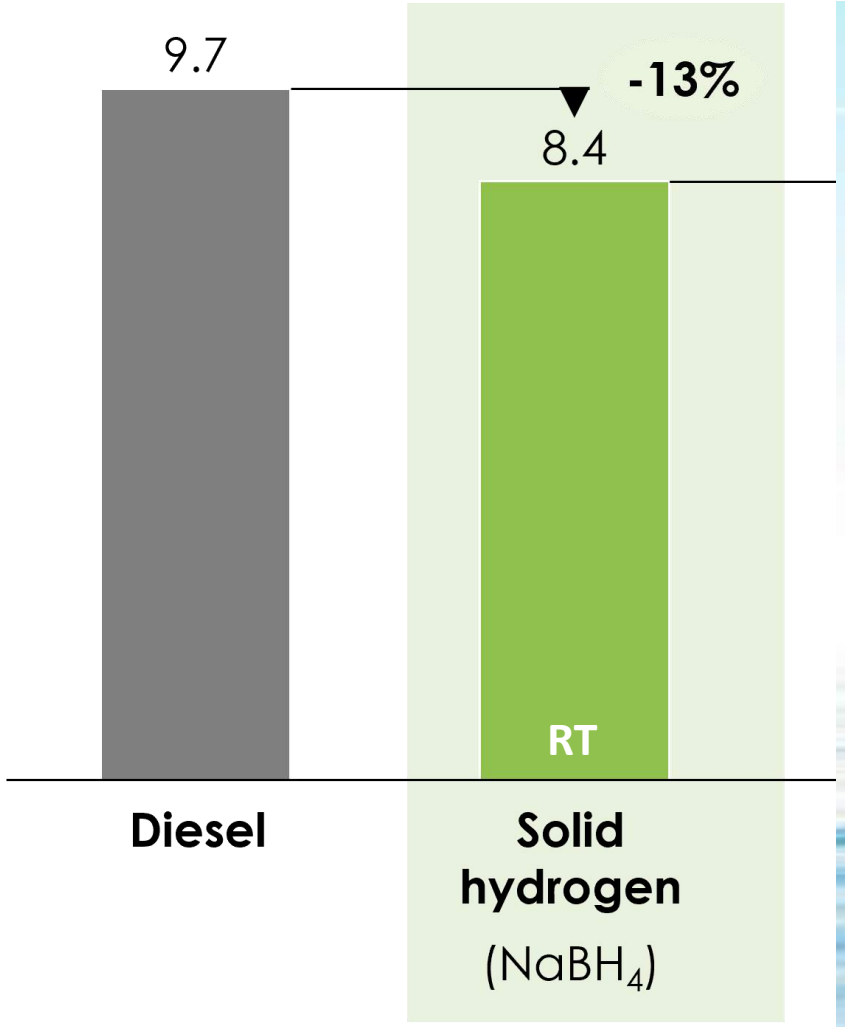


Safe and Circular H_2 carriers



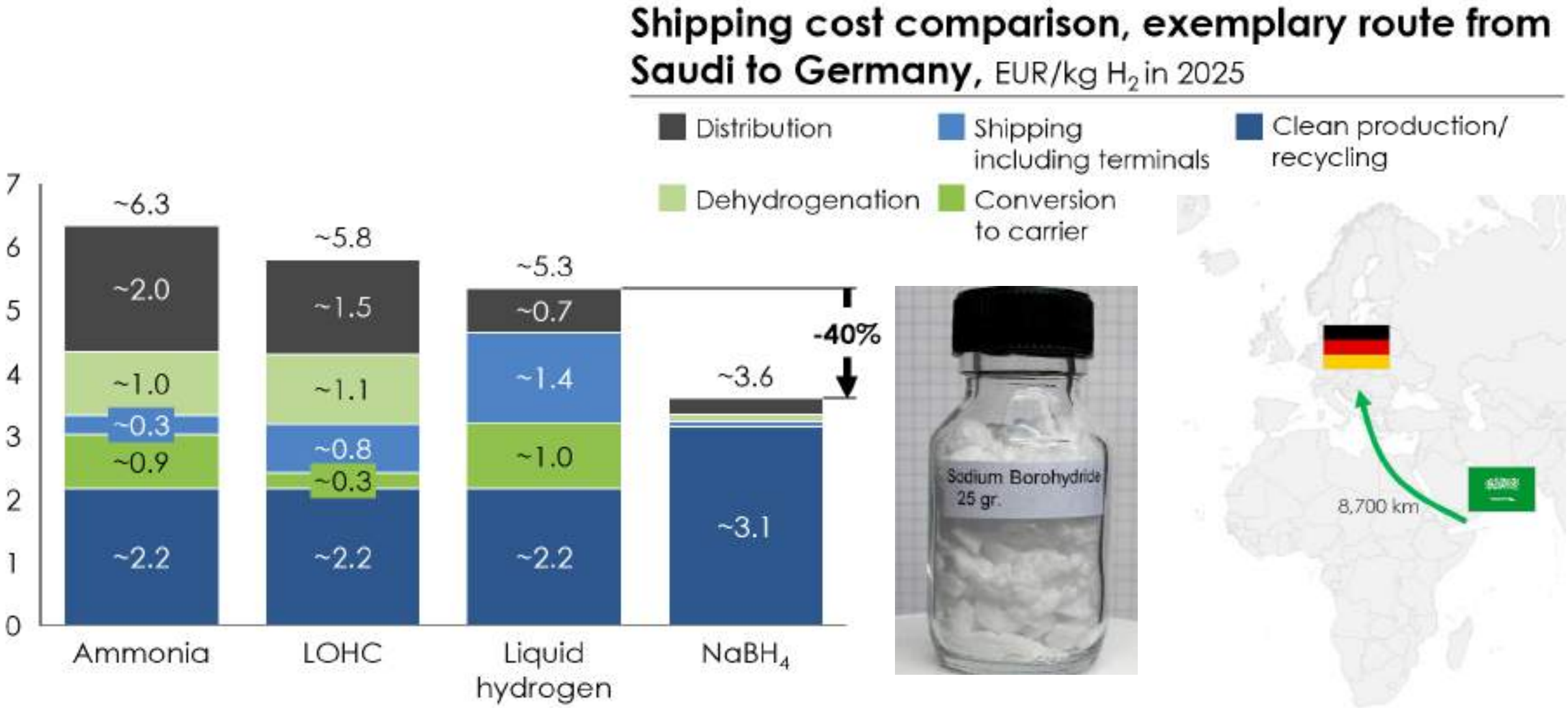
- High energy density is key

Safe and Circular H_2 carriers





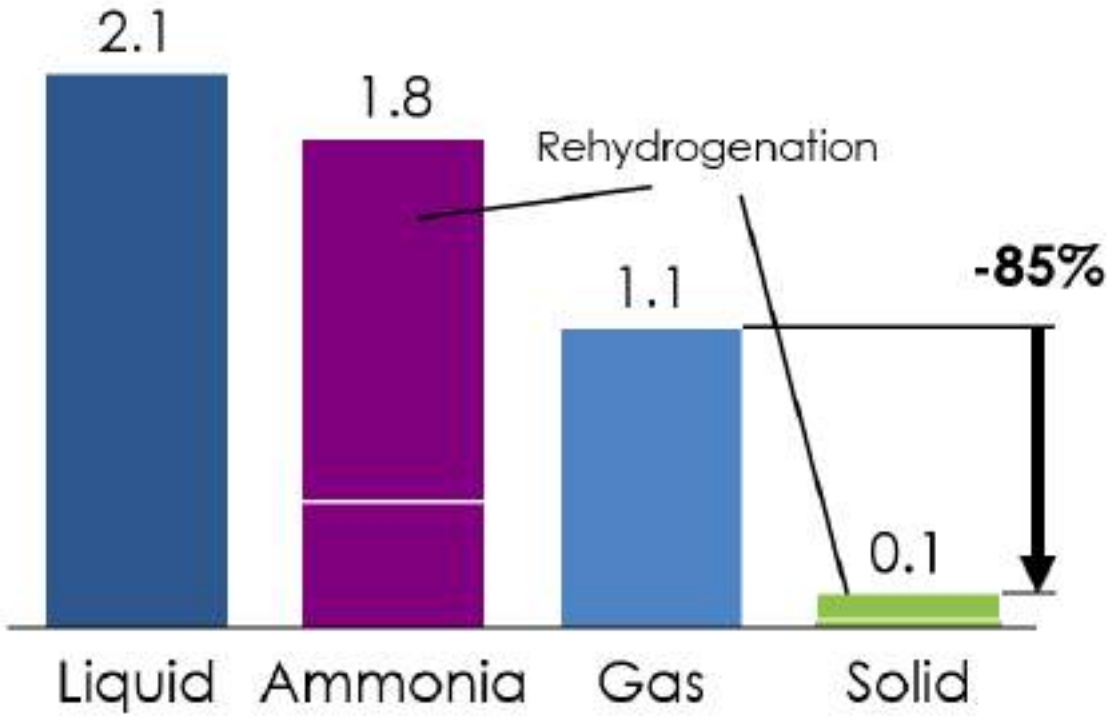
$NaBH_4$ is the cheapest H_2 carrier

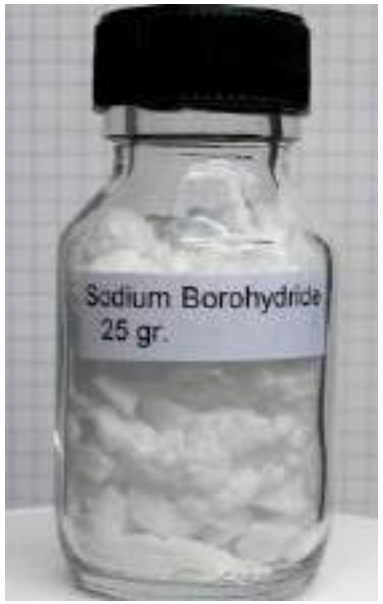


$NaBH_4$ is the cheapest storage vector

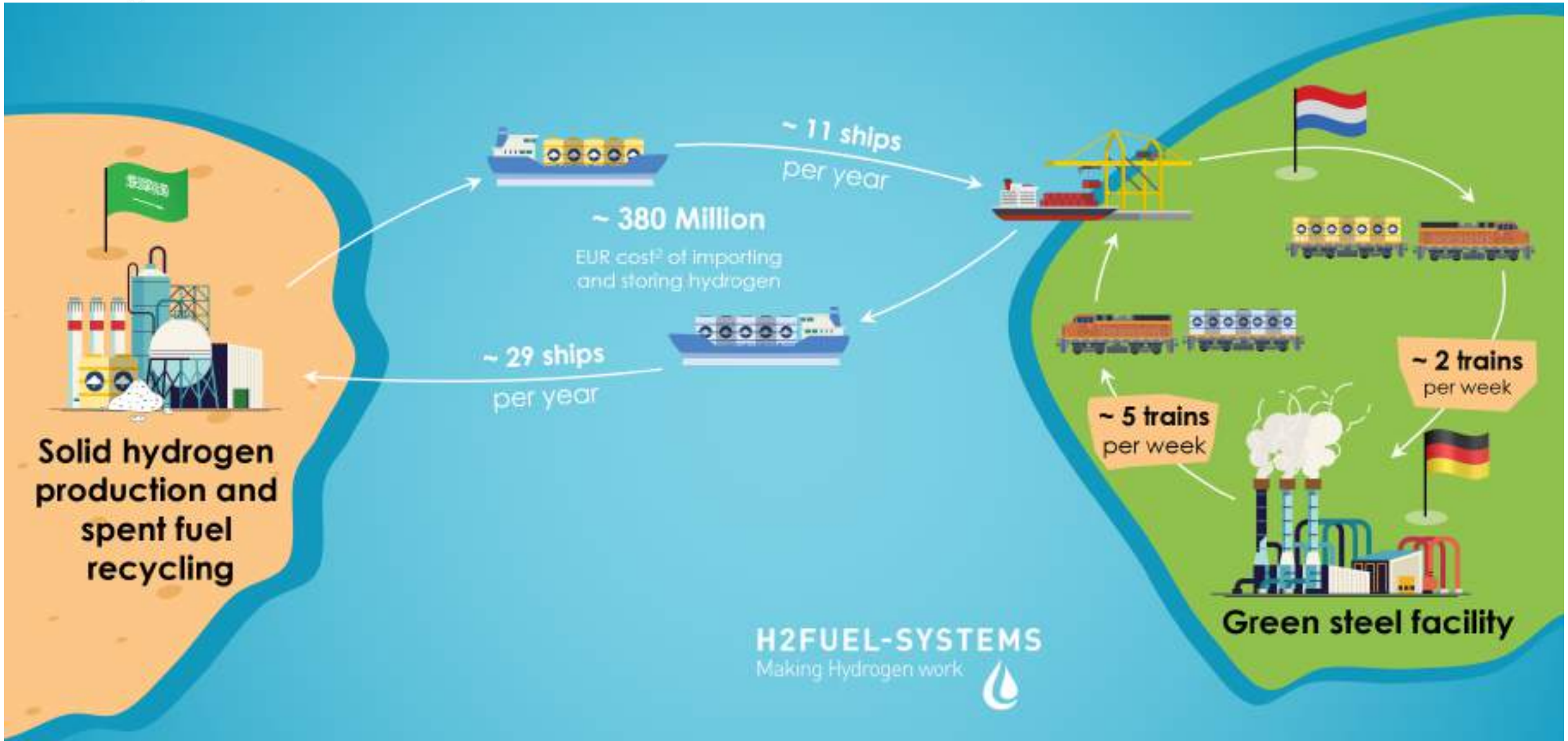
Long-term hydrogen storage cost comparison

6 months storage costs in 2030, including rehydrogenation, EUR/kg H_2





$NaBH_4$ to supply a steel factory

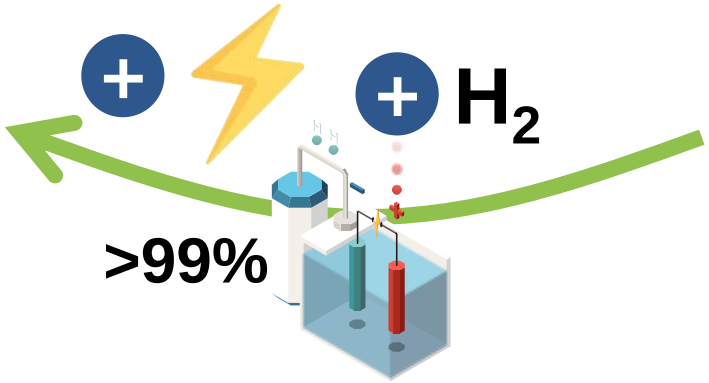


H2Fuel-UvA Breakthrough Technology





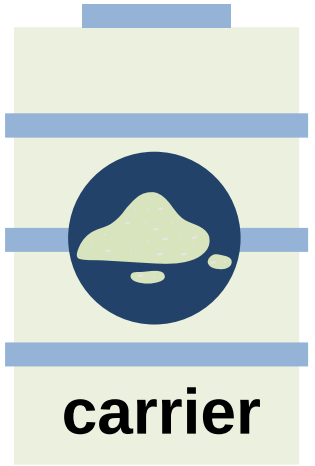
Adding water for release



Adding power and hydrogen for recycling



&



UNIVERSITEIT VAN AMSTERDAM

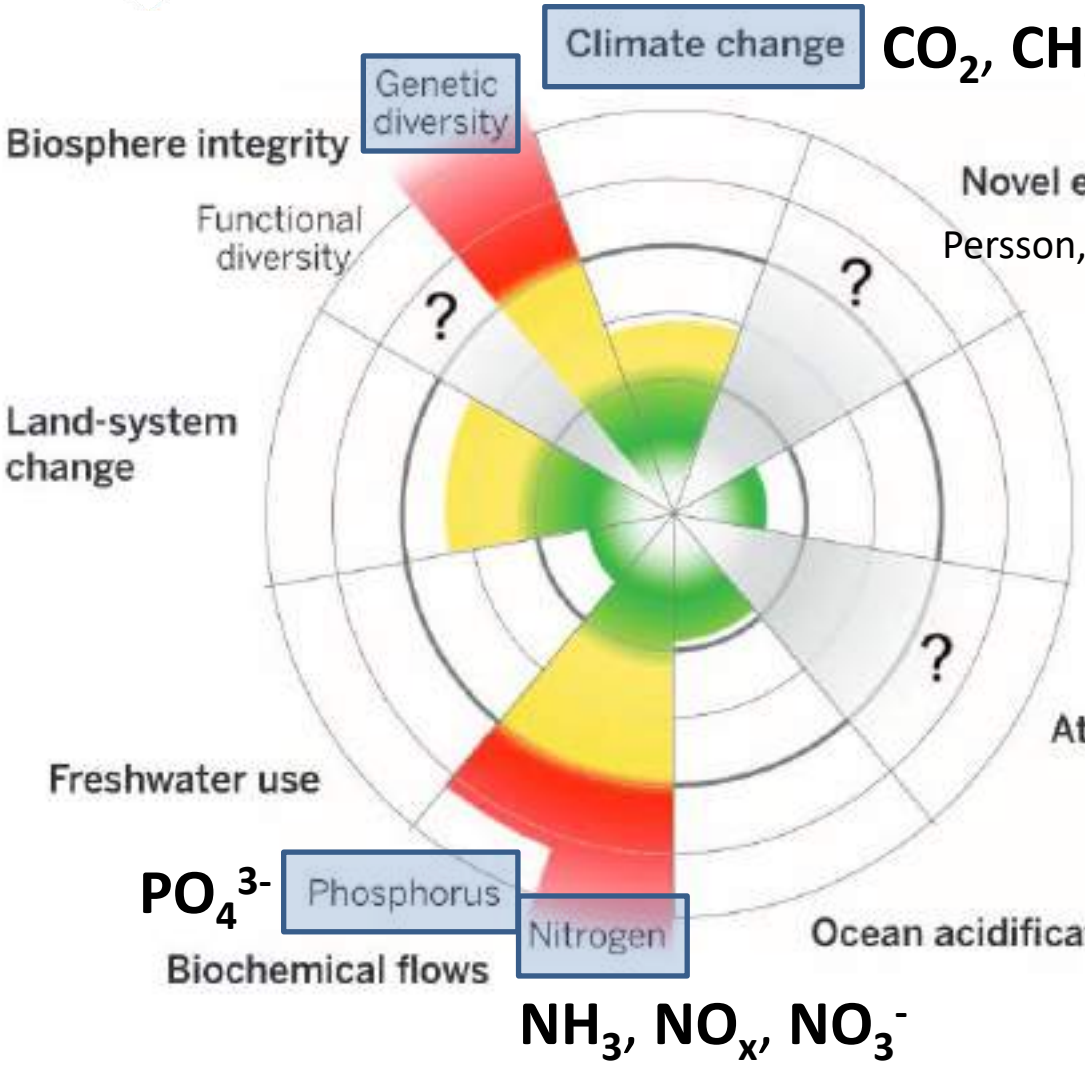
H2FUEL-SYSTEMS

Making Hydrogen work

Safe and Sustainable by Design



‘CHNOPS’: circular technologies are urgently needed



CO_2, CH_4

circular, zero emission energy carriers!

Persson, *Environ. Sci. Technol*. **2022**, *56*, 3, 1510

Safe by Design



PO_4^{3-}

NH_3, NO_x, NO_3^-

recovery & recycling of nutrients!

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

‘CHNOPS’: the origin of life…



Twin challenges of the energy transition and circular economy



Chris Slootweg

UNIVERSITEIT VAN AMSTERDAM