EESI
Environmental and Energy Study Institute

Materials will be available at:
www.eesi.org/022323camp
Tweet about the briefing:
#eesitalk @eesionline

Congressional Climate Camp: Non-CO2 Greenhouse Gases

Thursday, February 23, 2023

About EESI

EESI
Environmental and Energy Study Institute

Non-partisan Educational Resources for Policymakers

A bipartisan Congressional caucus founded EESI in 1984 to provide non-partisan information on environmental, energy, and climate policies

Direct Assistance for Equitable and Inclusive Financing Program

In addition to a full portfolio of federal policy work, EESI provides direct assistance to utilities to develop “on-bill financing” programs

Commitment to Diversity, Equity, Inclusion, and Justice

We recognize that systemic barriers impede fair environmental, energy, and climate policies and limit the full participation of Black, Indigenous, people of color, and legacy and frontline communities in decision-making

Sustainable Solutions

Our mission is to advance science-based solutions for climate change, energy, and environmental challenges in order to achieve ***our vision of a sustainable, resilient, and equitable world***.

Policymaker Education

Briefings and Webcasts

Live, in-person and online public briefings, archived webcasts, and written summaries

Climate Change Solutions

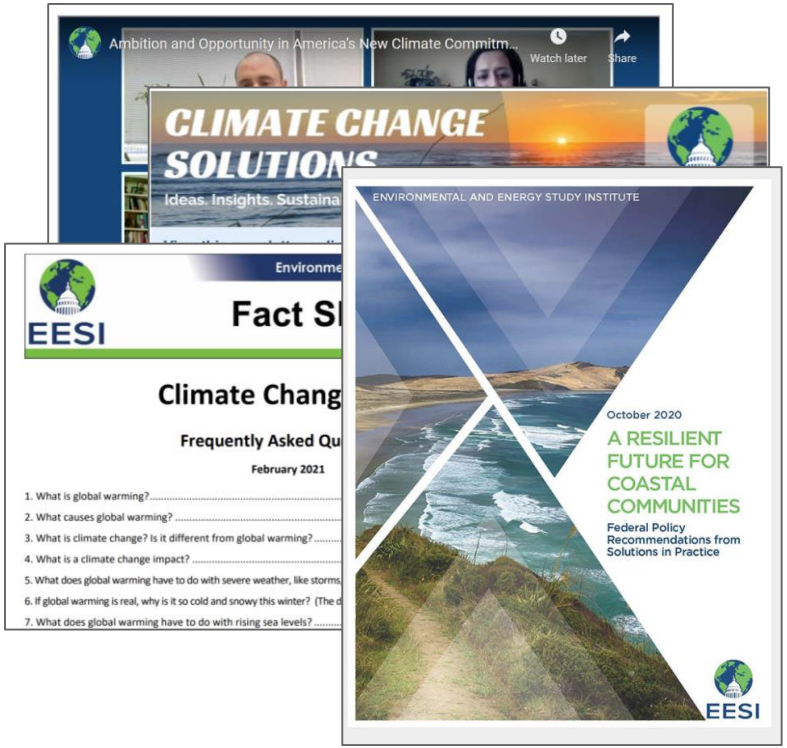
Bi-weekly newsletter with everything policymakers and concerned citizens need to know, including a legislation and hearings tracker

Fact Sheets and Issue Briefs

Timely, objective coverage of environmental, clean energy, and climate change topics

Social Media (@EESIOnline)

Active engagement on Twitter, Facebook, LinkedIn, and YouTube



EESI
Environmental and Energy Study Institute

Congressional Climate Camp

Budget and Appropriations | Thursday, January 26, 2-3:30 PM

Public Polling on Climate Change | Thursday, February 9, 2-3:30 PM

Non-CO2 Greenhouse Gases | Thursday, February 23, 2-3:30 PM

Implementing the *Inflation Reduction Act* and *Infrastructure Investment and Jobs Act* | Thursday, March 9, 2-3:30 PM

Briefing RSVP here: eesi.org/2023cc

Non-CO_2 – Fast Climate Solutions to Slow Warming in the Near Term

Gabrielle Dreyfus, Chief Scientist

Institute for Governance & Sustainable Development (IGSD)

EESI Congressional Climate Camp

23 February 2023

Strategies Targeting Non-CO_2

Slow warming in the next 20 years

Cutting SLCPs could avoid 4X more warming in 2050 than decarbonization alone

Improve health

Black carbon and ozone (including from methane) are major air pollutants; avoid millions of premature deaths

Increase food security

Avoid billions in dollars in crop losses from ozone and heat damage; cut N_2O with precision agriculture

Avoid energy waste

Fix leaks and capture emissions that waste 110 million metric tons of methane every year

Long-lived Greenhouse Gases (GHG)

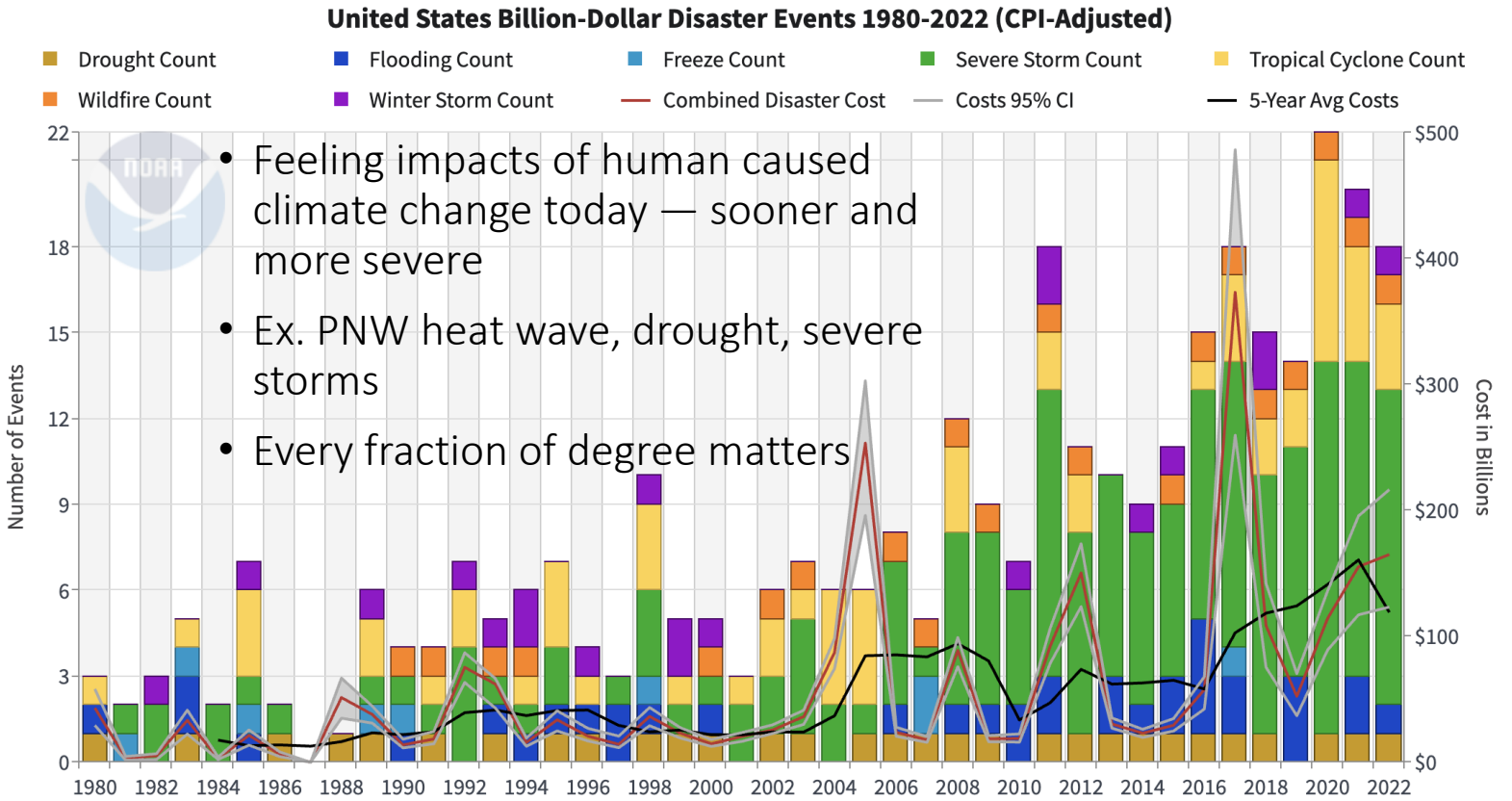
Super Climate Pollutants

Short-lived Climate Pollutants (SLCP)

	Potency over 20 years	Potency over 100 years	Lifetime	Impacts
Carbon dioxide (CO_2)	1	1	100 – 1000s years	Long-term warming Ocean acidification
Nitrous oxide (N_2O)	273	273	109 years	Long-term warming Ozone-depleting
Methane (CH_4)	81	28	11.8 years	Near-term warming Ground-level ozone
Hydrofluorocarbons (HFCs)	1 – 12,400	1 – 14,600	15 years (average)	Near-term warming
Ground-level ozone (O_3)	*Not directly emitted*		weeks	Criteria pollutant
Black carbon	2400*	660*	days	Criteria pollutant (constituent of $PM_{2.5}$)

*IPCC AR6 WGI (2021) Table 7.SM.7; * IPCC AR5 WGI (2013) Table 8.SM.17*

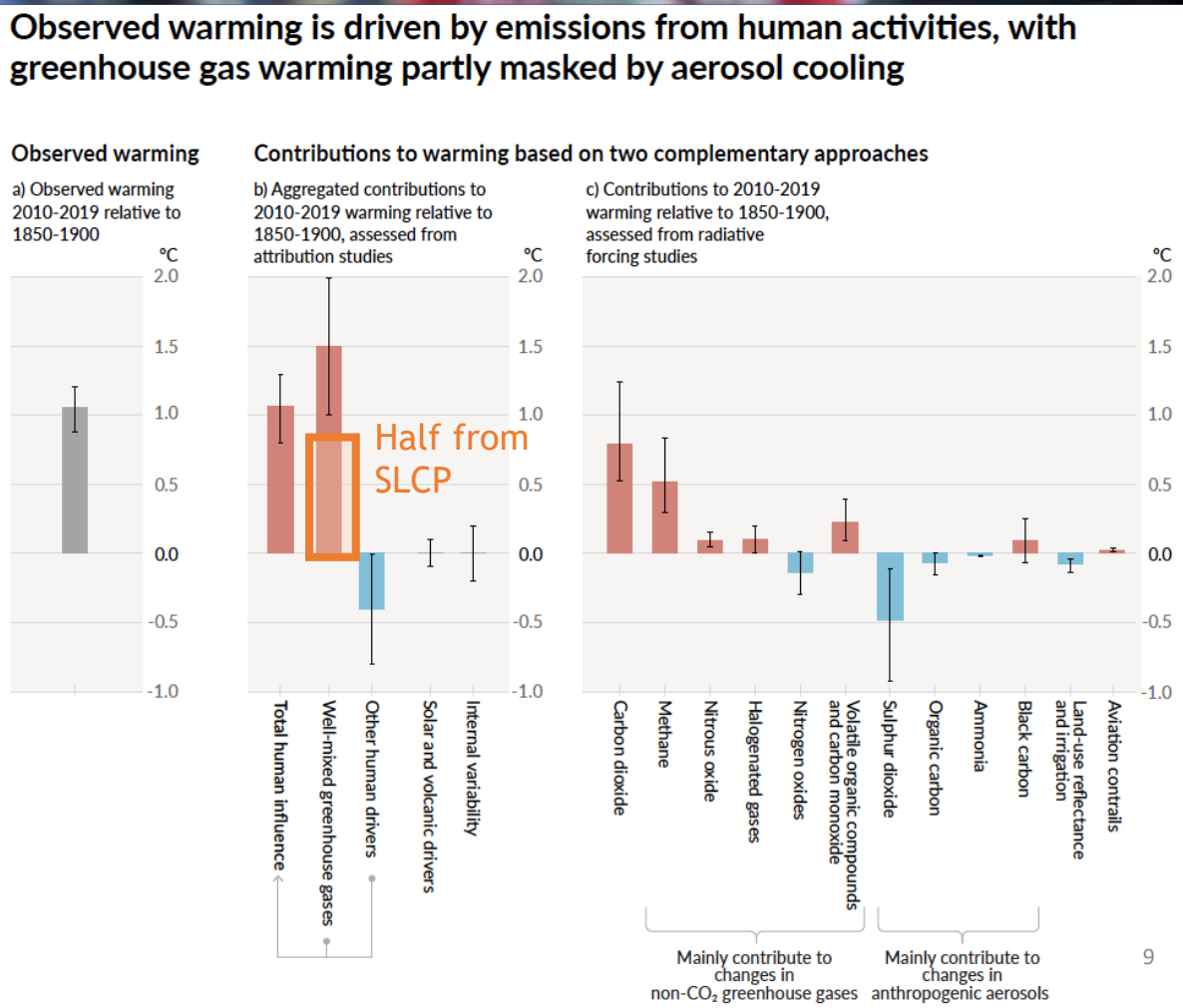
Climate Change Impacts Today



Short-lived climate pollutants (methane, HFCs, black carbon, ozone) contribute half of total warming

Cutting SLCPs could avoid 4X more warming in 2050 than decarbonization alone

IPCC AR6 WGI Figure SPM.2

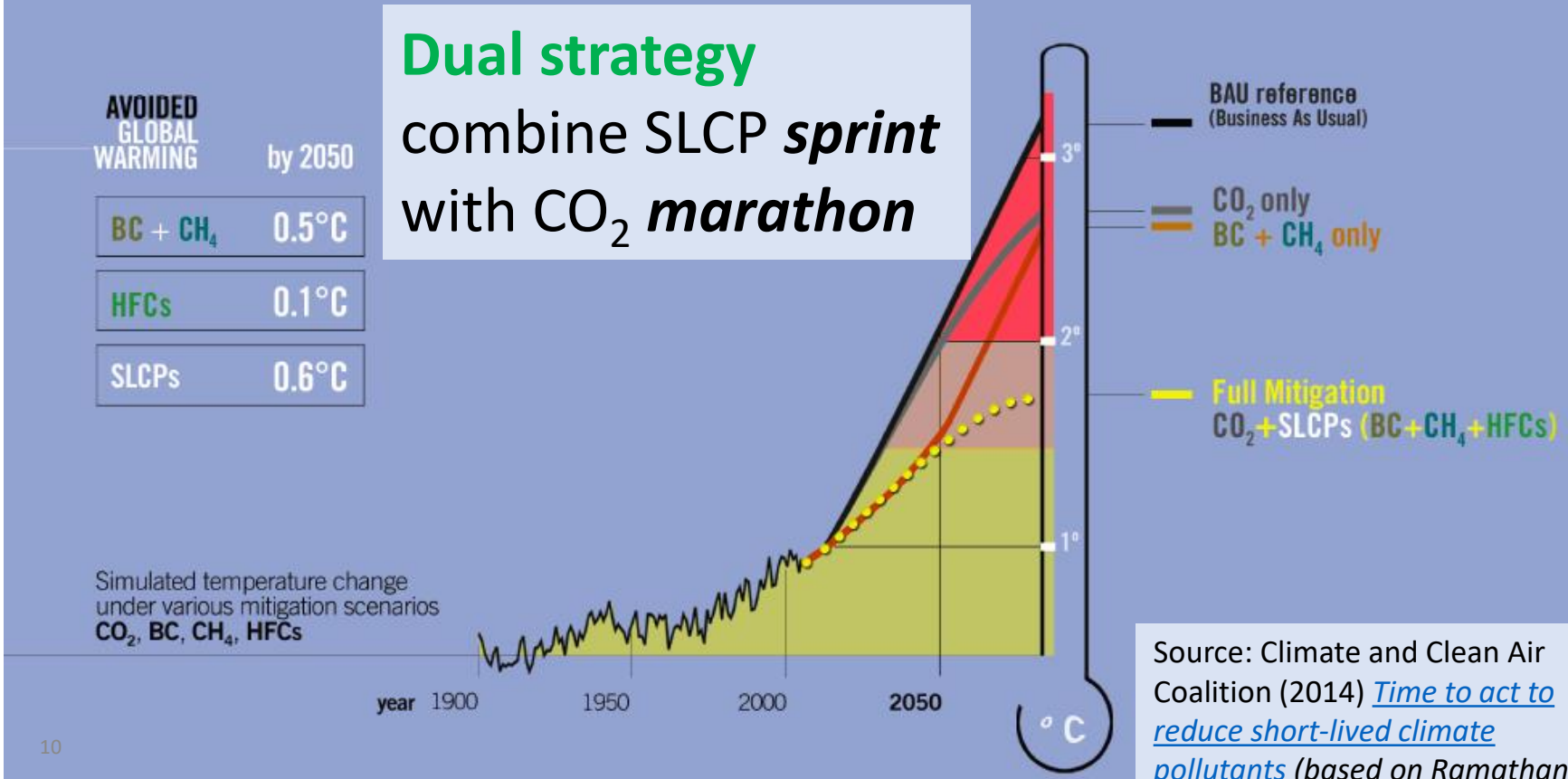


SLCP Climate Benefits Avoided global warming

Rapid implementation of SLCP mitigation measures, together with measures to reduce CO_2 emissions, would greatly improve the chances of keeping the Earth's temperature increase to less than 2°C relative to pre-industrial levels.

Dual strategy

combine SLCP ***sprint*** with CO_2 ***marathon***



Source: Climate and Clean Air Coalition (2014) *Time to act to reduce short-lived climate pollutants (based on Ramathan)*

Montreal Protocol – Benefits Extend Beyond Fixing the Ozone Hole

- Ozone hole is recovering thanks to compliance with 1987 Montreal Protocol on Substances that Deplete the Ozone Layer and amendments phasing out HCFCs.
- Avoided 0.5–1.0°C of warming by 2050 by stopping build-up of potent CFCs, HCFCs, Halons; protecting terrestrial plants and carbon sink from UV will avoid up to an additional 1.0°C by 2100.
- Avoided hundreds of millions of cases of skin cancer and cataracts.
- 2016 Kigali Amendment phases down production and use of HFCs; ratified by Senate in September 2022; EPA currently implementing American Innovation and Manufacturing (AIM) Act of 2020.

WMO (2022) Scientific Assessment of Ozone Depletion; Young et al. (2021)

Implementing the 2016 Kigali Amendment and aggressively phasing down HFCs will avoid 0.1°C by 2050

Even more with energy efficiency

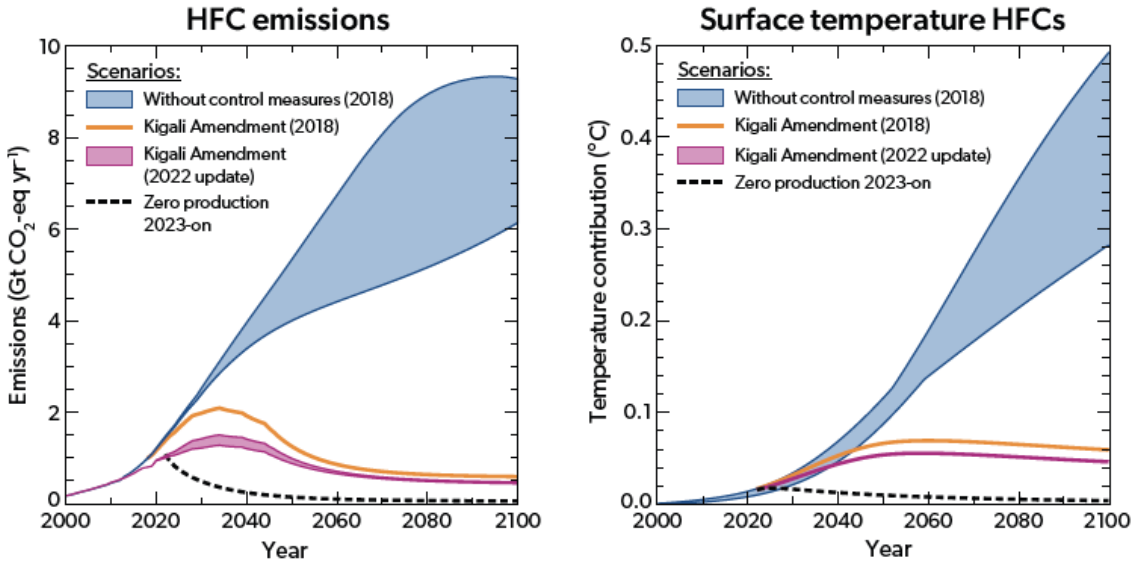


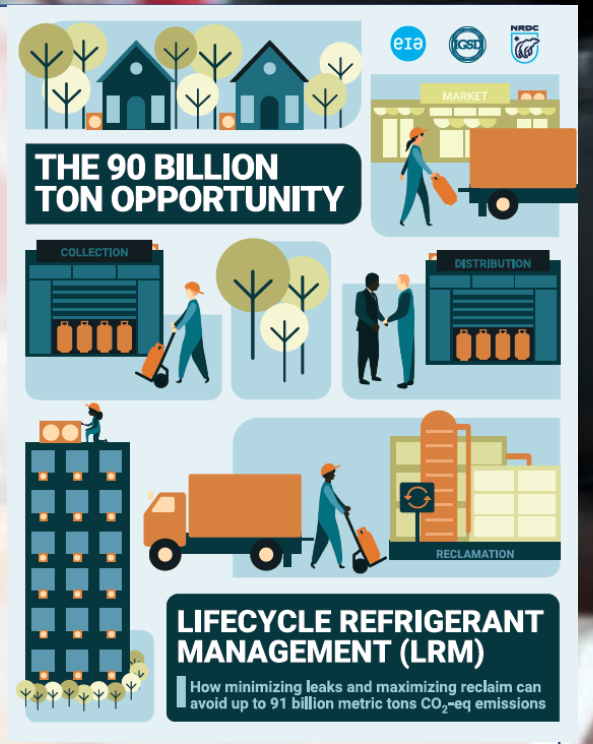
Figure ES-4. HFC emissions (left) and their impact on global average surface temperature (right). Shown is a scenario without global HFC control measures (the 'baseline' scenario from the 2018 Assessment, blue area) and the 2018 and 2022 scenarios assuming full compliance with the Kigali Amendment (orange and pink, respectively). Also shown is a scenario assuming that the global production of HFCs ceased in 2020 (black dashed line). For comparison, the total warming from all greenhouse gases is projected to be 1.4 °C to 4.4 °C by the end of the 21st century, relative to 1850–1900, following IPCC (2021) projections. The contribution from HFC-23 emissions is not included here.

WMO (2022) Executive Summary. Scientific Assessment of Ozone Depletion

Lifecycle Refrigerant Management

- Roughly 100 billion metric tons CO_2e avoidable emissions this century (*additional* to Kigali Amendment)
- Refrigerant and foam banks will continue to grow under the HFC phase-down
- Most emissions are preventable through reducing leaks and end-of-life release
- ~60% consumption for filling existing equipment

ODS & HFC Refrigerants ($GtCO_2e$)	Current	Through 2050	Through 2100
United States	3.6	6.9	9.2
Global	34	61	91



EIA, NRDC, IGSD (2022)

Strategies Targeting Non-CO_2

Slow warming in the next 20 years

Cutting SLCPs could avoid 4X more warming in 2050 than decarbonization alone

Improve health

Black carbon and ozone (including from methane) are major air pollutants; avoid millions of premature deaths

Increase food security

Avoid billions in dollars in crop losses from ozone and heat damage; cut N_2O with precision agriculture

Avoid energy waste

Fix leaks and capture emissions that waste 110 million metric tons of methane every year

Resources

- Climate and Clean Air Coalition https://www.ccacoalition.org/en
- IGSD (2022) The Need for Fast Near-Term Climate Mitigation to Slow Feedbacks and Tipping Points.
- IGSD (2023) A Primer on Cutting Methane: The Best Strategy for Slowing Warming in the Decade to 2030.
- Theodoridi C., Hillbrand A., Starr C., Mahapatra A., & Taddonio K. (2022) The 90 Billion Ton Opportunity: Lifecycle Refrigerant Management (LRM) - How minimizing leaks and maximizing reclaim can avoid up to 91 billion metric tons CO2-eq emissions, *EIA, NRDC, IGSD*.
- WMO *et al.* (2022) *Executive Summary*, *in* Scientific Assessment of Ozone Depletion: 2022, Geneva, Switzerland.

Thank you!

Gabrielle Dreyfus
gdreyfus@igsd.org

A Nord Stream Disaster Every Day

A large disturbance in the sea can be observed off the coast of the Danish island of Bornholm Tuesda Sept. 27, 2022 following a series of unusual leaks on two natural gas pipelines running from Russia under the Baltic Sea to Germany have triggered concerns about possible sabotage. Danish Prime Minister Mette Frederiksen says she "cannot rule out" sabotage after three leaks were detected on Nord Stream 1 and 2. (Danish Defence Command via AP)

"The methane gushing out of the damaged Nord Stream pipelines is another type of climate catastrophe. It represents the amount of methane — emitted every single day — on average from oil, gas and coal energy systems, totaling about 110 million metric tons annually. Most of this wasted methane could be avoided or captured at low net cost and often at a net savings."

Otto, Shindell, Dreyfus (2022) The Hill https://thehill.com/opinion/energy-environment/3672232-a-nord-stream-disaster-every-day/

Non-CO_2 Climate Solutions to Slow Warming in the Near Term

Gabrielle Dreyfus, PhD

Chief Scientist

Institute for Governance & Sustainable Development

EESI Congressional Climate Camp

23 February 2023

Short-lived climate pollutants: Black carbon and methane

Susan Anenberg, PhD

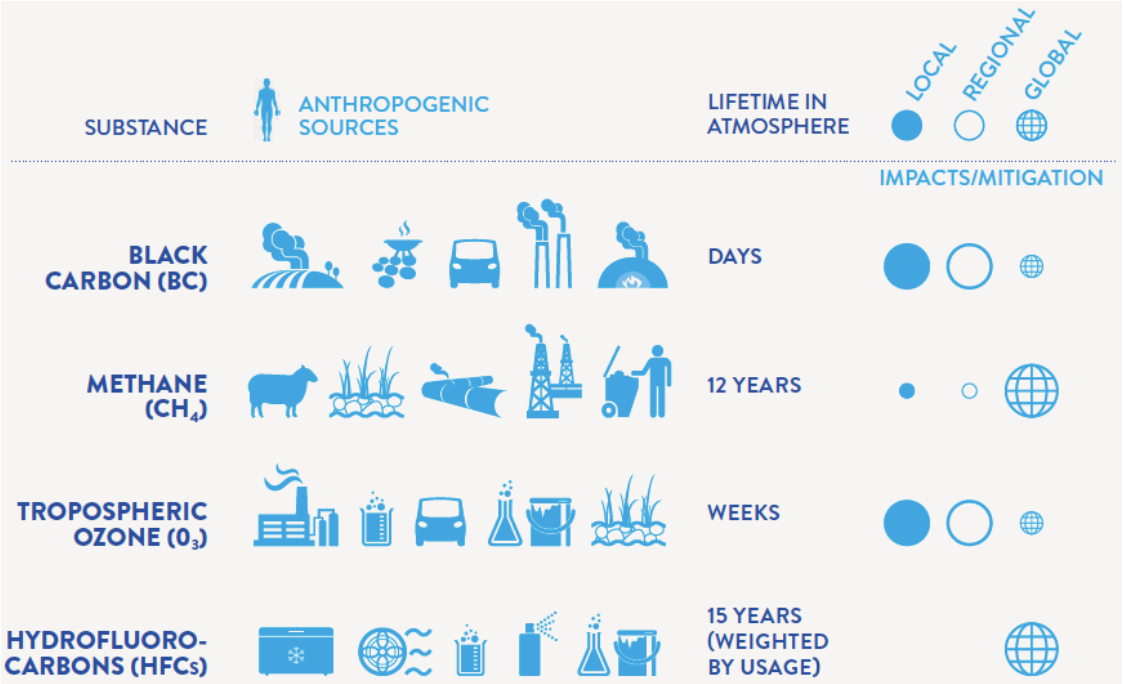
February 23, 2023

Congressional Climate Camp: Non-CO2 Greenhouse Gases

Milken Institute School of Public Health
THE GEORGE WASHINGTON UNIVERSITY

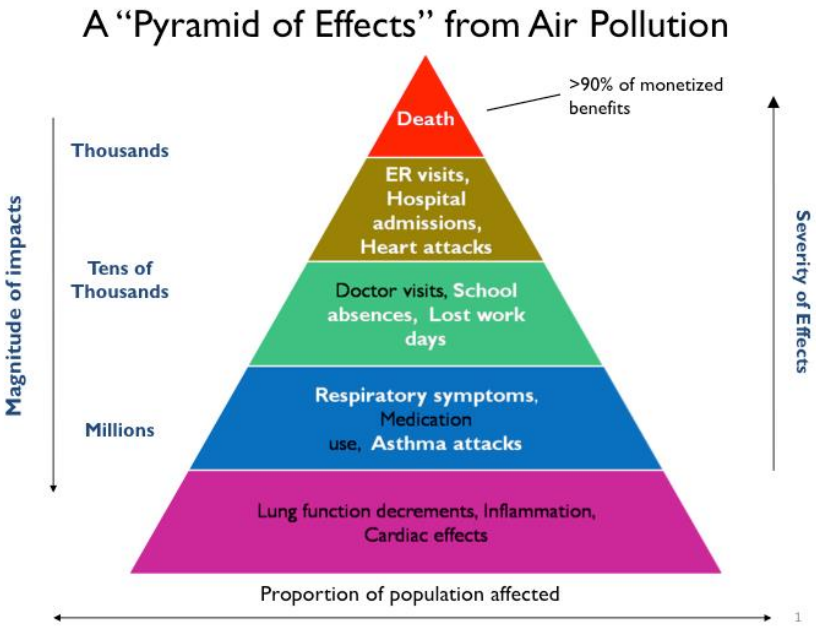
Short-Lived Climate Pollutants

- Short-lived climate pollutants refer to species that are *both* climate-warming agents and air pollutants.
- I will focus on two of many short-lived climate pollutants: black carbon (a component of $PM_{2.5}$) and methane (a precursor to ozone).

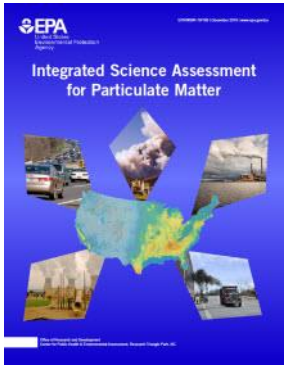


https://www.ccacoalition.org/en/science-resources

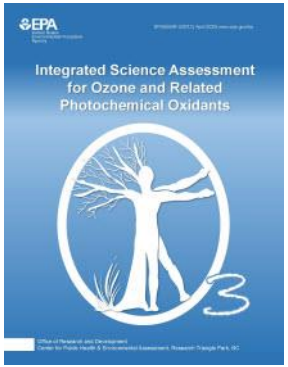
Health effects of major air pollutants



https://www.epa.gov/benmap/how-benmap-ce-estimates-health-and-economic-effects-air-pollution

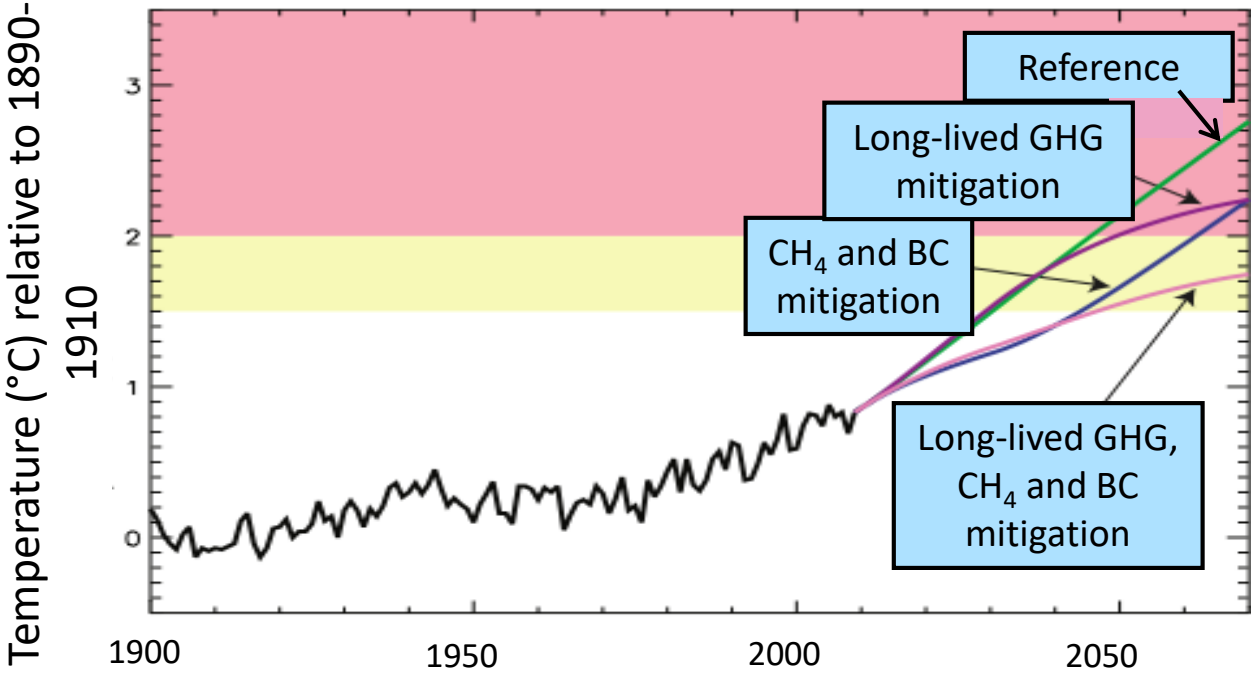


$PM_{2.5}$
- Cardiovascular effects
- Respiratory effects
- Nervous system effects
- Cancer
- Mortality



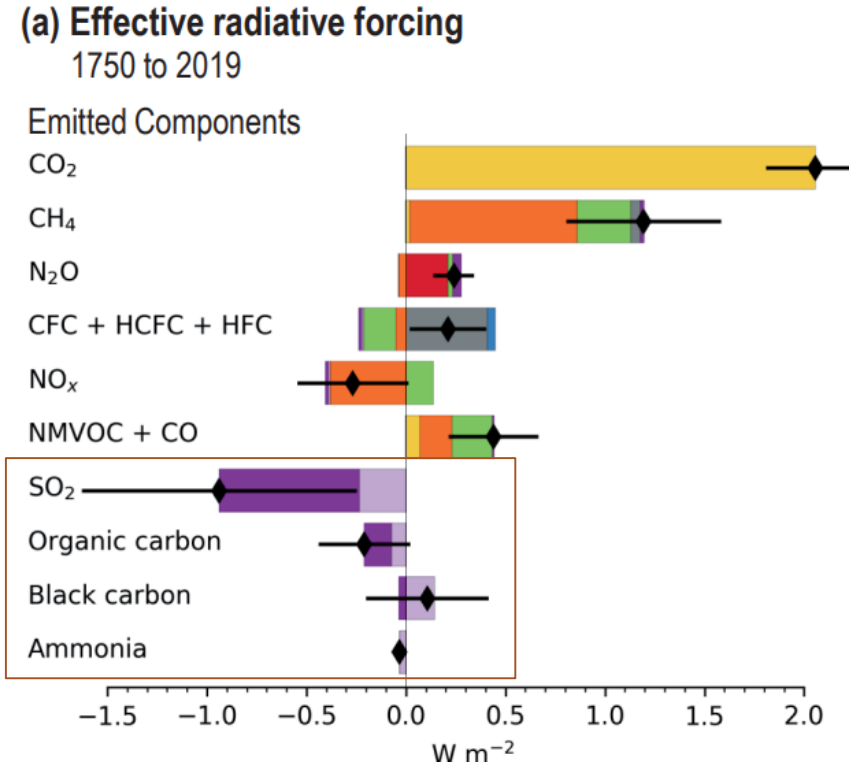
Ozone
- Respiratory effects
- Cardiovascular effects
- Mortality

Which path will we take?



UNEP/WMO Integrated Assessment of BC and Ozone, 2011
Shindell et al. Science, 2012

Particulate Matter Impacts on Climate



IPCC AR6 WGI. (2021). *Technical summary*.

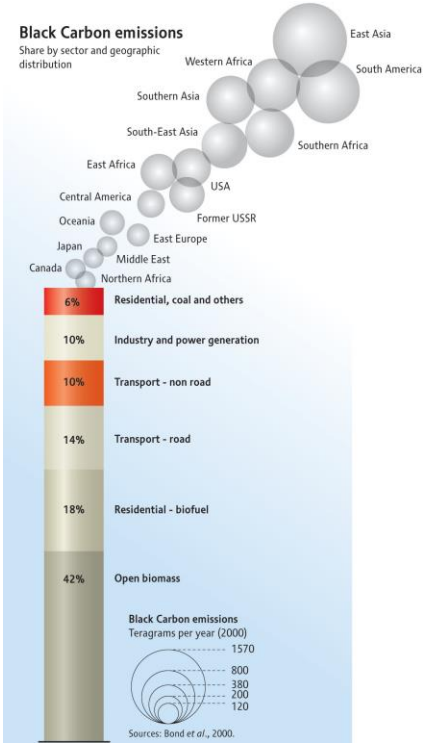
Black Carbon

Diesel vehicles emit black carbon (soot) into the atmosphere.

Photo: US Environmental Protection Agency

Black Carbon Sources

- Black carbon, a component of $PM_{2.5}$, is an important short-lived climate pollutant and is emitted by diesel exhaust, biomass for cookstoves, and the burning of coal and biofuels.
- Developing nations are the highest emitters of black carbon.
- Black carbon particles are strong absorbers of solar radiation, and the global warming potential of black carbon over 100 years ranges between 1,055–2,020 (relative to a global warming potential of 1 for CO_2).



Source: GRID-Arendal/UNEP

BLACK CARBON (BC)

Black carbon, or soot, is part of fine particulate air pollution ($PM_{2.5}$) and contributes to climate climate.

SOURCES

Black carbon is one of many particles and gases that are emitted when diesel, coal, and other biomass fuels are burned.

- HOUSEHOLD ENERGY — 51%
- TRANSPORT — 26%
- AGRICULTURE — 8%
- INDUSTRIAL PRODUCTION — 5%
- WASTE — 5%
- FOSSIL FUEL OPERATIONS — 3%
- LARGE-SCALE COMBUSTION — 2%

IMPACTS

CLIMATE

Absorbs sunlight and converts it to heat

HEALTH

Deaths from

- Heart desease 29%
- Stroke 24%
- Lung desease 25%
- Lung cancer 43%

- 7 million pollution-related deaths every year

LIFETIME IN ATMOSPHERE: UP TO 2 WEEKS

Since black carbon does not last long in the atmosphere, efforts to reduce it will bring immediate benefits for the climate and human health.

SNOW & ICE

Accelerates the melting of snow and ice

WEATHER

- Prevents clouds from being formed
- Alters regional weather patterns and rainfall

AGRICULTURE & ECOSYSTEMS

- Reduces sunlight
- Affects plant health and productivity

CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

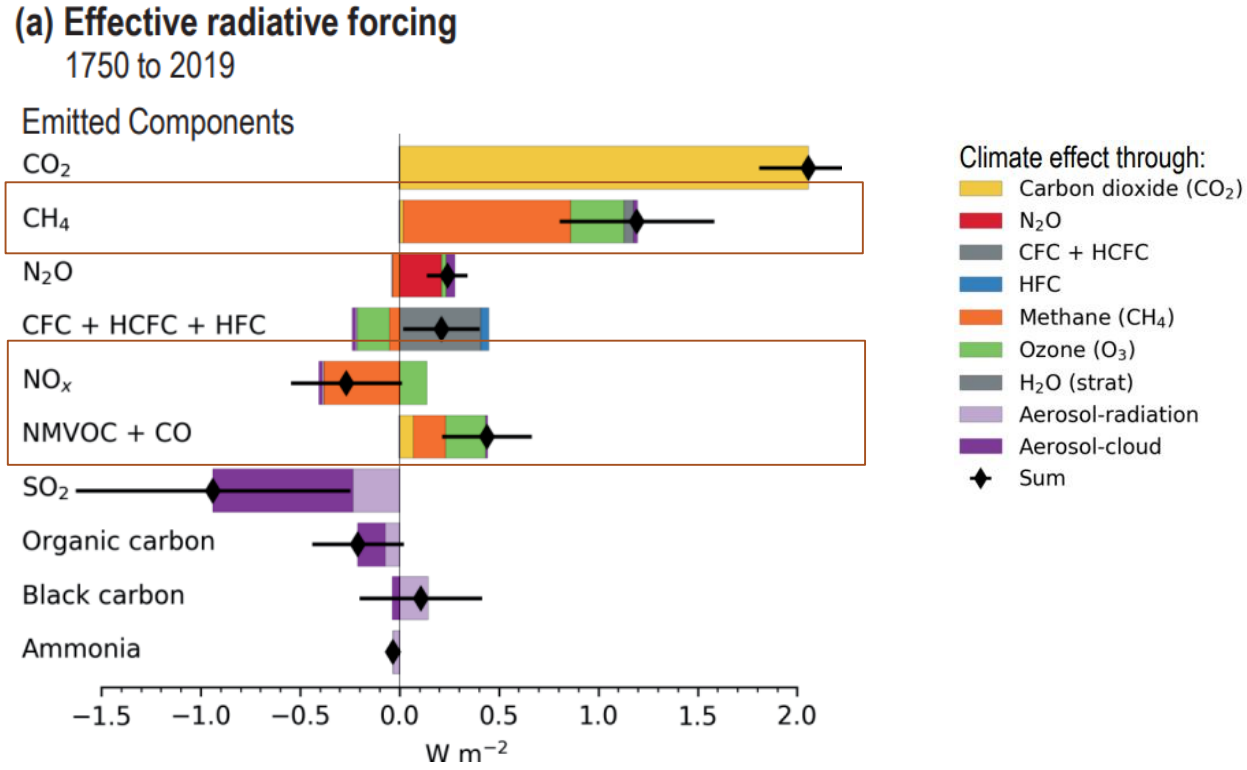
www.ccacoalition.org/black-carbon

Black Carbon: Mitigation Options

HOUSEHOLD ENERGY	▪ Replace traditional cooking to clean burning modern fuel cookstoves ▪ Replace traditional cooking and heating with clean-burning biomass stoves ▪ Eliminate kerosene lamps ▪ Replace lump coal with coal briquettes for cooking and heating ▪ Replace wood stove and burners with pellet stoves and boilers
INDUSTRIAL PRODUCTION	▪ Modernize traditional brick kilns to vertical shaft brick kilns ▪ Modernize coke ovens to recovery ovens
TRANSPORT	▪ Use diesel particular filters for road and off-road vehicles ▪ Fast transition to Euro VI/6 vehicles and soot-free buses and trucks ▪ Eliminate high-emitting diesel vehicles
AGRICULTURE	▪ Ban open-field burning of agricultural waste
FOSSIL FUELS	▪ Capture and improve oil flaring and gas production
WASTE MANAGEMENT	▪ Ban open burning of municipal waste

https://www.ccacoalition.org/en/slcps/black-carbon

Ozone Precursors and Radiative Forcing



IPCC AR6 WGI Technical Summary, 2021

METHANE (CH_4)

Methane emissions caused by human activities are one of the most significant drivers of climate change. Methane is also the main precursor of tropospheric ozone, a powerful greenhouse gas and air pollutant.

SOURCES

Methane is one of the fastest growing greenhouse gases in the atmosphere. Human activity causes 2/3 of emissions.

% = global emissions

IMPACTS

CLIMATE

Responsible for 40% of warming since the industrial revolution

86x times more powerful than carbon dioxide over a 20-year period

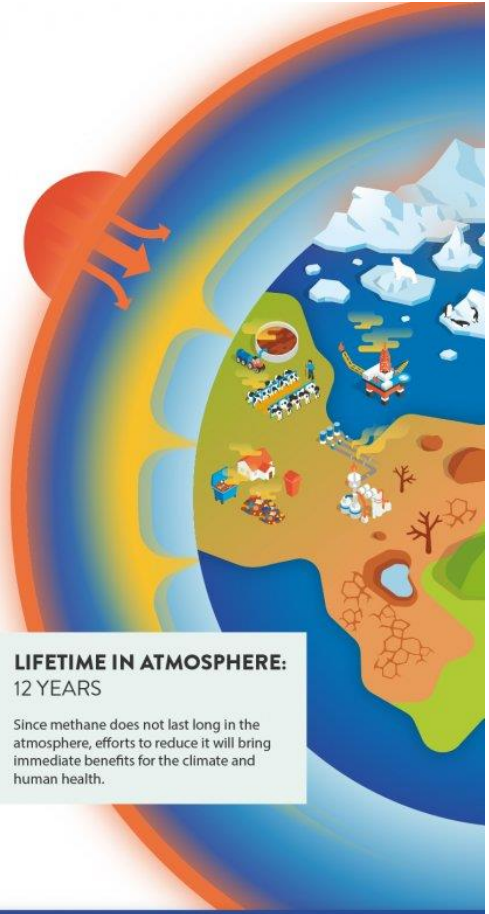
HEALTH

Increasing emissions are driving a rise in tropospheric ozone air pollution, which causes 1+ million premature deaths annually. Methane is responsible for roughly 1/2 of these deaths.

- Respiratory diseases
- Heart disease
- Damaged airways and lung tissue

AGRICULTURE & ECOSYSTEMS

Up to **15%** annual yield losses of soy, wheat, rice and maize



LIFETIME IN ATMOSPHERE:
12 YEARS

Since methane does not last long in the atmosphere, efforts to reduce it will bring immediate benefits for the climate and human health.

CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

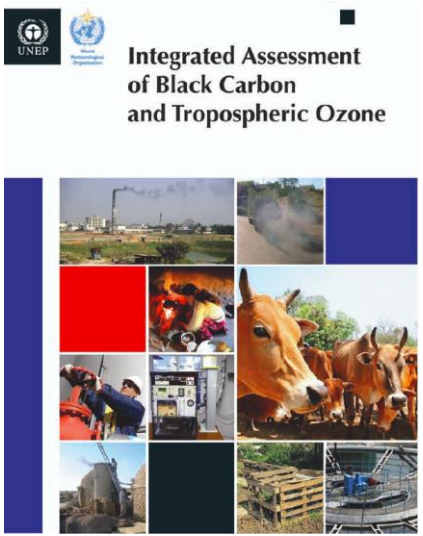
www.ccacoalition.org/methane

Methane: Mitigation Options

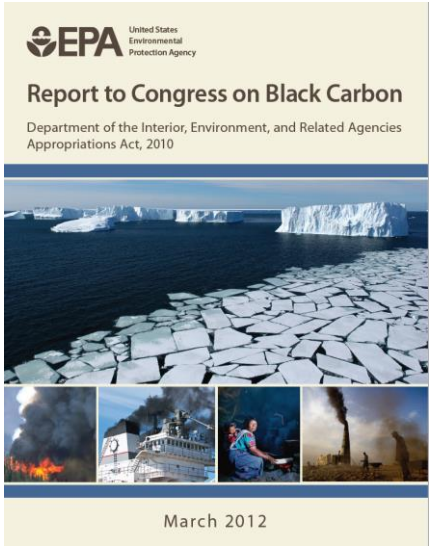
AGRICULTURE	▪ Improve manure management and animal feed quality ▪ Apply intermittent aeration of continuously flooded rice paddies ▪ Improve animal health and husbandry by combining herd and health management, nutrition and feeding management strategies ▪ Introduce selective breeding to reduce emission intensity and increase production ▪ Promote farm-scale anaerobic digestion to control methane emissions from livestock ▪ Adopt guidelines on healthy dietary choices
FOSSIL FUELS	▪ Carry out pre-mining degasification and recovery and oxidation of methane from ventilation air from coal mines ▪ Reduce leakage from long-distance gas transmission and distribution pipelines ▪ Extend recovery and utilization from gas and oil production ▪ Recover and use gas and fugitive emissions during oil and natural gas production
WASTE MANAGEMENT	▪ Separate and treat biodegradable municipal waste, and turn it into compost or bioenergy ▪ Upgrade wastewater treatment with gas recovery and overflow control ▪ Improve anaerobic digestion of solid and liquid waste by food industry ▪ Upgrade primary waste water treatment ▪ Divert organic waste ▪ Collect, capture and use landfill gas

https://www.ccacoalition.org/en/slcps/methane

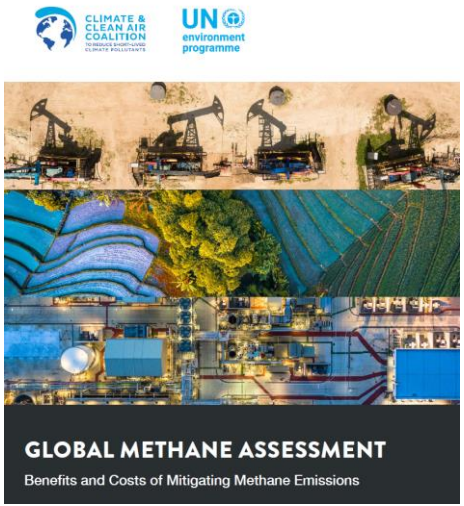
Key Resources



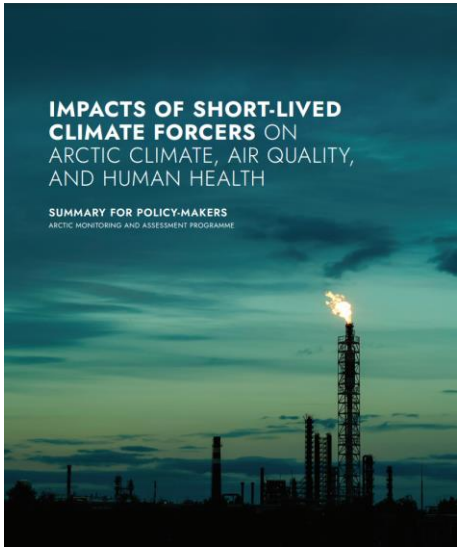
2011



2012



2021



2022

Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants

CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

77 countries

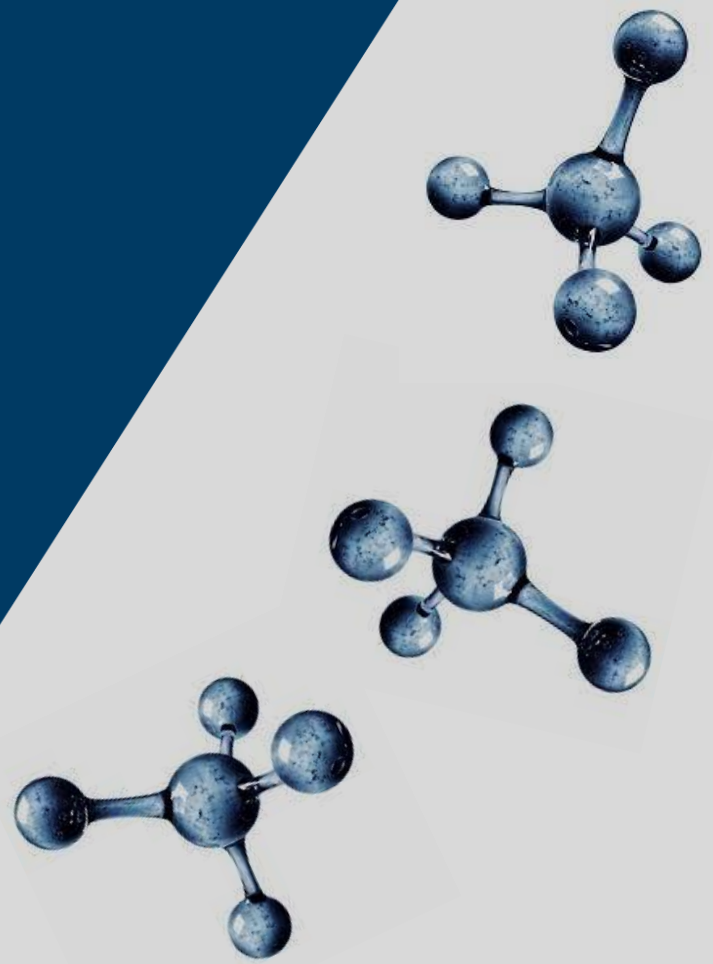
78 non-state partners

- **National Planning Hub**
  Black carbon Methane
  Tropospheric ozone
  Hydrofluorocarbons (HFCs)
- **Cooling Hub**
  Black carbon
  Hydrofluorocarbons (HFCs)
- **Household Energy Hub**
  Black carbon Tropospheric ozone
- **Heavy-Duty Vehicles and Engines Hub**
  Black carbon
- **Agriculture Hub**
  Black carbon Methane
- **Fossil Fuels Hub**
  Black carbon Methane

Methane: Congressional Climate Camp on Non-CO_2 Greenhouse Gases

Deborah Gordon
Senior Principal, Climate Intelligence Program

EESI Briefing Series
February 23, 2023



THE
NORTH STAR.

THE EVIDENCE IS CLEAR: THE TIME FOR ACTION IS NOW.

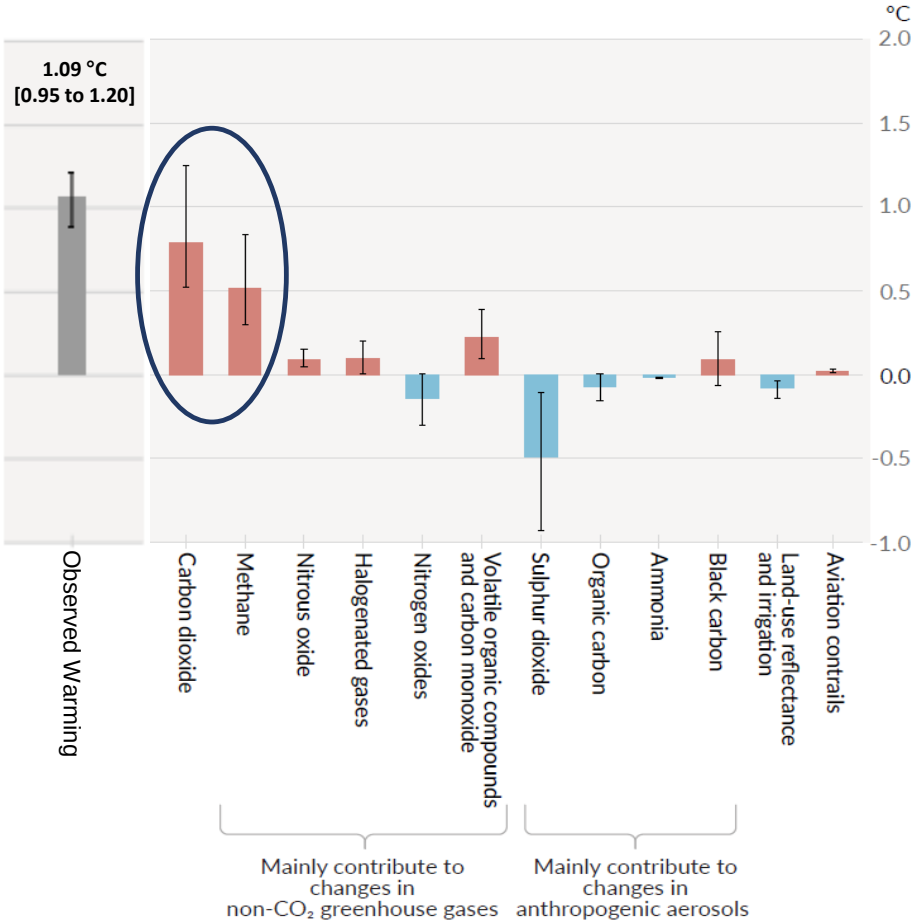
—Intergovernmental Panel on Climate Change

Average annual greenhouse gas emissions were at their highest levels in human history over the past decade.

We can halve emissions by 2030.

Methane is playing a major warming role.

- Methane is >80 times more climate forcing than CO_2 using a 20-years global warming potential
- But methane's ~10-year lifetime, it is **>100 times more** climate forcing than CO_2
- **IPCC finds that climactic warming from methane rivals carbon dioxide, within error.**

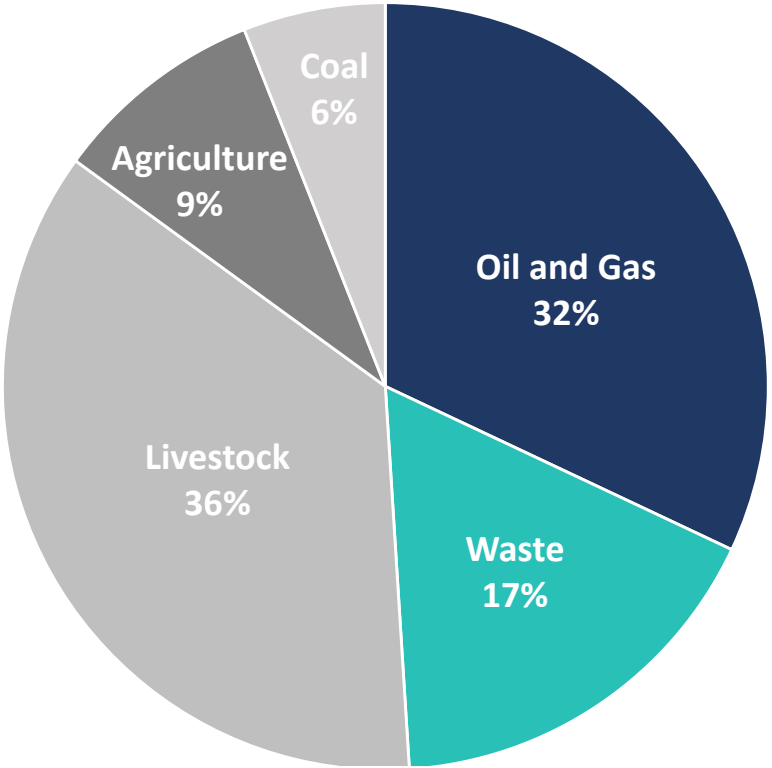


Assessed contributions to observed warming in 2010–2019 relative to 1850–1900. Source: IPCC, AR6, Figure SPM.2, 2021.

Methane emissions are concentrated in a few sectors.

28 Mt per year in US
Estimated* total human-made methane

**** Carbon Mapper aerial surveys and satellites are identifying significant methane super-emitters that suggest undercounting in***
Current national (and global) methane inventories.



2020 US Methane Emissions, by source

Source: US EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2020," 2022.

What is co-emitted with methane?

Natural Gas Main Components	Volume %
Methane	<70 - >90%
Natural Gas Liquids	5-15%
CO_2 & H_2S	5-40%
Oxygen, nitrogen & other impurities	1-5%

Air Toxins in Gas Study Samples	Concentration (ppm_v)
Benzene	165
Toluene	161
Ethylbenzene	13
Xylene(s)	75

HARVARD STUDY RESIDENTIAL* GAS, 2022

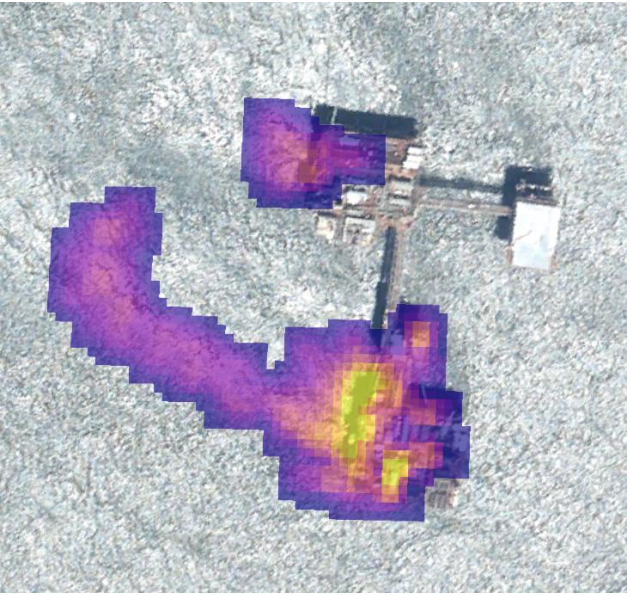
*RESIDENTIAL PIPELINE GAS MAY HAVE FEWER TOXIN CONTENT THAN INDUSTRIAL GAS


RMI
Methane in
Oil & Gas
and
Waste
Sectors

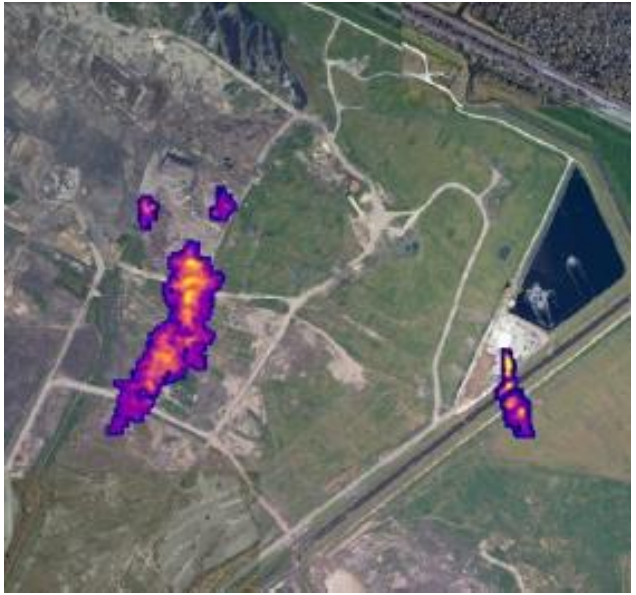
Making emissions visible

Targeting the outsized threat and opportunity by preventing super-emitters

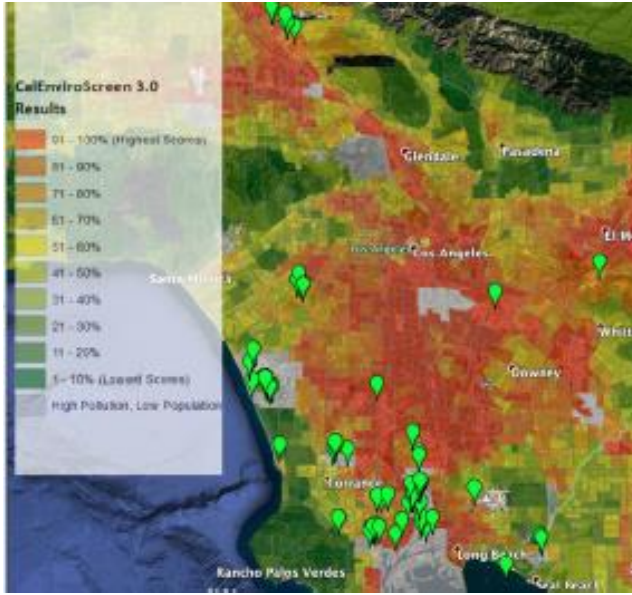
Climate, air quality, public health and environmental justice issues



GOM Offshore Platform:
66% methane leakage rate in state waters



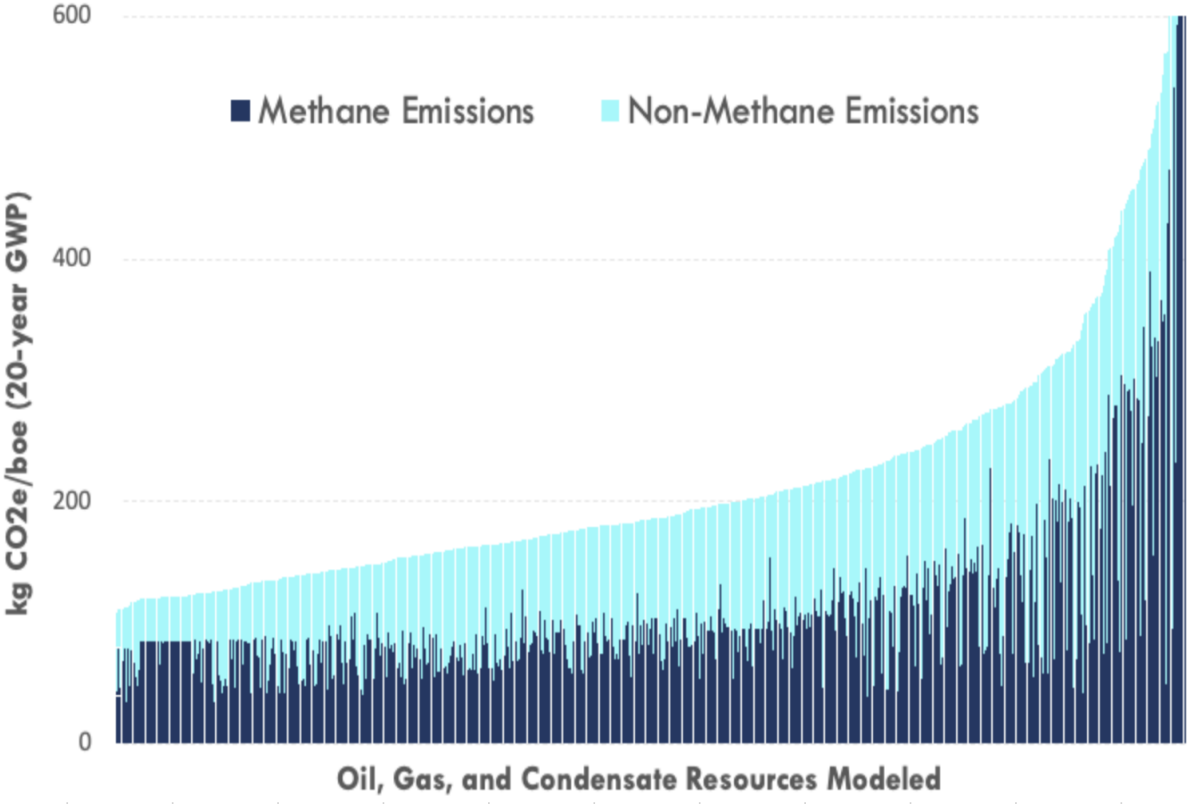
New Orleans Landfill:
2,000 kg methane per hour

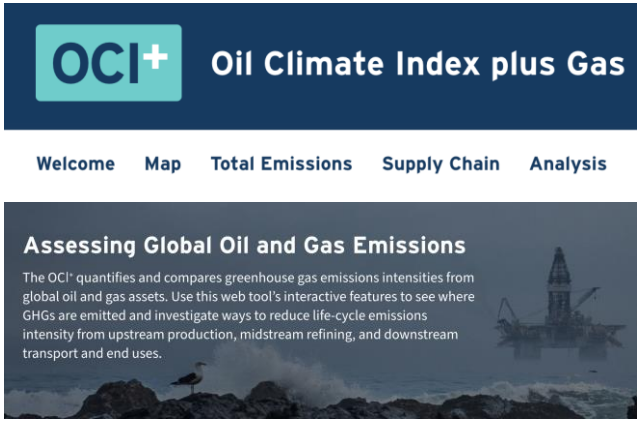


Methane super-emitters in disadvantaged communities

Quantify, attribute, and mitigate methane

Preventing leakage eliminates one-half of the oil and gas industry's climate impact.





Source: RMI, OCI+ Web tool, 2023.
Modeling ~70% global O&G supplies.

RMI Oil and Gas Solutions Initiative

Leverage emissions transparency for decarbonization across supply chains

Expanded emissions visibility → **Will drive decarbonization on several fronts**

- Emissions-differentiated **market** activation
- Climate-aligned **corporate** business models
- Better **investor** portfolio allocations
- Informed **government** policy and regulation

We can manage what we can measure

It's wasteful, harmful, and dangerous to leak gas.

The oil and gas industry is the #2 source of human-made methane.

But it's #1 for reduction potential.

Leaking over ~3% of produced gas makes it more damaging to the climate than coal.

Publicly track oil and gas asset ownership to ensure consistency between federal and state agencies.

Waste MAP (Methane Assessment Platform)

- Visualizes data for decision makers
- Combines top down and bottom up emissions
- Deep dives provide feedback loop with richer data

Proposed Concept

Two-Pronged Approach to Waste Methane Mitigation

WASTE MAP

Open-Source Platform

designed to collect and improve availability and robustness of global waste sector data and enable methane emissions transparency

Decision Support Tools

the platform will include a heat map of methane emissions from waste, strategic playbooks for waste methane mitigation, and case studies

COUNTRY DEEP DIVES

On-the-Ground Support

Subnational and national engagement to support a pathway for waste management improvements, improve public health, and reduce environmental impact

Information Sharing

Creating and Convening a network of waste experts and peer-to-peer exchange to share global waste management practices.

Prioritized methane in this decisive decade.

Increase transparency:

−Fund public methane monitoring to spot leakage in industry supply chains using satellites, aerial leak detection, and ground-based optical imaging.

Track methane:

−Track, quantify, and attribute emissions through non-proprietary reporting so that responsible parties develop mitigation plans and curtail emissions.

Establish methane markets:

−Use an independent, verifiable certification process to differentiate commodities and price them based on their emissions to incentivize rapid methane reduction.

Advance policymaking:

−Convert voluntary market standards, meet national pledges, adopt mandatory performance standards, extend methane fees, and create financial instruments.

What we've learned over the past 40 years shapes what we choose to work on

Expertise

- Energy systems
- Supply chains
- Market forces

+

Influence

- Access to key actors
- Radical collaboration
- Communication

+

Impact

- Catalytic opportunities
- Relentless monitoring + evaluation

+

Inclusion

- Deeply committed to DEIJ
- Transition benefits all

=

RMI PORTFOLIO

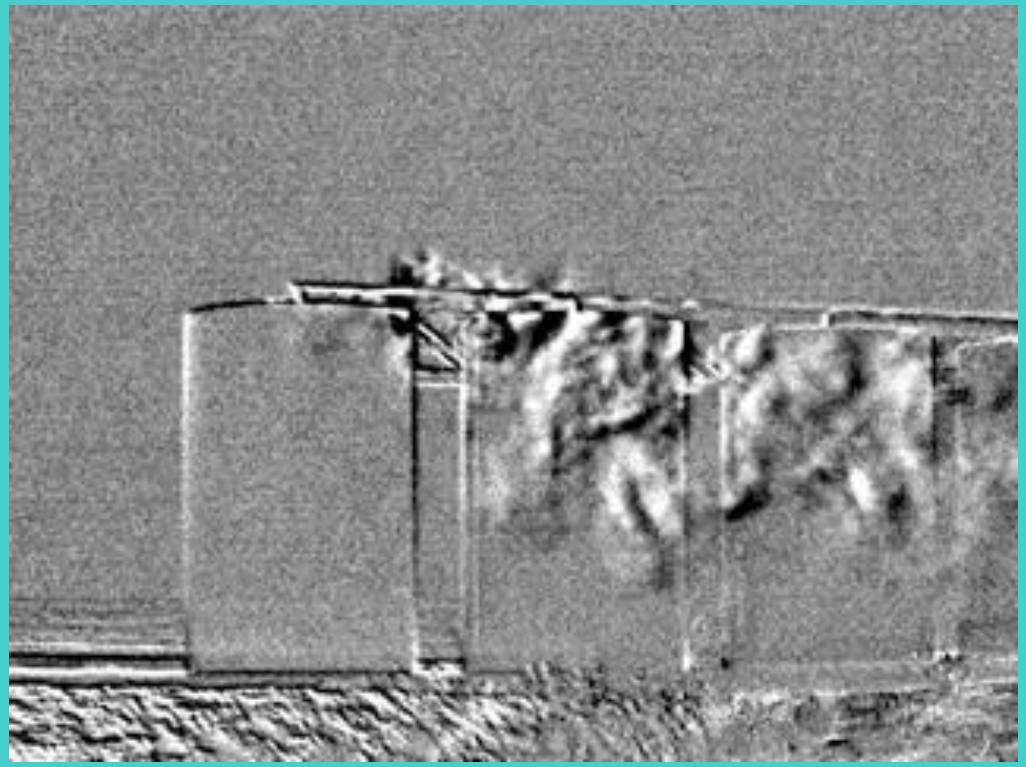
RMI
ENERGY. TRANSFORMED.

RMI is transforming global energy use to secure a clean, prosperous, zero-carbon future — for all.

In addition to preserving natural resources and mitigating climate change…

“Cutting methane emissions [is] a critical environmental justice opportunity and a critical way to save hundreds of thousands of lives."

— Rick Duke
Senior director and White House liaison
for U.S. special climate envoy John Kerry



Thank you!

Deborah Gordon
dgordon@rmi.org
@RMIemissions

Agricultural Emissions of Nitrous Oxide and Methane

Environmental and Energy Study Institute, Briefing Series: Congressional Climate Camp

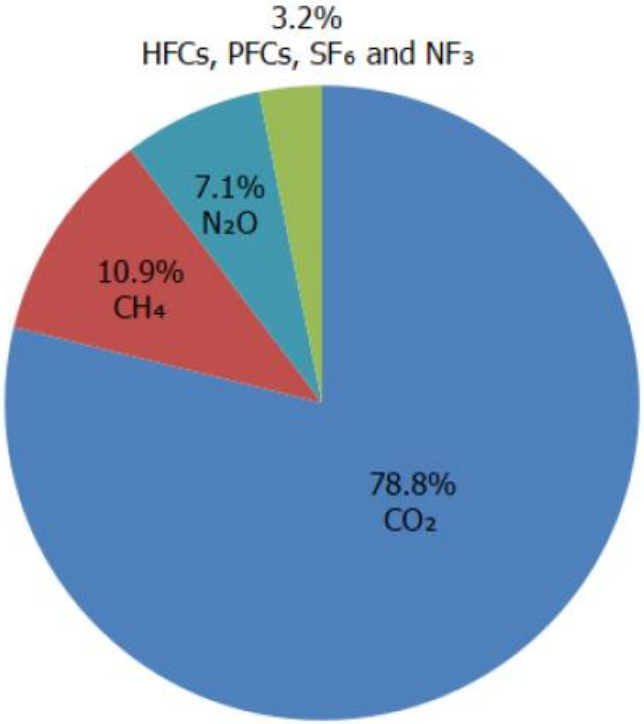
February 23, 2023

Eric A. Davidson

Professor, University of Maryland Center for Environmental Science

Principal Scientist, Spark Climate Solutions

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%



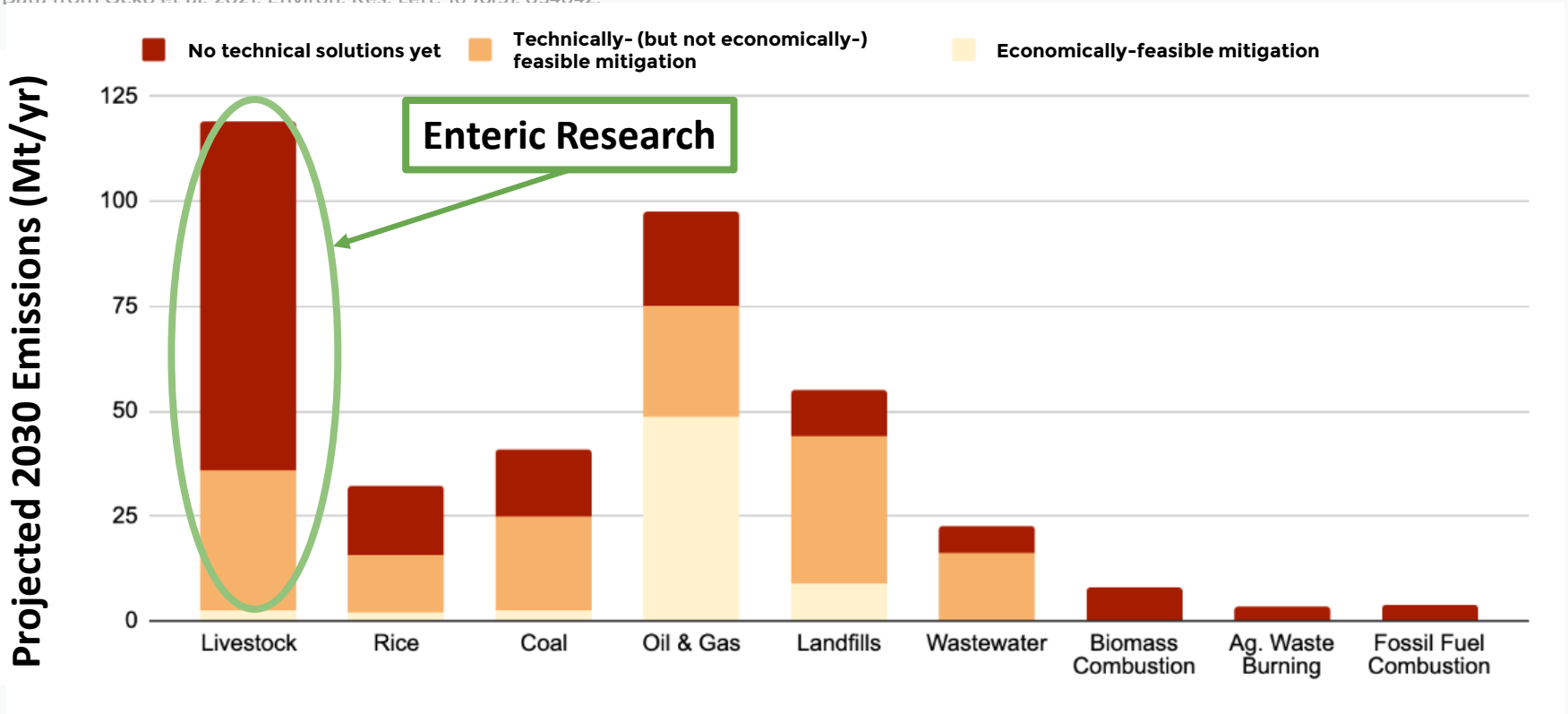
Agriculture sector contribution:
~40% of CH_4 emissions
~75% of N_2O emissions
~10% of total GHG emissions

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.

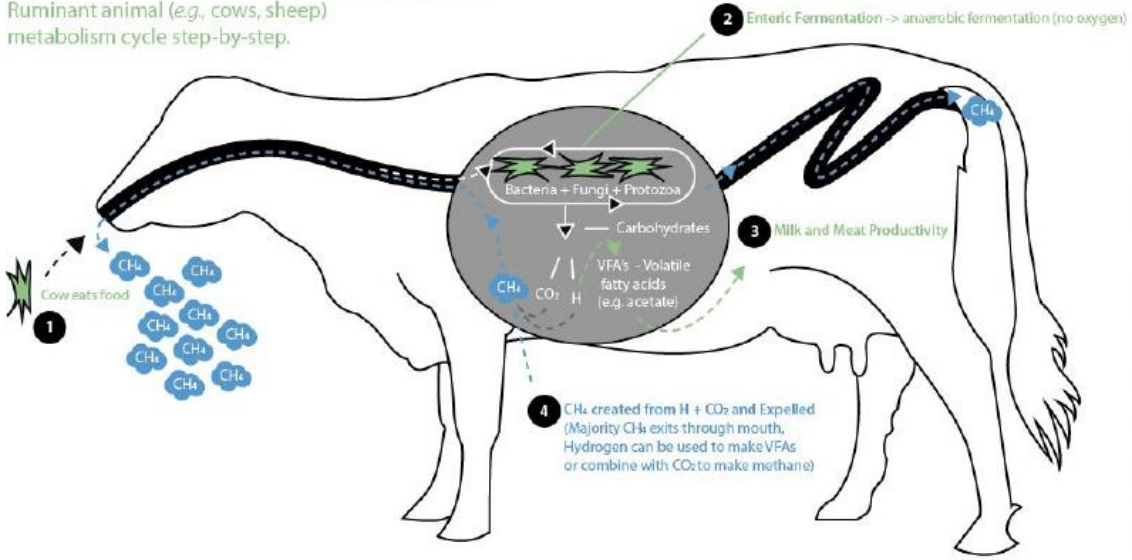


Note: Portion of emissions shown as addressed using methane removal are hypothetical.

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

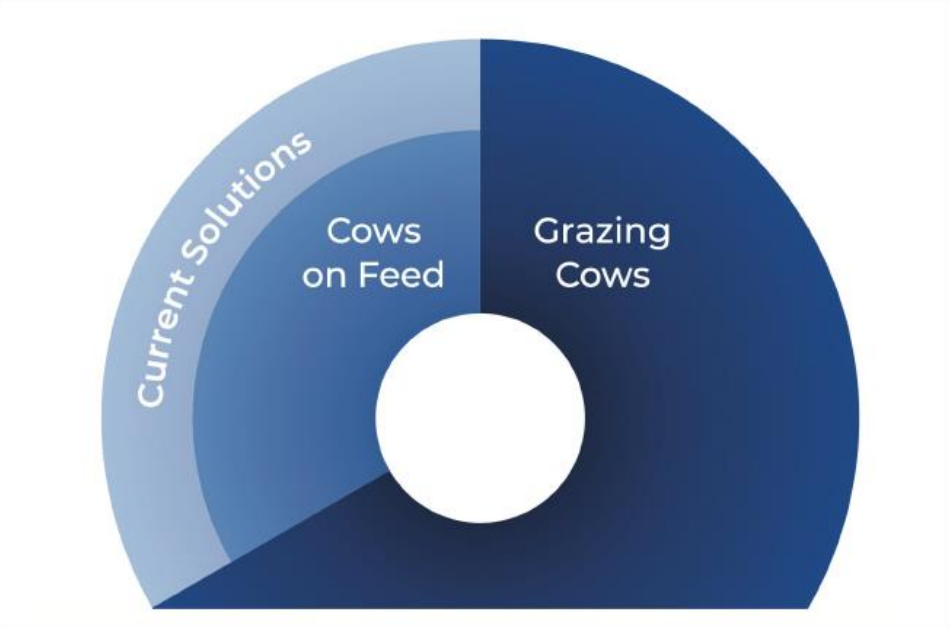
Feed formulation for low methane

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.



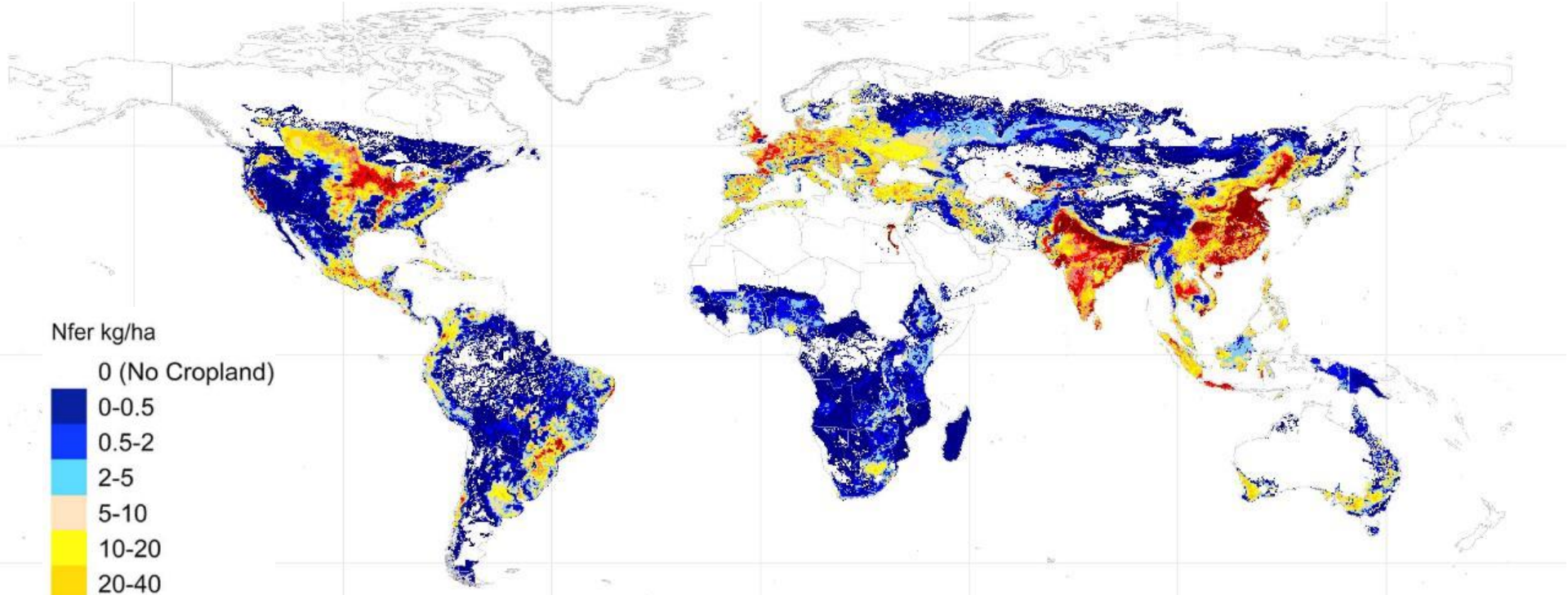
What will happen without action and new technology

- 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

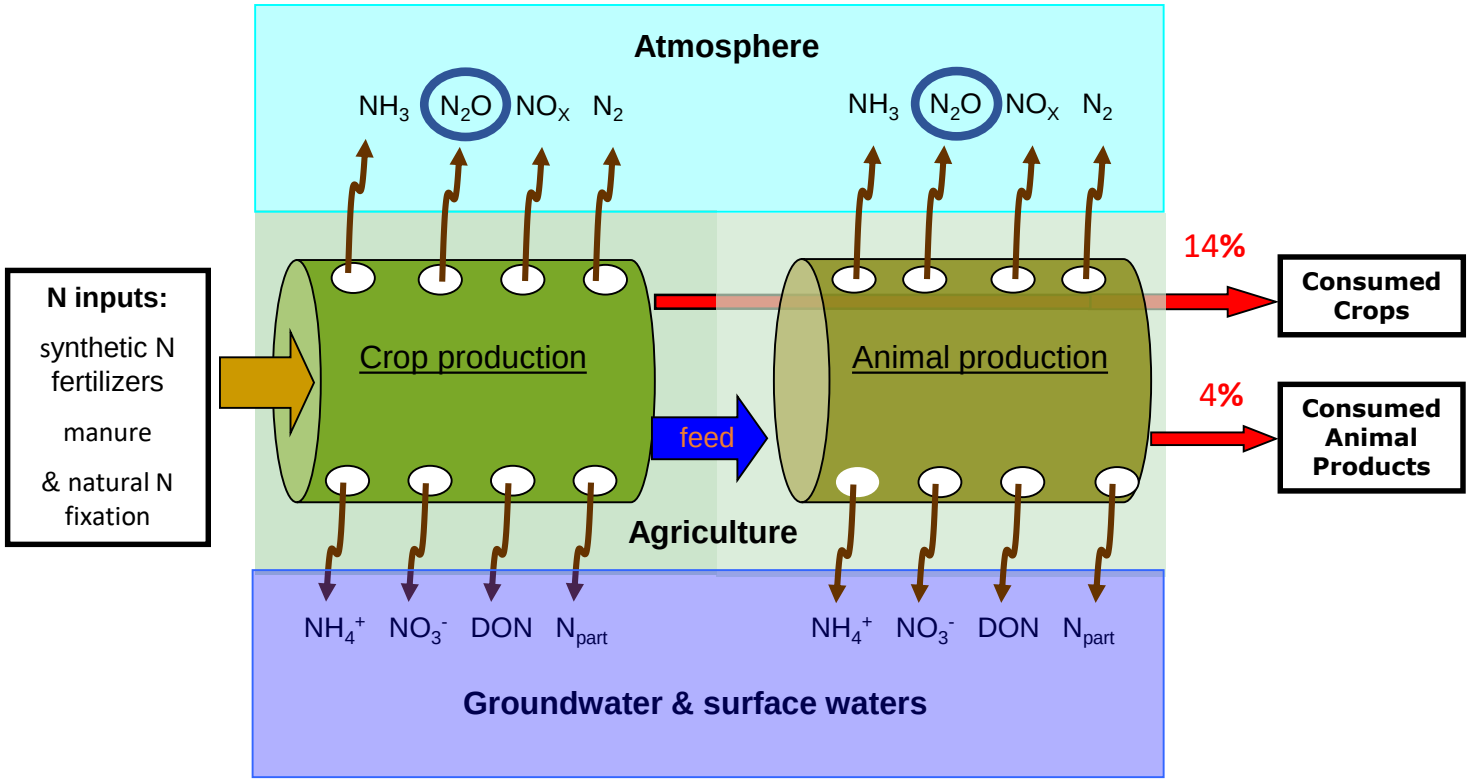


Global nitrogen fertilizer input for 2015

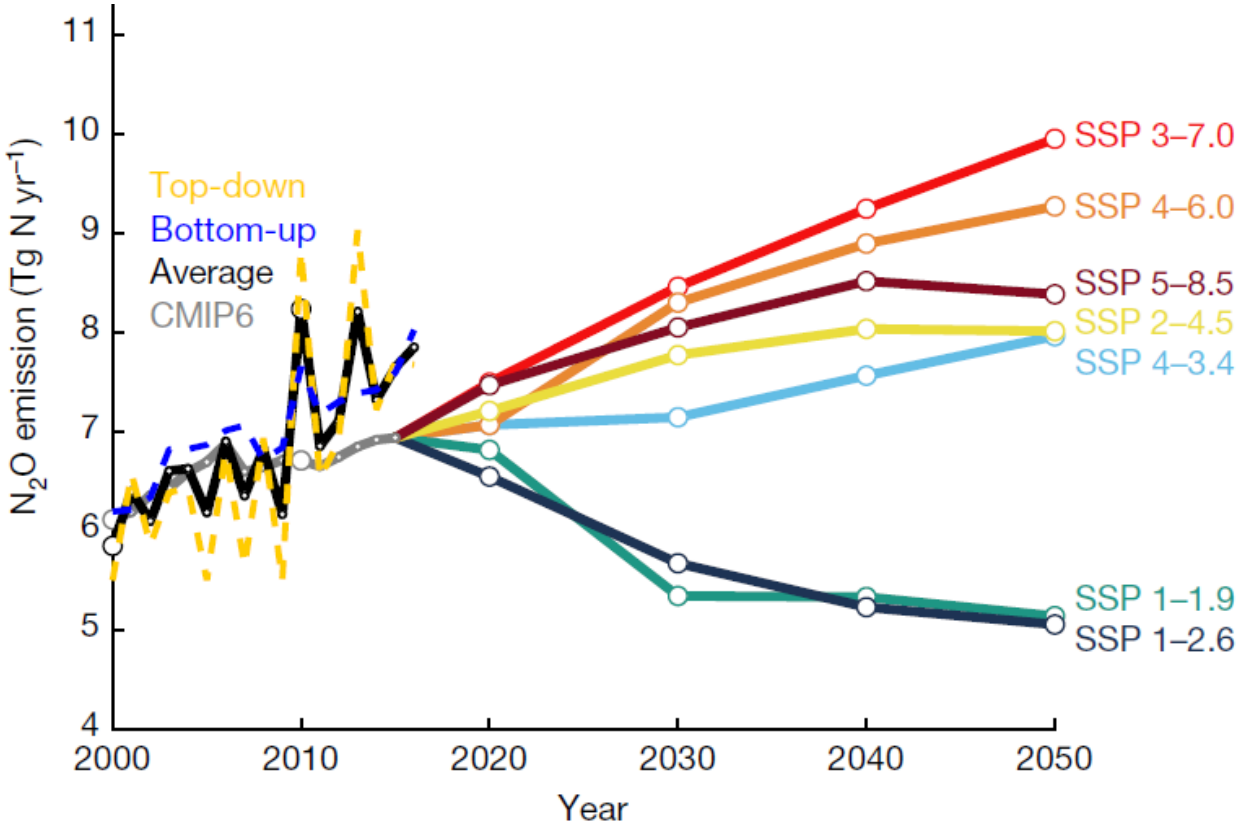
(Mueller *et al.*, 2017, Global Biogeochemical Cycles)

(*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

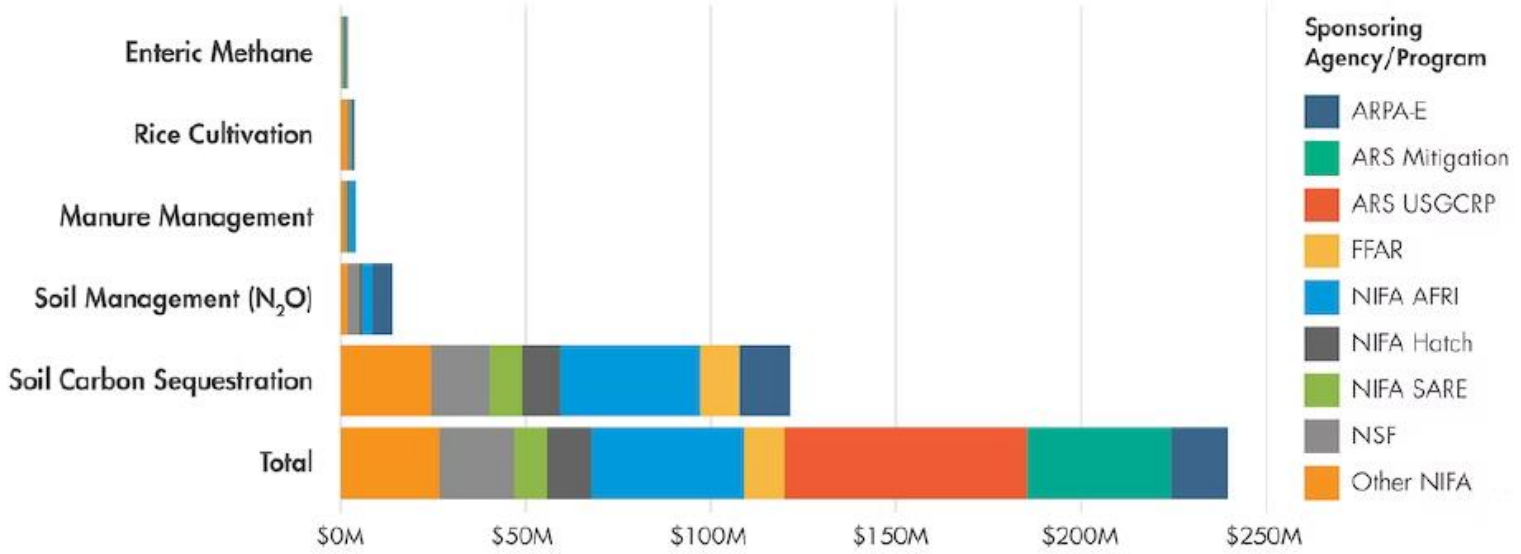
- **Social science investigations of farmer decision making and technology adoption**
- **Farmer engagement in on-farm research**

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)

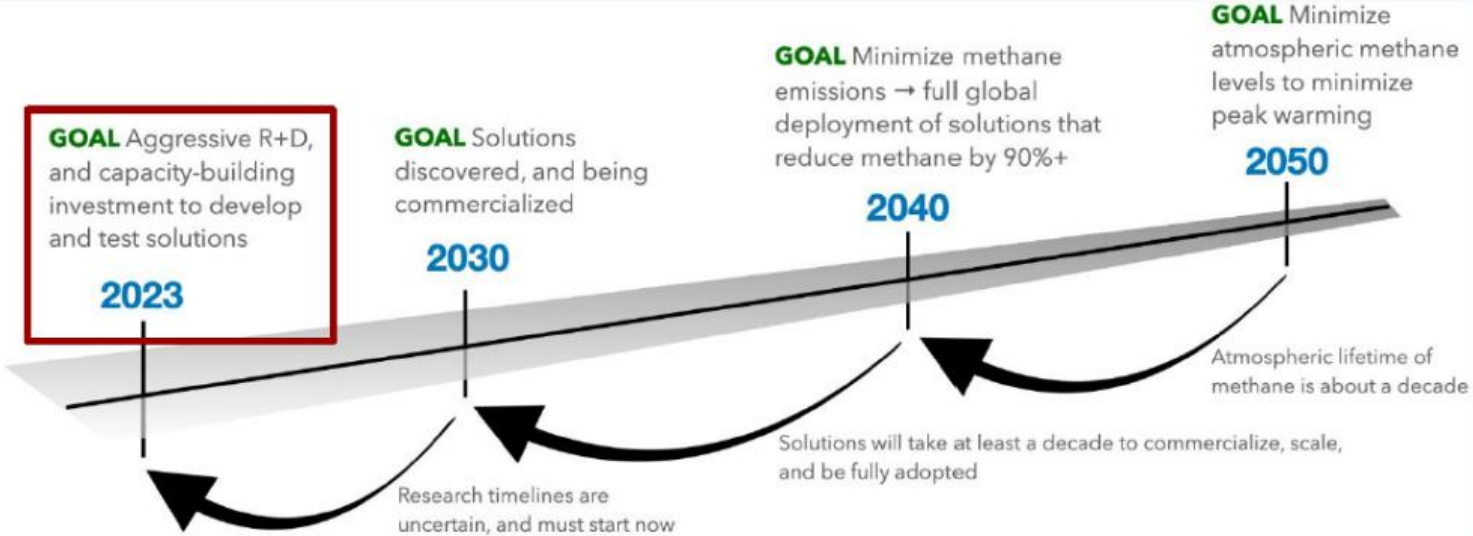


LAB TO FARM

BREAKTHROUGH INSTITUTE

The Next Decade is Critical

MINIMIZING PEAK TEMPERATURES REQUIRES LIVESTOCK ENTERIC METHANE RESEARCH TODAY



EESI
Environmental and Energy Study Institute

What did you think of the briefing?

Please take 2 minutes to let us know at:
www.eesi.org/survey

***Materials will be available at*:**
www.eesi.org/022323camp

***Tweet about the briefing*:**
#eesitalk @eesionline

Thursday, February 23, 2023