Methane Removal Webinar – NASEM 10/12/23 notes by SC CAN members

Sections 1,2 by Jennie Dushek
Sections 3,4 by Pauline Seales
Section 5 by Susan Cavalieri

Introduction
NASEM two-day meeting on atmospheric methane removal

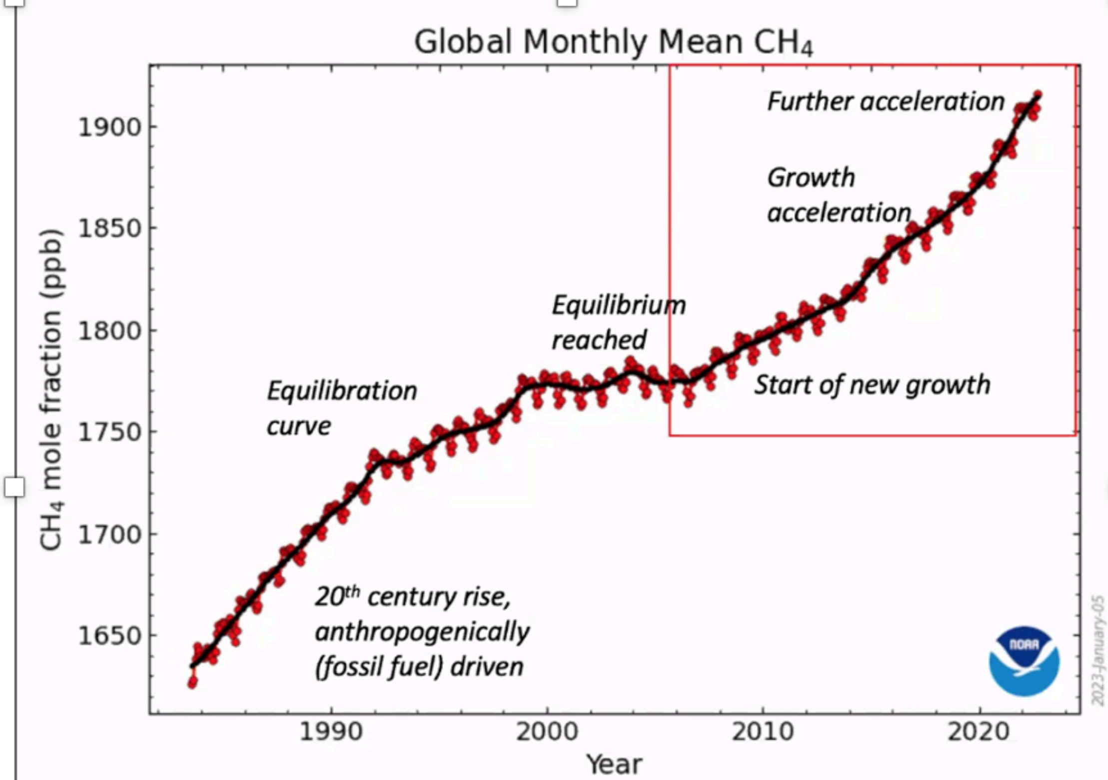
The National Academy of Science, Engineering and Medicine is an organization of thousands of scientific experts who work together to provide (hopefully objective) information and advice on "some of society's toughest challenges." These experts work for free, supported by their individual institutions.

The purpose of this meeting was to assemble experts who could exchange the knowledge necessary to write a report on the current prospects for removing methane from the atmosphere. Methane heats the atmosphere 80 times as fast as Carbon Dioxide. It's responsible for about a third of current warming.

In particular:
The National Academies will examine the need for atmospheric methane removal, assess the potential co-benefits of viable technological options, and recommend research that could improve understanding. The following topics will be addressed:
• Why might atmospheric methane removal be needed? What specific situations/scenarios might require deployment of methane removal?
• What are viable options for atmospheric methane removal? To the extent possible, assess how much methane could be removed from the atmosphere for each option, as well as the cost of deployment, technological efficiency, scale potential, potential risks, and key uncertainties and challenges.
• What potential tradeoffs, co-benefits, and unintended consequences should be considered in developing atmospheric methane removal approaches? What are potential social barriers associated with atmospheric methane removal?
• What new research is needed to improve understanding of atmospheric methane removal?

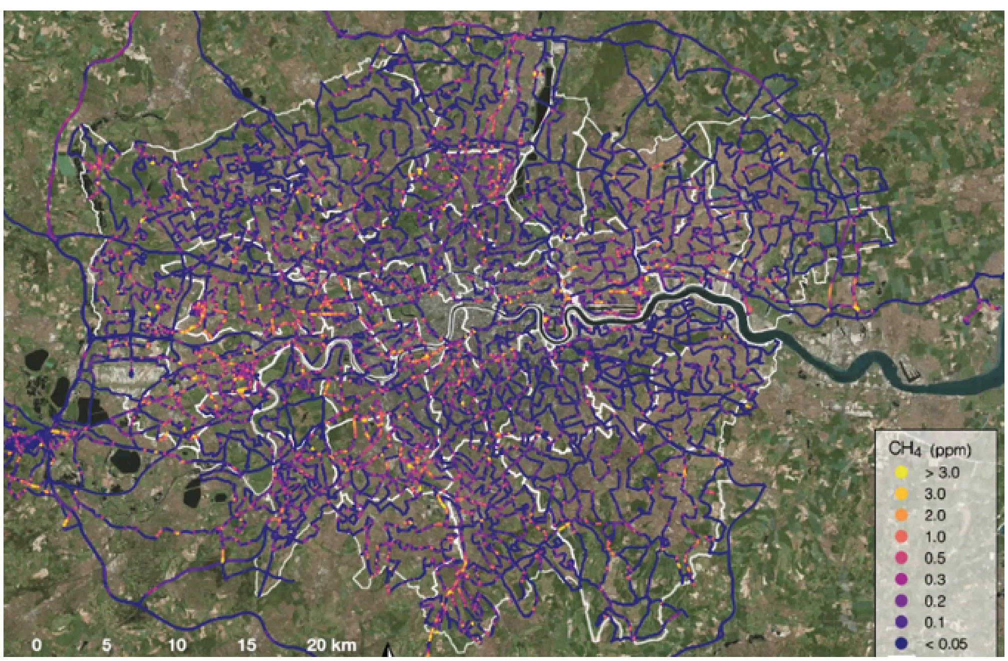
Session 1 Context

Euan Nisbet
Why we might want to remove methane.
Methane emissions are accelerating. Fossil fuel methane emissions are down somewhat, agriculture is increasing slowly but it's probably wetlands methane emissions that are contributing the most to accelerating methane emissions.
That said, drying out all the wetlands is a bad idea. Wetlands provide habitat and protect coast lines. Destroying them would release massive emissions all at once. We need to focus on agriculture and fossil fuel emissions.



Nisbet et al. (2023) Atmospheric methane: Comparison between methane's record in 2006–2022 and during glacial terminations. *Global Biogeochemical Cycles* 37: e2023GB007875

Leaks from natural gas lines in a city



Claire Henly, US State Depart
The Global Methane Pledge is a voluntary agreement by 150 countries, accounting for 70% of global GDP and 50% of global methane emissions, to reduce anthropogenic methane emissions by 30% by 2030. It includes the United States, but not big emitters China, India, and Russia.

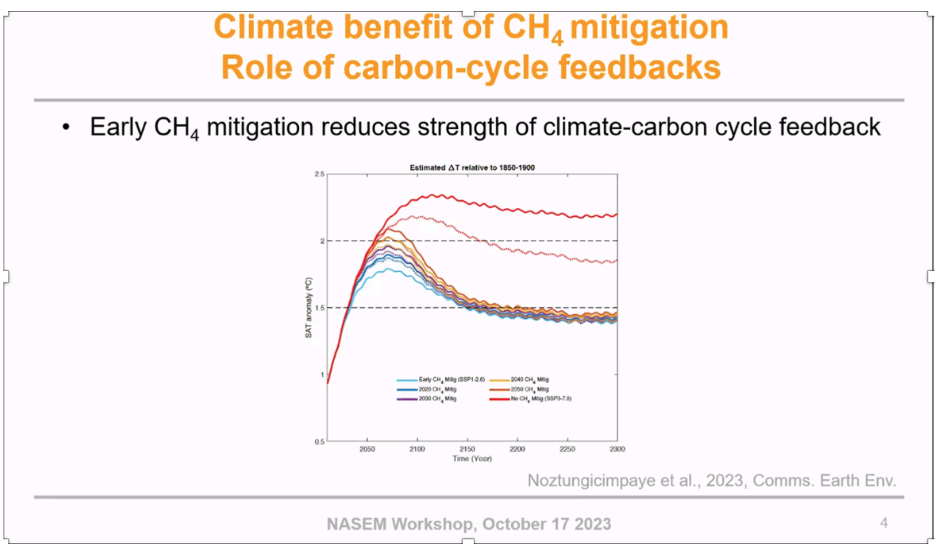
We have good increased awareness around the methane problem.
We still aren't very good at counting methane emissions accurately.
We need to improve inventory, methane reporting.

Methane reductions are a global target, not an individual emissions target.
Some countries' emissions come from agricultural, others from oil and gas.
Main limitation is it only covers 50% of current global emissions.

All of China's non-CO2 emissions are equal to the entire US economy and are not part of their target within the Paris agreement. We have a long way to go before we can include all methane emissions under the Paris agreement.

There is growing interest within the US government in reducing methane.
As one of the leaders of the global methane pledge, we are in a good position to lead.
But we have a long way to go with international engagement.

The sooner we start reducing methane emissions the better.



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Additional information:
- https://www.nationalacademies.org/event/40025_10-2023_atmospheric-methane-removal-needs-challenges-and-opportunities#sectionEventMaterials
- https://www.nationalacademies.org/our-work/atmospheric-methane-removal-development-of-a-research-agenda

• The recording of the plenary sessions will be made available on the event webpage after the workshop: https://www.nationalacademies.org/event/40025_10-2023_atmospheric-methane-removal-needs-challenges-and-opportunities
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Discussion period:
Methanotrophic bacteria break down methane into carbon dioxide and water.
$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
Even after methane breaks down, especially in the first 20-30 years, it continues warming the planet for a long time. The tail of the methane warming is caused mainly by two things: extra CO2 and remaining extra heat in the atmosphere and oceans.

Claire: Political decisions will determine how quickly methane emissions are reduced.
For example, when Argentina joined the Global Methane Pledge, their livestock lobby took out a full-page ad objecting to it. Some governments have decided not to join the pledge specifically because of their agricultural emissions.

Euan: There are easy things to do with manure and emissions in cow barns before you start talking about massive changes in diet.

Important to understand that as a wetland gets warmer, ot produces more methane and when it gets wetter, it also produces more methane. It's likely wetlands emissions will increase fairly dramatically.

Some places are using more nitrogen fertilizers that drain into wetlands, increasing the productivity of plants and microorganisms growing there. And with more productivity, you get more methane emissions.

[JD: Sea level rise will tend to counteract delta wetland emissions. Under sea level rise, a large proportion of wetlands will drown within a couple of hundred years and it will take a long time for wetlands to reform as they retreat up rivers.]

Session 2: Potential Atmospheric Methane Removal Technologies and Applications

Desiree Plata:
The discussion mainly focused on materials like palladium that catalyze, or speed up, chemical reactions to break down methane into water and carbon dioxide. Most of research on palladium has been in the automotive industry (catalytic converters)

There are lots of natural materials that cause methane oxidation.
Such technologist can be really useful in coal mines or dairy barns, where concentrations of methane are very high. Pulling methane out of the air outside is probably not worth while.

But methane removal infrastructure is big and expensive.

Matteo Cargnello, Stanford:

Palladium (used in catalytic converters) works really well to catalyze methane oxidation, but it's rare and expensive. For example, 1 microgram of palladium works about as well as 8 mg of copper. There are lots of options, including cobalt.

Shu Hu, Yale
Key R&D Questions
• How does photochemistry proceed in a gas phase?
• We need to understand the contribution of light, charge, and heat
• We need to discover new mechanisms for breaking down methane
• We should try heating just the place where the reaction is occurring and feeding the methane past that spot.

Most catalysis requires high temperatures, which are energy intensive processes. We don't want to use more energy than we have to. For now, the bulk of energy use goes to giant fans that pull the air into a methane removal unit.
But blue light shining on the surface of a catalyst speeds the reaction, breaking down methane into CO_2 (which has about 1/80th the warming potential of CH_4).
Photo reaction oxidizes methane
We have to think about how much methane capture and breakdown would make a difference.
He says an individual methane capture unit should capture about 100 kg methane capture per day, and we would need about 100,000 of these units.

We don't know how long such devices would last, what harmful byproducts they might produce or what effect those byproducts might have on climate or anything else. We need to think about when and where to deploy them. Maybe coal mines.

Matthew Johnson
Chemically, methane is very different from CO_2.
It acts like a noble gas, meaning it doesn't react easily and doesn't stick very well to catalysts.
Johnson proposes gas phase radicals, colliding at high speed, so 7 billion molecules/sec.

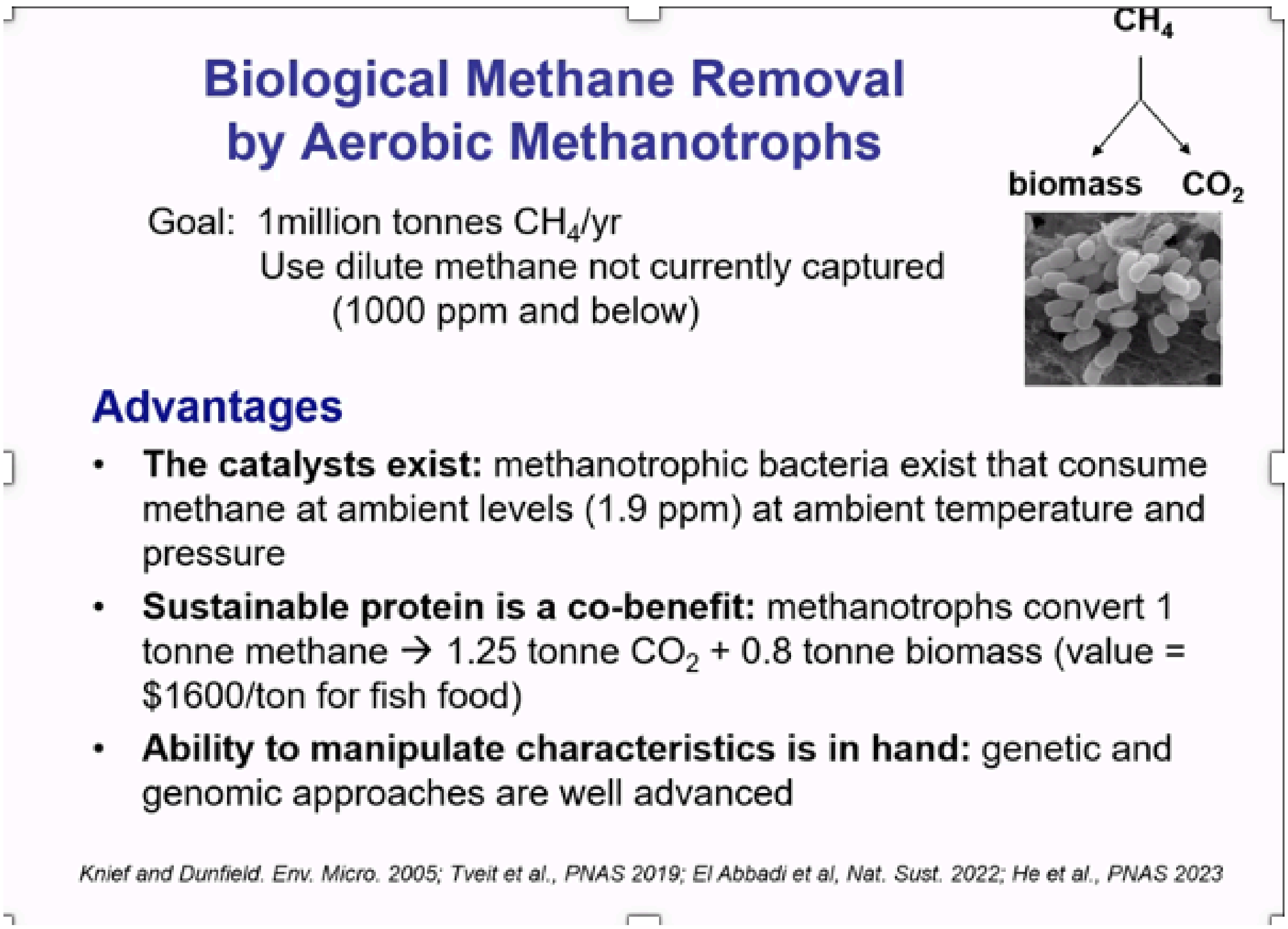
Once you make the radical, the radical "sees" the things it will react with. It won't react with nitrogen or oxygen. A chlorine radical sees methane and ozone. (July PNAS)
A naturally occurring process in the atmosphere over the Atlantic is making chlorine radicals that break down methane. The chlorine radicals are produced in a process triggered by iron dust from the Sahara Desert?? Not sure. Iron is also emitted by ship burning fossil fuels.

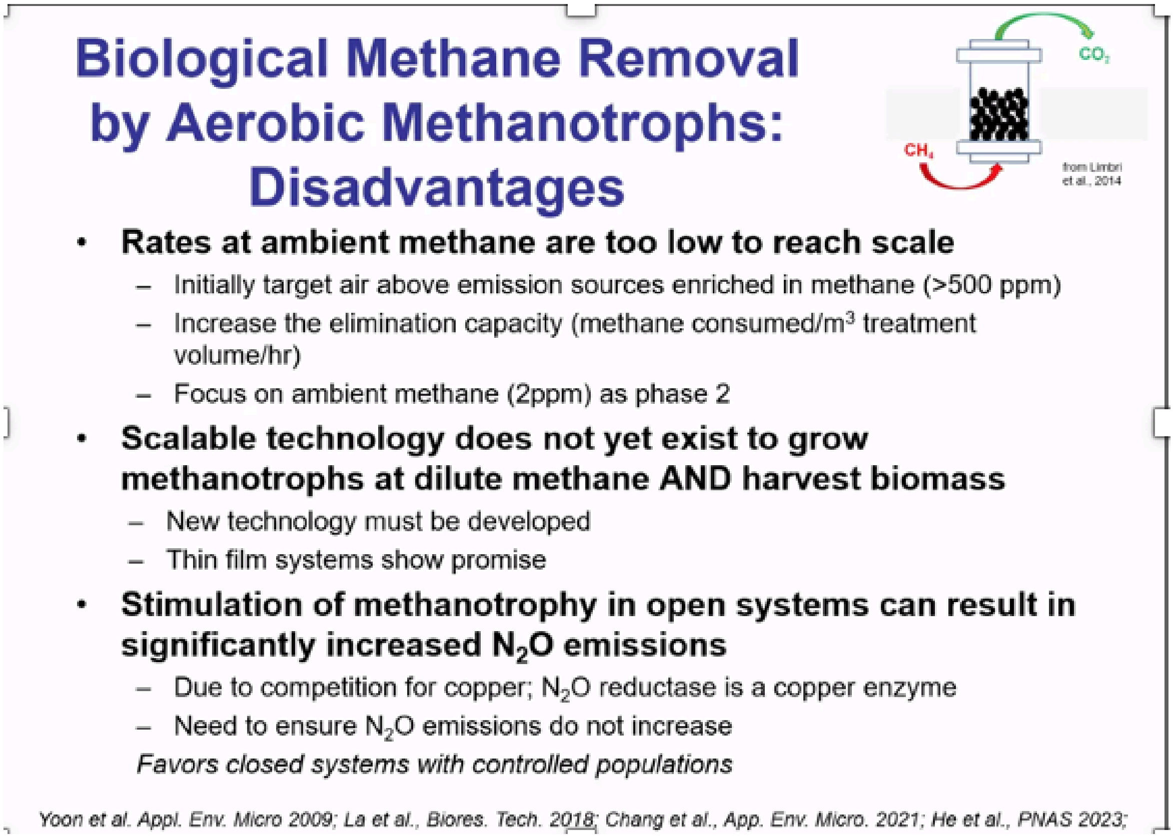
Depending on where the iron is emitted into the atmosphere, it can be helpful or not helpful. In some places it destroys methane (green on map); in others it destroys ozone (red on map).

Subir Roychoudhury
A week ago, I was in a mine measuring methane emissions.
Subir worked on controlling gases in enclosed environments like the Space Station.
Has data from prototypes. Catalytic oxidizer and "recuperator"

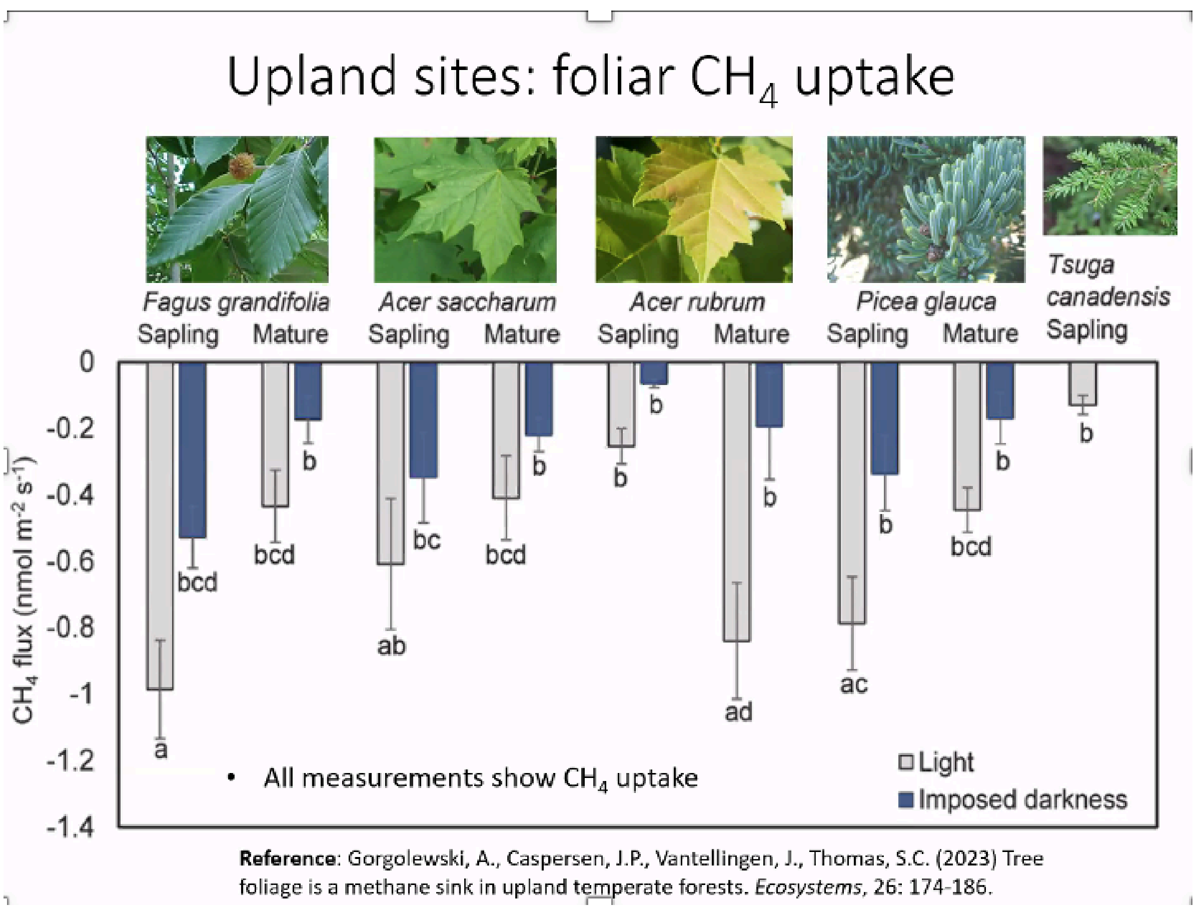
Mary Lidstrom, Univ of Washington
Bacteria can both generate methane and break it down.

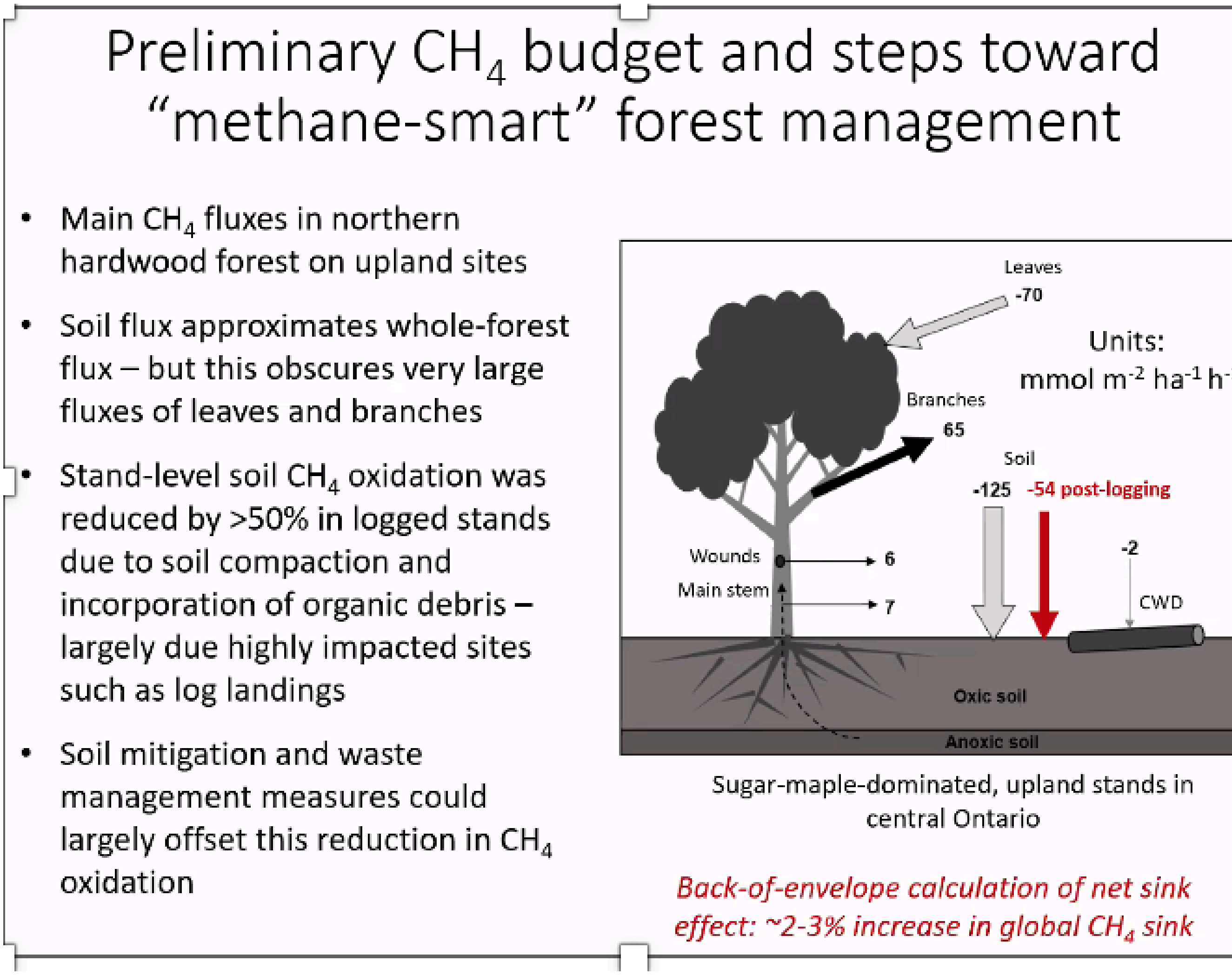
Biological Methane removal, can work in very dilute concentrations of methane but for now the technology favors working in enclosed spaces. Unknown environmental impacts also favor the closed system approach. Each biological methane removal unit can remove about 10 tons per year per. 100,000 tons. They think they can increase capacity 10-fold, so a million. A real stretch would be 50-fold increase 5-10 years out. A co-benefit is generating biomass that can be used to feed fish.





Trees also take up methane. Measurements are mostly of uptake by the trunks of trees because it's easier to measure than all the leaves. But leaves do absorb methane. But trees can also release methane.





Session 2 Miscellany and discussion
One important drawback is that methane is hydrophobic; it is repelled by water.
But the breakdown of methane generates water, so if water settles on the catalyst, the reaction slows.
However, under high temperatures of 350C, the water evaporates away, so it's not a problem. As you go down to cooler temperatures, water becomes a problem. But some catalysts work even in the presence of water.

Q: What is the possibility of something that absorbs methane?
Absorbance of methane not possible, but you can absorb everything else in air except methane, in order to concentrate the methane. It's pretty challenging to find a material that would concentrate methane.

Methanotrophs work at 1% methane concentration. The challenge is getting it to lower ppm.

A number of technologies are ready to work at high concentrations of methane, like 500 ppm in coal mines. But such high concentrations are a safety issue in mines because the gas could explode. This is especially true at the high temperatures that most methane remove system need to operate. (I.e., the gas would explode and kill people.)

"MEPS" system uses shipping containers.
Works at room temperature so fewer safety issues.

Desiree: The regulatory environment is the problem
Absence of a compliance market is a barrier.
We need to get creative with resources and incentives.

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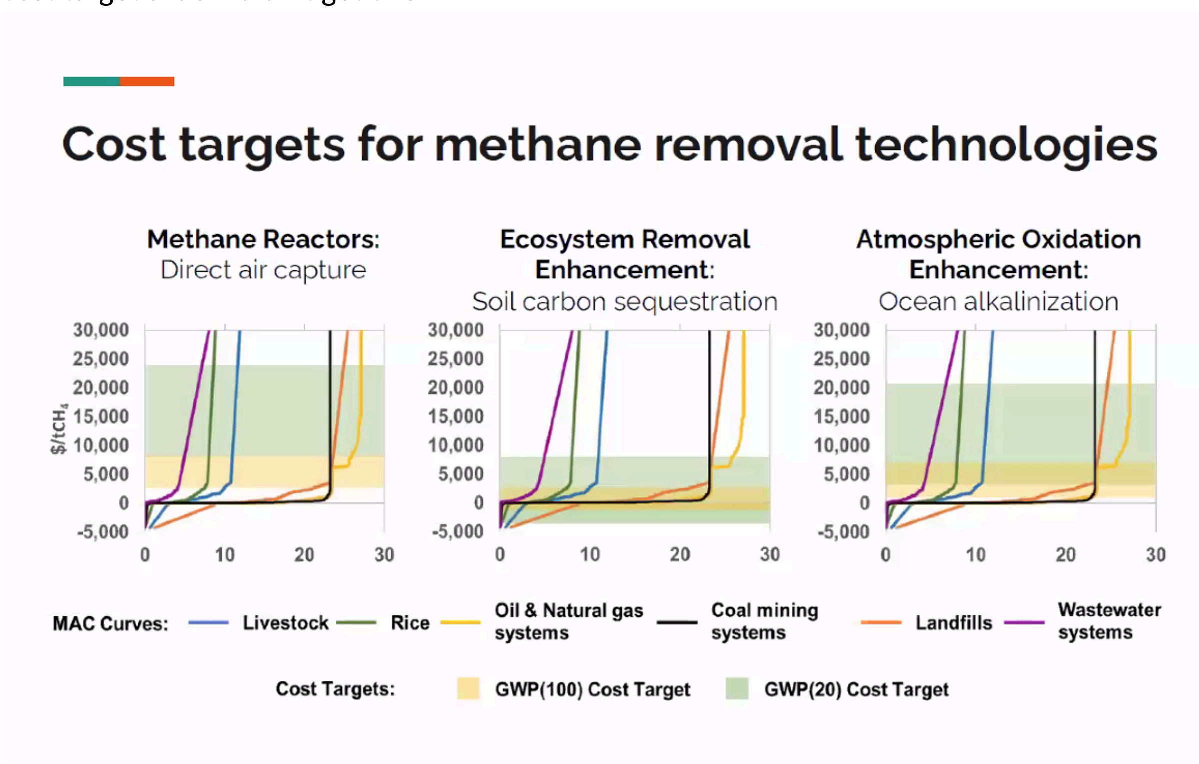
- <u>**Session 3 – Looking at cost/feasibility factors**</u>

  Lots of unknowns at present
  Cost target slide – didn't get this



Social and environmental impacts

- Social and environmental impacts are **highly uncertain** and include:
  - **Supply chain and life cycle impacts:** emissions from energy use, spent catalysts, manufacture and deployment of bio-cultures, etc.
  - **Environmental impacts of byproducts:** impact of semi-oxidized methane products on human health and the environment, etc.
  - **Climate change impacts:** formation of ground-level ozone and uncertain climate impacts of iron aerosols. etc.
  - **Socio-economic impacts:** job creation, loss of property values, public health costs if health risks materialize, etc.

Conclusions and policy recommendations

1. Extend research and development funding for methane removal.
2. Advance research and development in atmospheric and ocean modeling.
3. Support the development of monitoring, reporting, and verification systems
4. Fund demonstration project or first-of-a-kind pilot plants
5. Incentivize investments by creating markets for methane removal
6. Develop standards that would integrate technologies with existing systems
7. Facilitate public/private partnerships to guarantee demand
8. Reduce regulatory barriers while creating clear environmental standards
9. Foster meaningful community engagement and transparency
10. Support a "fair share" approach by placing responsibility for methane removal on major emitters (including the United States)

5min speeches

Julie Zimmerman – Yale

Science often addresses a problem BUT fails to address negative side effects

Green Chemistry addresses this

Green Chemistry & Green Engineering

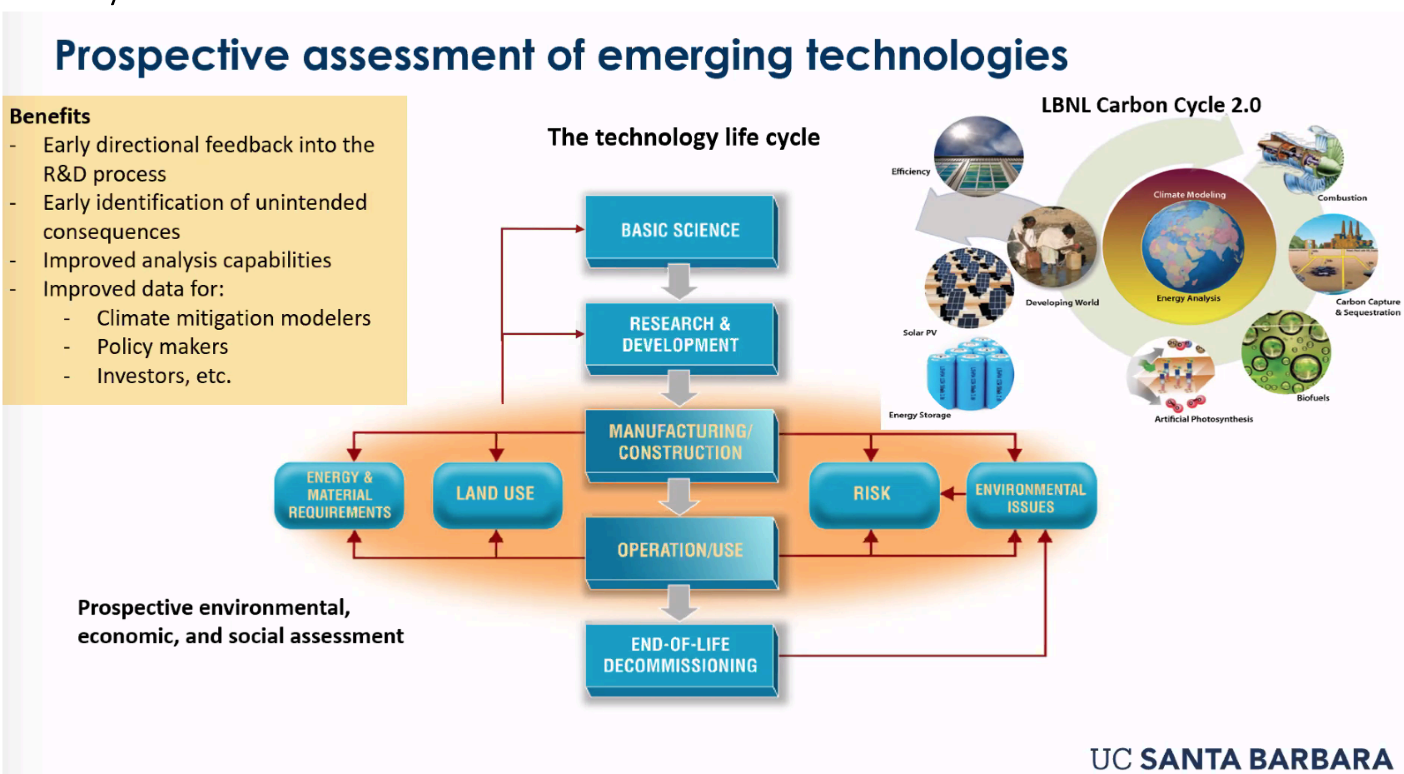
the **<u>design</u>*** of products or processes to reduce or eliminate the use and generation of hazardous** substances.

*Across the life cycle from acquisition to end of intended, useful life

**Hazardous includes global, physical and toxicological hazards

;tas and Warner, 1999; Anastas and Zimmerman, 2003

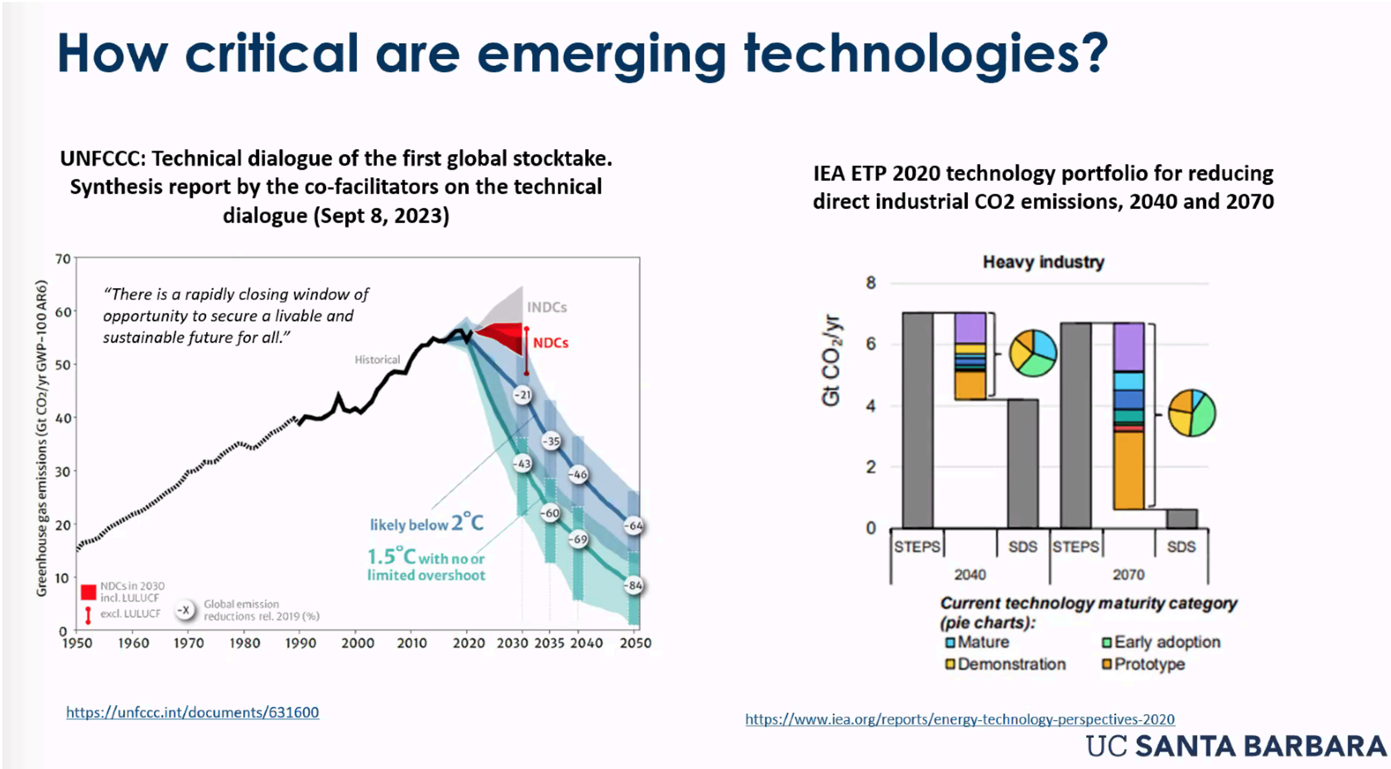
The design of products or processes
Requires changing the inherent nature of materials and resources
Renewable but not depleting, healthful and not toxic, restorative not degrading
Efficiency is not itself valuable – effectiveness is more real



Look more at natural biological processes

<u>Eric Masanet – UCSB</u>

Rapid deployment urgently needed

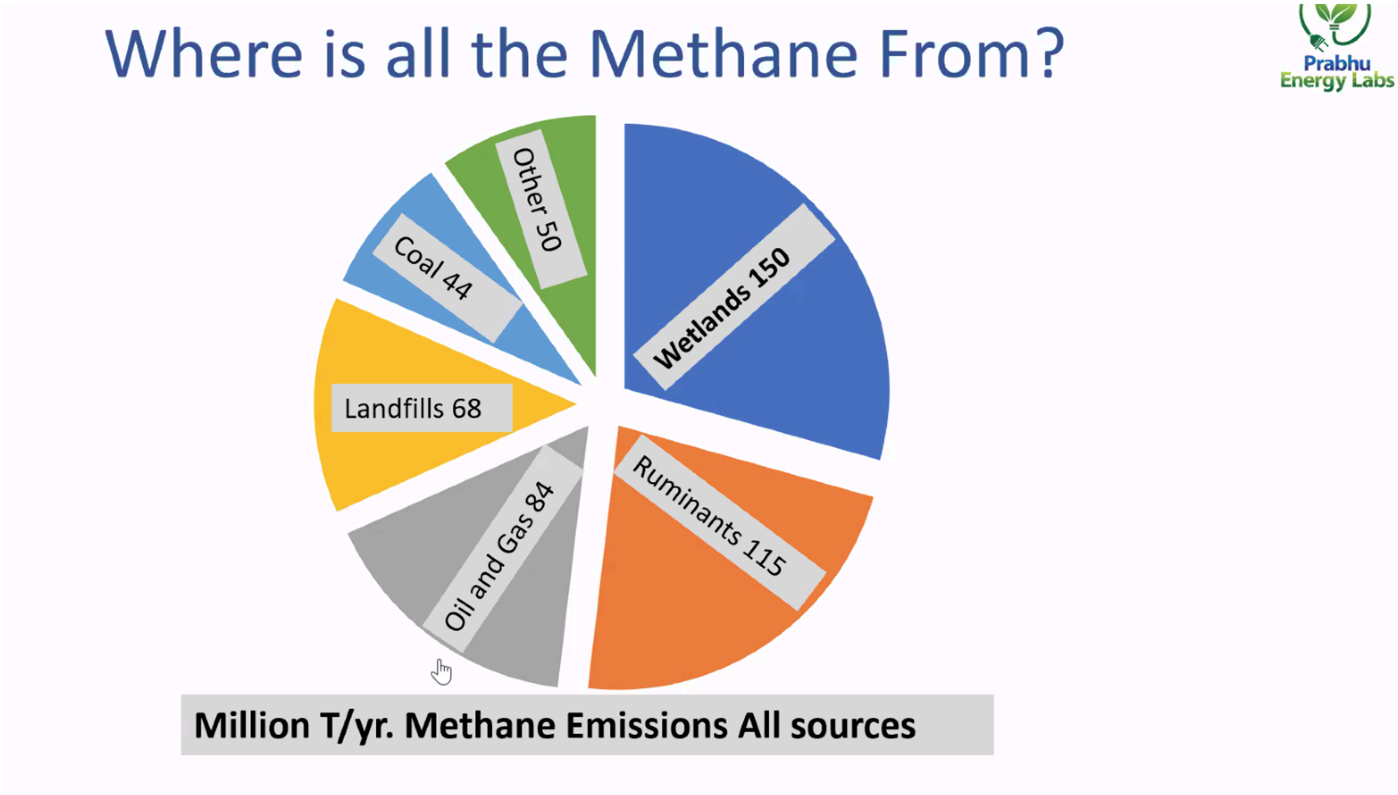


Most technologies not quite ready
Very complex slides

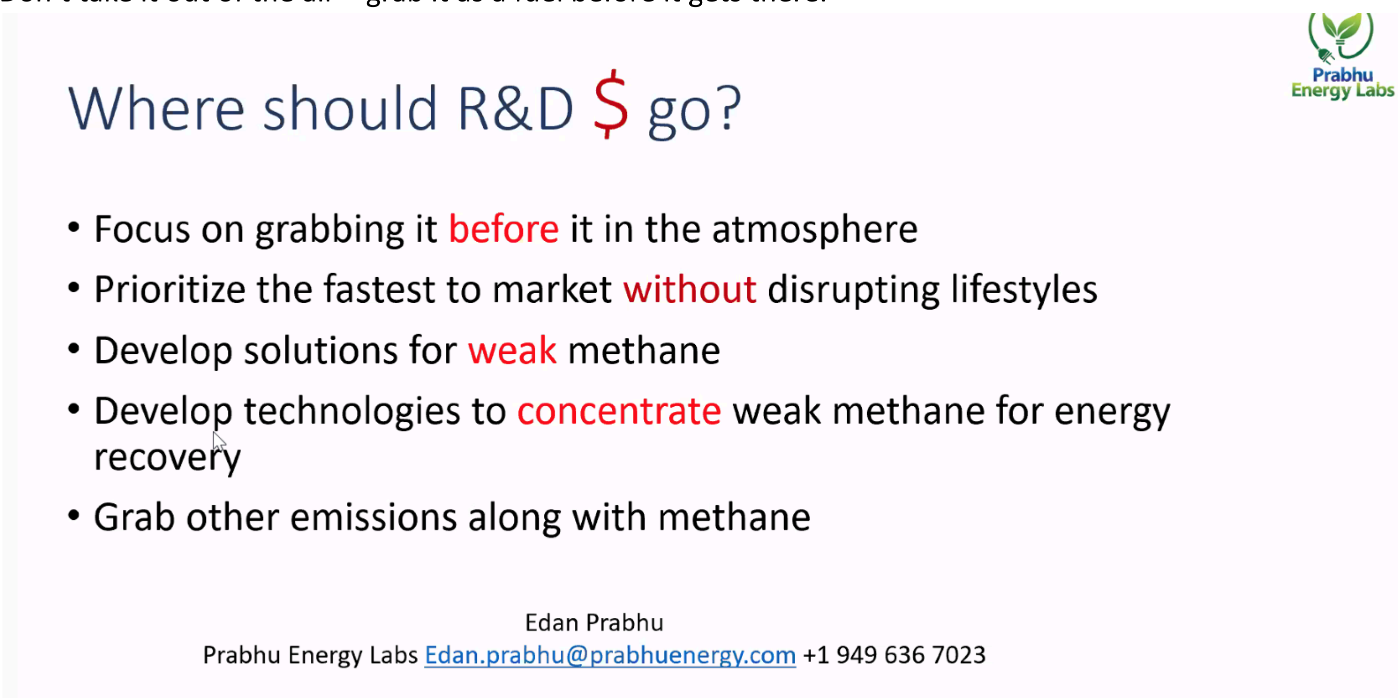
<u>Sarah Baker – Materials Lab LLNL</u>
Started talking about CO2 removal tech
Worked too long on improvement without understanding the risk
After proof of concept address RISKS
Scaling phase is not trivial – simulations and sharing can reduce time needed

<u>Edan Prabhu   Prabhu Energy Labs</u>
Too many academics – not enough applications
GWP =80 Must be used from now on

Half current CH_4 is natural   half man made



CH_4 best fuel on earth – most emissions are from low level sources
Don't take it out of the air – grab it as a fuel before it gets there.

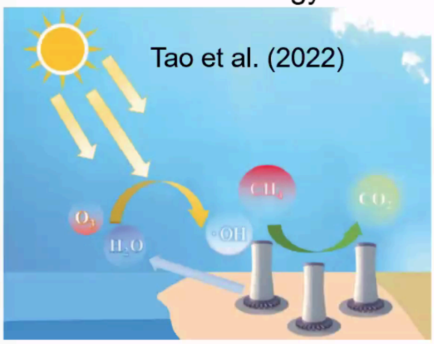


<u>Session 4   Methane Oxidation Methods Hannah Horowitz</u>

OH or Cl – main methane oxidation methods

Potential to increase methane removal via enhancement of tropospheric oxidation by OH and Cl: exact methods are uncertain

- OH: Downdraft energy towers?

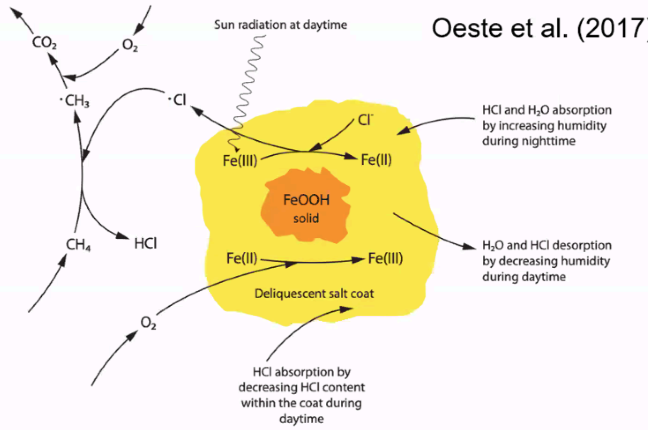


- OH: H_2O_2 towers?

inversion point TECHNOLOGIES LTD.

https://inversionpoint.org/

- Cl: iron salt aerosol?



H2O2 release idea
Limited area experiment with data scaled to global impacts
OH based – direct OH and H2O2
Chlorine based – (Br – natural sea salt includes Br – 3 versions)
Cl decreases OH – not good

Impacts on other climate forcers and ozone-depleting substances may be co-benefits or unintended consequences

Potential ozone-depleting substances

Greenhouse gas

	Troposphere						
	HCFC-123	Total inorganic aerosol	Dibromo-methane (CH_2Br_2)	Bromoform ($CHBr_3$)	Methyl ioidide (CH_3I)	Cl	ozone
H2O2_high	-74.2	11.0	-61.0	-39.3	-6.6	396.4	-38.5
OH_mid	-62.7	10.8	-46.0	-44.6	-12.9	45.2	-10.4
OH_high	-79.8	16.6	-59.5	-58.1	-21.2	72.3	-14.3
Cl2	30.7	6.8	36.9	10.8	-1.1	2185.2	-24.4
Cl2_BrCl_Br2	64.0	20.9	76.2	12.1	-7.9	1839.8	-67.7
Cl_iron*	1.7	7.8	3.7	2.5	-0.08	120	-5.2

Greenhouse gas

Negative radiative forcing

Iron Salt aerosol not reproducing earlier work

Results complex and mixed – includes ozone & pm2.5

Hannah recommends possibly Chlorine based but has some cautions. But probable Br contamination may be a problem?
For OH quantities needed were too high for 50% Methane reduction – Cl quantities about 100x less.

Limitations to current modeling

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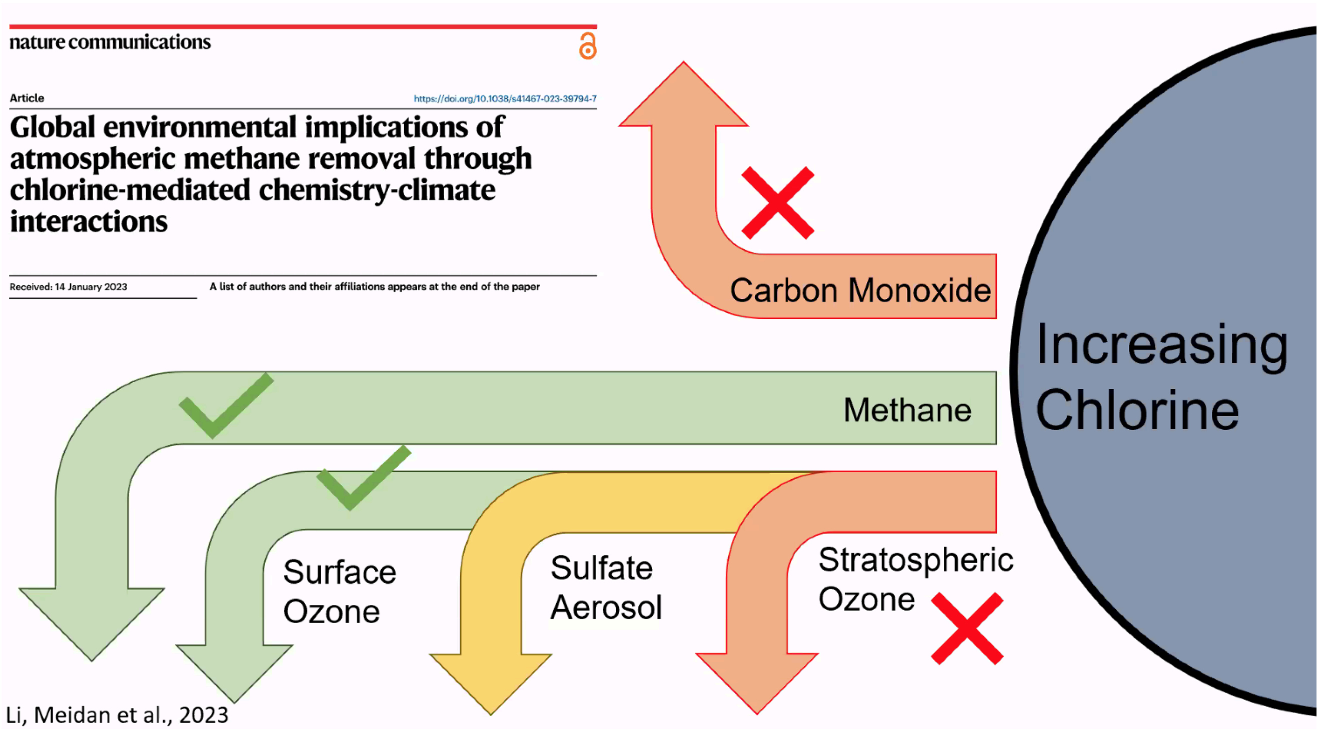

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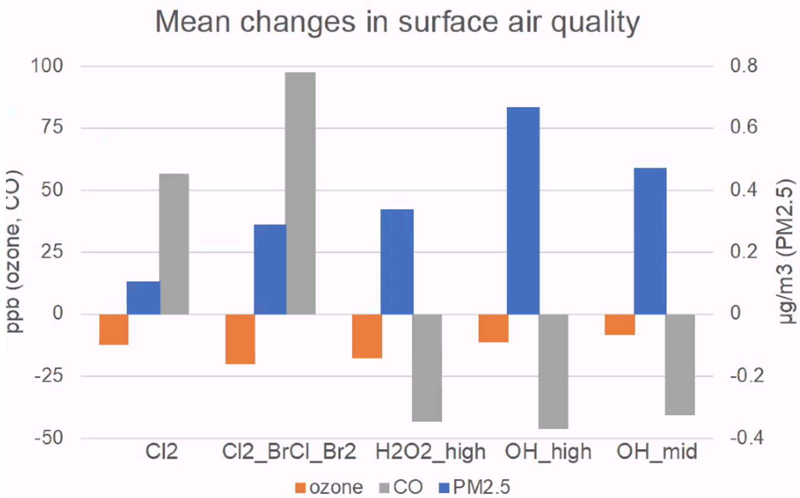
Greenhouse gas

Negative radiative forcing

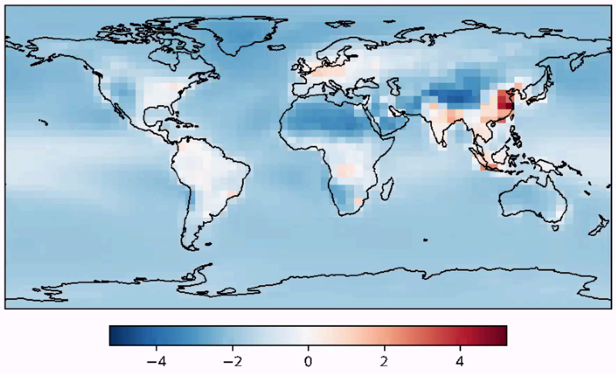
Surface air quality effects vary by species



- In the mean across all scenarios: surface ozone co-benefits, but surface PM2.5 increases
- Surface NO_2 changes are negligible in the mean (not shown)

Spatial variability: OH-based methods increase ozone in already polluted areas

Annual mean absolute difference in surface ozone, H_2O_2 - Standard



- Similar spatial pattern for all direct OH experiments
- Ozone increases up to 10 ppb in OH experiments and up to 52 ppb in H_2O_2 experiments in individual locations

Jncertainties and Implications

- Mass needed for OH-based methods to impact methane is likely greater than for Cl-based methods
- Impacts on air quality are mixed (ozone decreases, PM2.5 increases) and spatially variable. Location of OH-based methods matter in particular.
- Impacts on other climate forcers (HCFC-123, tropospheric ozone, aerosols) are co-benefit for OH-based methods, and mixed for Cl-based methods. Coupled sulfur-halogen chemistry may lead to different model results for sulfate aerosol.
- Potential increase in short-lived ozone-depleting substances for Cl-based methods.
- For Cl-based methods involving NaCl or iron salt aerosols, bromide contamination could result in worse outcomes across the board. Natural sea salt is likely not viable.
- Parameterization of iron salt aerosol is highly uncertain.

Alex

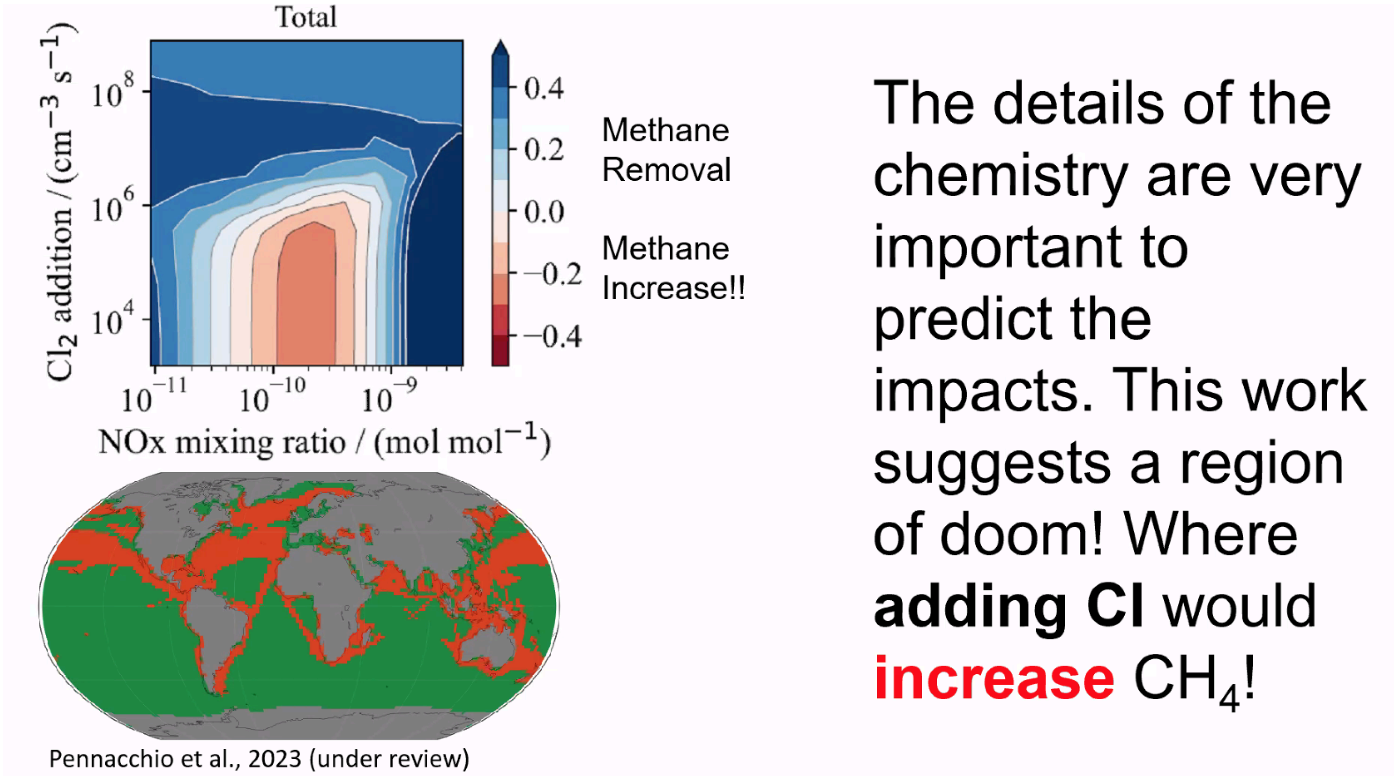
Archibald

Complex interaction with Cl O3 CH4

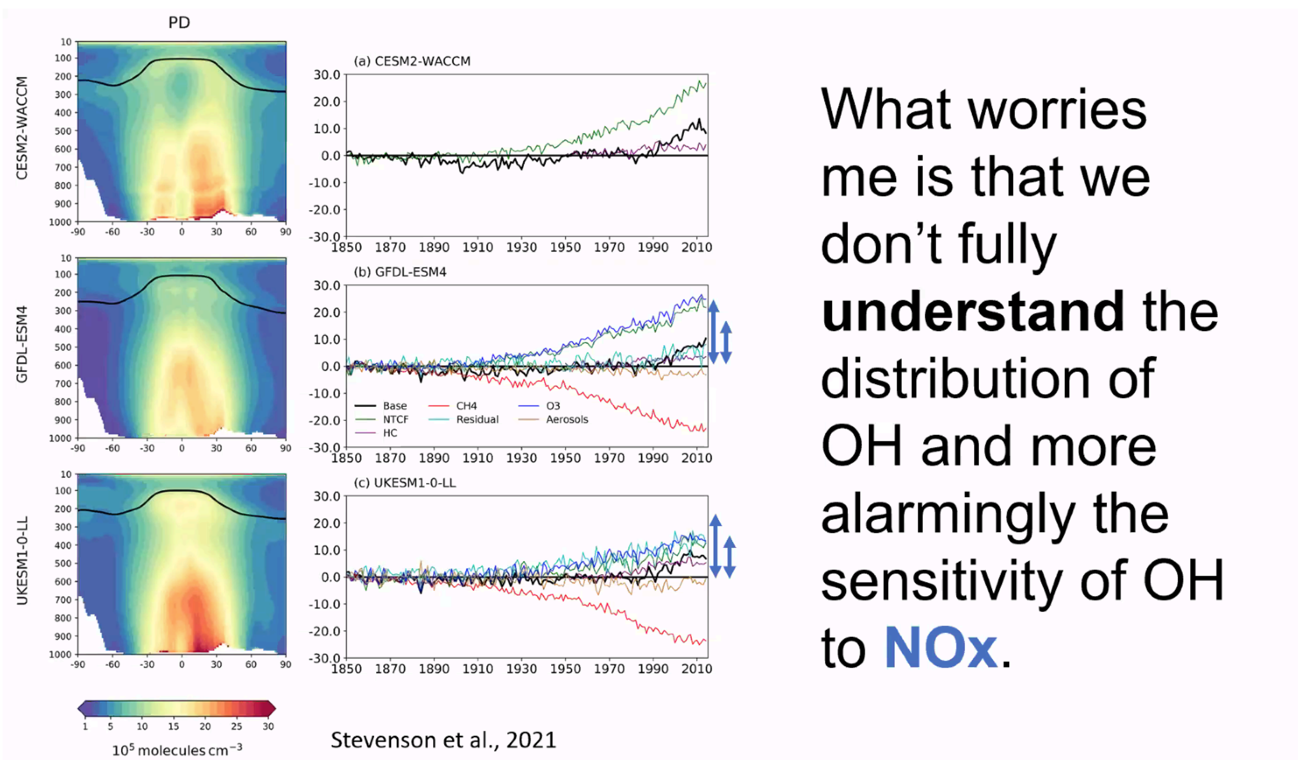
CH4 can go up not down

Other possibilities – stratospheric ozone loss – more skin cancer.

Effects of NOx complex and not known



Effects of NOx co

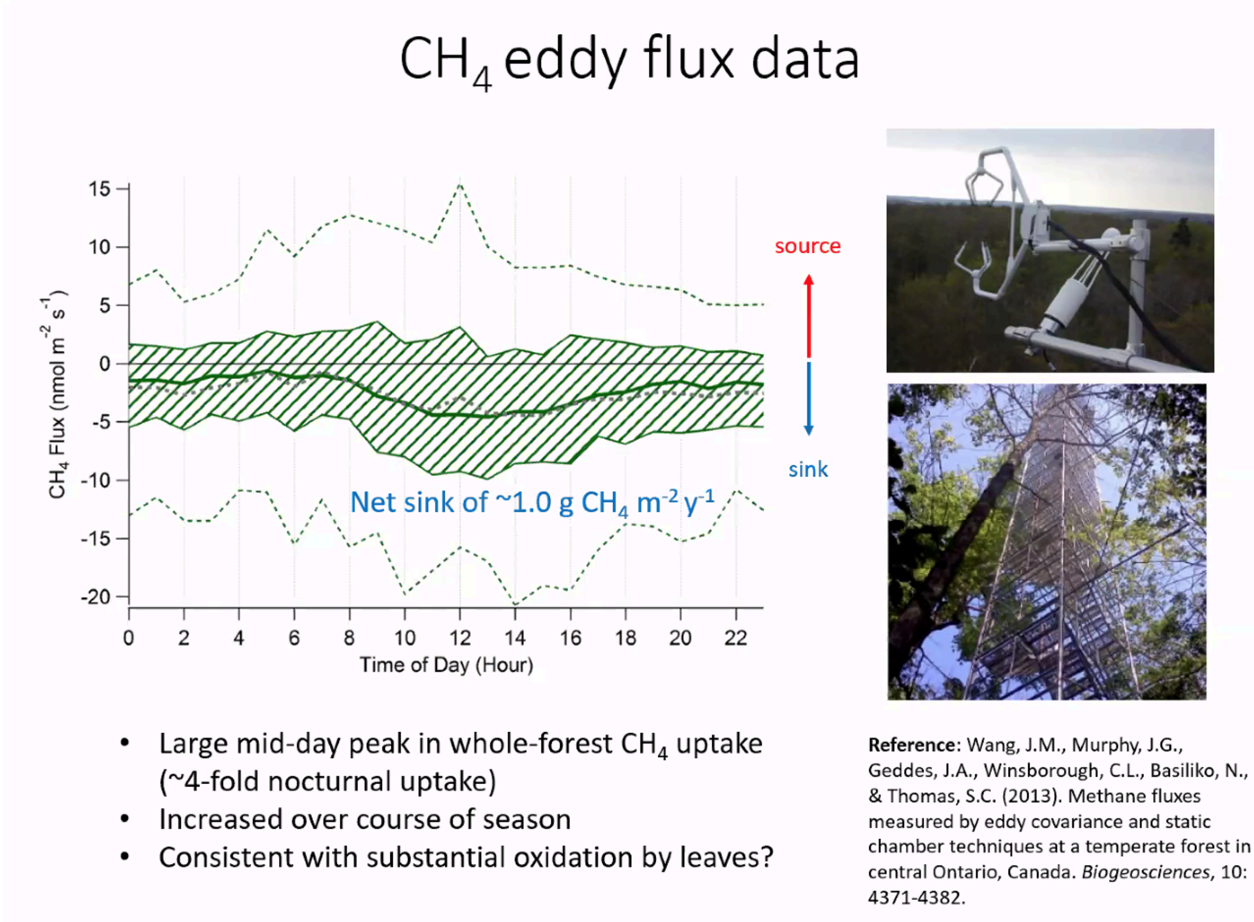


NOx

interactions complex and not known

<u>Sean Thomas</u>

Daily CH4 variations   Uptake by leaves?

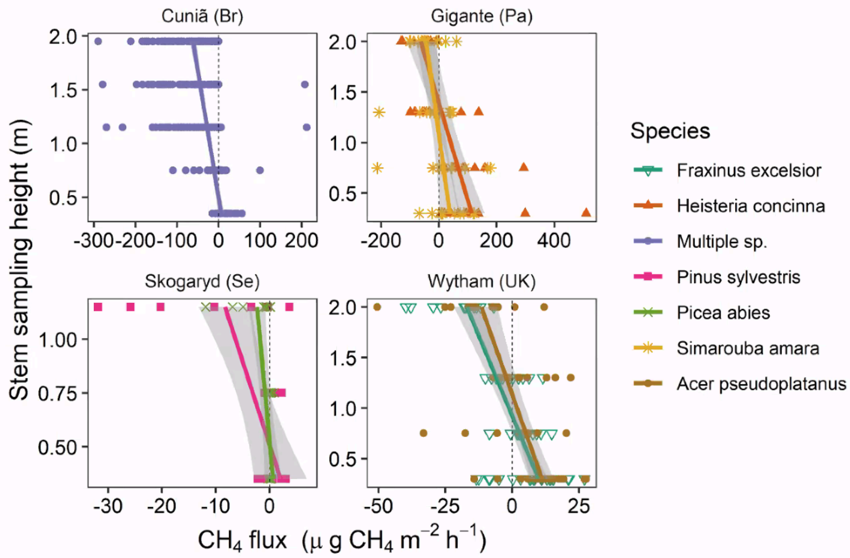


<u>Vincent Gauci – Birmingham UK</u>

Methane removal by woody surfaces

Results – bases of tree emit methane – upper surfaces absorb CH4

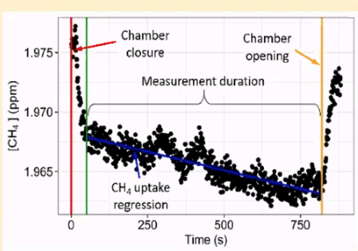
A synthesis of studies on free-draining 'upland soils'.



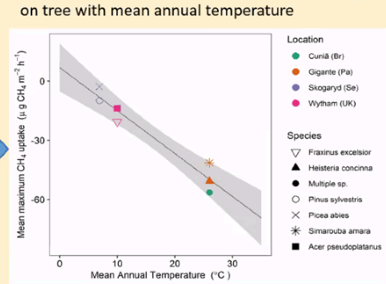
Problems – soil compaction during forestry – could be mitigated by soil mitigation and waste management. Restoration and biochar could help.

5M height – further from the river SINK increases – microbial uptake

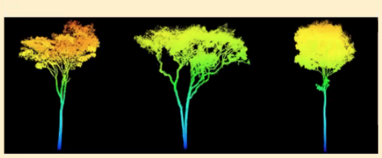
Flux measurements from multiple trees at multiple heights and across a climate gradient.



Regression of mean uptake values at highest point on tree with mean annual temperature



Terrestrial laser scanning creates new alometry (wood area index) for forest biomes.

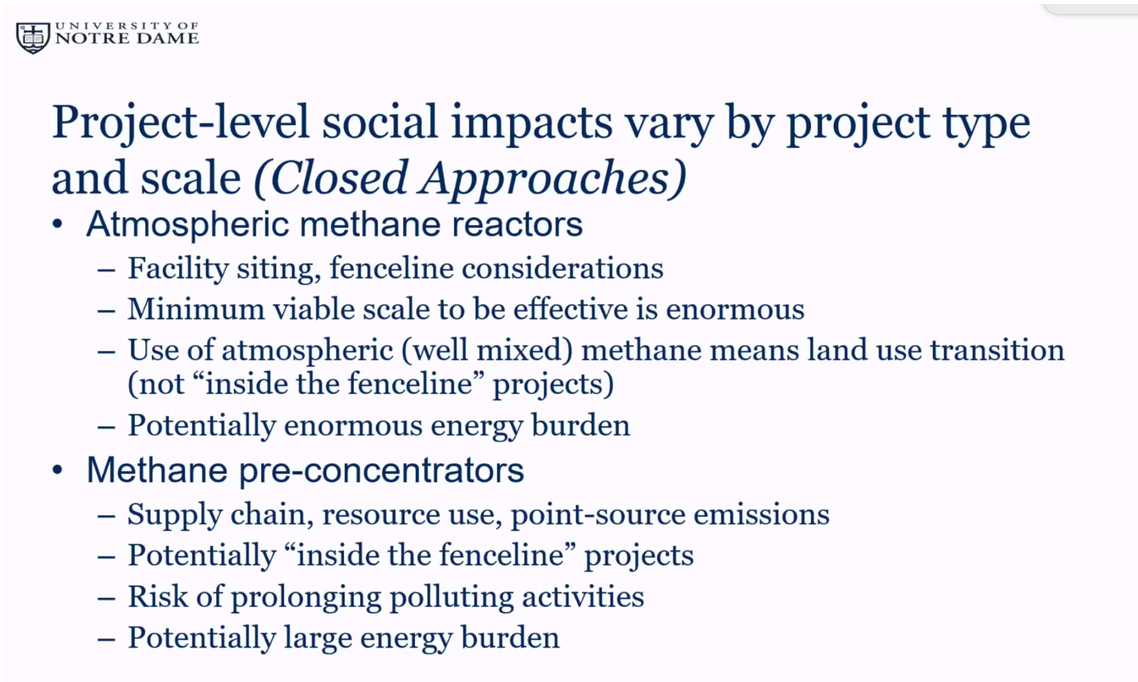


Forest land cover is estimated using two remote sensing products. Wood area index is applied to establish wood surface area for each biome and the regression modelling applied to establish methane uptake as informed by MAT. The result is a per-biome estimate of methane uptake by trees.

- We conservatively estimate total uptake by forests of ~**25-49.9 Tg** (million tonnes) each year.
- This is potentially larger than the global soil sink term
- Considering CH_4 uptake means tropical trees maybe ***~15% better for climate*** than when considering C uptake alone.
- The climate benefit of tropical and temperate reforestation is 12% and 7% greater than previously estimated, contributing an additional drawdown equivalent to **1.1 Pg** CO_2 yr^{-1} under conservative forest expansion scenarios.
- This first estimate is highly uncertain so we need to constrain variability and understand controlling factors and modifying variables.

Conclusion – tropical/temperate tree reforestation has big climate benefits – more than previous data indicated

<u>Session 5 - Societal implications</u>
<u>Emily Gilbert</u> – potential problems with siting of facilities in low rent areas
Also greenwashing problem reduction at facilities with real mitigation
how to govern? role?
project scales - local impacts



<u>Tom Dietz</u>
important to consider impacts on people and involve affected people **from the beginning**

Simon Nicholson

governance problem

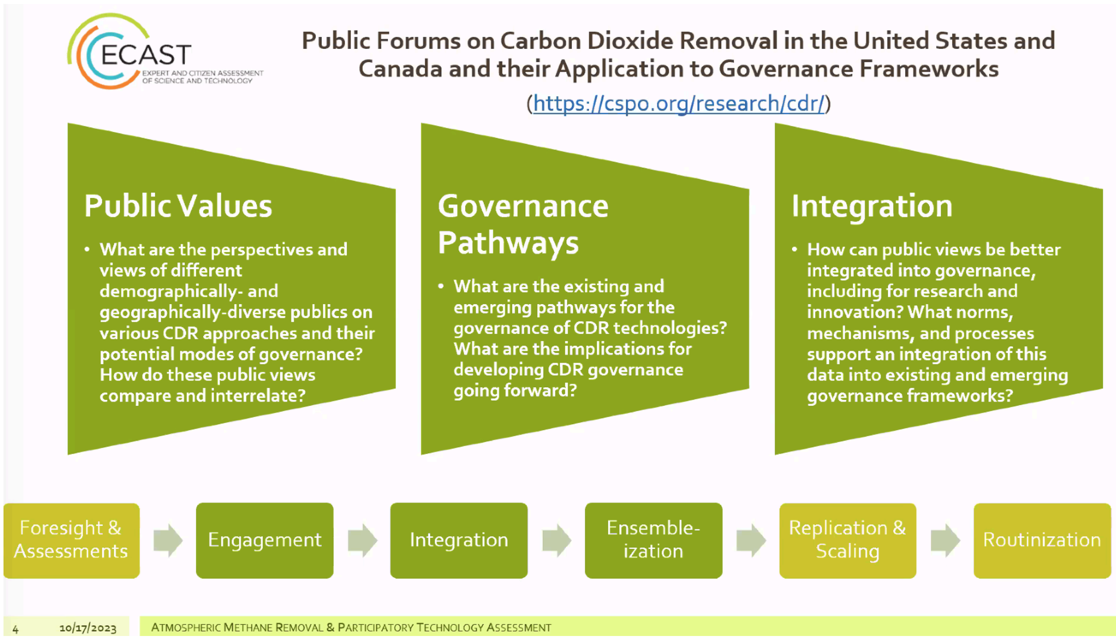
example DAC hubs no planned in areas where people don't want them - $$ better spent on real mitigation social innovation needed.

Genuine public engagement needed - funded by public sources not developers. Needs to be on-going.

Shuchi Talati

Mahmud Farooque

new tech needs social peer review in parallel with scientific peer review.



My very informal takeaways after my late arrival at the meeting on 10/18:

Regarding H2

- H2 losses to must be less than 10%
- Green H2 is acceptable
- Blue H2, mainly produced from fossil gas, is a threat to the methane budget

Critical materials:

- In addition to the mining for production of solar panels and batteries, the elements copper and aluminum are needed for transmission lines. Cu forms the core of the wires, Al surrounds the core.

Methanotrophs:

- Organisms that utilize methane. They are found in increased concentrations is rice paddies and wetlands and are adapted to local conditions
- Methane can be oxidized by the organisms to produce fertilizer and animal feed but adding more to the soil probably won't work.