

Agricultural Emissions of Nitrous Oxide and Methane

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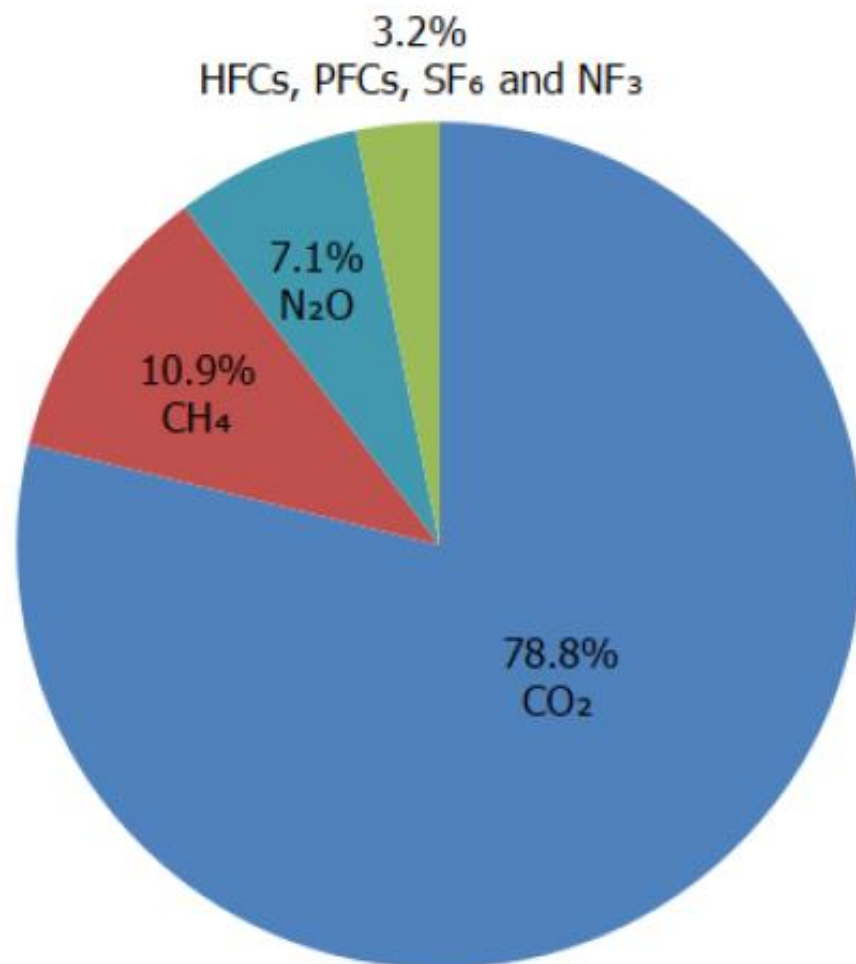
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However, when using 20-year GWPs, the calculated contribution of CH₄ increases from 11% to 24% and the total contribution from agriculture increases from 10% to 15%



Agriculture sector contribution:
~40% of CH₄ emissions
~75% of N₂O emissions
~10% of total GHG emissions

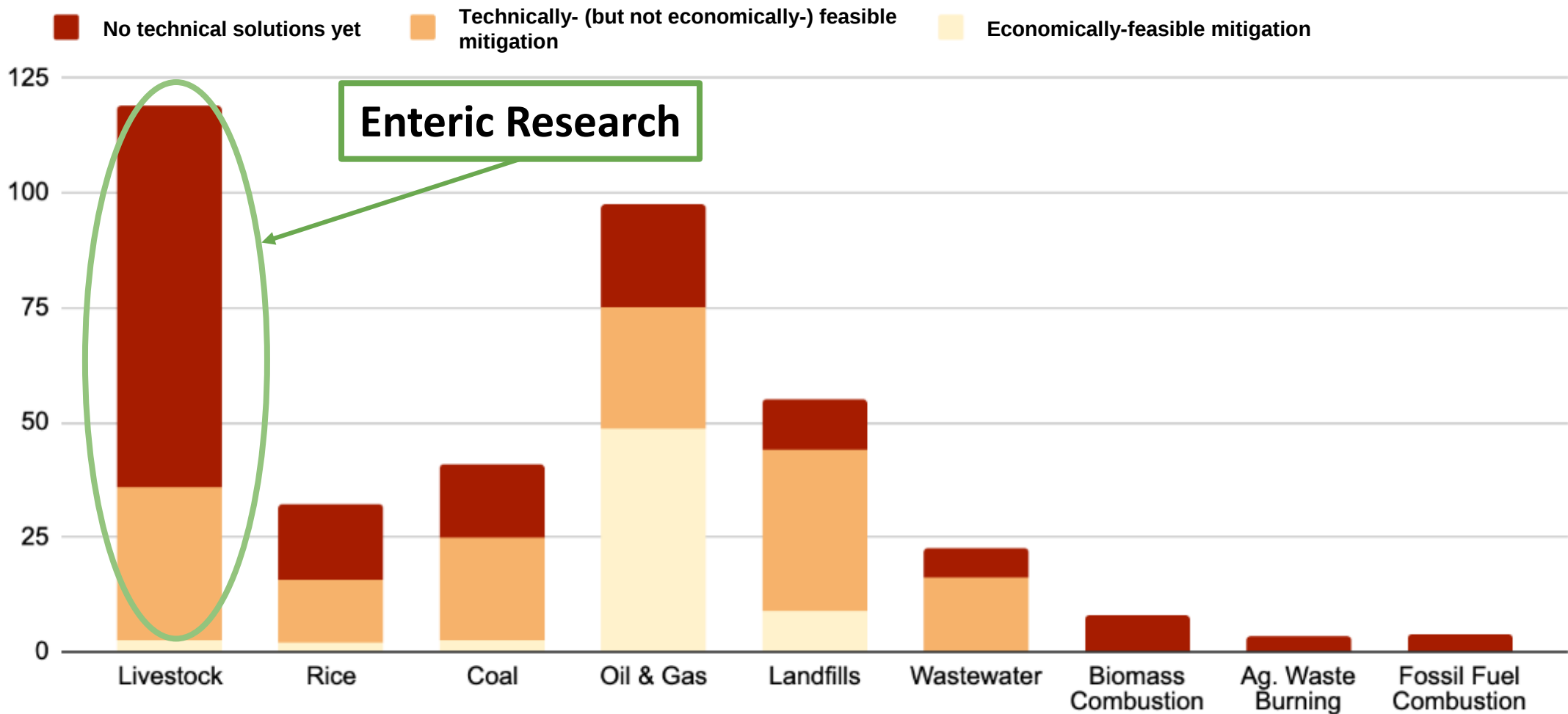
N₂O is not only a potent GHG, but also an important reactant in destruction of the protective layer of stratospheric ozone

2020 U.S. Greenhouse Gas Emissions by Gas
(Percentages based on MMT CO₂ Eq. using 100-year Global Warming Potential)
Source: EPA

Livestock emissions are the largest category without the needed suite of solutions yet

Data from Ocko et al. 2021. Environ. Res. Lett. 16, 16(5), 054042

Projected 2030 Emissions (Mt/yr)



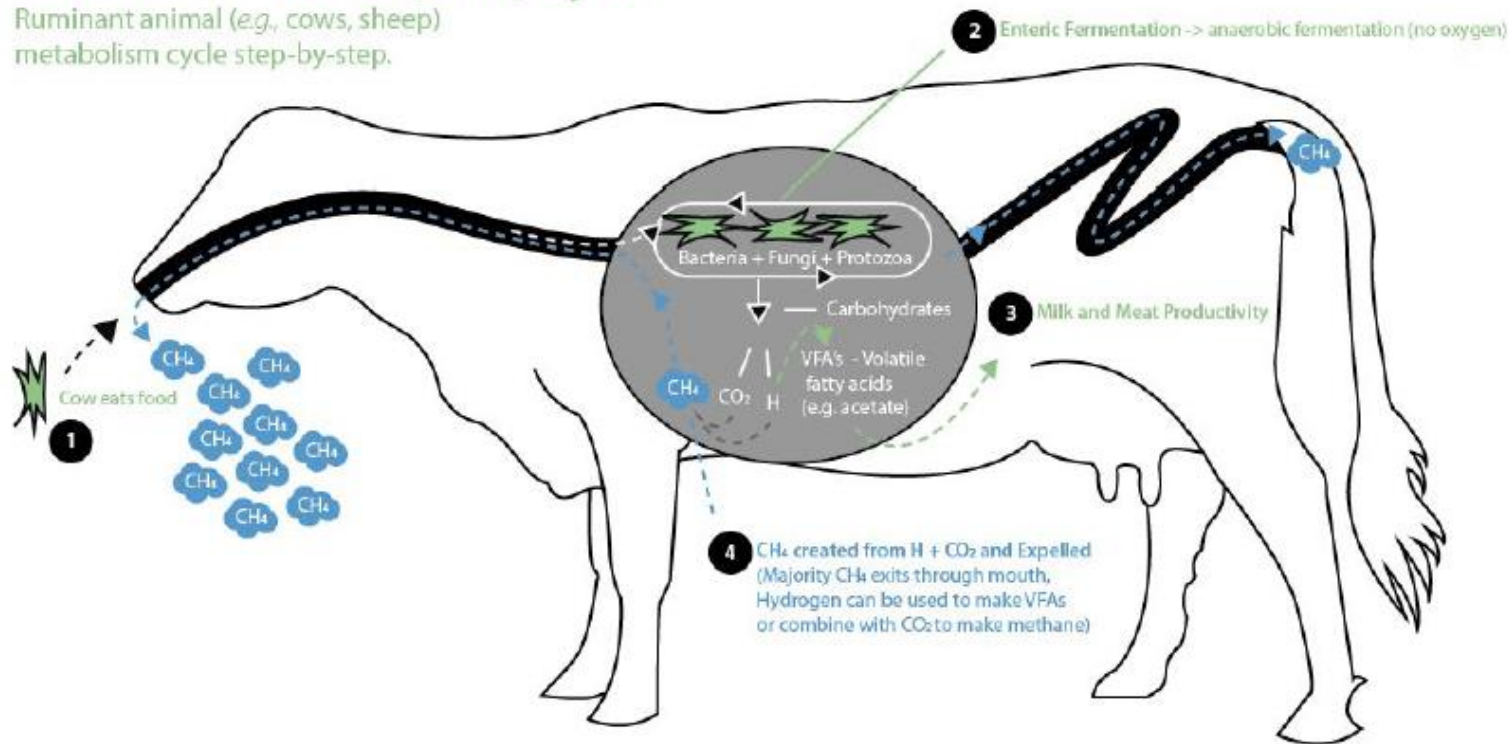
Note: Portion of emissions shown as addressed using methane removal are hypothetical.

Science and Solution Categories at a glance.



Enteric Methane (CH₄) Cycle

Ruminant animal (e.g., cows, sheep)
metabolism cycle step-by-step.



Cutting Edge Methane Reduction Approaches

Block methane-forming enzymes

e.g., Bovaer (3-NOP), red seaweed (bromoform)

+ Small amount needed, in use now

- Only 30% reduction, not formulated for grazing

Re-engineer microbiome

e.g. anti-methanogen vaccine

+ Could scale globally quickly

- Unproven

Feed formulation for low methane

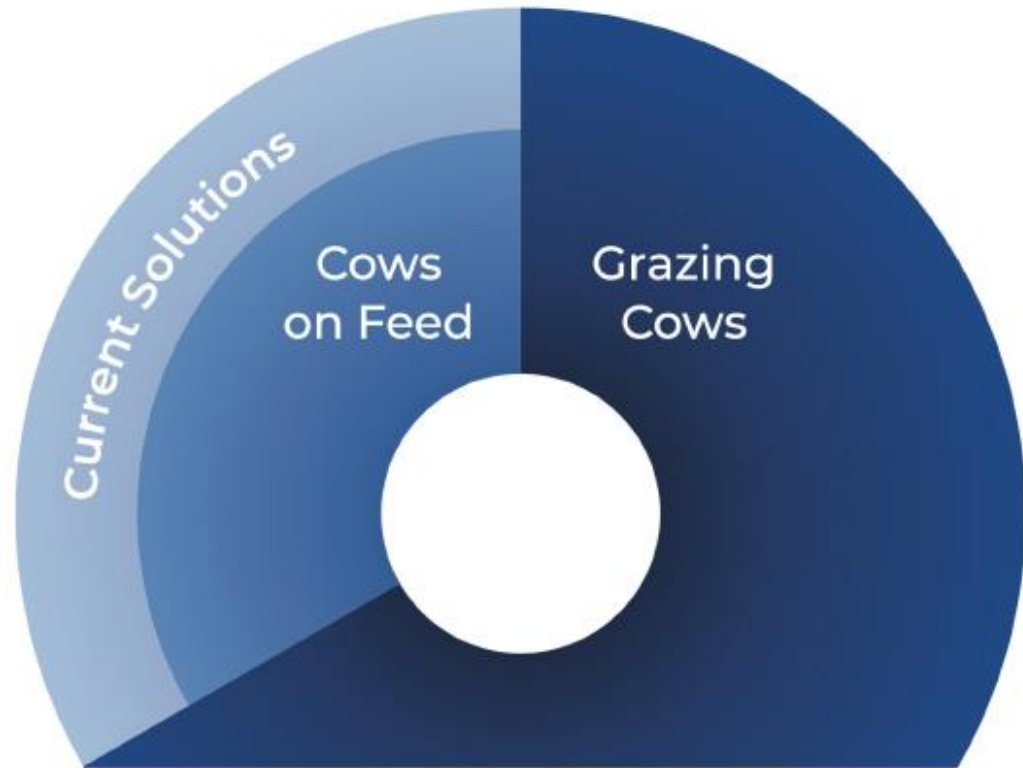
e.g., nitrates

+ Improves meat & milk production

- Not formulated for grazing

The methane produced by a cow is energy wasted; it could be used by the cow to produce more meat or milk, hence increasing profitability for the farmer.

Two-Thirds of US emissions are from grazing cattle, which are much harder to access than housed cattle.



What will happen without action and new technology

- Enteric Emissions projected to increase 30% by 2050
- Enacting proven solutions will reduce those emissions by 30%
- Therefore without innovation we will stand still

Commercial solutions can only address <10% of US livestock enteric methane emissions (less globally)

Too Much

Too Little

Nfer kg/ha

0 (No Cropland)

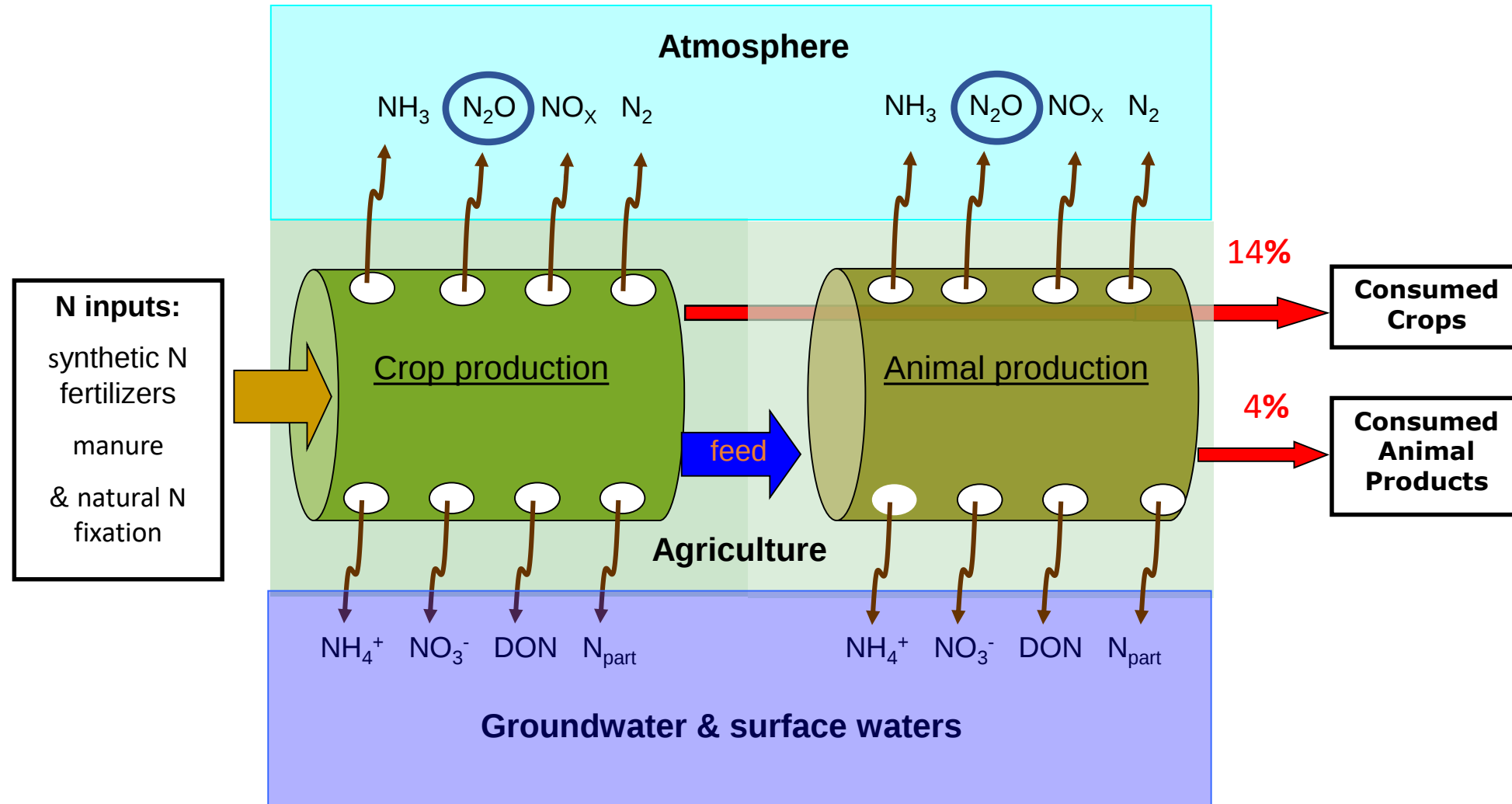


Global nitrogen fertilizer input for 2015

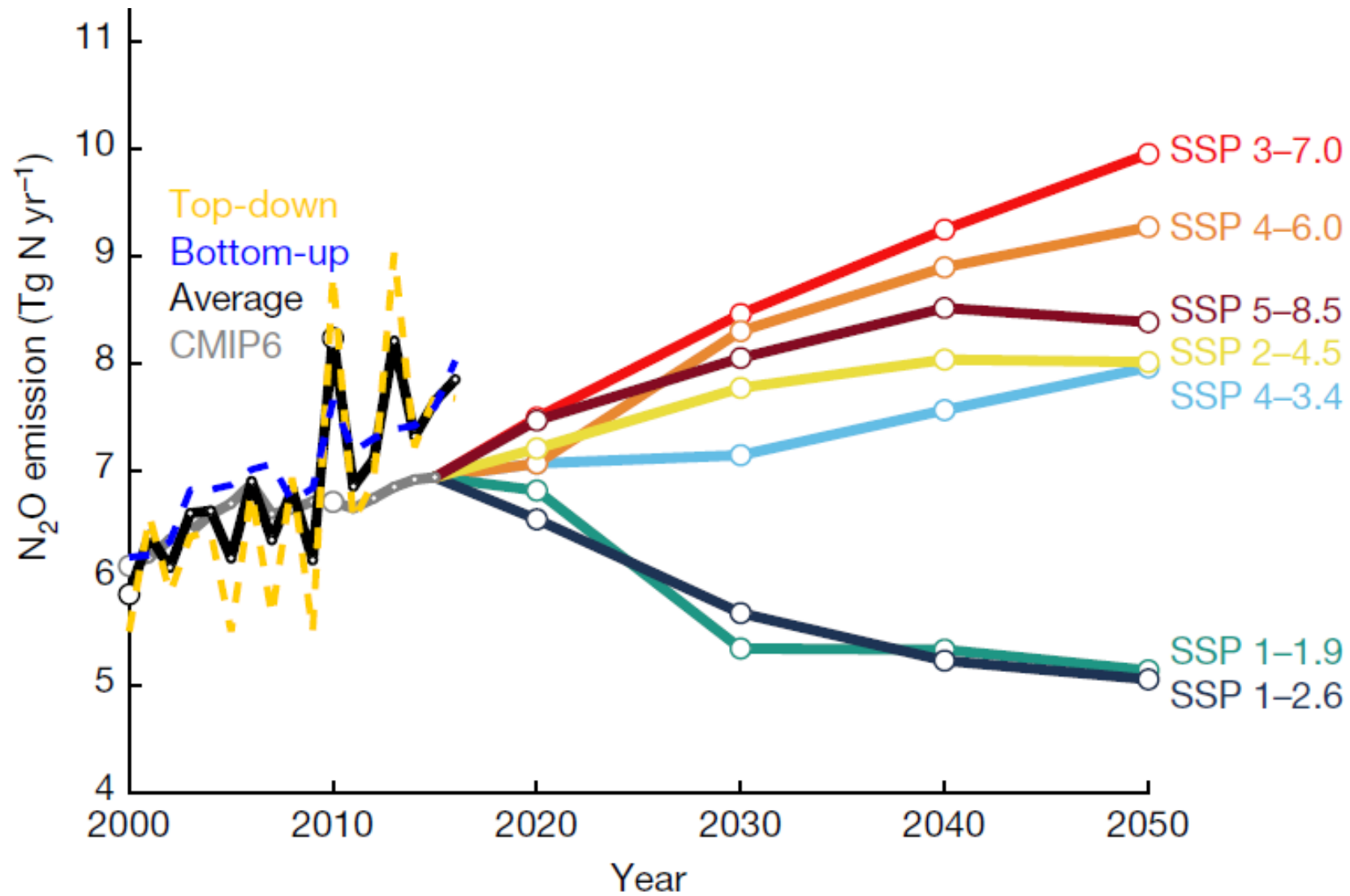
(Mueller *et al.*, 2017, Global Biogeochemical Cycles)

(produced by Zhang lab; Houlton *et al.*, 2020, *Earth's Future*)

Nitrogen: A Very Leaky Element



Oenema et al. 2009. Agriculture, Ecosystems & Environment, 133, 280-288.



Historic and projected N₂O emissions under the Shared Socioeconomic Pathways (SSPs) in the Coupled Model Intercomparison Project Phase 6 (CMIP6) for the sixth assessment (AR6) of the IPCC. Tian et al. 2021. Nature

The 4Rs for incrementally improving nitrogen use efficiency in croplands:

- 1. Right Source: slow release fertilizers, balanced nutrients**
- 2. Right Rate: soil testing, crop sensors, on-line tools, professional crop advisors and extension agents**
- 3. Right Time: spring vs. fall; more frequent but smaller doses aligned with crop growth needs**
- 4. Right Place: broadcasting vs. injection into the soil**

Agronomic practices and technologies to improve nitrogen use efficiency:

- Cover crops**
- Nitrification inhibitors**
- Conservation tillage**
- Increased crop diversity**
- Re-integration of crop and livestock production**
- Livestock feed management and manure management**
- Precision agriculture**
- Regenerative agriculture/climate smart agriculture**

Non-technological needs for improving nitrogen use efficiency

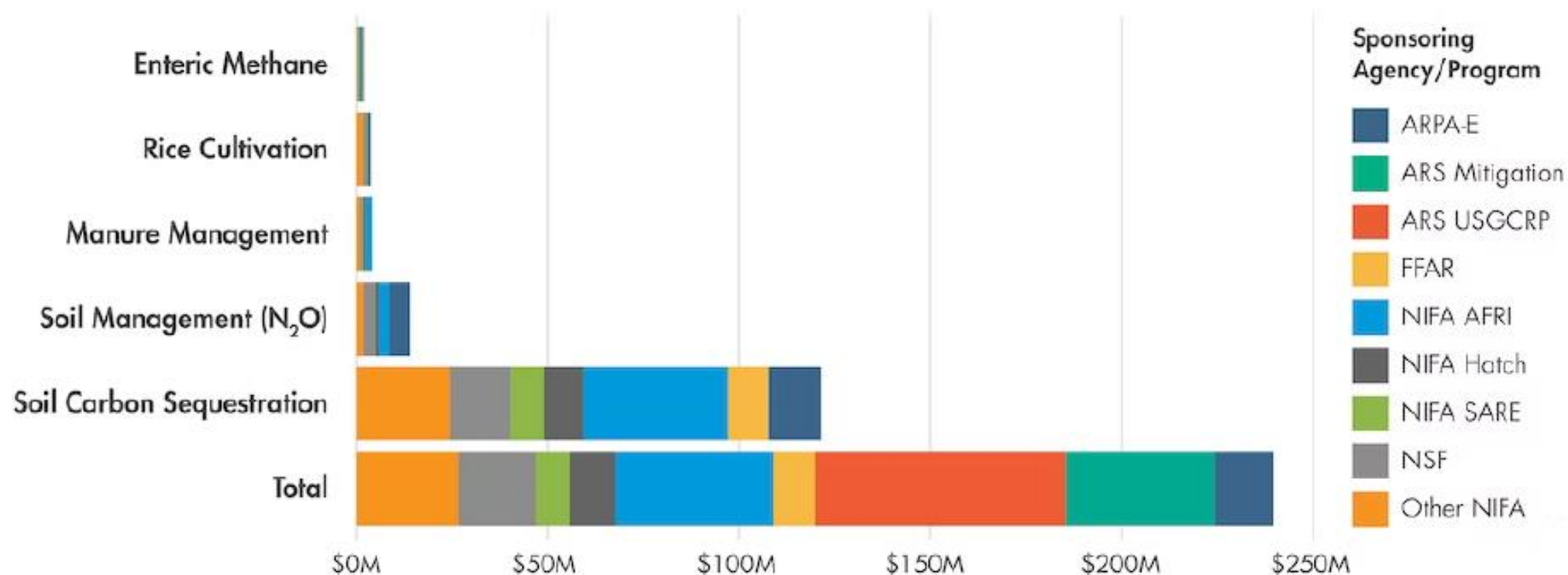
- **Social science investigations of farmer decision making and technology adoption**
- **Farmer engagement in on-farm research**

Longer-term, more transformational strategies needing R&D:

- **N fertilizer synthesized with renewable energy or through new catalytic pathways and possibly at the farm scale**
- **Crop breeding to extend growing seasons, reduced grain N, and retain N in roots**
- **Feeding livestock synthetic amino acids in lieu of N-rich crops**

These transformative advances would begin to uncouple N₂O emissions from food production

Figure ES-1: Agricultural R&D Spending on Climate Mitigation (2017–2021 Average)



The Next Decade is Critical



MINIMIZING PEAK TEMPERATURES REQUIRES LIVESTOCK ENTERIC METHANE RESEARCH TODAY

