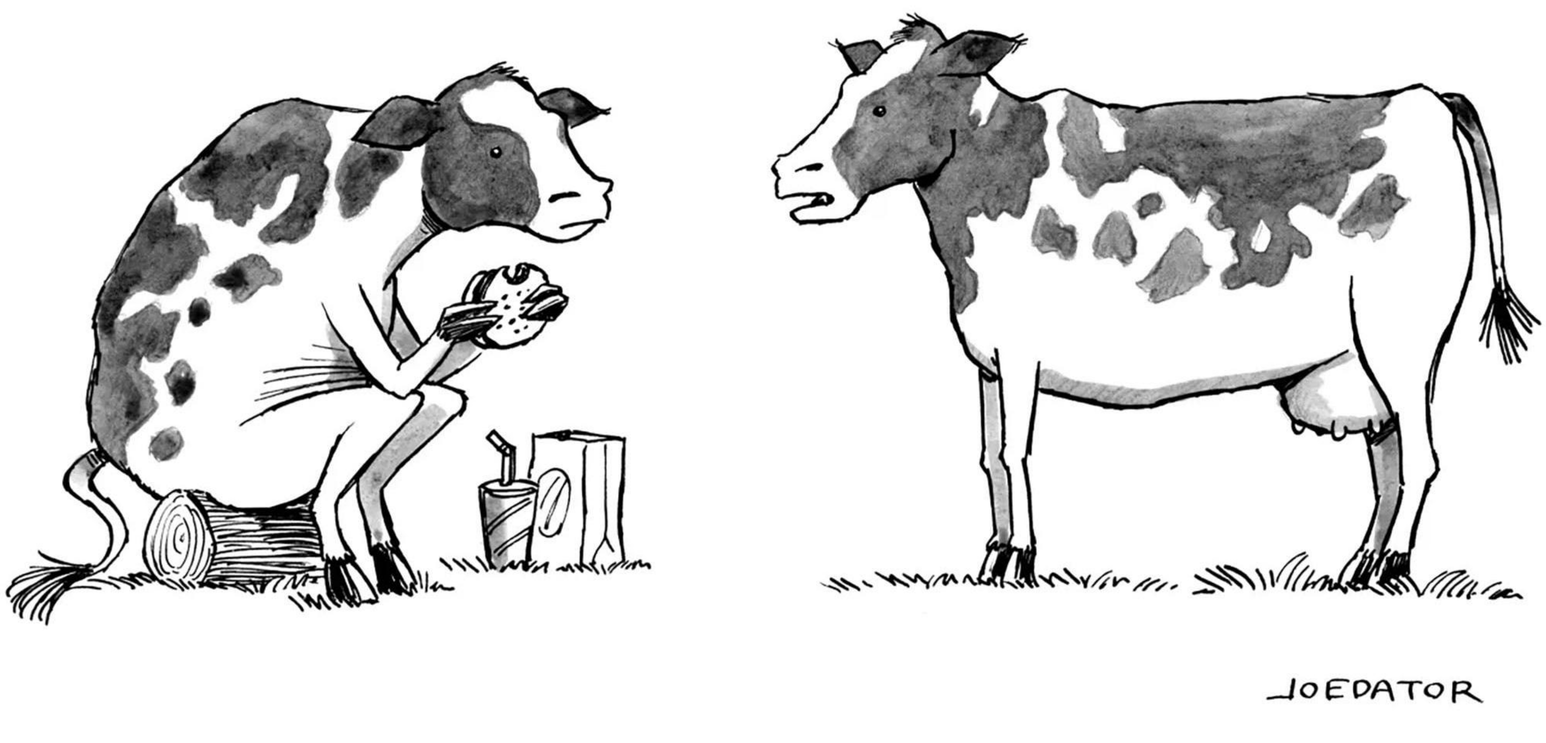
Lecture 15: Modern Climate Change Drivers II



"I don't care if it's plant-based, you're creeping everyone out."

ERT 102

Fall 2025

Today's Learning Outcomes

1. Be able to explain how agriculture contributes to carbon emissions
2. Be able to explain why agricultural practices, such as conservation tillage and cover crops, are able to reduce carbon emissions
3. Be able to explain the reason slash-and-burn agriculture is used in tropical regions
4. Be able to explain why reduction of methane and nitrous oxide can help us quickly reduce emissions, in comparison to reductions to CO_2
5. Know how to "fix" CH_4 and N_2O emissions

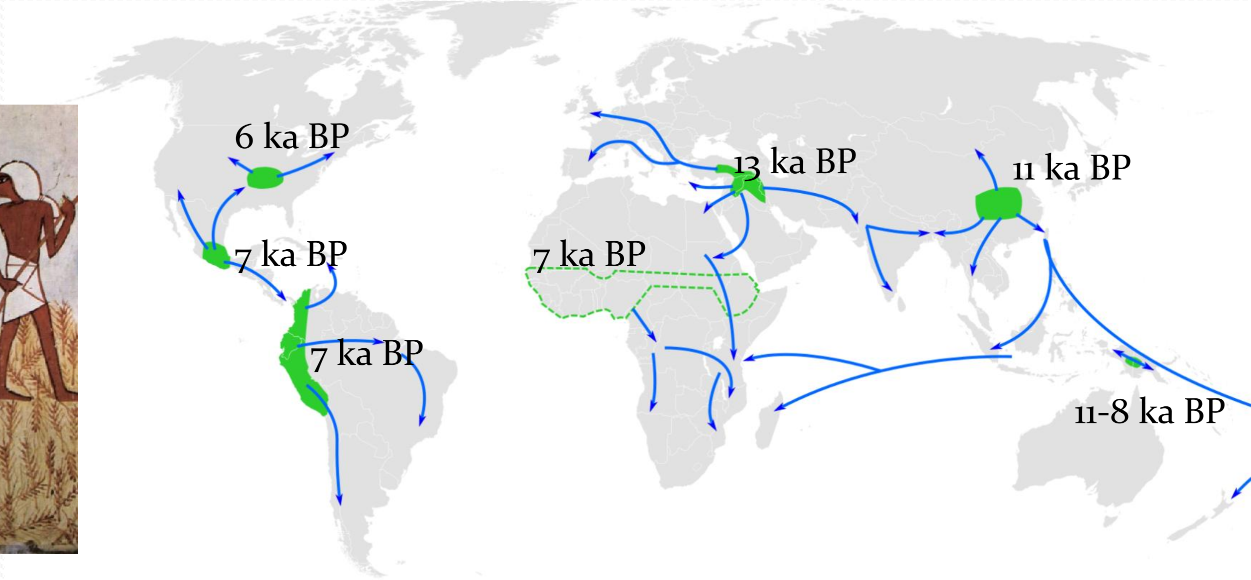
Emissions by Sector and Cause

- CO_2 emissions from burning of fossil fuels to support all sectors is 74% of USA total emissions
- Other processes that release CO_2 make up another 6%
  - Ex. land clearing & degradation
- Methane is ~11%
- Nitrous oxide is ~6%

Agriculture is the main source of both of these

Agriculture

- Humans started impacting the Earth long before the industrial revolution

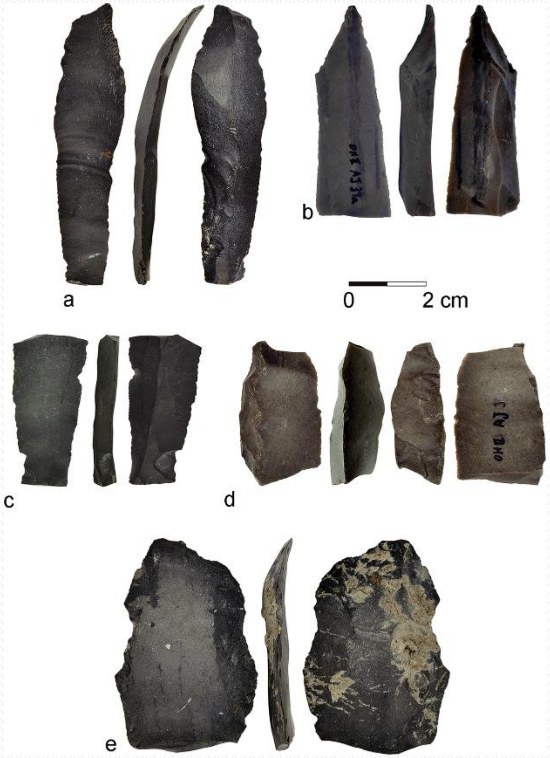


Multiple dawns of agriculture, beginning 13,000 ka BP in Mesopotamia

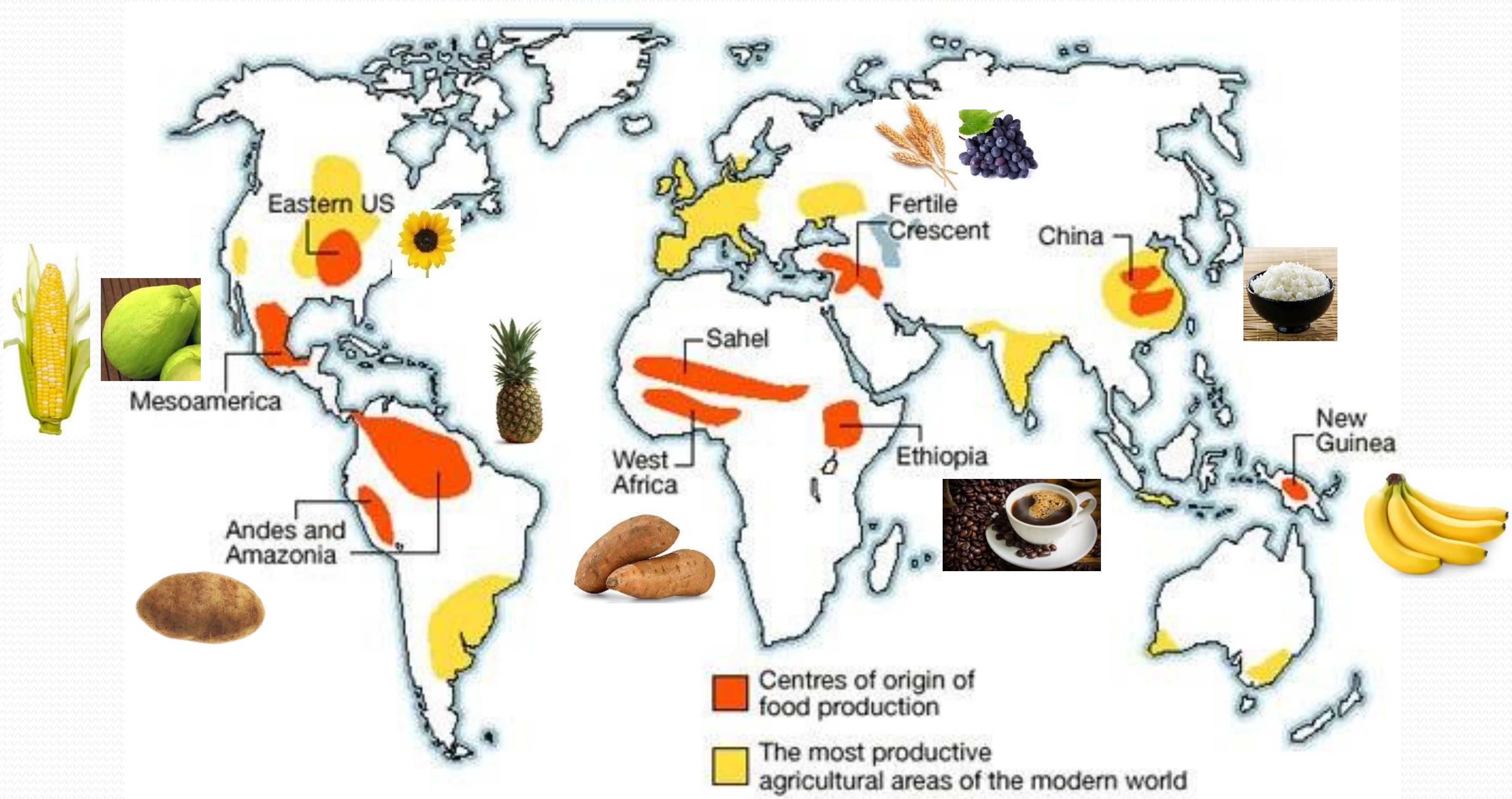
Origins of Agriculture

- Agriculture became established ~13,000 years ago

- But evidence for earlier proto-agriculture by 23,000 years ago in Israel
  - Based on presence of weed species and wild barley/oats
  - Also found some early tools for processing plants

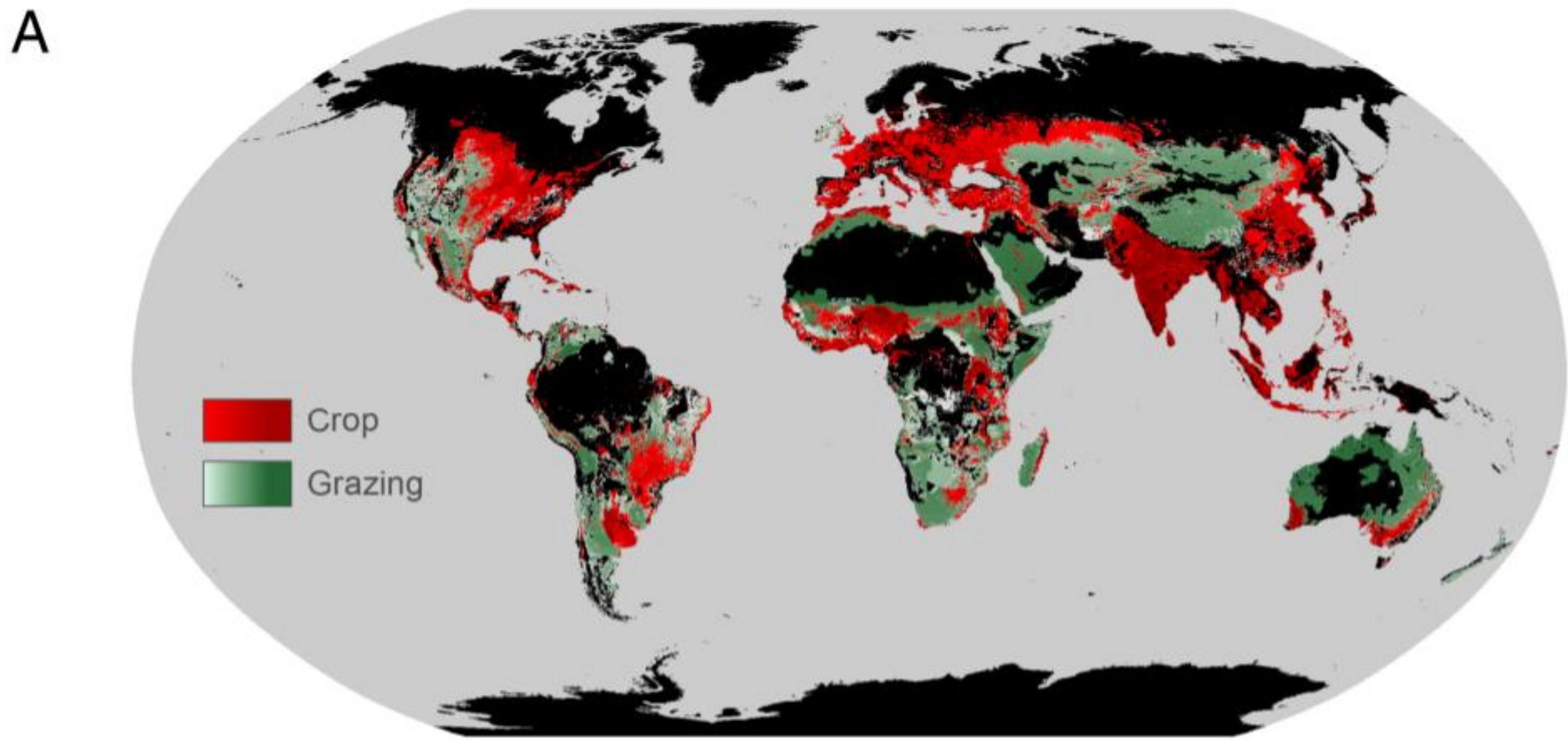


Origins of Agriculture



Early Human Influence on Climate

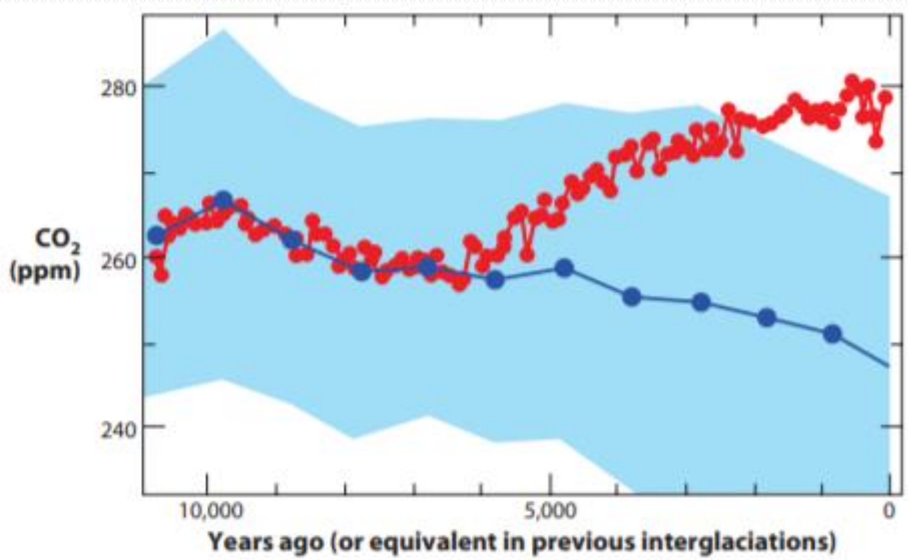
Agriculture and Pastoralism

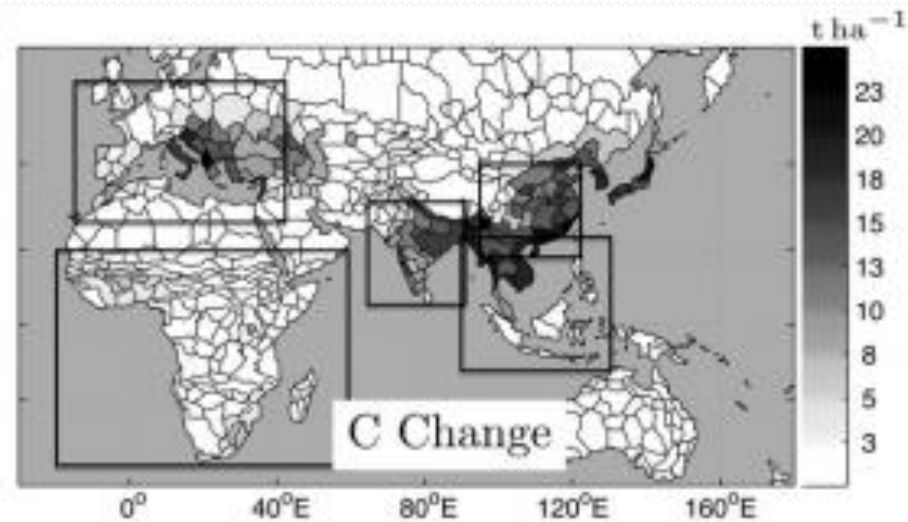


Early Human Influence on Climate

- Early humans released 60-320 Pg C due to agriculture since 10,000 BC
  - Net accumulation from humans is >7 Pg <u>per year</u>

- Possible our pre-industrial benchmark of 280 ppm was already higher than it would have been without humans





Carbon losses by 2000 BC

How does agriculture cause C loss?

- Rapidly [years] through burning, increased soil respiration, and increased soil erosion

How does agriculture cause C loss?

Soil tillage….

Aeration + Respiration

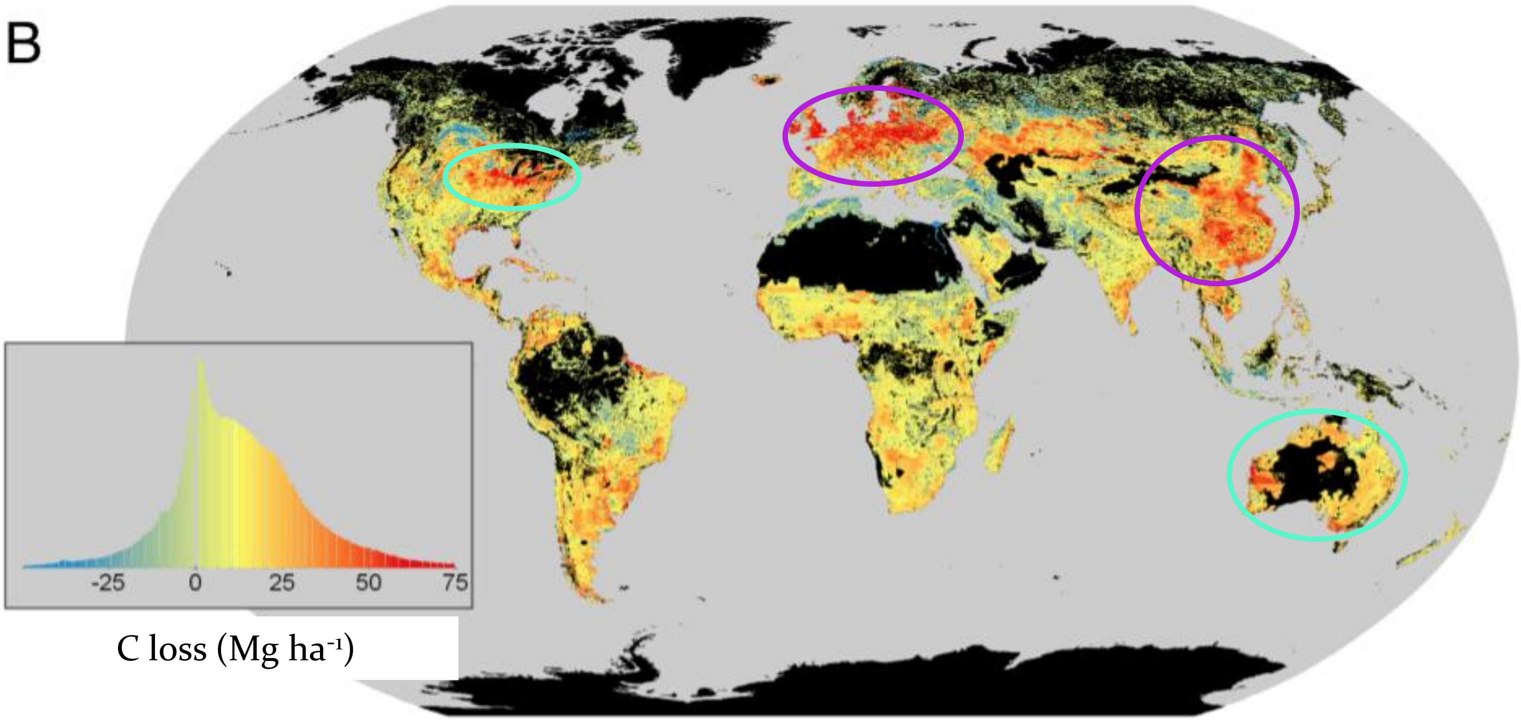
Erosion + Respiration

- Then slowly [decades-centuries]…with soil C loss which is much harder to reverse

Soil Damage

- Intensive agriculture leads to increased rates of soil erosion (20x faster than average natural rate) by…
  - Increased irrigation (water transport of sediment)
  - Clearing of land decreases soil stability
  - Large animal herds can compress ground and reduce permeability → more topsoil erosion

- Ultimately leads to a net loss of **12-17 million acres <u>a year</u>** in productive agricultural land
  - 1/3 to ½ the area of New York State



- Soil C loss of ~116 Pg since the dawn of agriculture and pastoralism [equivalent to 10 years of fossil fuel use]

- Highest losses in ancient farmlands (Europe/China)
  - But some intense recent agriculture (Australia, Great Lakes)

Reducing Soil Erosion & C Loss

- Crop rotation: rotating which parcels of land are used for harvests and letting others occasionally lie fallow allows the soil to recover a bit

- Intercropping: planting different crops in mixed patterns (maximize soil use and stability)

- Shelterbelts: planting of trees of tall shrubs at the edge of fields to reduce wind erosion

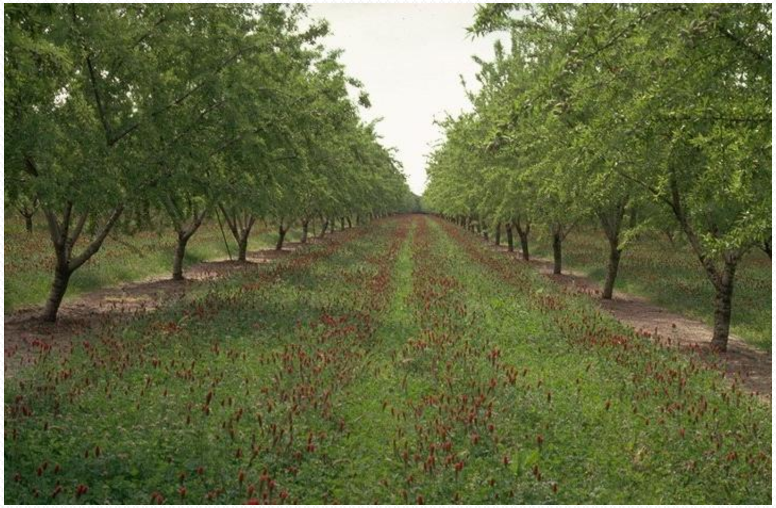
Below: Shelterbelt research farm at the University of Nebraska, Lincoln

Above: Intercropping of crops in Africa
(Kale, onion, fennel, lettuce)

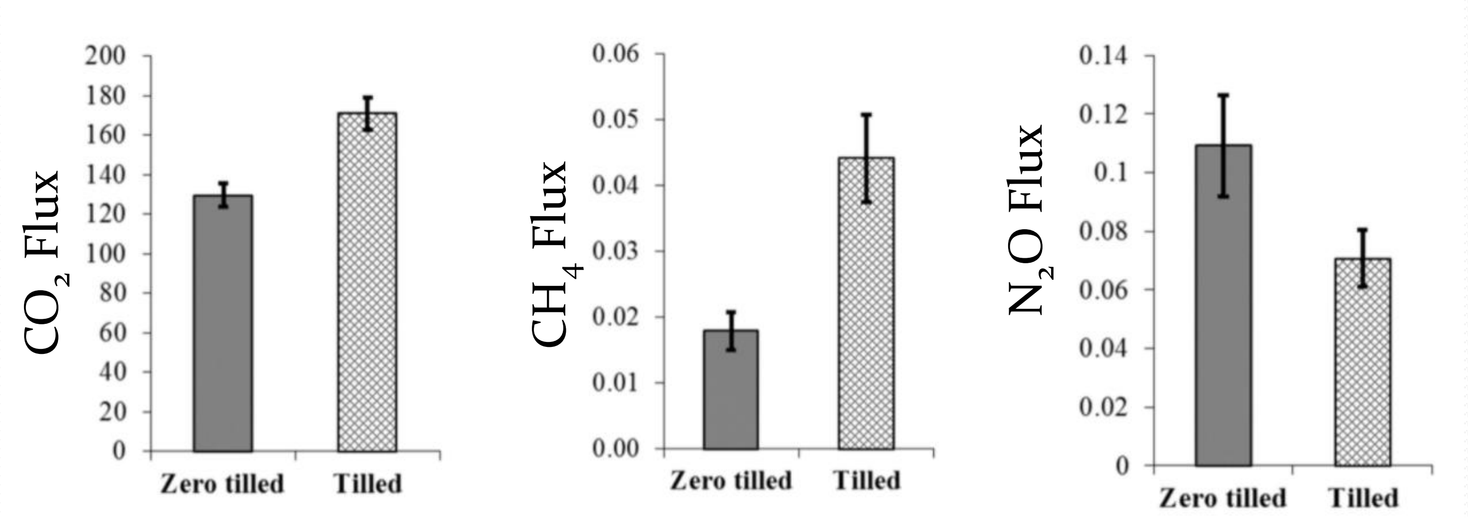
Reducing Soil Erosion

- Conservation Tillage
  - Techniques that reduces tilling
  - Leave waste in fields after harvest
  - Reduces tractor use
    - soil compaction
  - No-till farming in ~21% of US farms

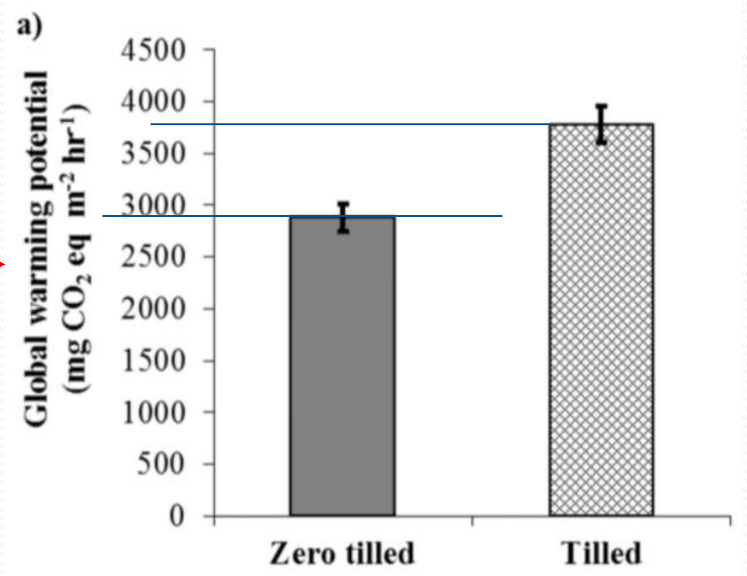
- Cover Crops
  - Plant a temporary crop with no intention to harvest
  - Holds soils in place



Conservation Tillage Emissions Reduction

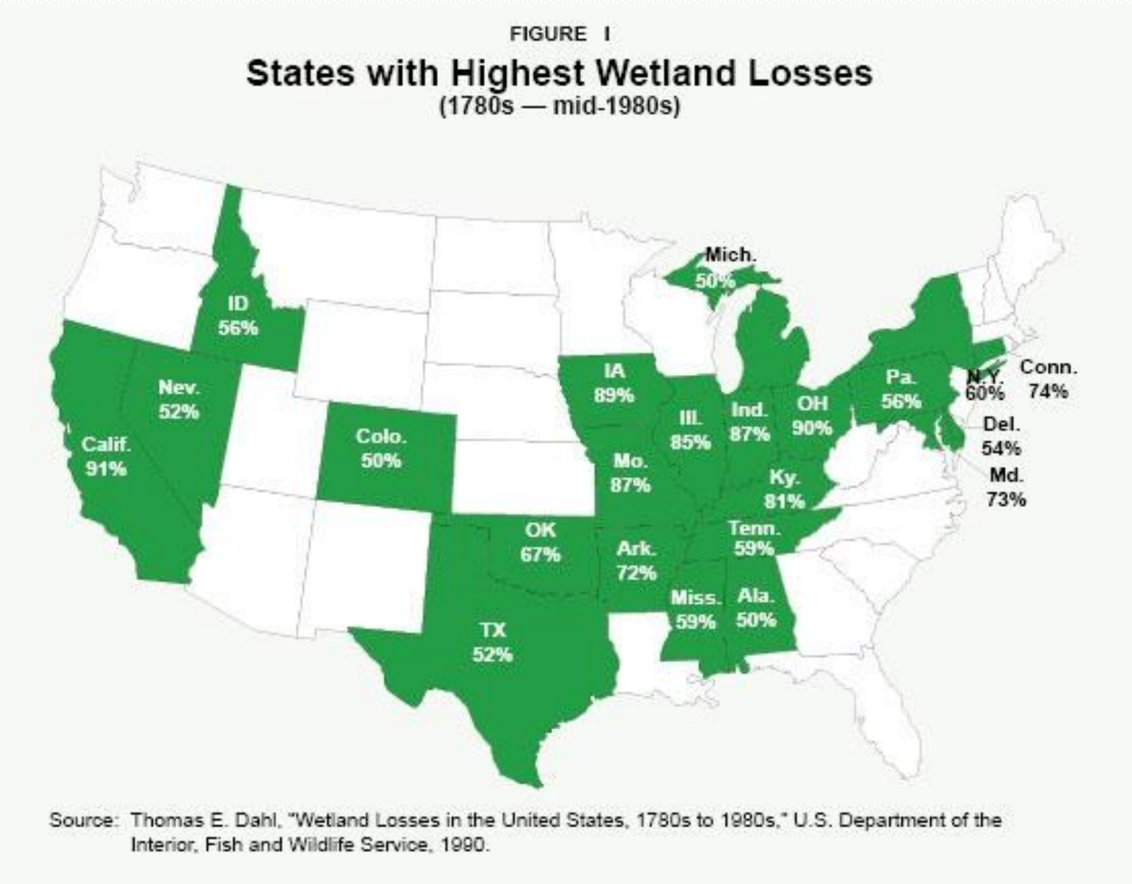


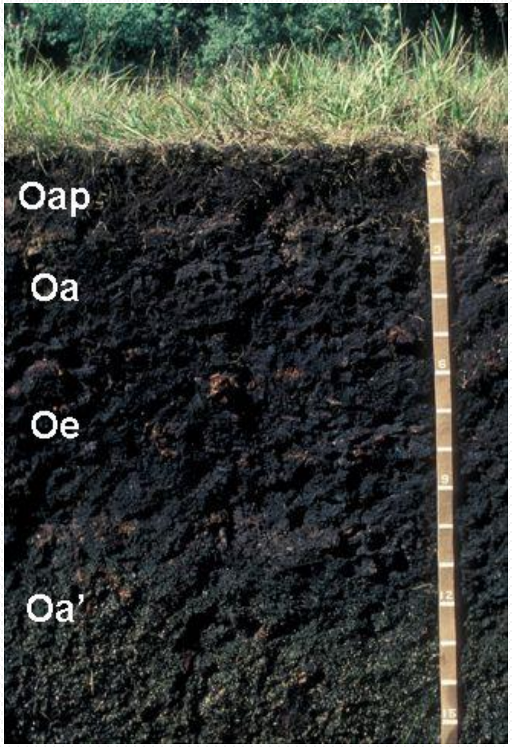
Total GHG effect reduced by 25% in zero-till versus tilled fields



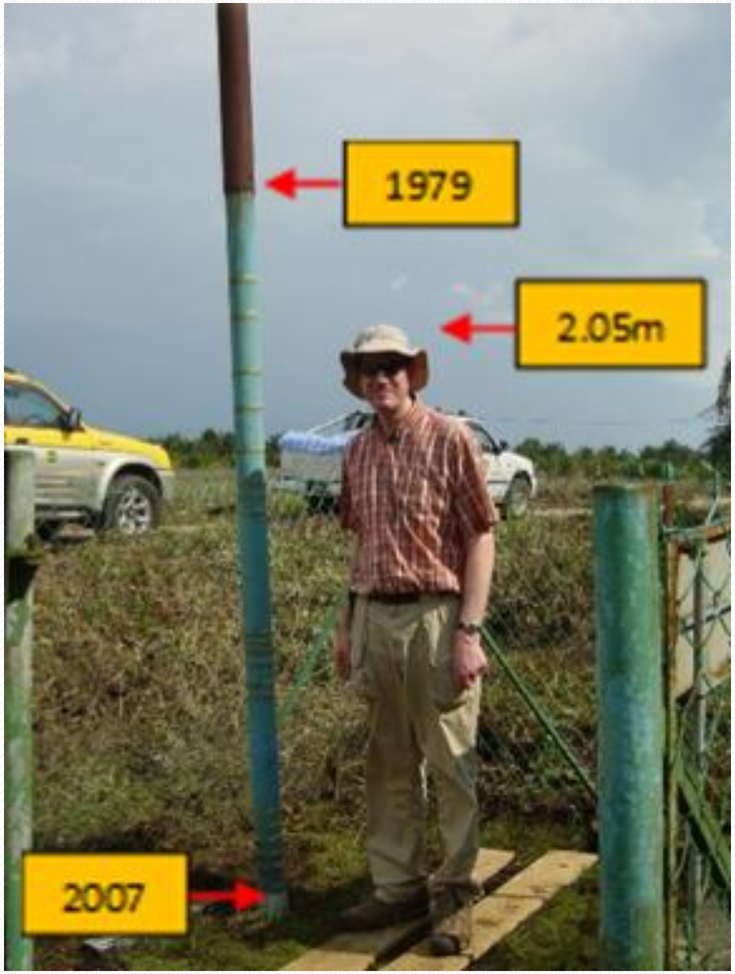
Draining the Swamp (for crops)

- Wetland drainage for agriculture has also caused massive soil C losses





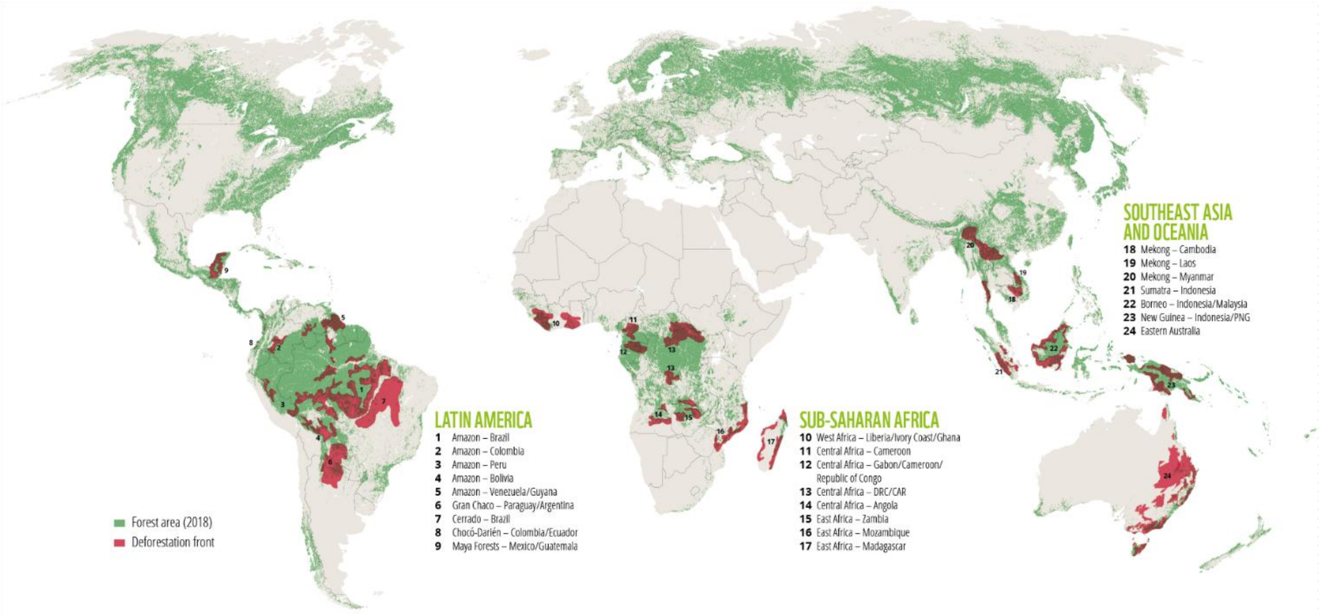
Lots of C in wetland soils
(low respiration rates)



Modern conversion to agriculture is happening in rainforests

Drivers:

- Countries transitioning from low to high population density
- No better place to farm
- Poverty
- Extractive industries



Logging Industry

The Expectation

(Not true for the most part, except in Indonesia!)

The Reality

(It’s only economical to drag the most high-value trees hundreds or thousands of miles out of the rainforest)

The Real Logging Threat

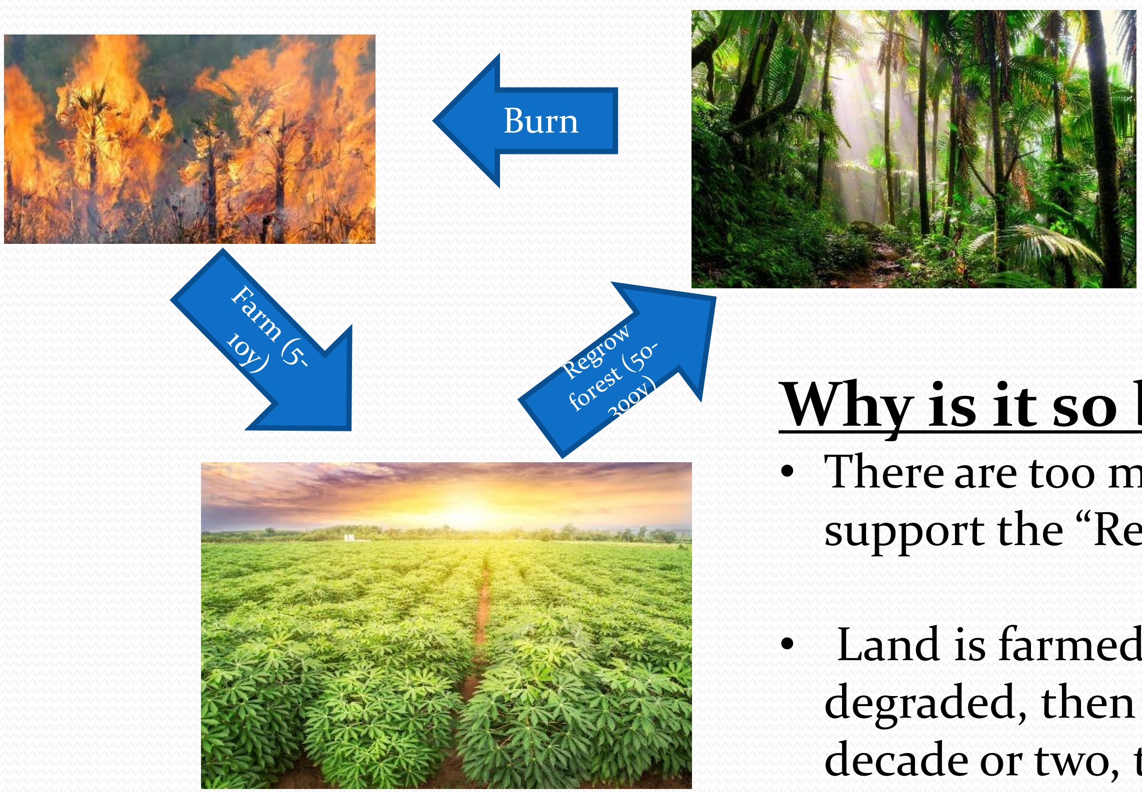
Roads

- You need a road to get a tree out of the rainforest
- You also need a road to get your crops out of the rainforest
- Clearcutting of land for agriculture by poor small-scale farmers almost always follows road construction by multinational timber companies

Slash & Burn

- Dominant form of agriculture in the tropics
- Tropical forest soils are incredibly nutrient-poor (high C in and out)
- What are you going to do with a ton of non-economical trees on some land you want to farm?
- You burn them. It gets rid of the trees and the ashes have a lot of nutrients
- When the nutrients run out in 5-10 years, burn down a new plot of land

Slash-and-burn agriculture was a sustainable practice for **<u>thousands of years</u>**

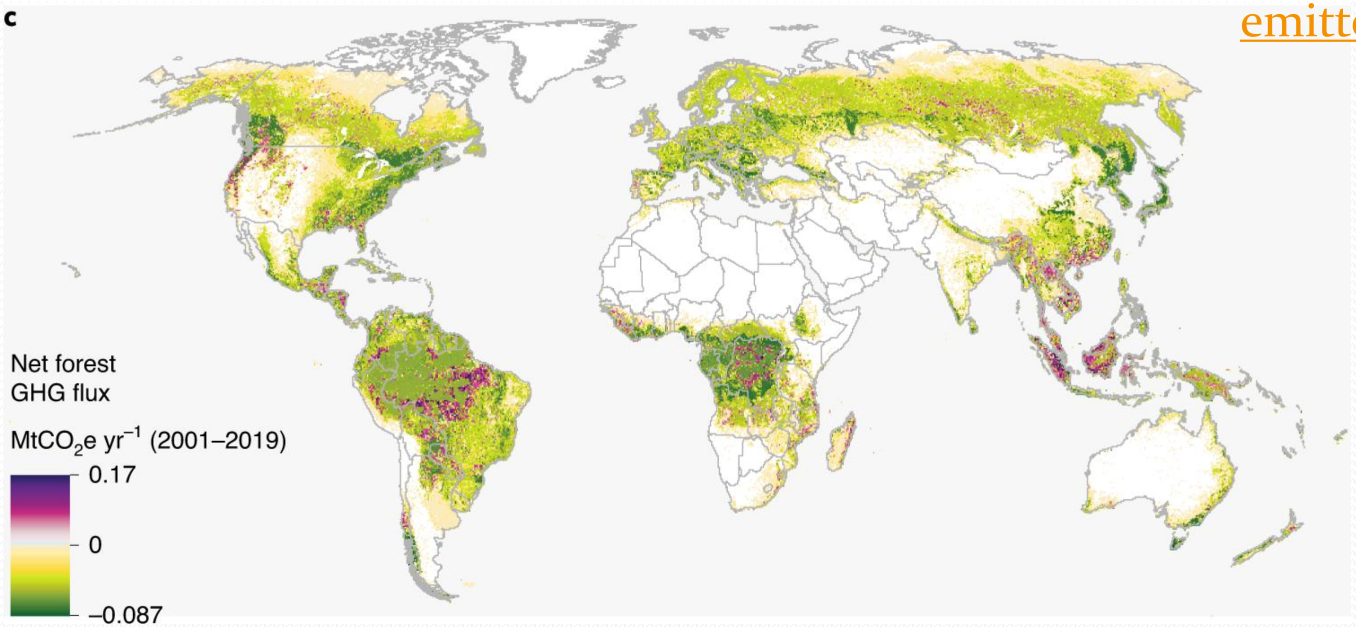


<u>Why is it so bad now?</u>

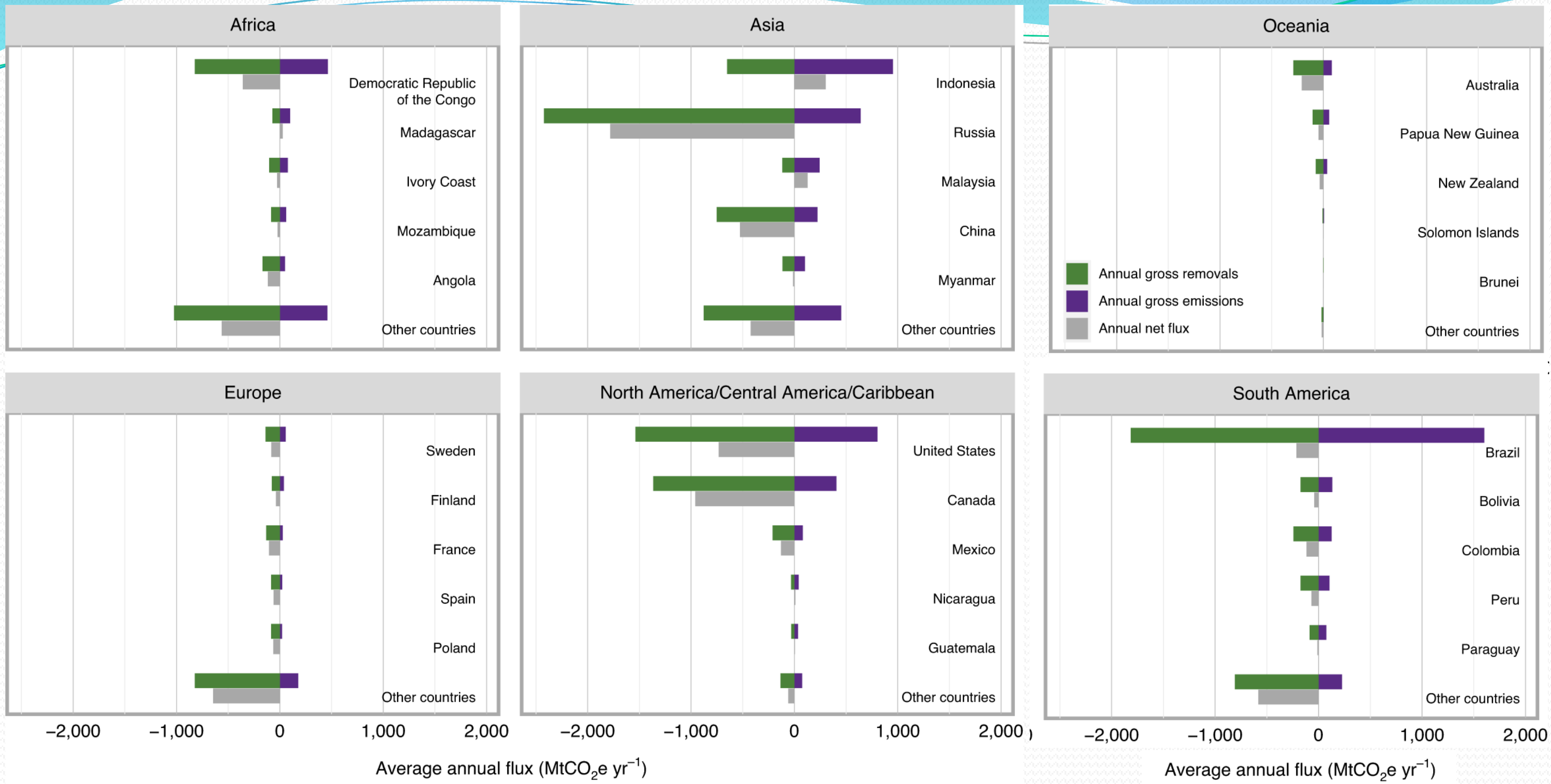
- There are too many people now on the Earth to support the "Regrow forest (50-300y)" stage
- Land is farmed now until it is permanently degraded, then maybe left to regrow for a decade or two, then farmed again

Net GHG Flux from Forests to Atmosphere

Amazon Rainforest is, or close to, a net emitter of carbon now



Net annual GHG flux. For display purposes, maps have been resampled from the 30-m observation scale to a 0.04° geographic grid. Values in the legend reflect the average annual GHG flux from all forest dynamics occurring within a grid cell, including emissions from all observed disturbances and removals from both forest regrowth after disturbance as well as removals occurring in undisturbed forests.

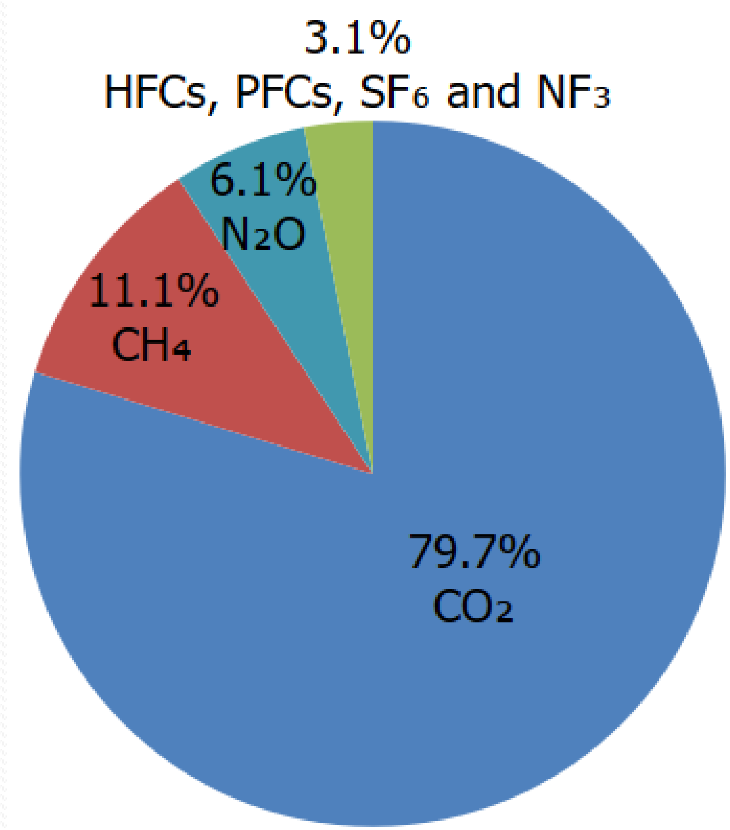


Net forest-related fluxes (grey bars) are shown with their two component gross fluxes: gross emissions from land-use change and other forest disturbances (purple) and gross removals occurring in undisturbed forests as well as removals from forest regrowth after disturbance (green). The top five countries per region are ranked high to low on the basis of gross emissions, with all other countries in the region grouped into ‘other countries’.

Contribution to Warming

- Pie chart shows the contribution warming of different gases emitted by the USA
- CO_2 dominates with other gases making up 20%
  - Do these other 20% matter much in halting and potentially reversing climate?

Overview of U.S. Greenhouse Gas Emissions in 2022



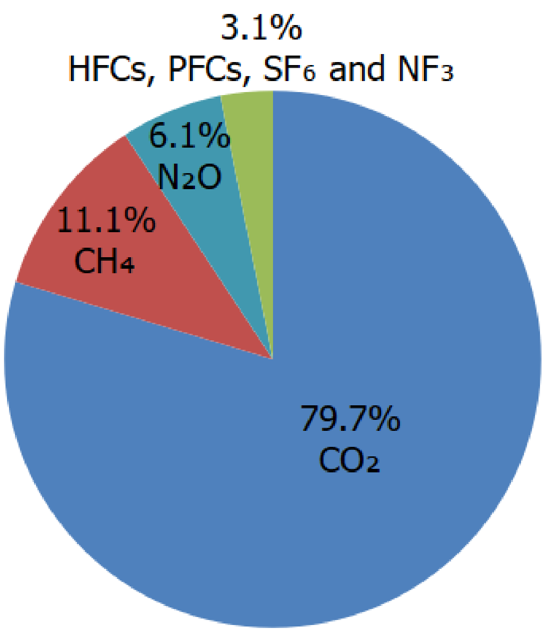
Emissions by Sector and Cause

- CO_2 emissions from burning of fossil fuels to support all sectors is 71% of USA total emissions

- Other processes that release CO_2 make up another 6%
  - Ex. land clearing, degradation

- Methane (CH_4) is ~11%

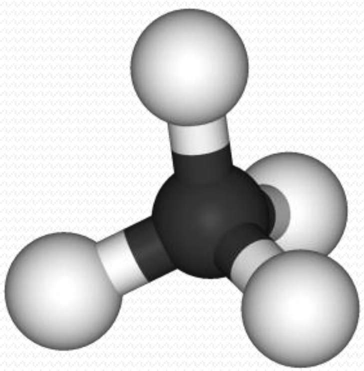
- Nitrous oxide (N_2O) is ~6%



Residence Time and Decay

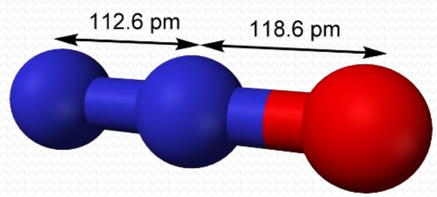
- While CO_2 is stable long-term both CH_4 and N_2O break down fairly quickly
  - i.e. they do not pile up like CO_2 emissions do

Degrade



Methane
CH_4

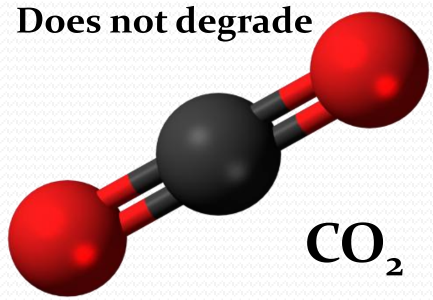
Degrades to CO_2
Mean residence time:
12 yeas



Nitrous Oxide
N_2O

Degrades to NO_2
Mean residence time:
114 years

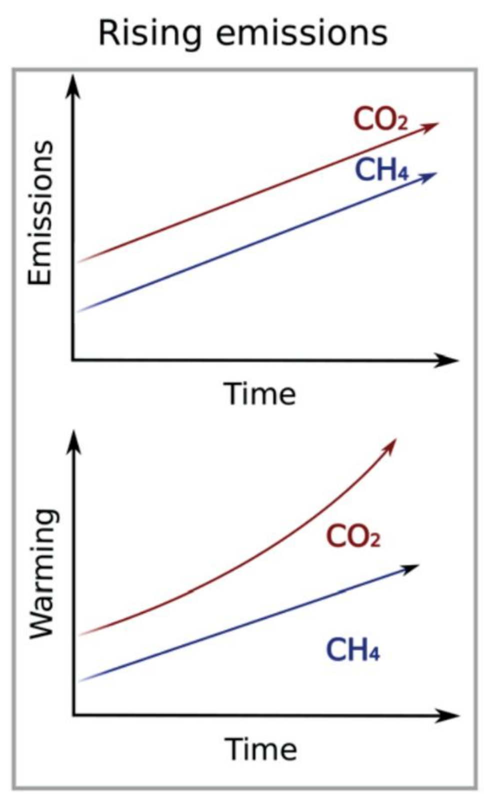
Does not degrade



CO_2

Methane Emissions & Breakdown

- If methane emissions hold steady they will level out



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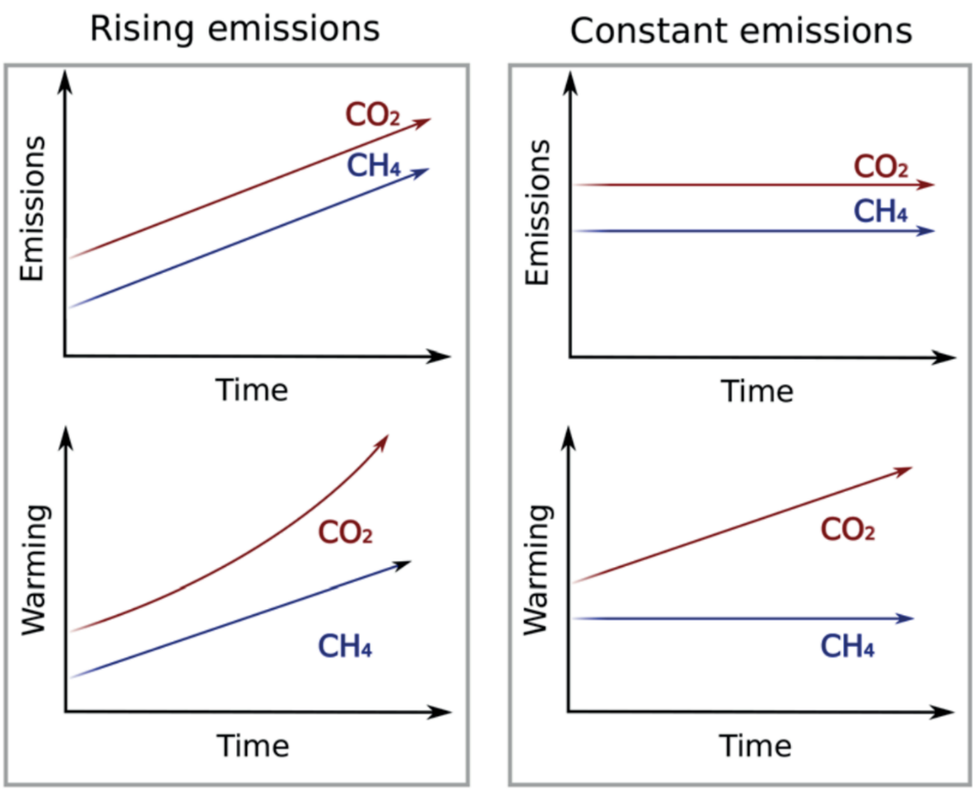

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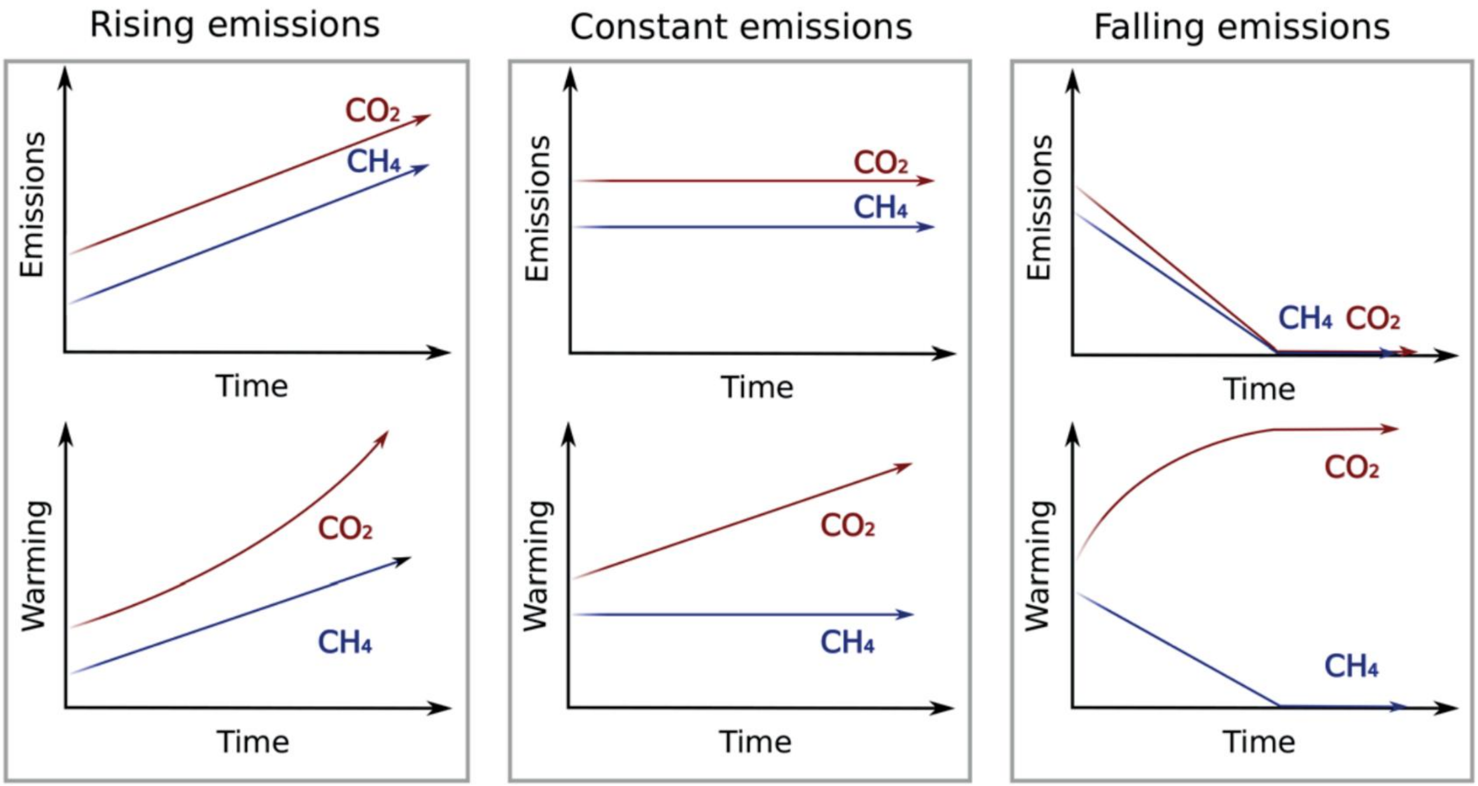


Global Warming Potential

- Combine the warming effectiveness with how long a gas will warm for before degrading

Everything standardized to one unit of CO_2

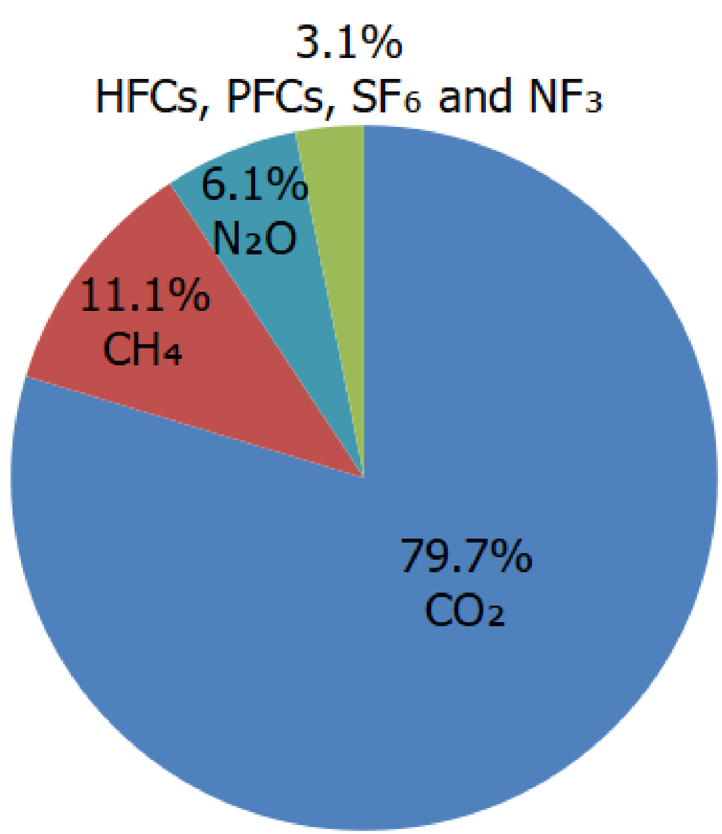
LIFETIME AND GLOBAL WARMING POTENTIAL OF HUMAN-GENERATED GREENHOUSE GASES

Gas	CO_2	CH_4	N_2O	CFC-11	CFC-12	HCFC-22
Lifetime years	Multiple	12	114	45	100	12
Global warming potential						
20 years	1	72	289	6,730	11,000	5,160
100 years	1	25	298	4,750	10,900	1,810
500 years	1	8	153	1,620	5,200	549

Why focus on the small stuff?

- These non-CO_2 gases are only 20% of the total
- But these gases are "low hanging fruit" for reducing total emissions
- Everybody produces CO_2
- Certain sectors produce **a lot** of non-CO_2 gas, and everybody else produces very little

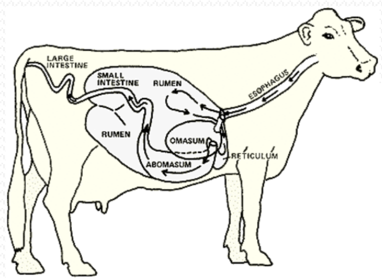
Overview of U.S. Greenhouse Gas Emissions in 2022



Methane Sources

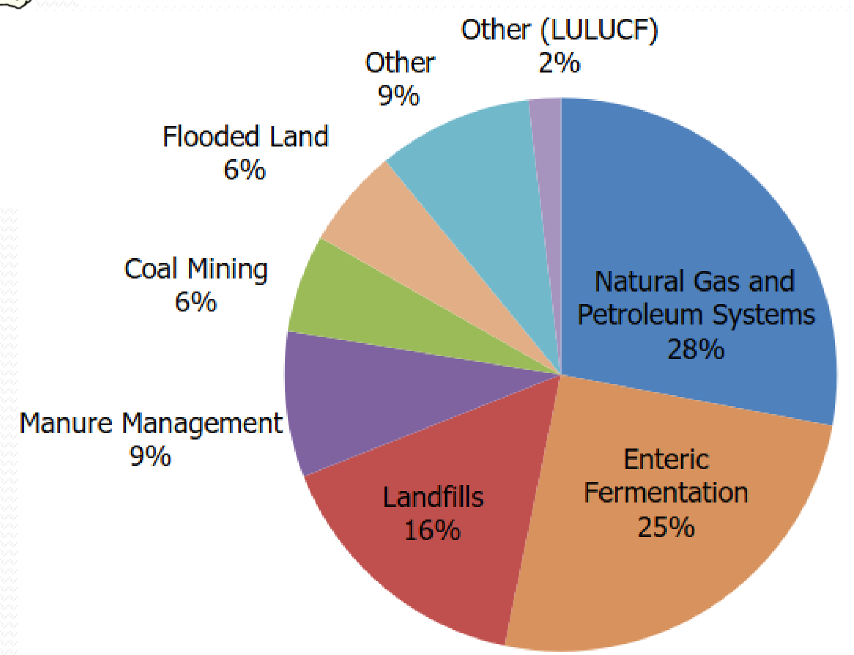
#1 Agriculture

Cow guts (enteric fermentation)



Steaming piles of manure

U.S. Emissions of Methane by source in 2022

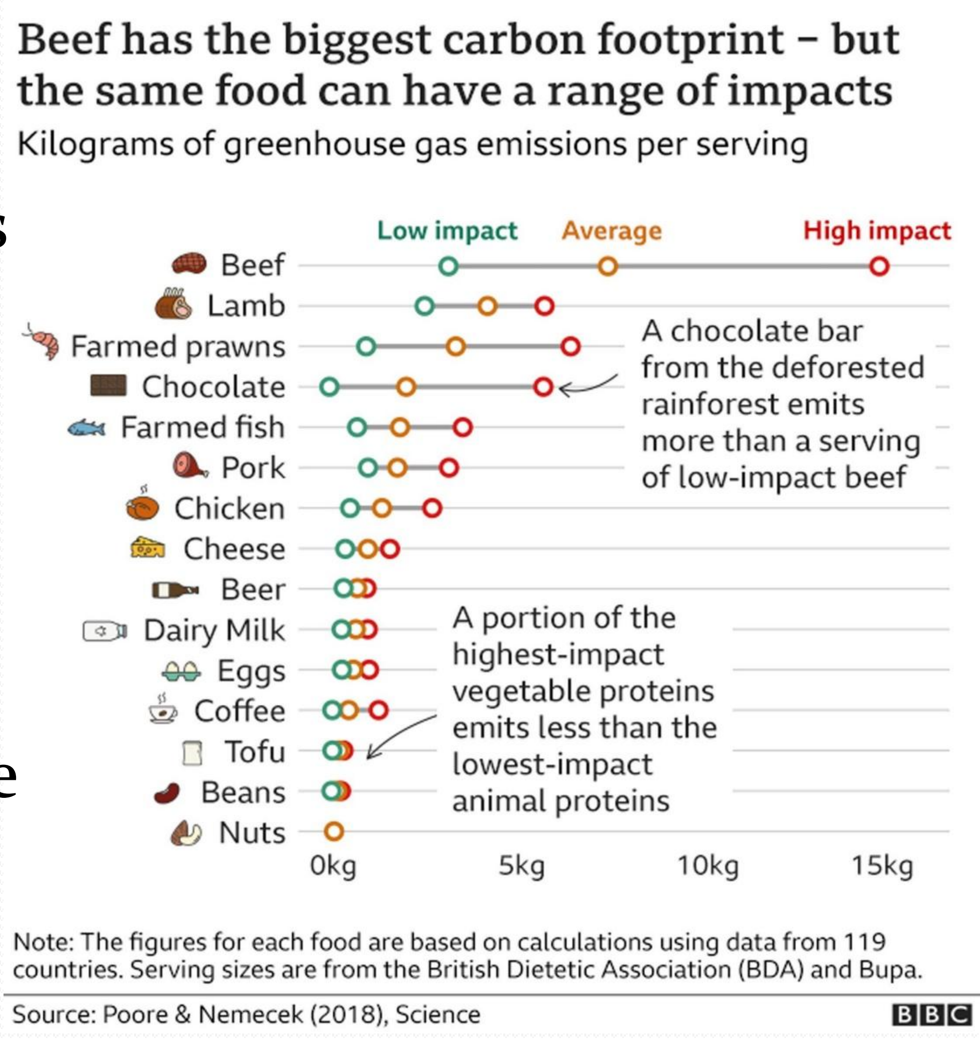


Microbes make methane in these oxygen-free environments

Food and GHG Emissions

- Methane release from enteric fermentation is part of why total emissions for beef and lamb (both ruminants) are so high compared to pork or chicken (non-ruminants)

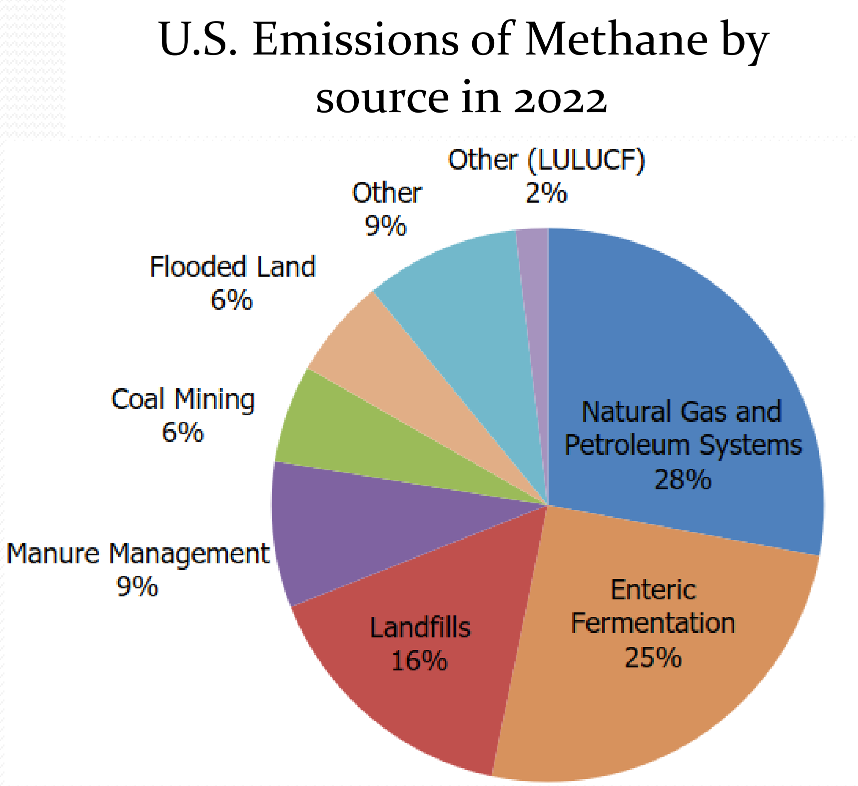
- Larger animals also require more food and land, both of which emit GHGs



Methane Sources

#2 Fossil fuel production

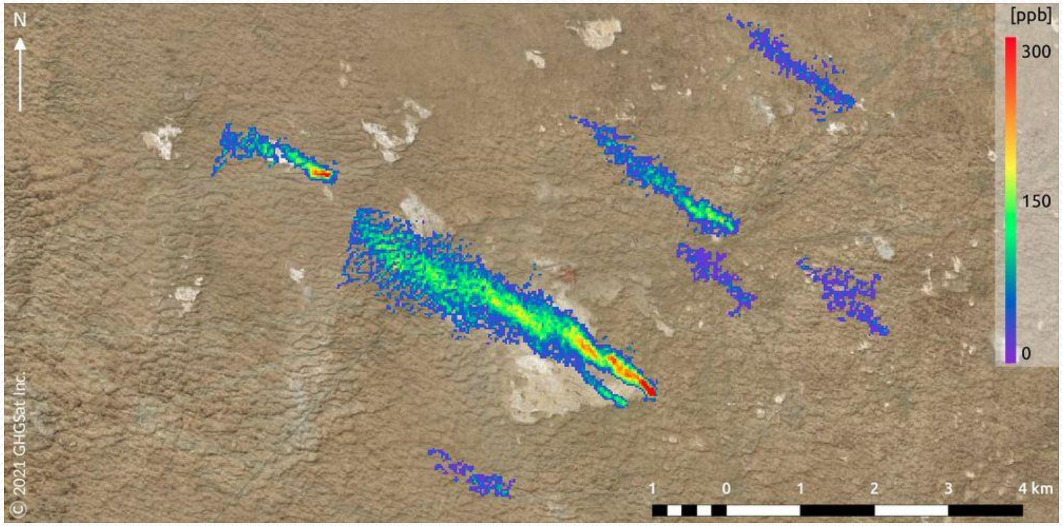
- Oil and coal both contain methane
- Natural gas has methane
- Same environments which [preserve fossil fuels]() (anaerobic) also produce methane which gets trapped too



Mine, crush, or abandon coal and you will release methane

Methane Sources - Leaks

- Natural gas infrastructure is **leaky**
  - Wells, pipelines, use-points all leak methane



Methane plumes sensed from space, from natural gas wells.

Big, super emitting events do contribute some

But persistent, slow leaks from wells and pipelines are the major drivers

Why does methane leak?

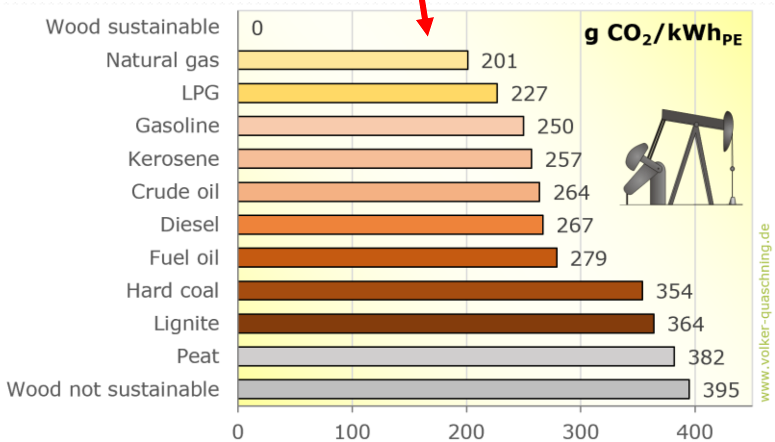
- **Cost of doing business**
  - Many wells are too productive to abandon, not productive enough to justify cost to fix leaks

- **Abandoned wells**
  - Cap wells and take them off your books, even if they're still leaking

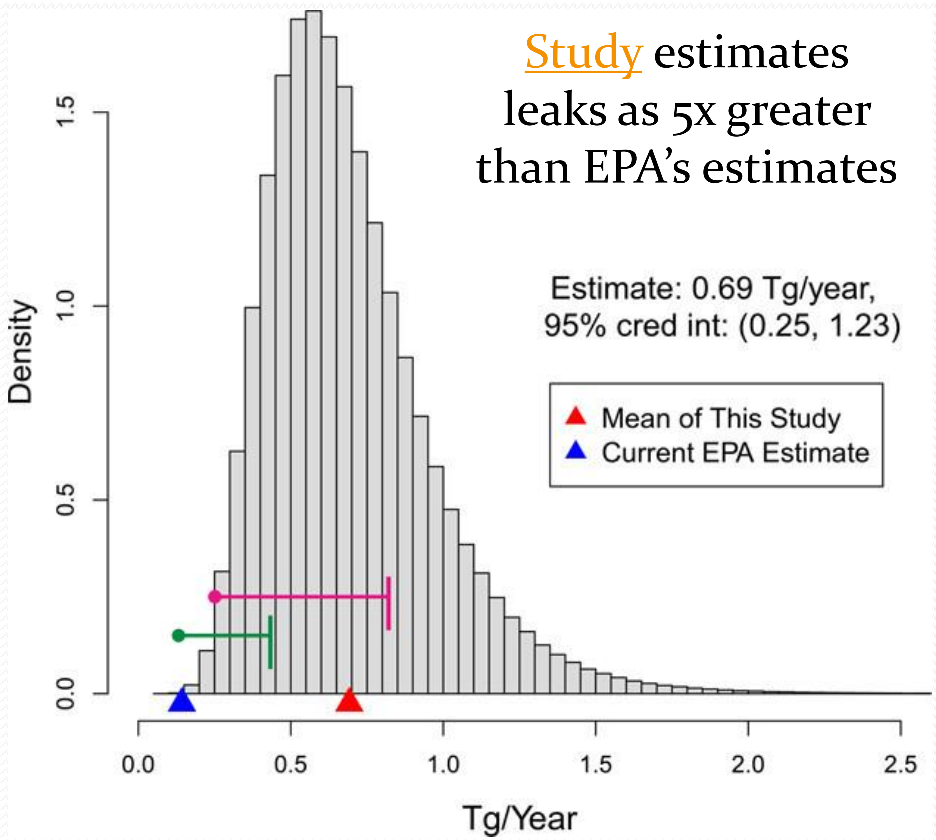
- **Externalized liabilities**
  - Very leaky wells of Shell, BP sold to mom and pop producers (hard to target politically)

Natural Gas Benefit Caveat

This doesn't take into account methane leaks!!!



Study estimates leaks as 5x greater than EPA's estimates



Methane leaks erase 30-100% of the benefit of burning natural gas over coal!

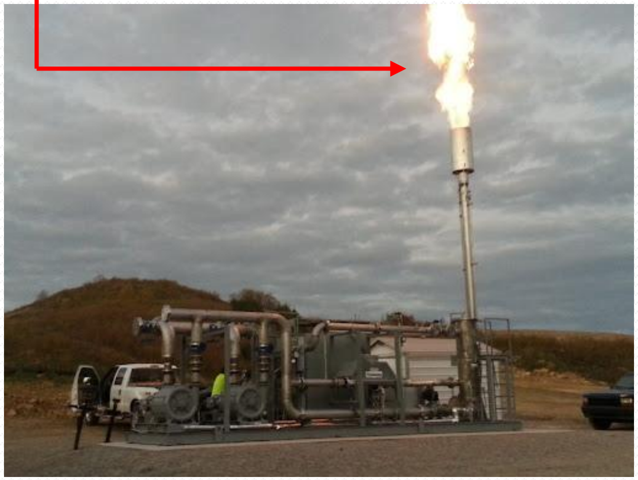
Methane Sources

#3 Piles of rotting trash

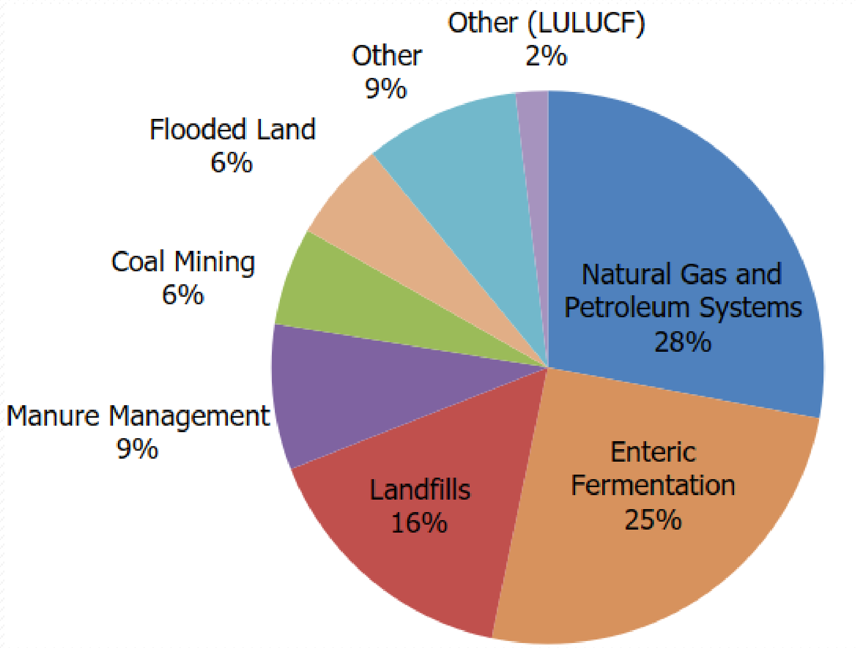
- Same microbes as in piles of rotting manure

Flaring (i.e. completely combusting) excess methane

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

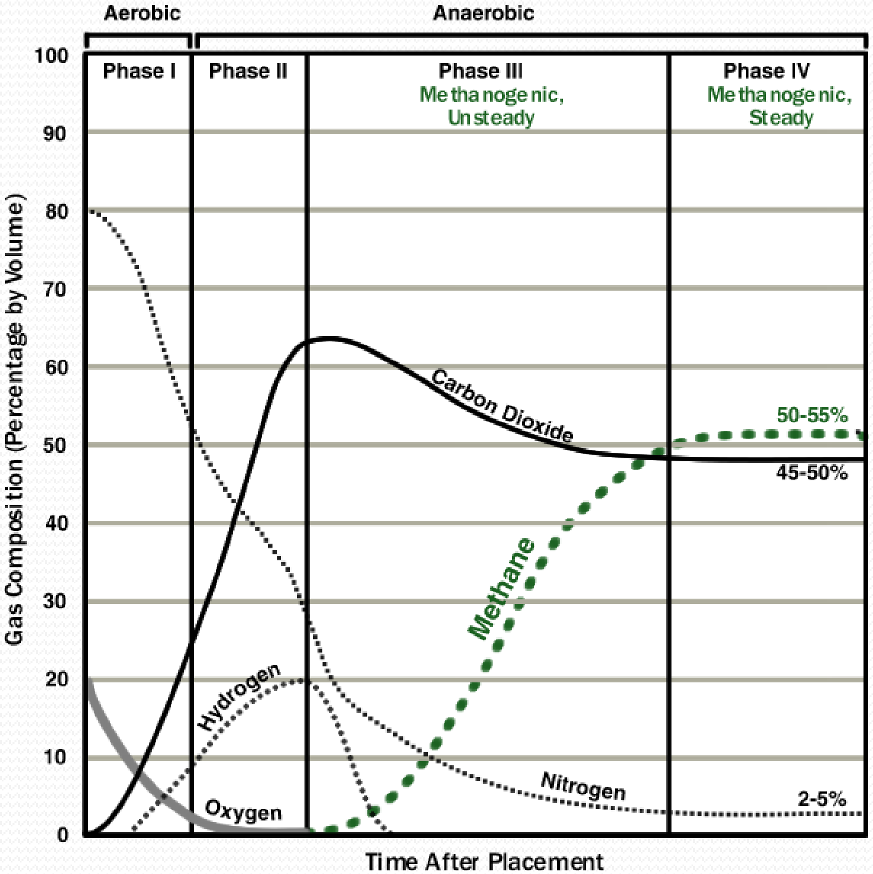


U.S. Emissions of Methane by source in 2022



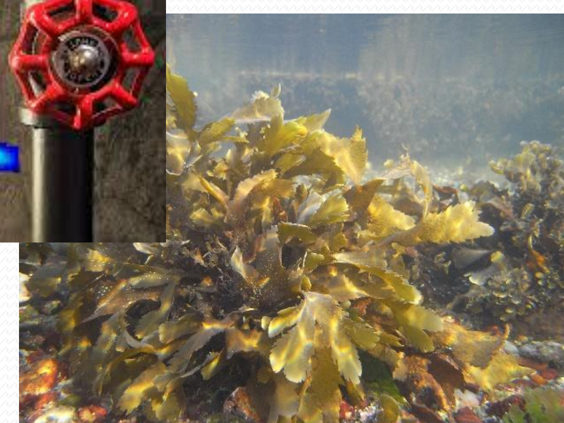
Landfill Gas (LFG)

- Can capture and burn to produce heat → electricity
  - Better than just flaring it off since we get some use of it



How to “fix” methane.

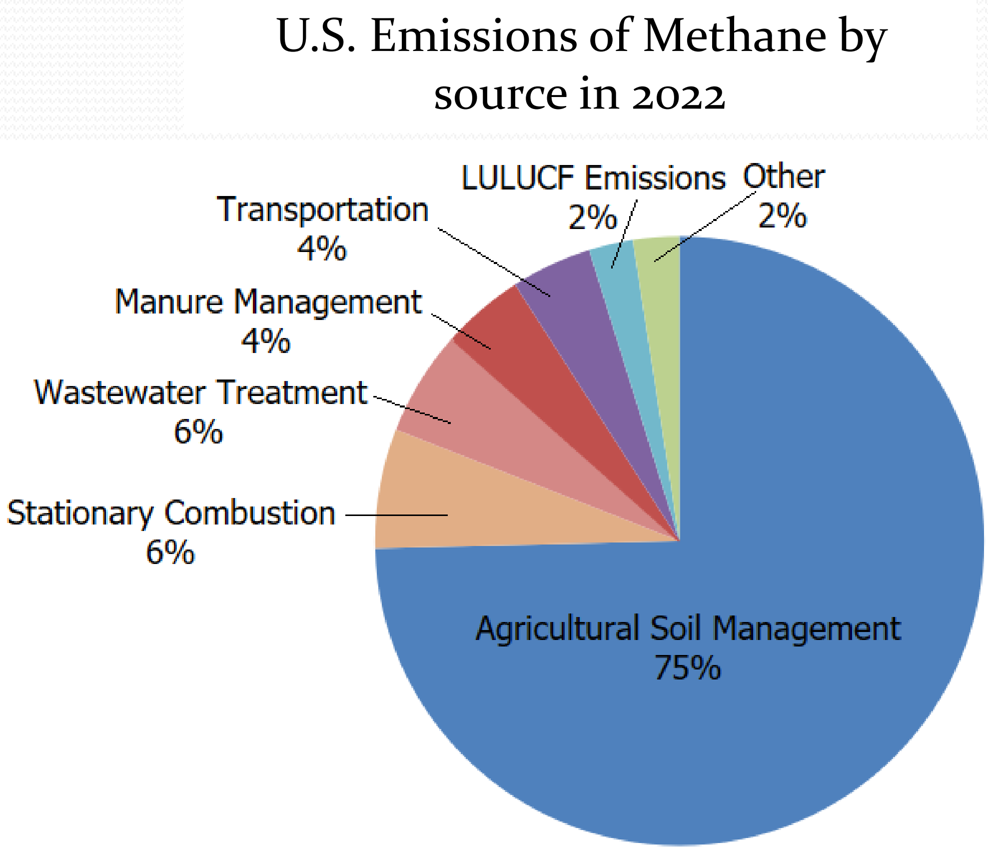
- More renewables
- Regulate leaks TIGHTLY
- Eat less beef, switch to non-ruminants if not vegetarian
- “Fix” cows?
- Capture, don’t flare methane from landfills, oil wells, etc.

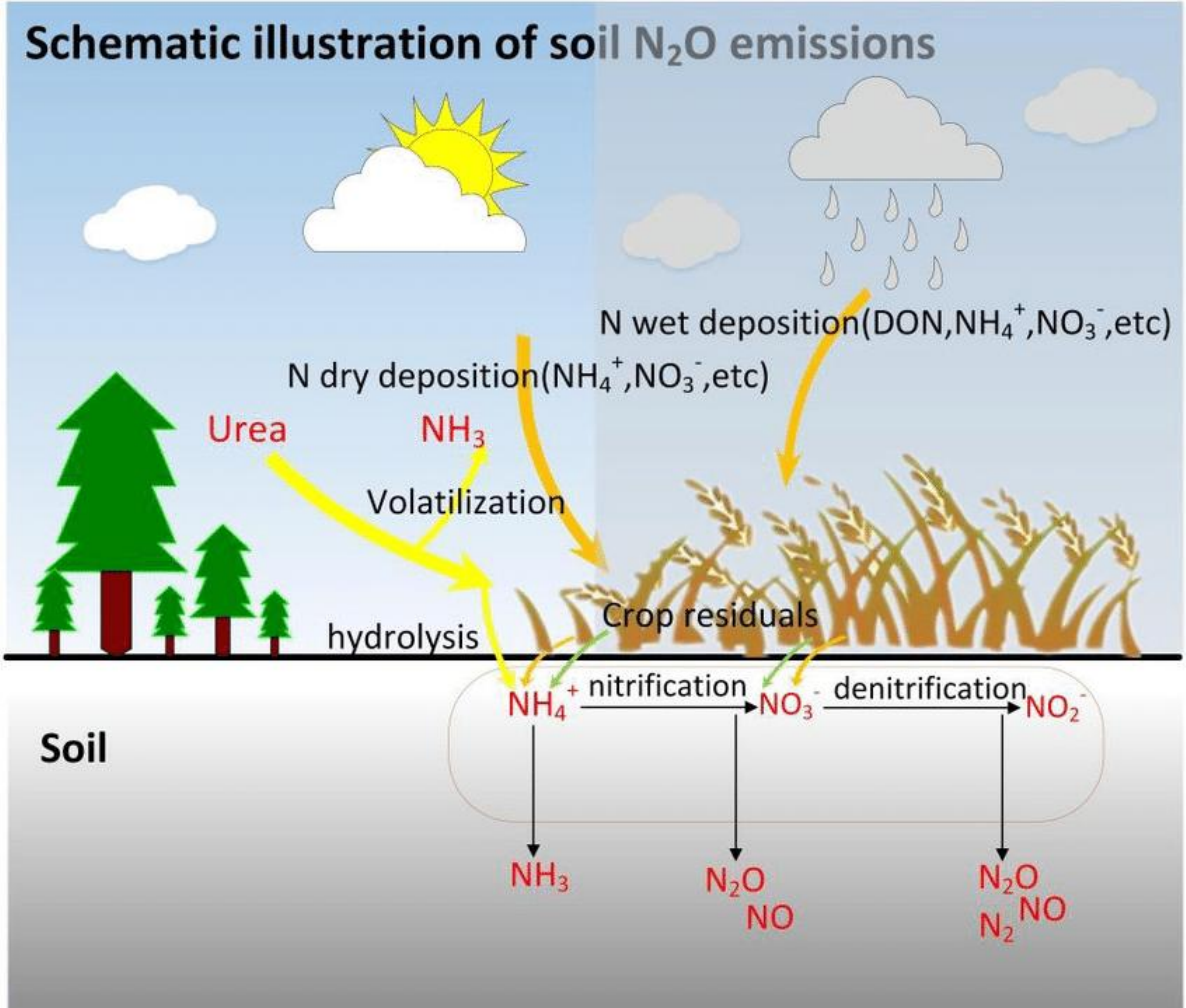


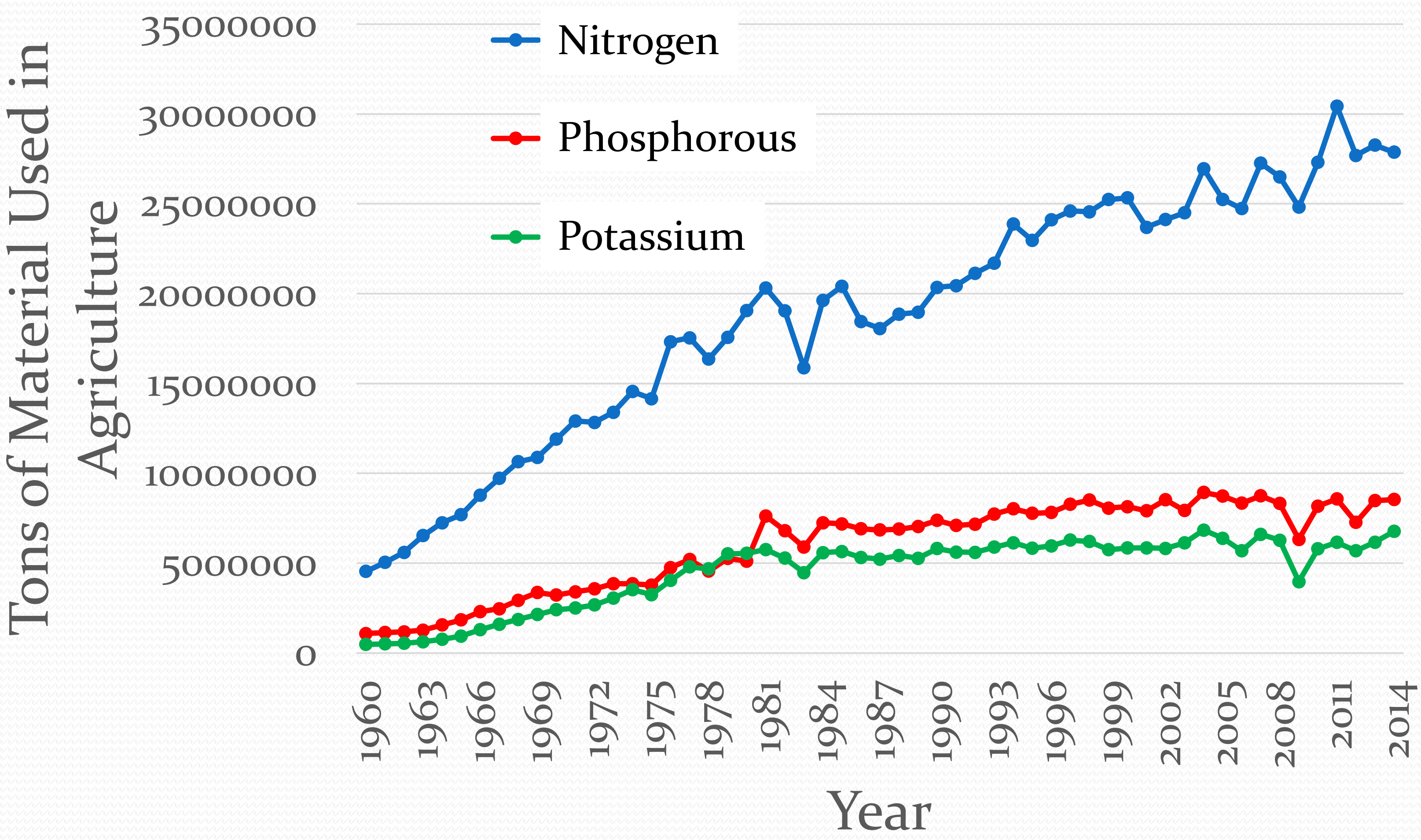
Nitrous Oxide Sources

#1 Forever and always… nitrogen fertilizers on fields

- Lots of N fertilizer & saturated, no-oxygen conditions = nitrous oxide
- Produced mostly by bacterial action in the soils




Schematic illustration of soil N_2O emissions
N wet deposition(DON,NH_4^+,NO_3^-,etc)
N dry deposition(NH_4^+,NO_3^-,etc)
Urea
NH_3
Volatilization
Crop residuals
hydrolysis
Soil
NH_4^+
nitrification
NO_3^-
denitrification
NO_2^-
NH_3
N_2O
NO
N_2O
N_2
NO



Tons of Material Used in Agriculture
35000000
30000000
25000000
20000000
15000000
10000000
5000000
0
Nitrogen
Phosphorous
Potassium
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005
2008
2011
2014
Year

Following nitrogen across the landscape…

Fertilizer runs off of agricultural fields…

… then goes into wetlands, where saturated, oxygen-free conditions produce nitrous oxide

How to "Fix" Nitrous Oxide

- Many of the same solutions as reducing soil erosion
  - Fallow fields rebuild organic matter
  - Injecting fertilizer while planting in conservation tillage approaches
  - Cover crops of legumes (peas, soybeans, peanuts) have symbiotic nitrogen-fixing bacteria that fertilize soil
- Recycling of compost as an organic fertilizer

Whenever any citizen of the United States discovers a deposit of guano on any island, rock, or key, not within the lawful jurisdiction of any other Government, and not occupied by the citizens of any other Government, and takes peaceable possession thereof, and occupies the same, such island, rock, or key may, at the discretion of the President, be considered as appertaining to the United States.
— *Section 1 of the Guano Islands Act (1856)* **[10 islands claimed in total]**

The central role of wetlands in methane, nitrous oxide and carbon dioxide

- Wetlands are where you find saturated, oxygen-free conditions
- Wetlands are huge nitrous oxide producers
- They also produce a lot of methane (30% of total methane)
- But they also store a lot of organic C, preventing release as CO_2

- On balance wetlands store carbon, but need to control N inputs

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