Agricultural Emissions of Nitrous Oxide and Methane

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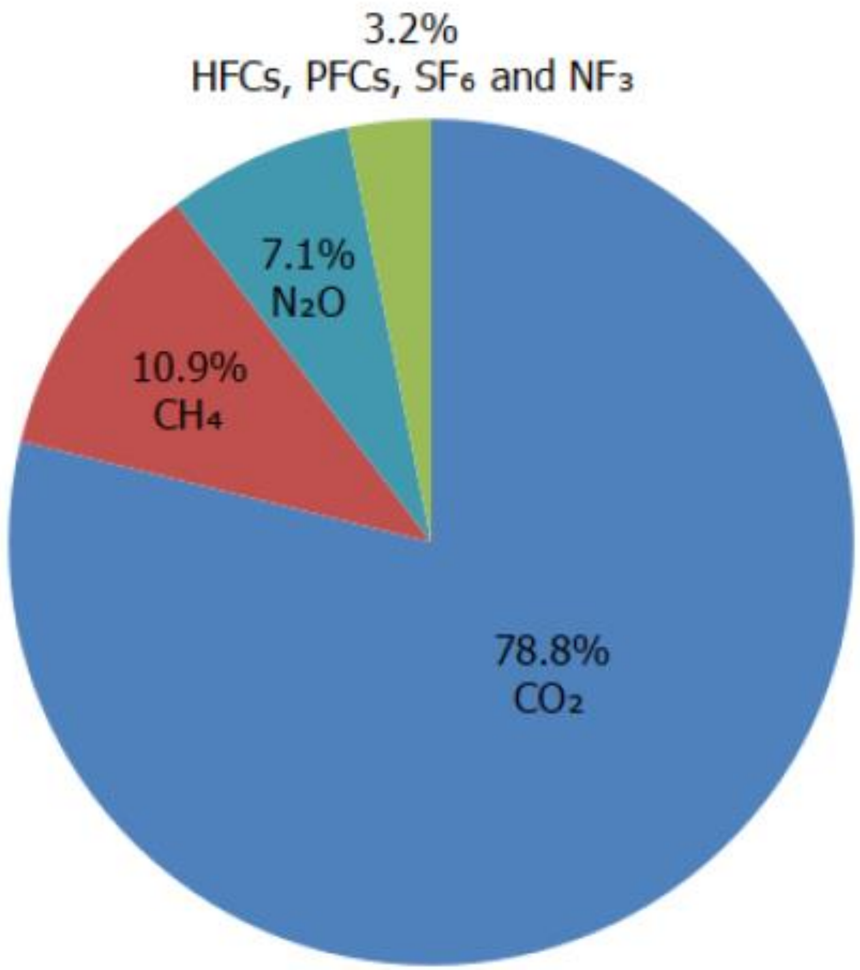
However, when using 20-year GWPs, the calculated contribution of CH_4 increases from 11% to 24% and the total contribution from agriculture increases from 10% to 15%



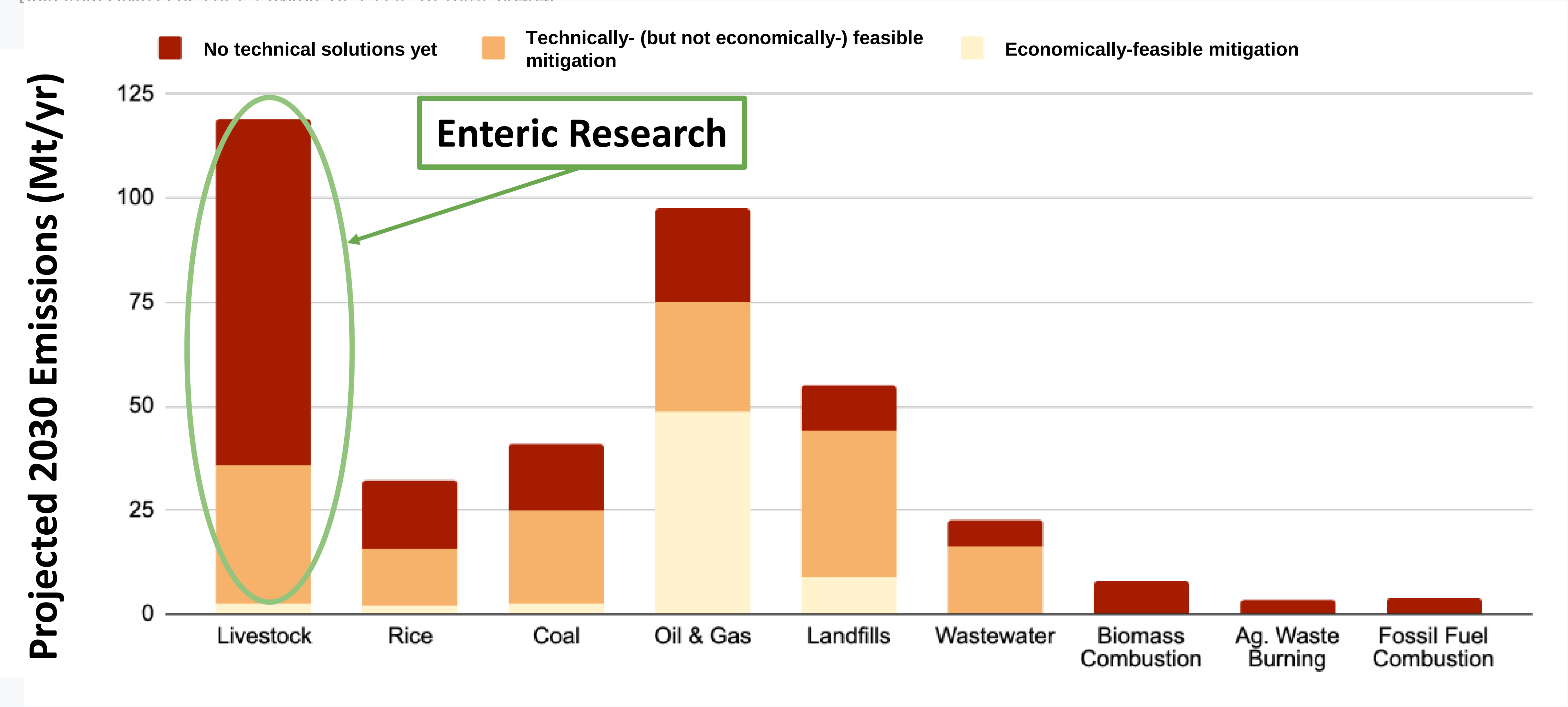
Agriculture sector contribution:
~40% of CH_4 emissions
~75% of N_2O emissions
~10% of total GHG emissions

N_2O 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

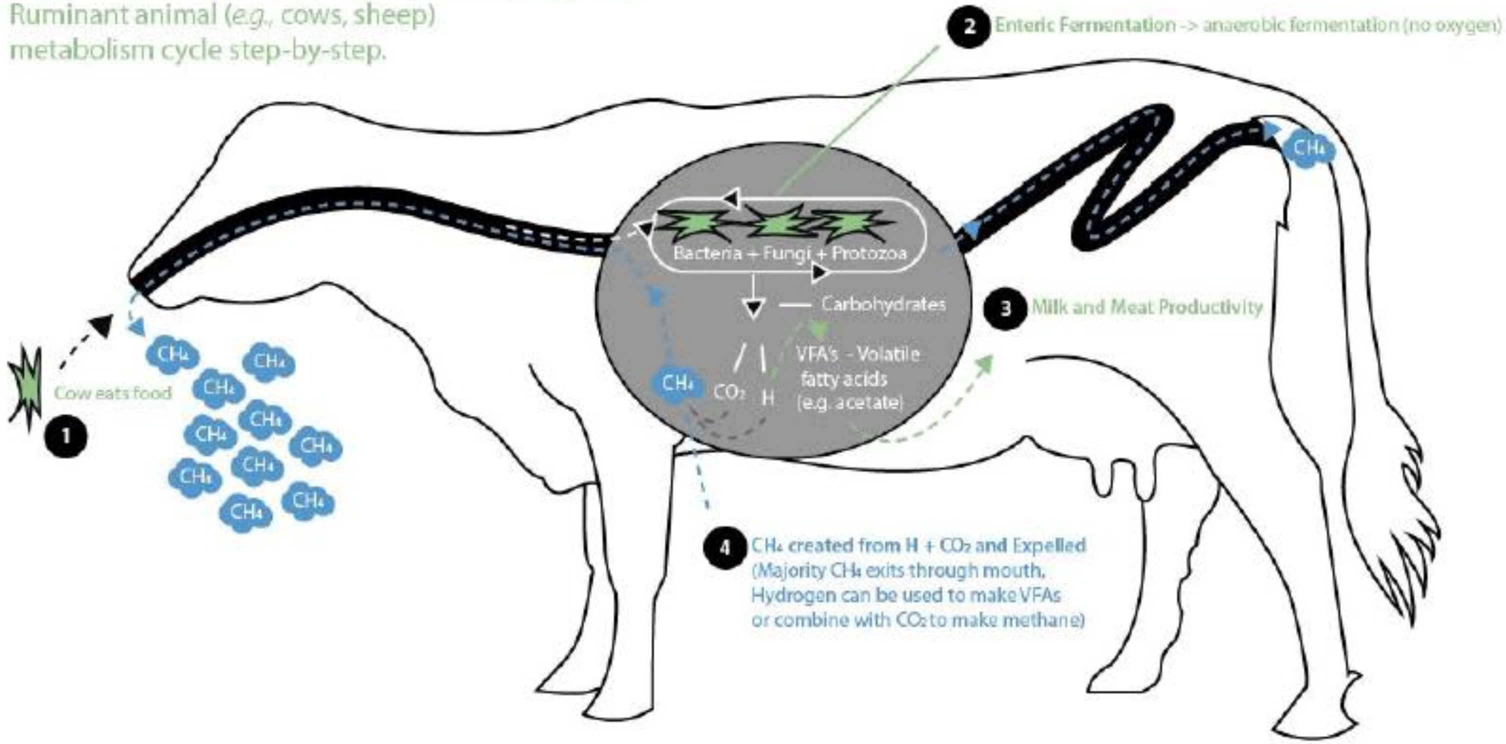


Note: Portion of emissions shown as addressed using methane removal are hypothetical.

Science and Solution Categories at a glance.

Enteric Methane (CH_4) 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**

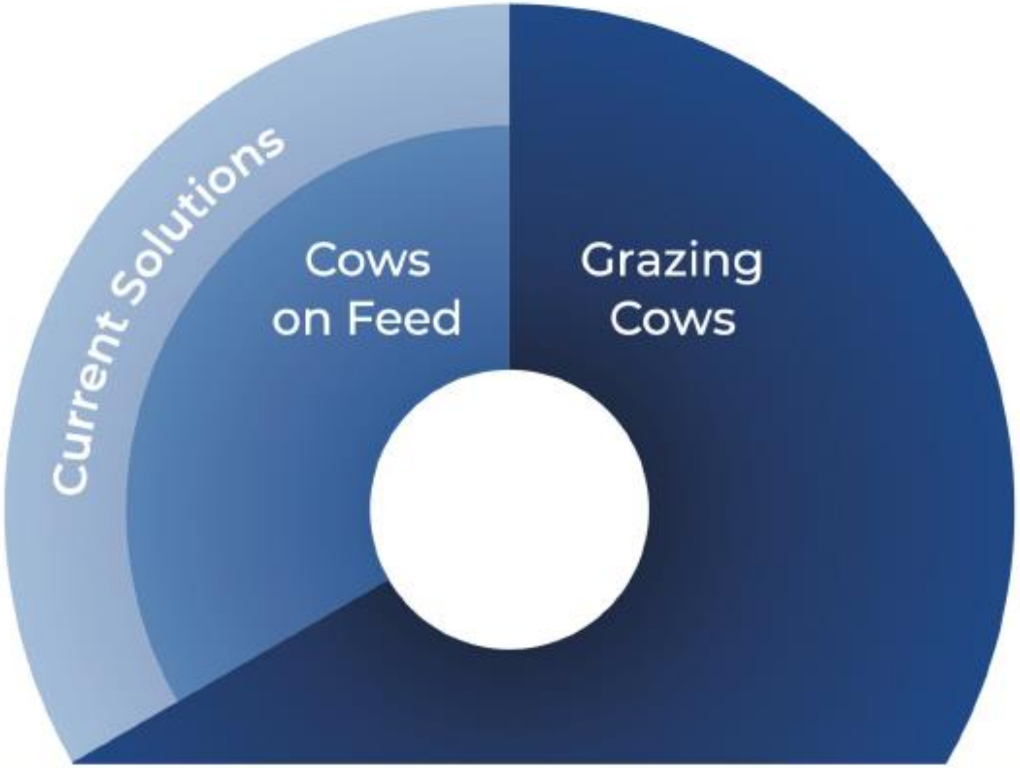
Feed formulation for low methane

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.



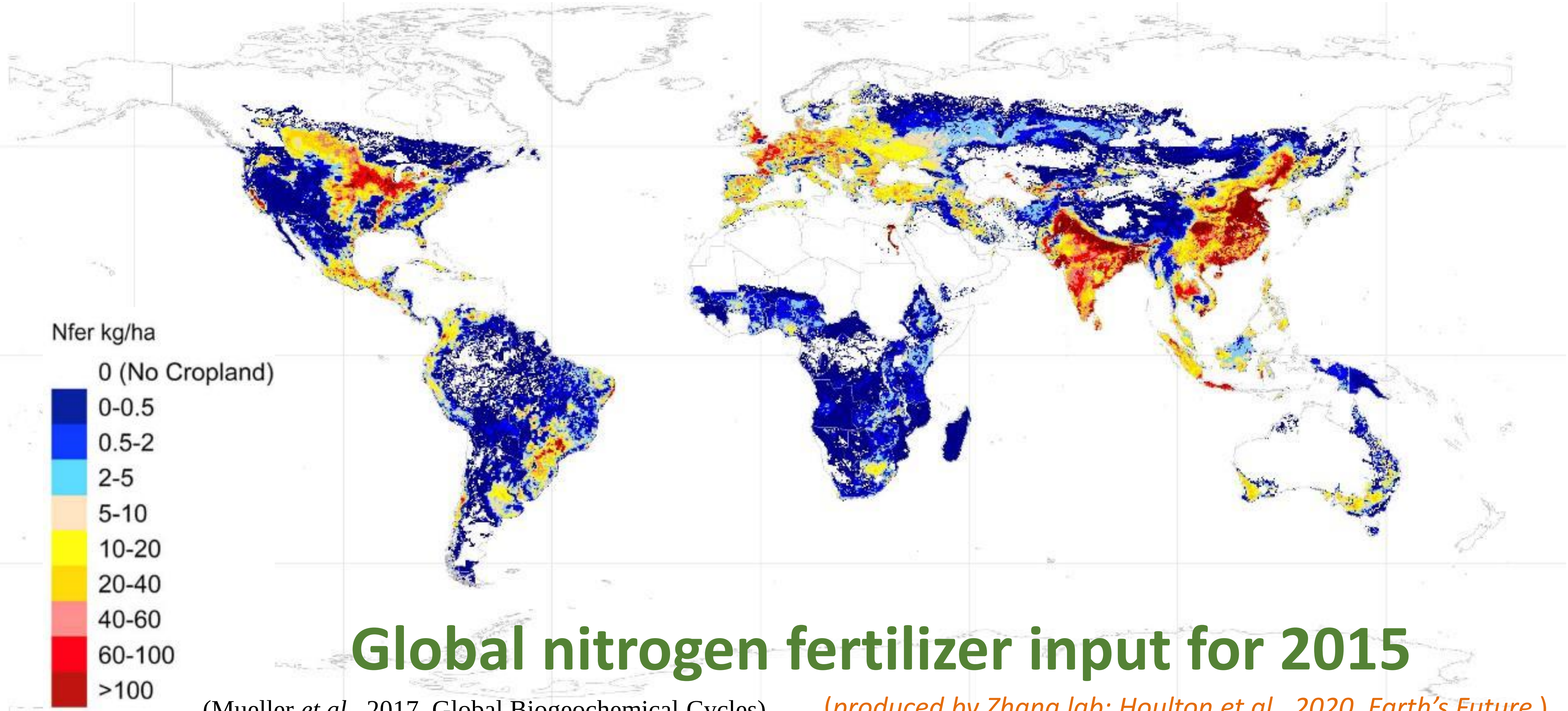
What will happen without action and new technology

- 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

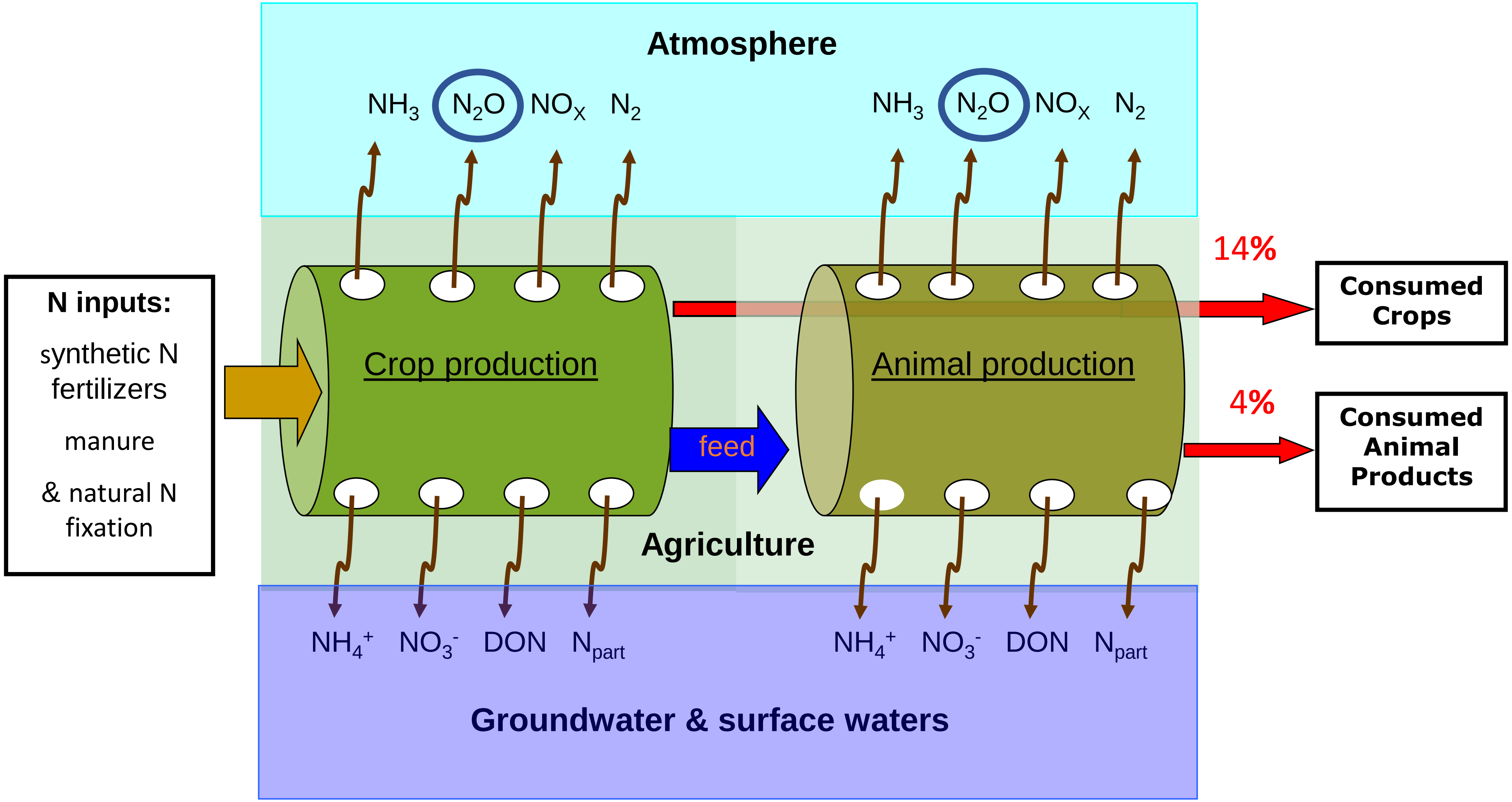


Global nitrogen fertilizer input for 2015

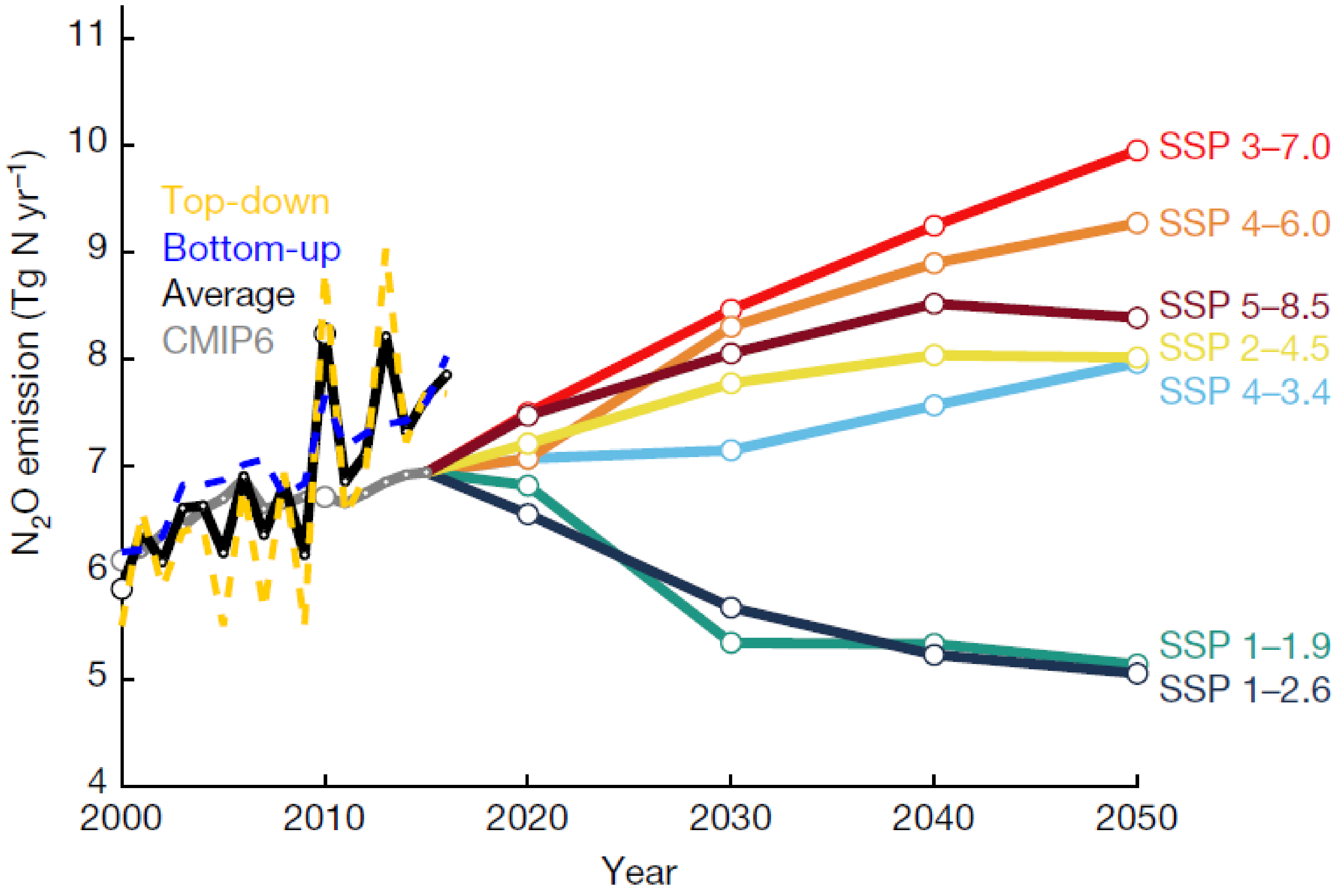
(Mueller *et al.*, 2017, Global Biogeochemical Cycles)

(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 N_2O 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

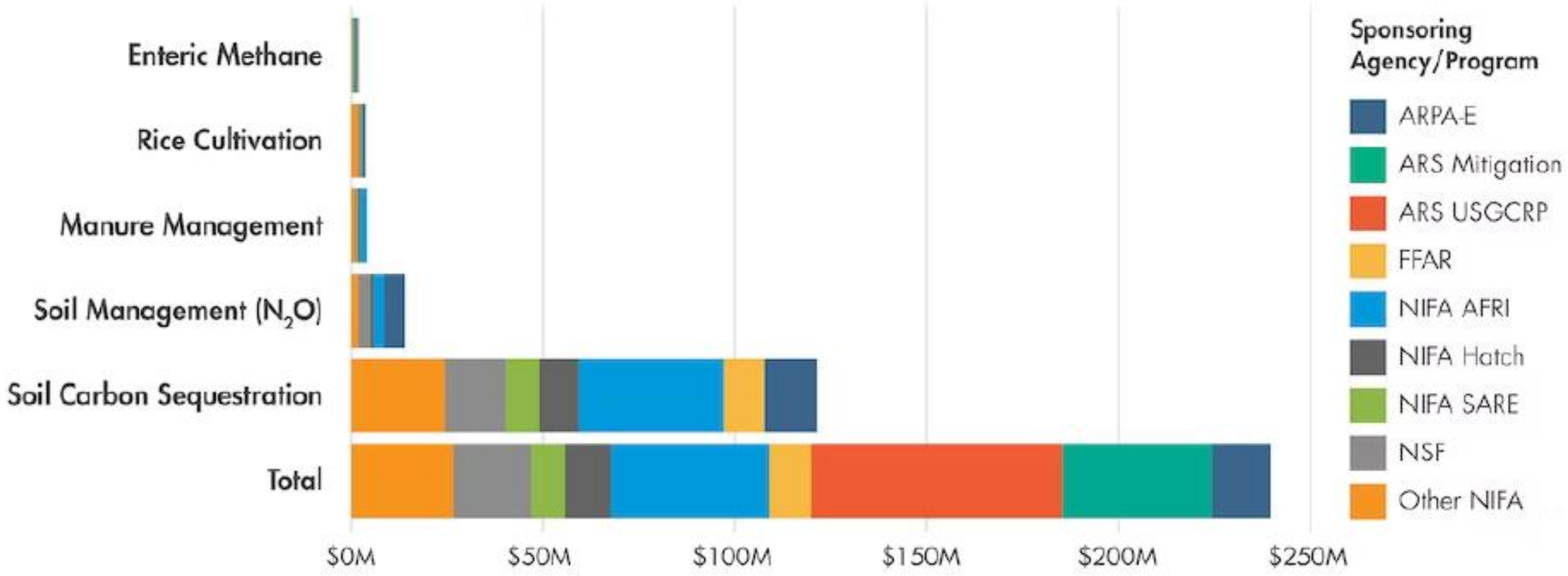
- **Social science investigations of farmer decision making and technology adoption**
- **Farmer engagement in on-farm research**

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 N_2O emissions from food production

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



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The Next Decade is Critical

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