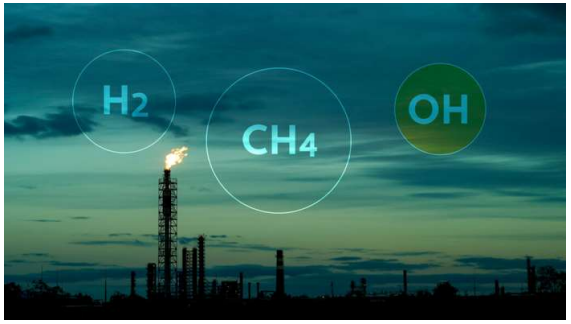


GLOBAL H_2 CYCLE DYNAMICS IN THE ENERGY TRANSITION

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Politecnico di Torino 1859

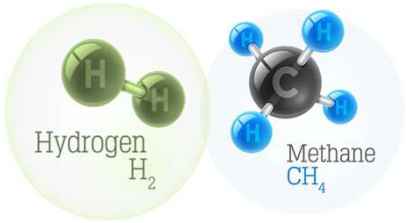
PRINCETON UNIVERSITY

High Meadows Environmental Institute

Carbon Mitigation Initiative

PRESENTATION OUTLINE

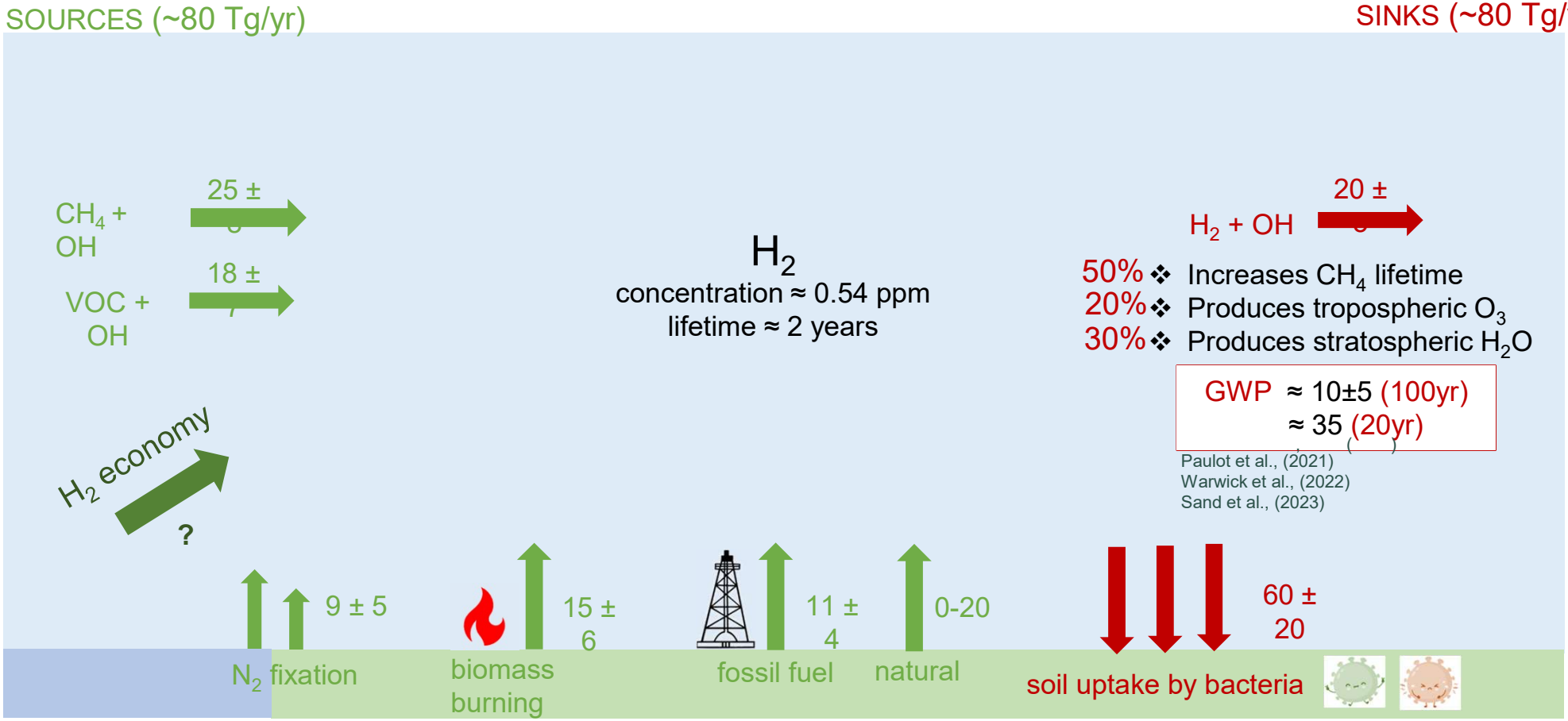
INTRO
THE H_2 CYCLE AND ITS LINKS WITH CH_4



THE H_2 SOIL SINK AND ITS HYDROCLIMATIC CONTROLS

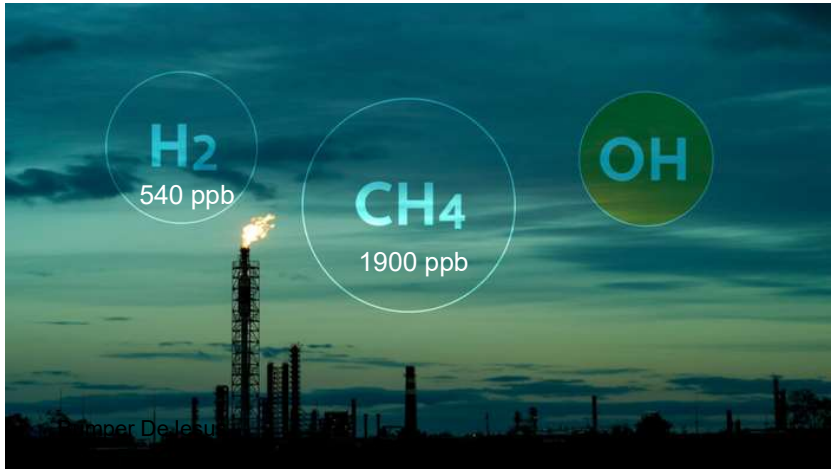
OUTLOOK
BEYOND THE H_2 CYCLE

GLOBAL H_2 CYCLE AND INDIRECT CLIMATE IMPACT

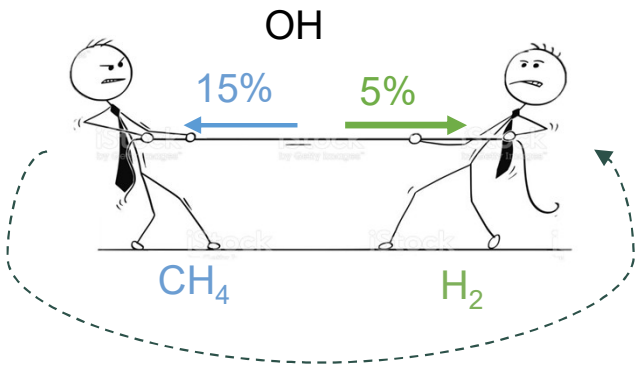


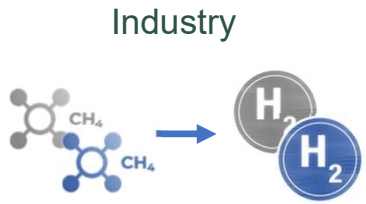
Flux estimates (Tg/yr) from Ehhalt and Roher, 2009, Tellus B

TANGLED H_2 & CH_4 BUDGETS



- Most abundant reactive trace gases
- Competing for the OH sink
- Atmospheric CH_4 oxidation produces H_2
- Natural gas is used to produce H_2

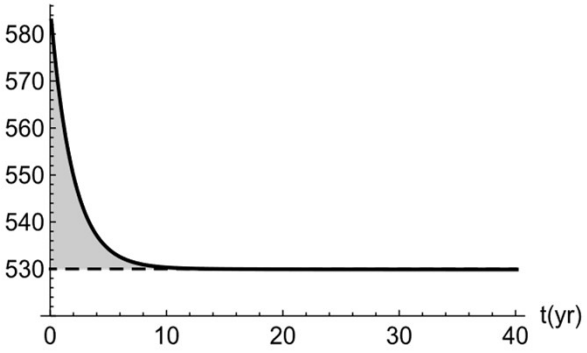


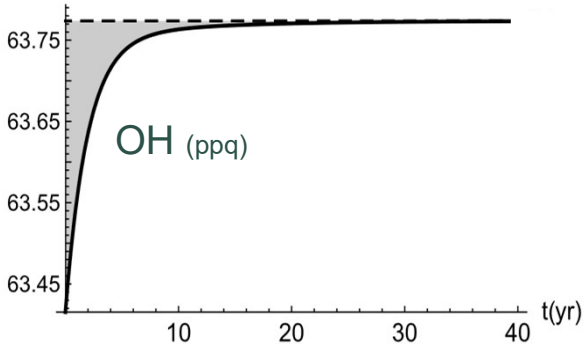


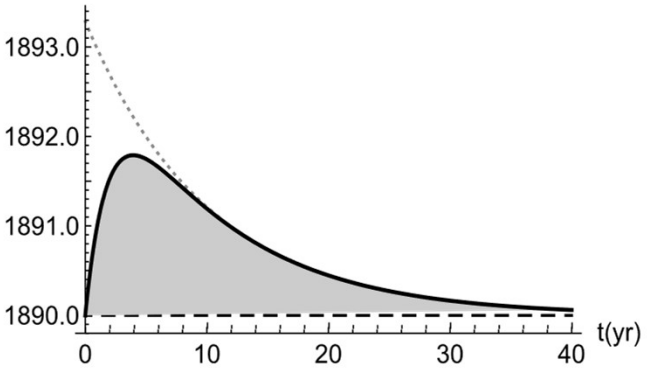
>60% of current production

Bertagni et al., Nat. Comm. (2022)

IMPACT OF H_2 EMISSIONS ON ATMOSPHERIC CH_4



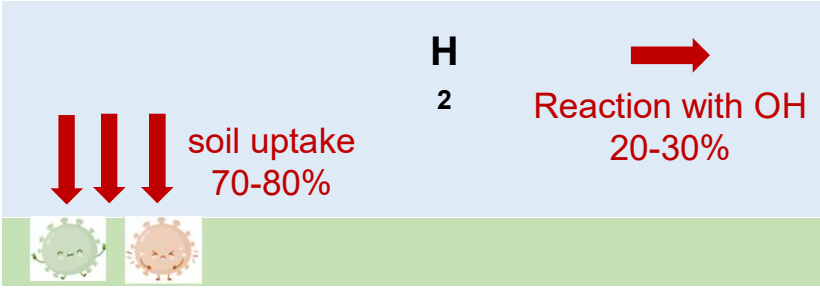




1. Long-term impact (CH_4) of a short-lived gas (H_2)
2. Main risk actually related to CH_4 emissions for H_2 production
3. H_2 impacts significantly mitigated by the soil sink

Bertagni et al., Nat. Comm. (2022)

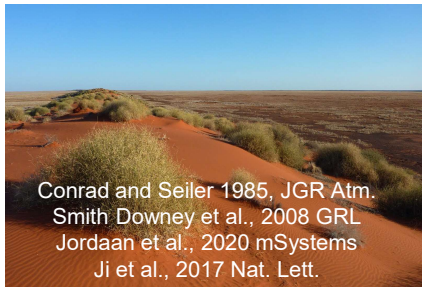
THE OVERWHELMING ROLE OF BACTERIA IN SOILS



1980s: First measures of soil H_2 uptake, believed to be abiotic

2010: First isolation of high-affinity H_2-oxidizing bacteria (HA-HOB)
Constant et al., 2010, Env. Microb.

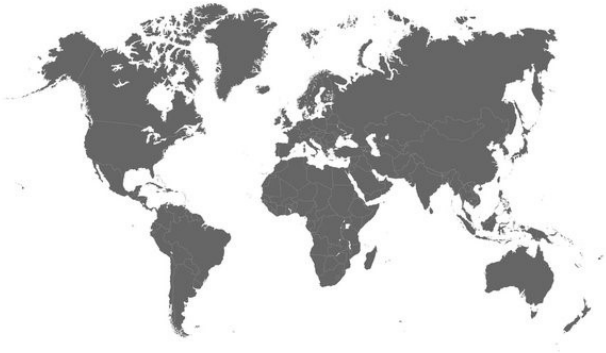
Since 2010: Hydrogenase has been found in 21 bacterial phyla
Greening and Grinter, Nat. Rev. Microbiol. (2022)



ADDRESSING THE UNCERTAINTY

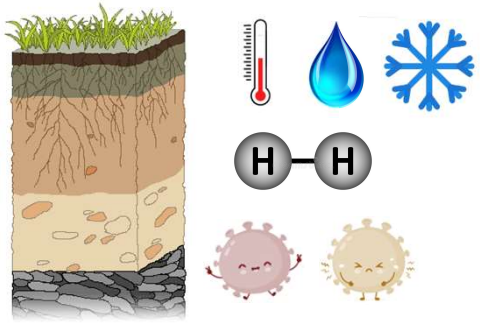
Global calculations

- ❑ Scaled to match the sources (top-down)
- ❑ Poorly parametrized (e.g., constant over all land)

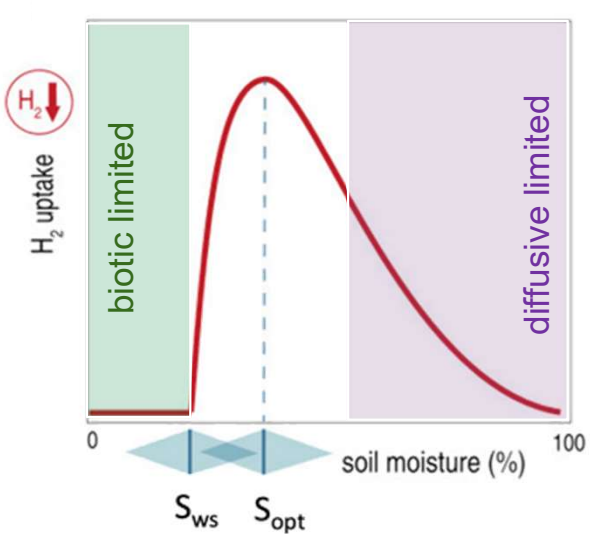


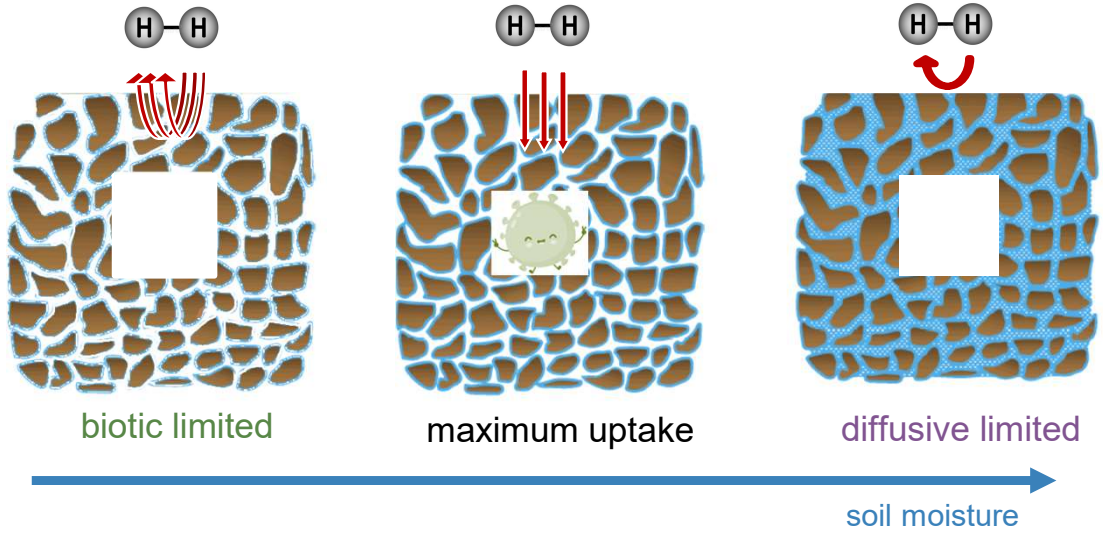
Research goals

- ❑ Develop a mechanistic model based on hydroclimatic drivers
- ❑ Assess the crucial role of soil moisture and its temporal fluctuations
- ❑ Quantify the uptake potential and limitations

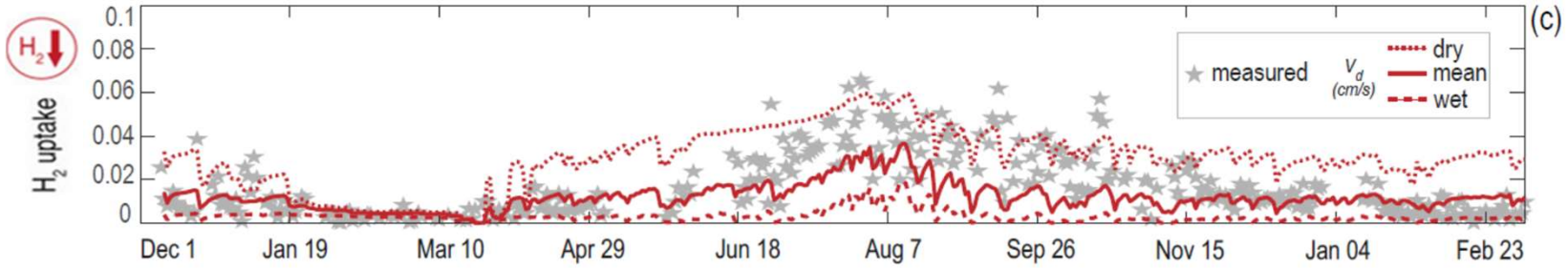


THE CRUCIAL ROLE OF SOIL MOISTURE





Comparison with field data from the Harvard Forest *(Meredith et al., 2017 Glob. Change Biol.)*



Bertagni et al., Glob. Biog. Cycles (2021)

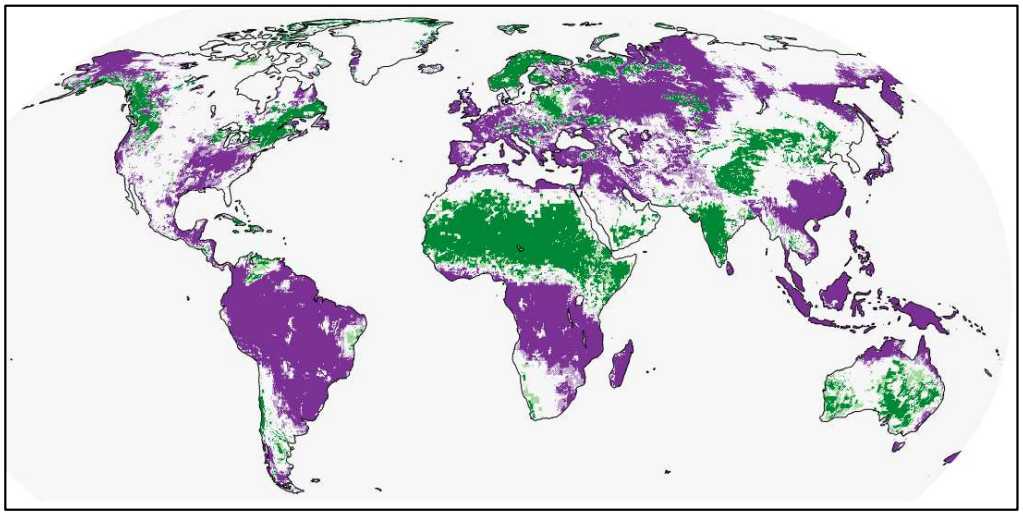
GLOBAL ABIOTIC AND BIOTIC LIMITATIONS

biotic velocity \ **diffusive velocity** /

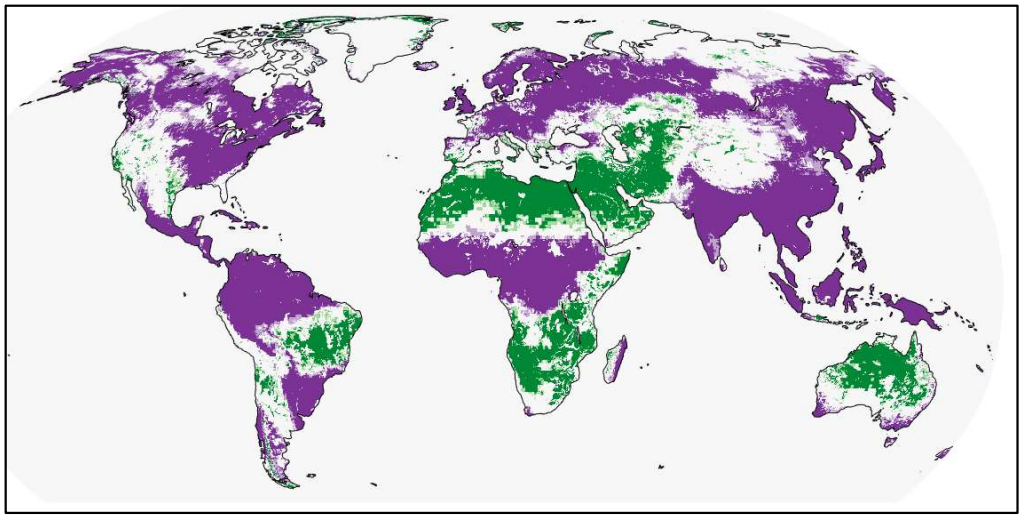
$$v_d = \frac{v_{BD}\, g_T}{g_T + v_{BD}}$$

$v_{BD} \gg g_T$	$v_d \sim g_T$	**diffusive limited**
$g_T \gg v_{BD}$	$v_d \sim v_{BD}$	**biotic limited**

January-February 2019

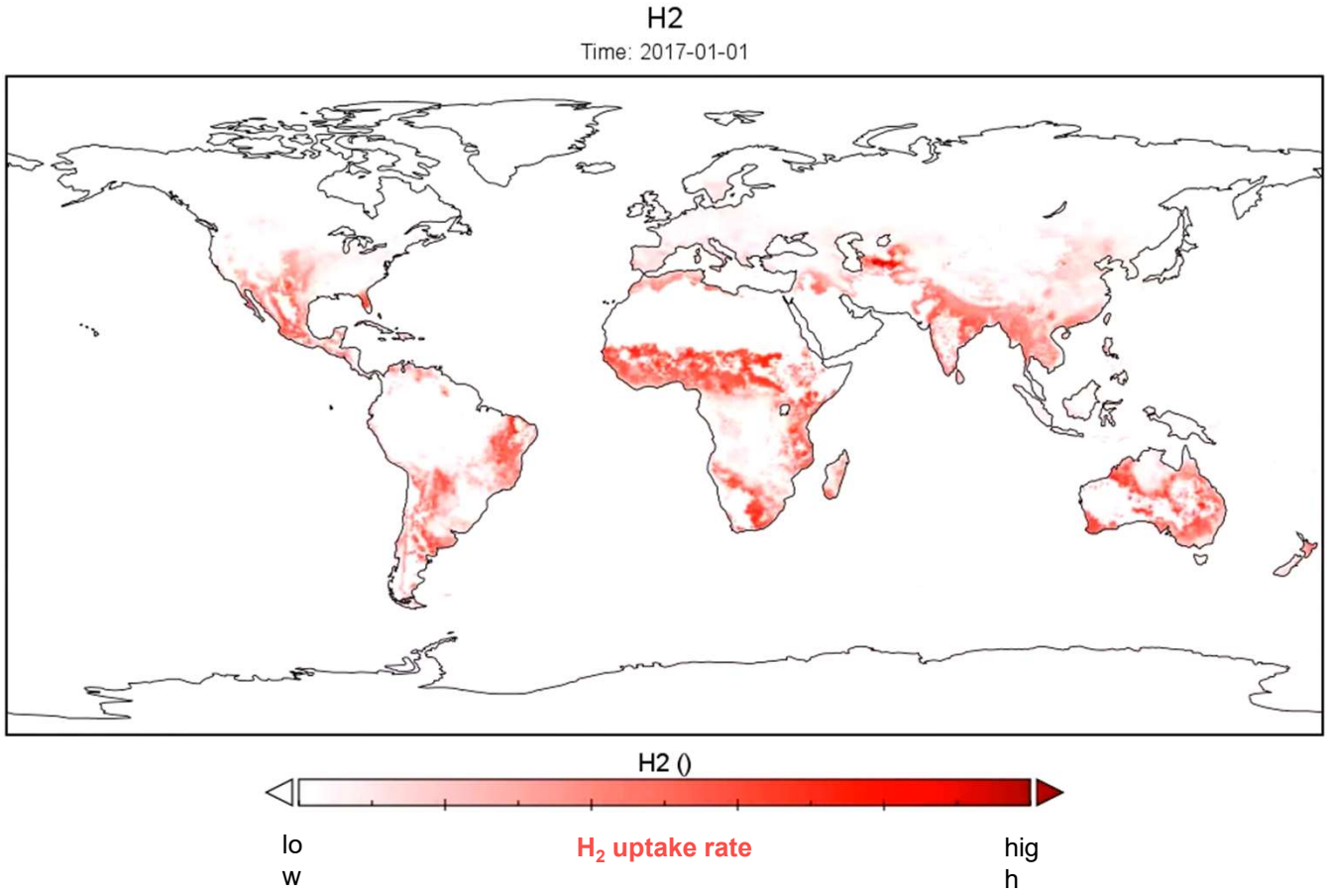


July-August 2019



Bertagni et al., Glob. Biog. Cycles (2021)

HYDROCLIMATIC-DRIVEN GLOBAL H_2 UPTAKE



Bertagni et al., Glob. Biog. Cycles (2021)

Advancements:

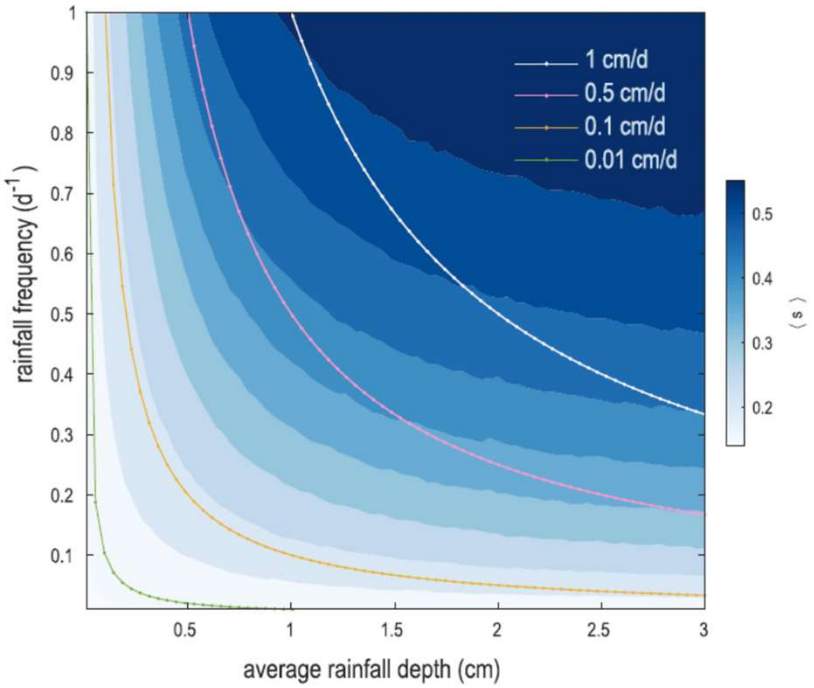
- Hydroclimatic-driven parametrization
- For all soil types
- Global uptake limitations
- Now in the GFDL climate model

Challenges:

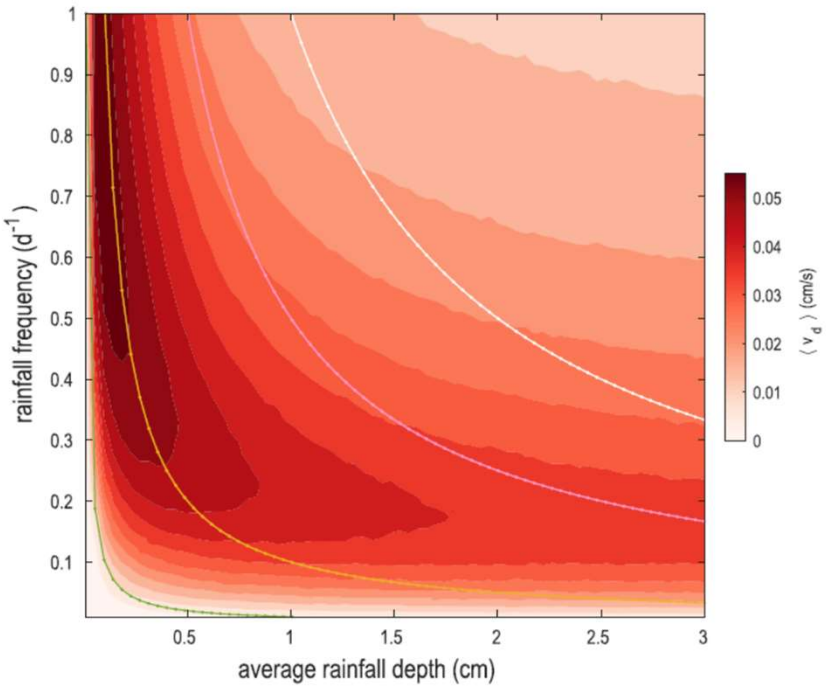
- Temporal dynamics
- Sensitivity to moisture data
- Biotic parameters

HOW RAINFALL IS DISTRIBUTED IN TIME MATTERS

average soil moisture

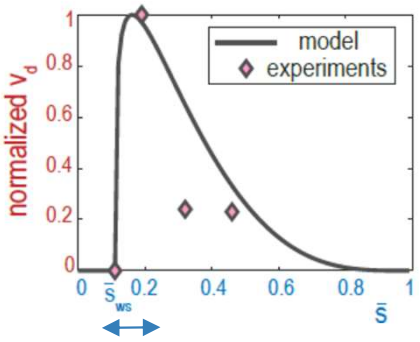


average deposition velocity



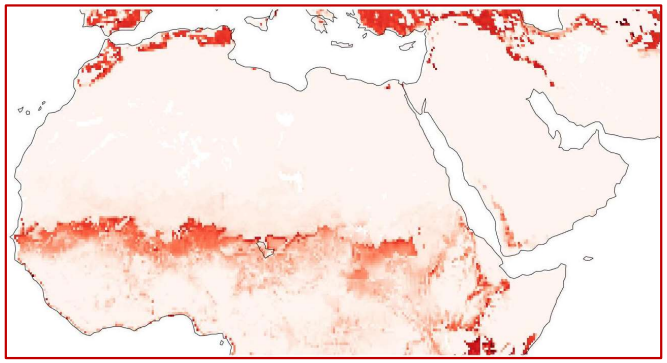
Bertagni et al., 2021, Global Biogeoc. Cycles

SEMI-ARID REGIONS: POTENTIAL HOTSPOTS BUT CHALLENGING FOR MODELS

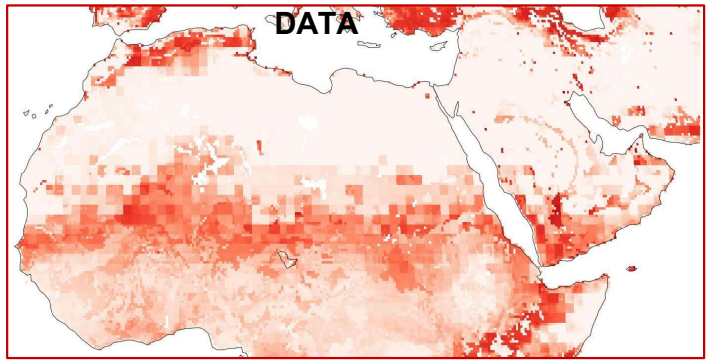


Very sensitive to soil moisture

ERA5 DATA



GLDAS DATA



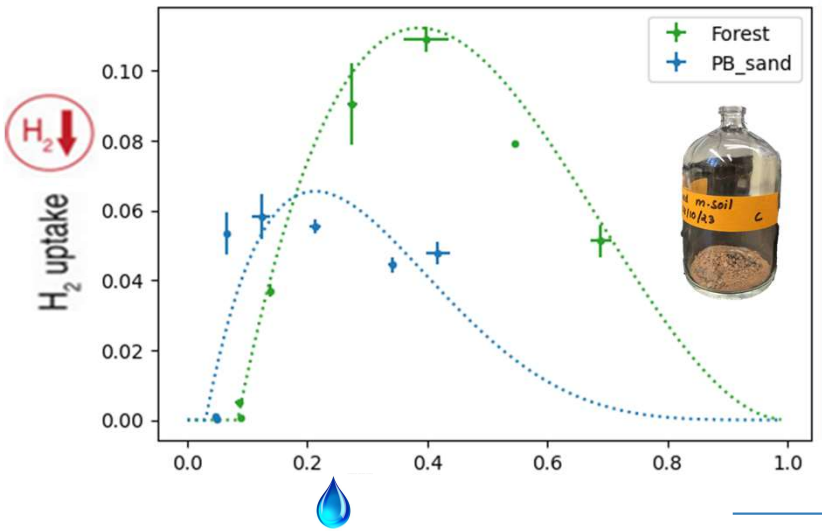
July - August 2019

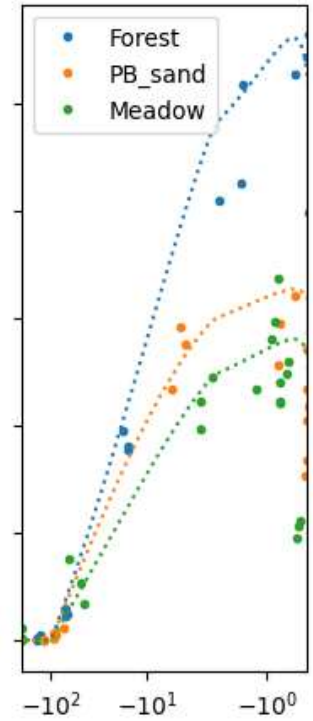
Relatively small hydrological uncertainties have great impacts on the soil sink representation

Bertagni et al., GBC (2022)

EXPERIMENTAL CONSTRAINTS ON BIOTIC THRESHOLD

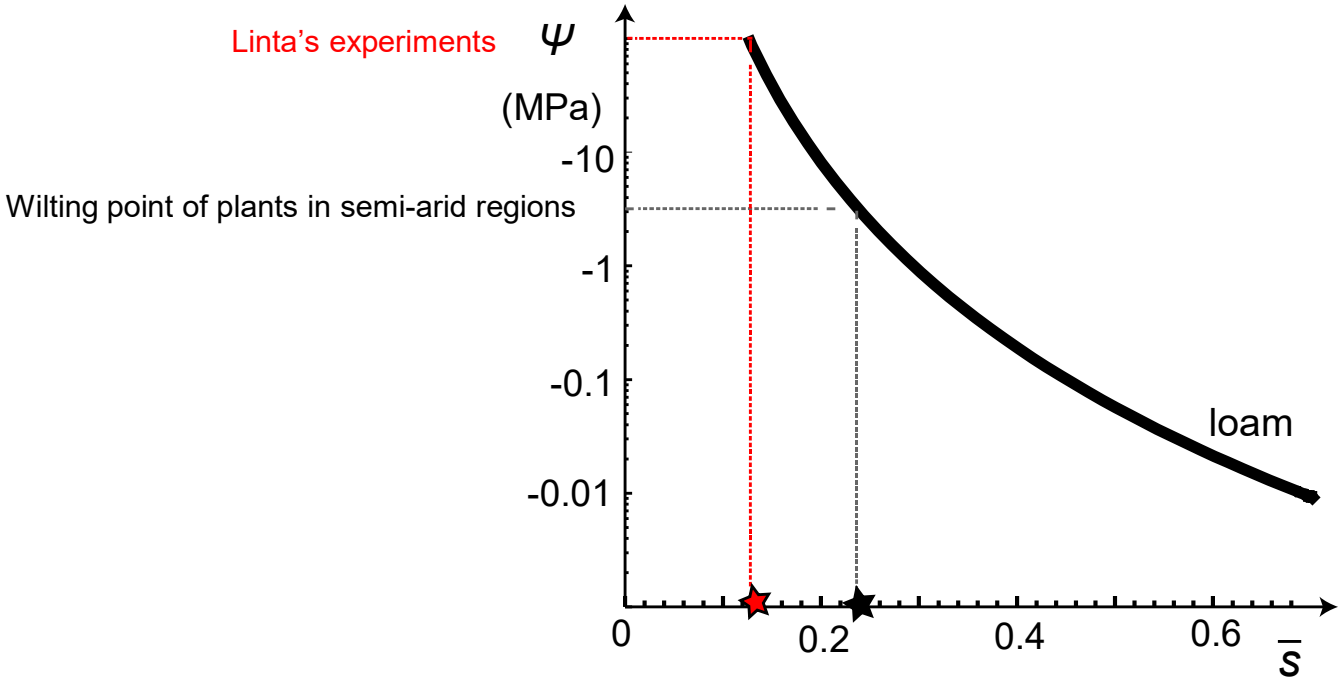
Reji et al., in preparation





Bacteria much more drought resistant than what we assumed

IMPLICATIONS: MORE CHALLENGES FOR SEMI-ARID REGIONS



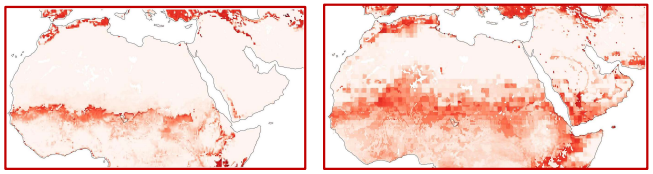
Small difference in moisture threshold that is challenging for hydrological data

KEY MESSAGES

1) The soil sink is critical and mitigates H_2's climatic impacts

2) Hydrology exerts both physical and biological controls on the soil sink

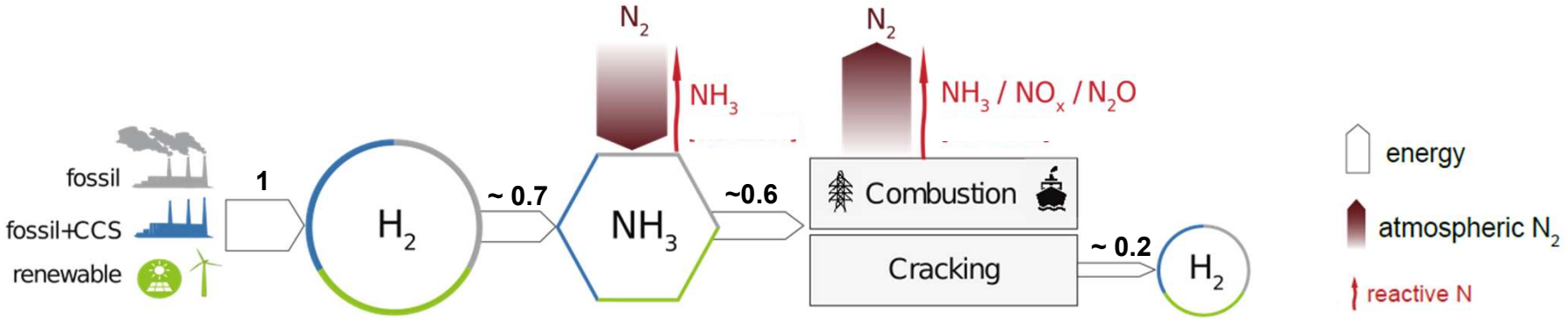
3) Despite our advancments, there are still significant uncertainties in the soil sink representation, especially in semi-arid regions



The environmental implications of H_2 energy go beyond the H_2 cycle

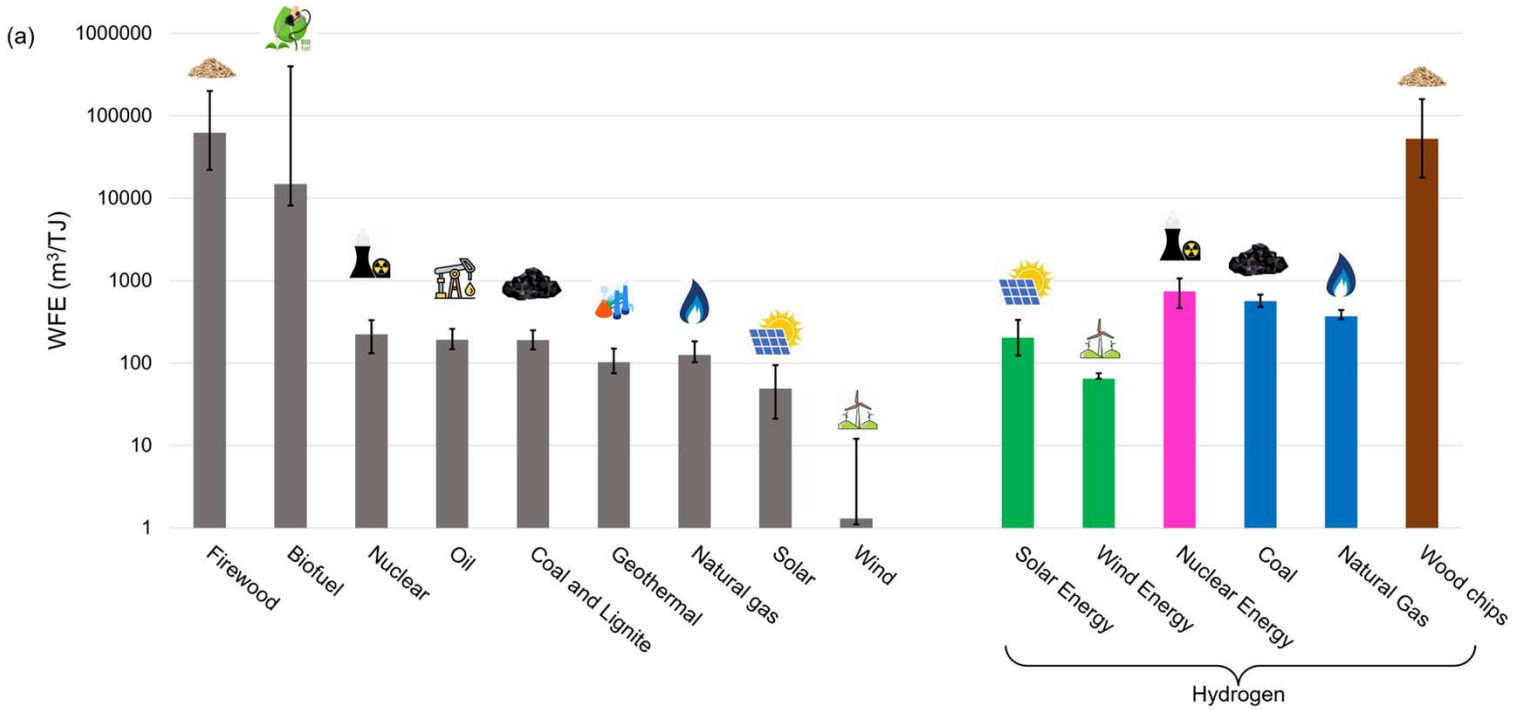
AMMONIA (NH_3) FOR H_2 TRANSPORT AND CONCERNS FOR THE NITROGEN CYCLE

$$N_2 + 3\,H_2 \longrightarrow 2\,NH_3$$



Bertagni et al., PNAS (2023)

THE WATERFOOTPRINT OF H_2 PRODUCTION

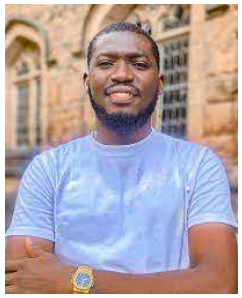


Olaitan, Bertagni, & Porporato, (2024), STOTEN

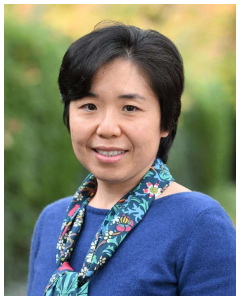
FINAL, PERSONAL THOUGHT AND ACKNOWLEDGMENTS

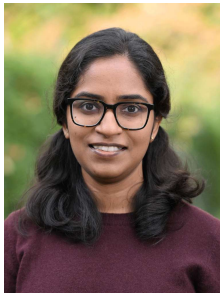
Don’t Let Fear Hold Us Back

Let’s Use It to Push Us Forward


Damola Olaitan


Amilcare Porporato


Xinning Zhang

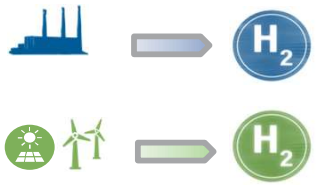

Linta Reji


Fabien Paulot

Happy to take questions

matteo.bertagni@polito.it

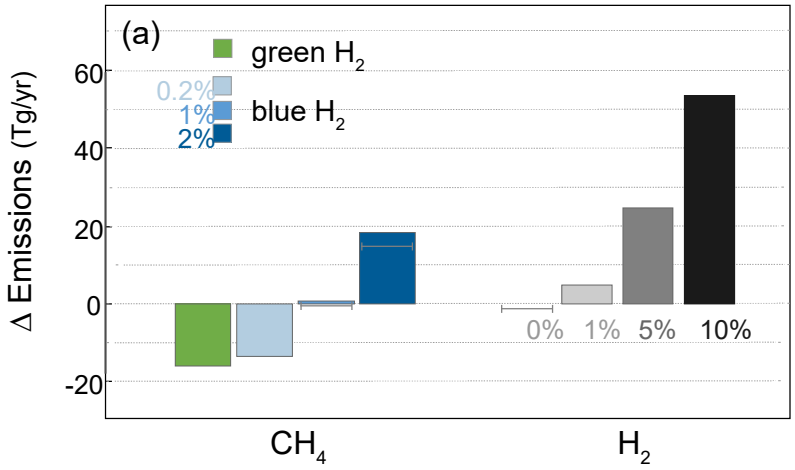
ATMOSPHERIC METHANE RESPONSE TO H_2 ENERGY

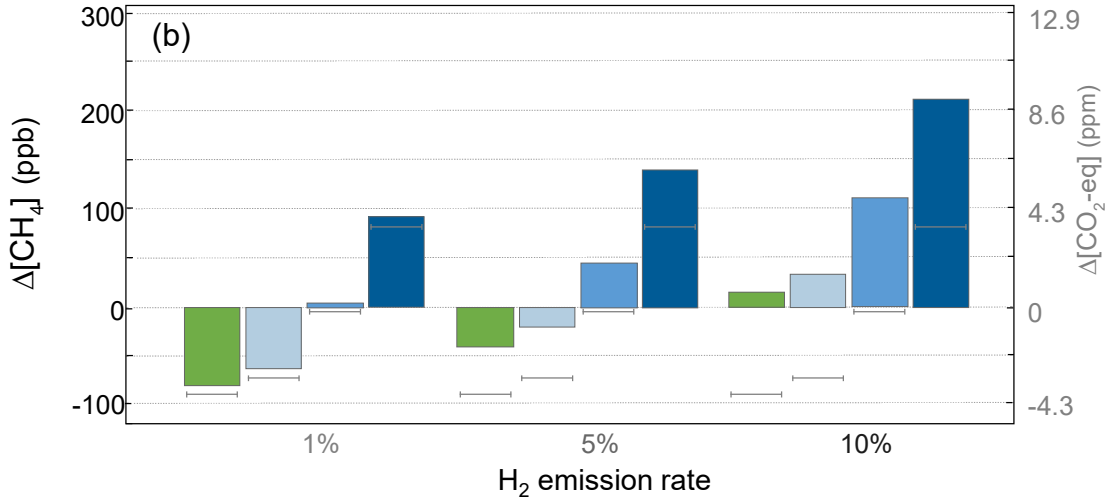


entails CH_4 and H_2 emissions

only H_2 emissions

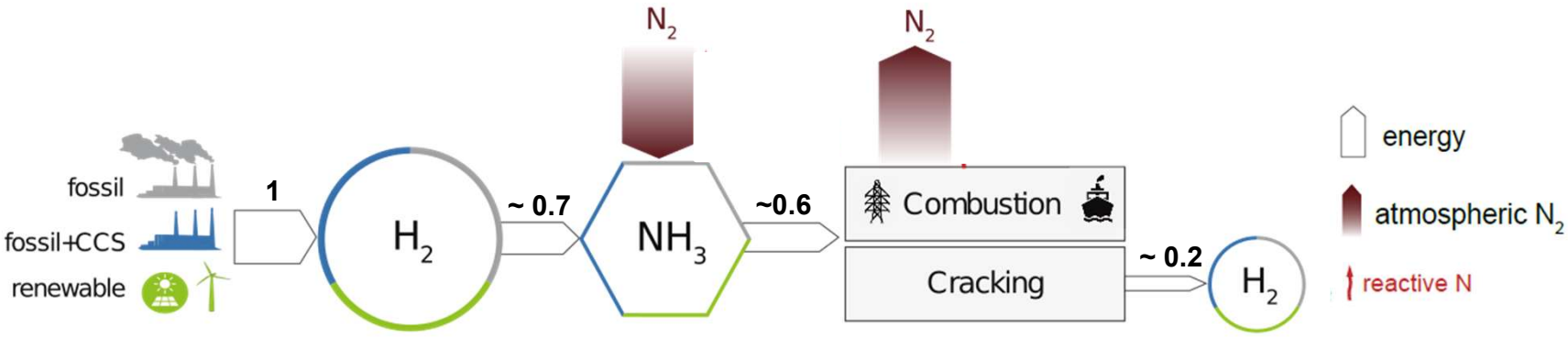
- H_2 displaces around 15% of fossil-fuel energy (~500 Tg/yr, Net Zero IEA 2021)



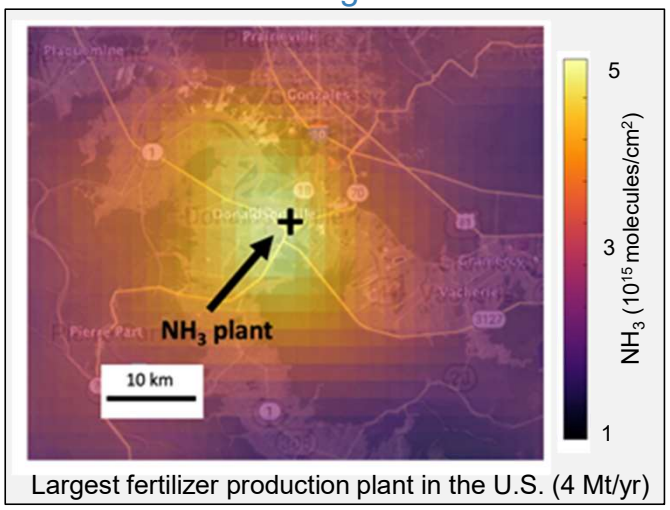


Bertagni et al., Nat. Comm. (2022)

NH_3 VALUE CHAIN AND CONCERNS FOR THE NITROGEN CYCLE

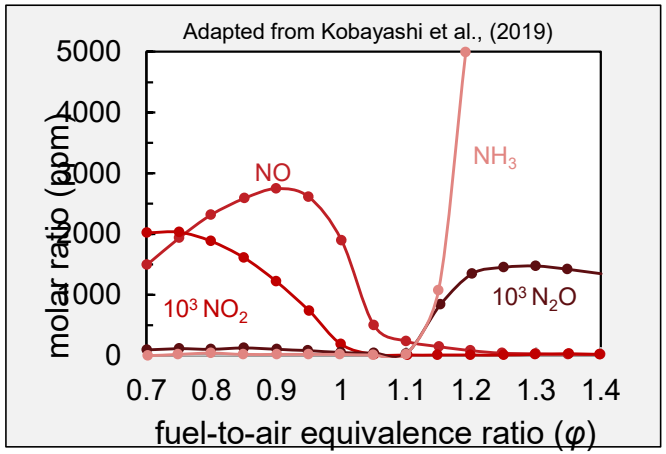


Leakages

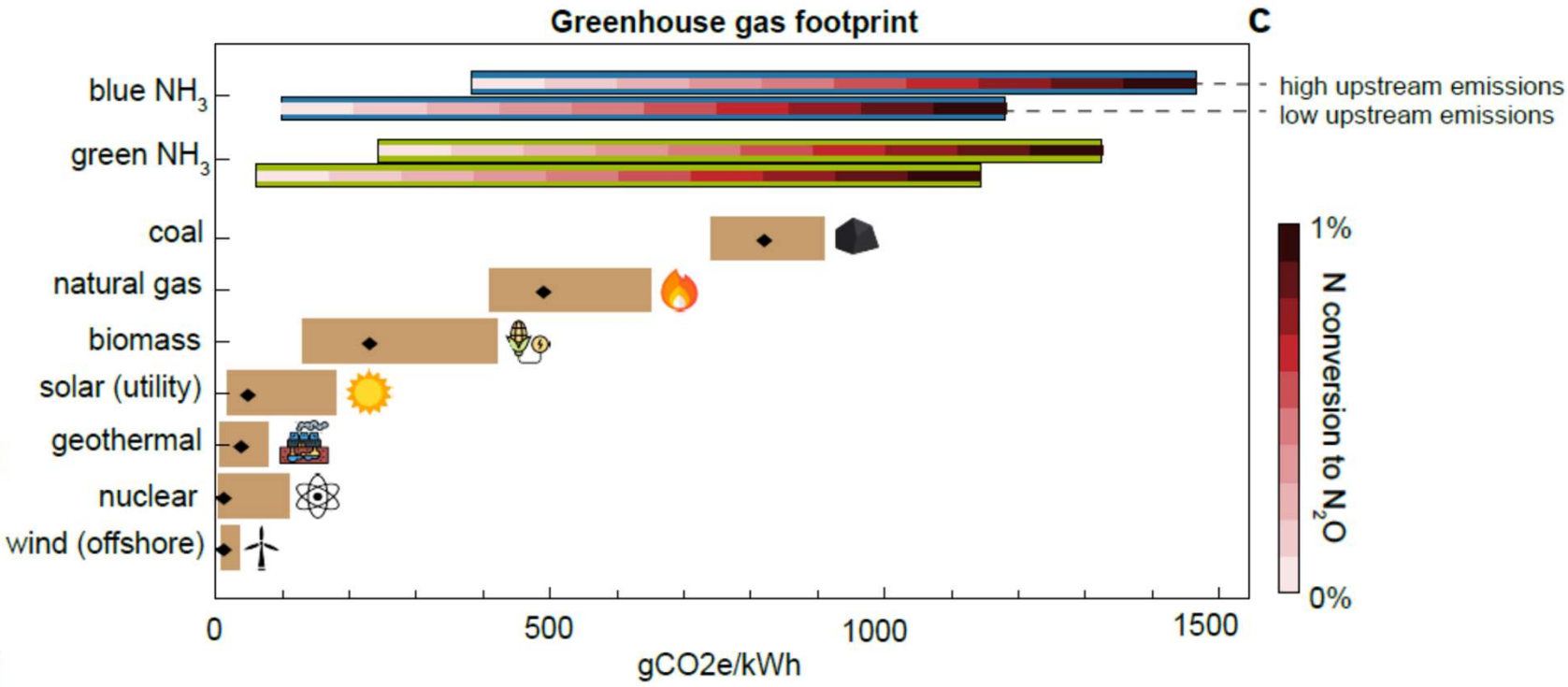


Largest fertilizer production plant in the U.S. (4 Mt/yr)

Combustion Byproducts



Bertagni et al., PNAS (2023)



C
E

NH_3 energy requires careful optimization through best-use pathways, practices, tech, and regulations.

Bertagni et al., PNAS (2023)