Reducing Global Emissions of Methane
The Other Key Greenhouse Gas

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Why Focus on Reducing Global Methane Emissions?

- **Methane has received much less attention than carbon dioxide (CO_2) as a driver of climate change**
  - Absolute quantities of anthropogenic methane (CH_4) emissions are *much less* than those of CO_2
  - And the half-life of CO_2 in the atmosphere exceeds 100 years, but CH_4 atmospheric lifetime is only about 12 years

- **However, methane has *very high global warming potential per unit,* compared with CO_2**
  - Over 100 years, each methane unit is *28 times* as effective in radiative forcing
  - And over 20 years, its *84 times* as effective!
  - Historically, methane is responsible for about *30%* of global warming since the industrial revolution

- **So, methane-emissions abatement can significantly reduce GHG concentrations, climate change, and damages … particularly in the *short term*!**

- **This can give the world time to:**
  - *"bend the curve"* on CO_2 emissions
  - conduct *research* on carbon mitigation and removal
  - *implement* longer-term strategies to mitigate and adapt to climate change

Harvard Initiative on Reducing Global Methane Emissions

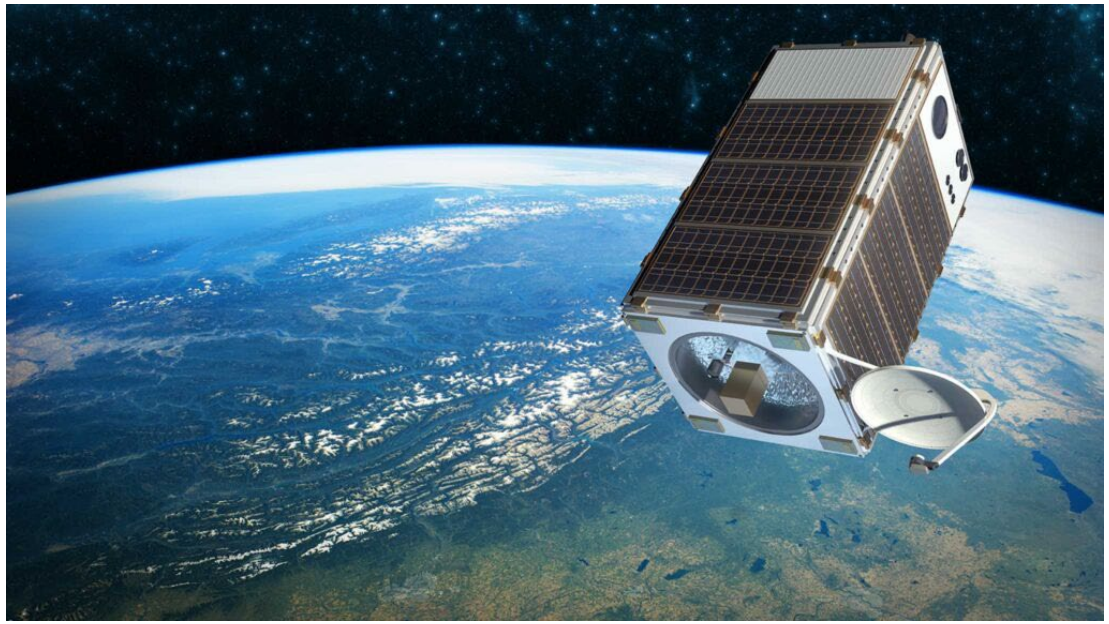
- **In 2023, we launched a Harvard-wide "Initiative on Reducing Global Methane Emissions"**
  - Sponsored by Harvard's Salata Institute on Climate and Sustainability
- **Goal is to achieve *meaningful and sustained* progress in methane emissions reductions …**
  - … through *research and effective engagement* with key stakeholders …
  - … to deliver information facilitating *design & implementation* of emission-reduction *policies & programs*
- **This presentation:**
  - Provides an overview of the Initiative (which I'm directing)
  - Briefly describes the specific Research Projects of the Initiative
  - Extra attention to projects involving economics

Harvard Initiative on Reducing Global Methane Emissions (continued)

- **Brings together two dozen researchers, including Harvard faculty from across university plus external collaborators**
  - *Seven departments* in FAS – from Sciences, Social Sciences, and Humanities
  - *Five professional schools*: Business, Engineering, Government, Law, and Public Health
  - *Disciplines*: physics, chemistry, biology, engineering, economics, political science, law, business, and history
  - By collaborating across research teams, *the whole can be greater than sum of its parts*: frequent interaction among researchers; building on synergies; advancing cross-disciplinary understanding
- **We're working to translate research into *useful* materials**
  - Preparing written *briefs* and *videos; and m*eetings with *government, NGO, and business leaders*
- **Overall theme: seeking to *translate* science into *action***
  - Engaging in *two-way communication* with government, business, NGOs, and international organizations
  - This includes governments and stakeholders at the international, regional, national, and sub-national levels
- **In first year (of three-year initiative), we launched *seven projects* …**

Satellite Observations of Atmospheric Methane for U.S. Reporting Needs

- **Goal:**
  - Increase *value of satellite observations* of atmospheric methane for reporting & regulation of methane emissions in the United States
- **Specifically:**
  - Improve *reporting* of methane emissions from landfills under U.S. EPA's Greenhouse Gas Reporting Program
  - Develop a *near-real-time satellite-based monitoring system* for verification of emission reductions and quantification of methane intensities (using Tropospheric Monitoring Instrument – TROPOMI – and MethaneSAT)



- **Leaders:**
  - *Daniel Jacob* – Department of Earth and Planetary Sciences, FAS
  - *Carrie Jenks* – Harvard Law School
- **Activity & Progress:**
  - Convened group of scientists & advocates on Jan. 18, 2024, to address landfills (see above); identify and implement steps to support revision of landfill performance standards under Clean Air Act Section 111
  - Development of real-time monitoring

Methane & Markets: Firm Incentives to Emit

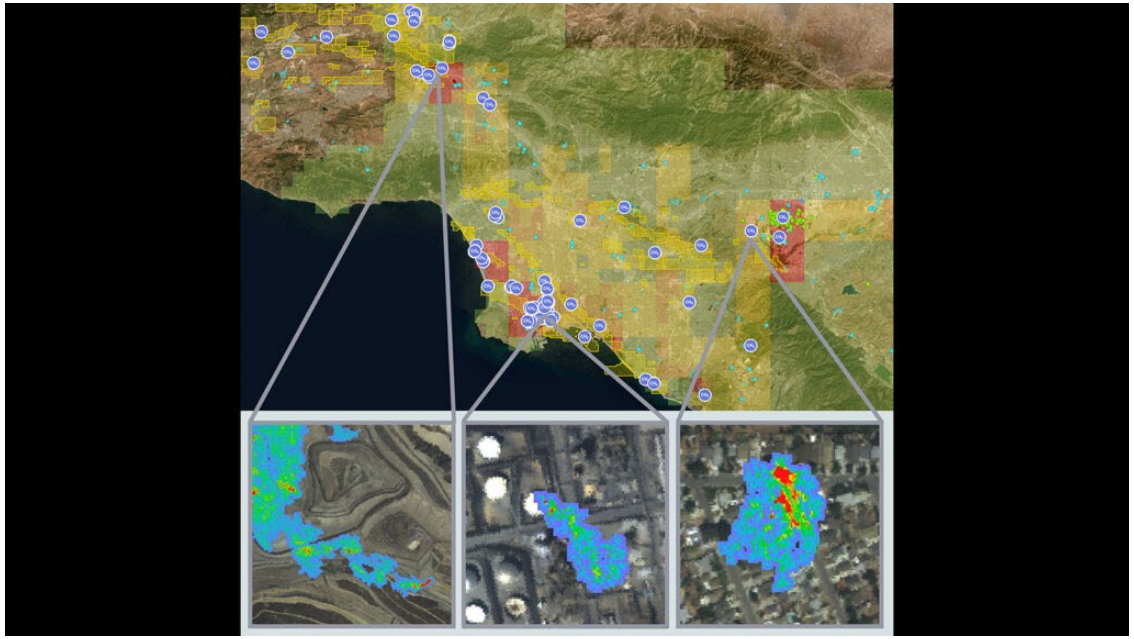
- **Goal:**
  - Explore economic factors that influence firms' decisions to emit methane rather than sell additional natural gas
- **Specifically:**
  - Analyze firm production and emissions decisions in response to oil & gas prices, and costs of capturing & transporting gas
- **Leaders:**
  - *Coly Elhai* – Department of Economics (PhD student)
  - *Toren Fronsdal* – Department of Economics (PhD student)
- **Activity & Progress:**
  - Launched analysis of effects of oil & gas prices on production & emissions decisions
  - With new data, executing more robust empirical analysis
  - Undertaking research trip to Permian Basin for first-hand observation of O&G companies' operations
  - Exploring pipeline investment to understand why capacity has not kept up with demand

Arctic Methane Emissions and Climate Mitigation

- **Goal:**
  - Estimate the *economic value* of narrowing uncertainty about future methane emissions from thawing permafrost
- **Specifically:**
  - Work draws in part on *findings from ongoing work* on monitoring & modeling emissions from permafrost thaw,
  - … both at the Salata Institute and in the Harvard component of TED/Audacious-funded Permafrost Pathways Project
- **Leaders:**
  - *James Hammitt* – Harvard T.H. Chan School of Public Health
  - *John Holdren* – Harvard Kennedy School
- **Activity & Progress**
  - Developed theoretical model of value of additional information
  - Calibrating model with IPCC estimates of emissions of CO_2 and CH_4 from thawing permafrost

Using Remote Sensing Data to Inform Micro-Histories of Release Sites

- **Goal:**
  - Better assess methane super-emitter sites, and understand more about the *social context* of methane emissions reductions – as a means to more effectively reduce emissions.
- **Specifically:**
  - Juxtapose *micro-histories* of methane emissions sites with satellite and aircraft imaging.
  - Develop new approaches to mapping those emissions.
- **Leaders:**
  - *Emma Rothschild* – Department of History, FAS
  - *Steven Wofsy* – Harvard John A. Paulson School of Engineering and Applied Science



- **Activity & Progress:**
  - First round of MethaneAIR data-gathering complete (domestic U.S.).
  - Research workshop to be held in fall 2024.

Methane and Trade

- **Goal:**
  - Develop and disseminate proposal for a Methane Border Adjustment Mechanism (MBAM) that can enhance ambition and activities by countries
- **Specifically:**
  - Based on proposal for a U.S.-EU MBAM by Kim Clausing, Luis Garicano, & Catherine Wolfram, develop user-friendly materials, and plan & execute engagements with policy makers
- **Leaders:**
  - *Catherine Wolfram* – Sloan School of Management, MIT
  - *Kim Clausing* – School of Law, UCLA
- **Activity & Progress:**
  - Produced a Research Brief summarizing proposal and next steps
  - Organized workshops and other engagements in Washington, D.C., planning underway for Brussels and Beijing (Climate & Trade)

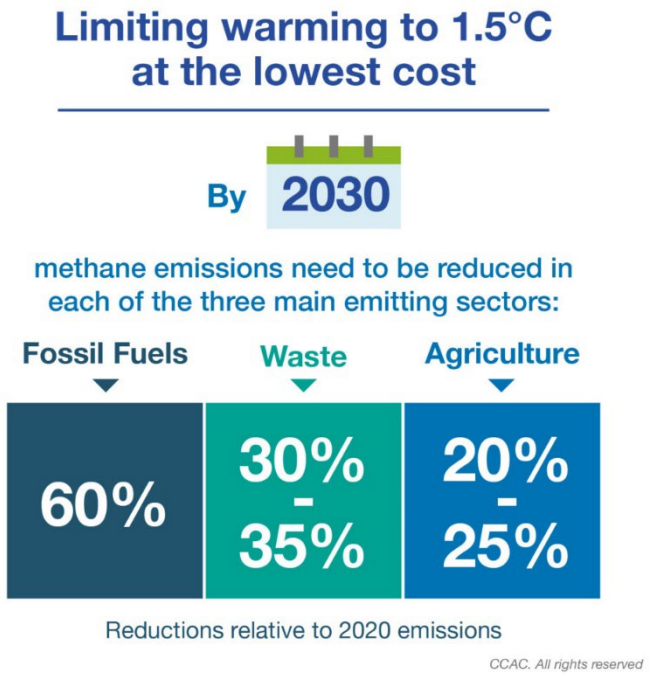
International Cooperation to Reduce Methane Emissions

- **Goal:**
  - Characterize *complex landscape* of international cooperation to reduce methane emissions; develop *recommendations* for further cooperation
- **Specifically:**
  - Examine how *large-emitting countries*, including China, might advance efforts to abate, in part through international cooperation
  - Address *interaction* of trade policy and efforts to reduce methane emissions
- **Leaders:**
  - *Robert Stavins* – Harvard Kennedy School
  - *Robert Stowe* – Harvard Project on Climate Agreements

- **Activity & Progress:**
  - Produce a paper (Spring 2025), describing & assessing complex landscape of international cooperation to reduce methane emissions, including: Paris Agreement NDCs; Global Methane Pledge; industry consortia, pledges, & mechanisms; and NGO partnerships
  - Begin to prepare proposals to enhance cooperation

Estimating Economic Costs of Reducing Methane Emissions

- **Goal:**
  - Apply *empirical methods* to improve cost estimates, and identify *policy instruments* to reduce abatement costs
- **Specifically:**
  - Review literature on three types of cost estimates: *engineering cost* estimates; *econometrically estimated* costs; and costs *revealed* through public policies
- **Leaders:**
  - *Joseph Aldy* – Harvard Kennedy School
  - *Forest Reinhardt* – Harvard Business School
  - *Robert Stavins* – Harvard Kennedy School

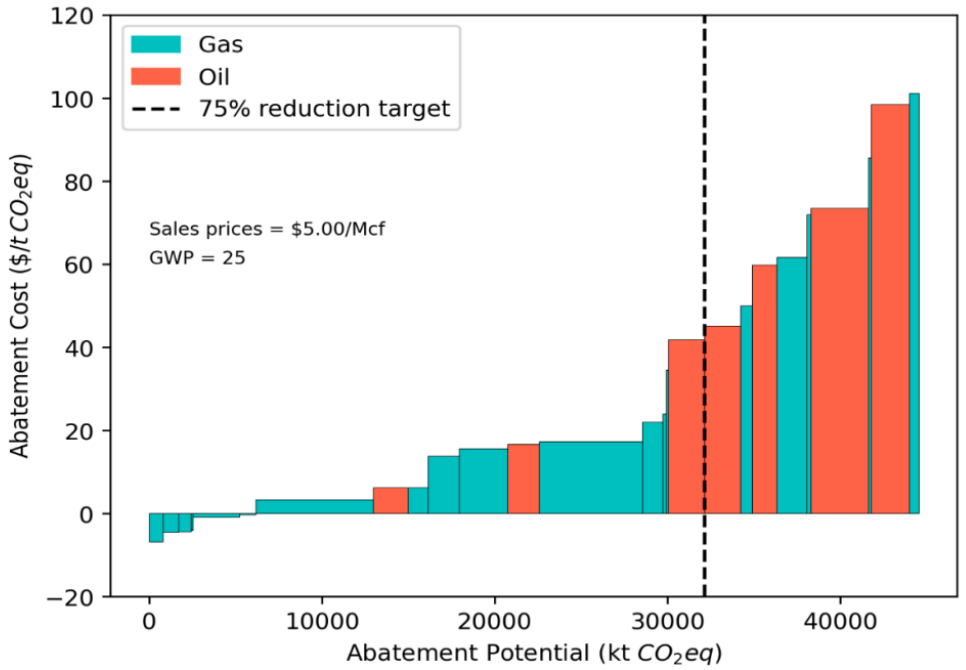


- **Activity & Progress:**
  - Release working paper and policy brief in Fall of 2024 that ***surveys and synthesizes*** abatement cost estimates in O&G sector
  - Second Year: original econometric estimates of abatement costs, w/data on O&G fugitive methane emissions, technologies, oil & gas production and prices, etc.

Survey & Synthesis of Methane Emissions Abatement Costs: Prospective Engineering Cost Estimates

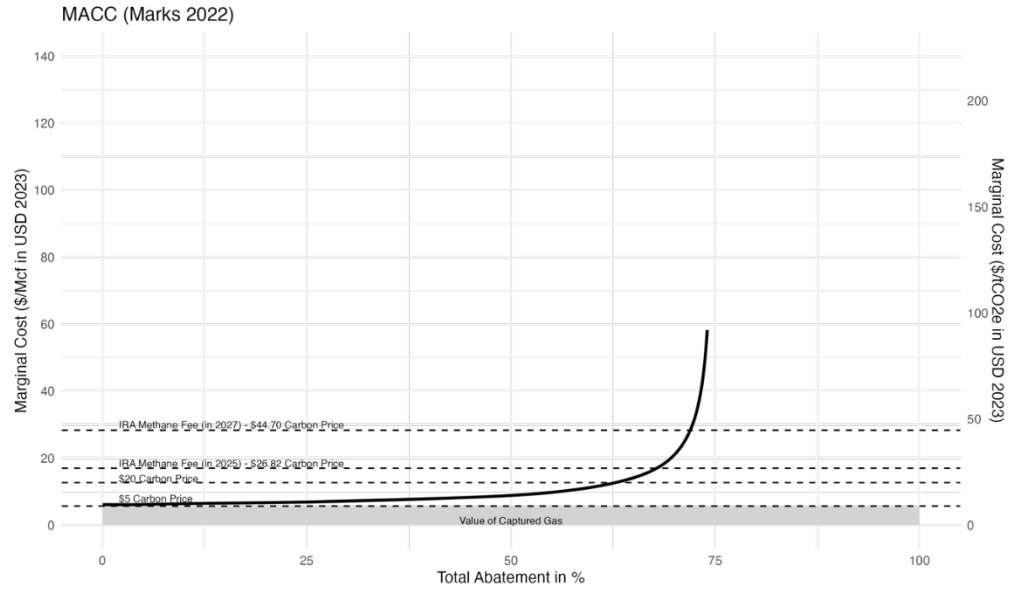
- **Engineering Cost Estimates**
  - Bottom-up estimates of costs, using emission factors, estimates of investment & operation costs of various actions
  - Results: estimates of average costs per ton of 33 reduction options range from \$11/ton CO_2e to \$40/ton CO_2e for Canadian oil and gas operations; includes value of saved methane

- **Concerns**
  - Upward-sloping bar chart may not be marginal abatement cost; each bar represents average cost among operators for discrete technology or process change
  - Some apparently low-cost means may not include costs of searching for and detecting leaks
  - Recovered methane cannot always be sold into market; for example, operator may only be connected to a crude oil pipeline, not a natural gas pipeline



Survey & Synthesis of Methane Emissions Abatement Costs: Retrospective Empirical Cost Estimates #1

- **Inferring Methane Abatement Cost from Variation in Natural Gas Prices & Emissions**
  - Intuition: If natural gas prices increase, operators have increased incentives to capture & sell (leaking) methane
  - Data: Gas prices at 96 local trading hubs across the USA over a 6-year period (Marks 2022); and methane emission estimates that were reported to U.S. Greenhouse Gas Reporting Program (not measured)
- **Analysis**
  - Panel regression
  - No need to identify how emissions are reduced; analysis posits that operators search over available options
- **Results**
  - Marginal methane price (tax, etc.) of \$5/ton CO_2e could induce operators to reduce emissions by about 60%
  - Methane fee levels from IRA increase over time (dotted lines) may result in more than 70% reduction (but beyond scope of natural gas prices used to estimate the model)

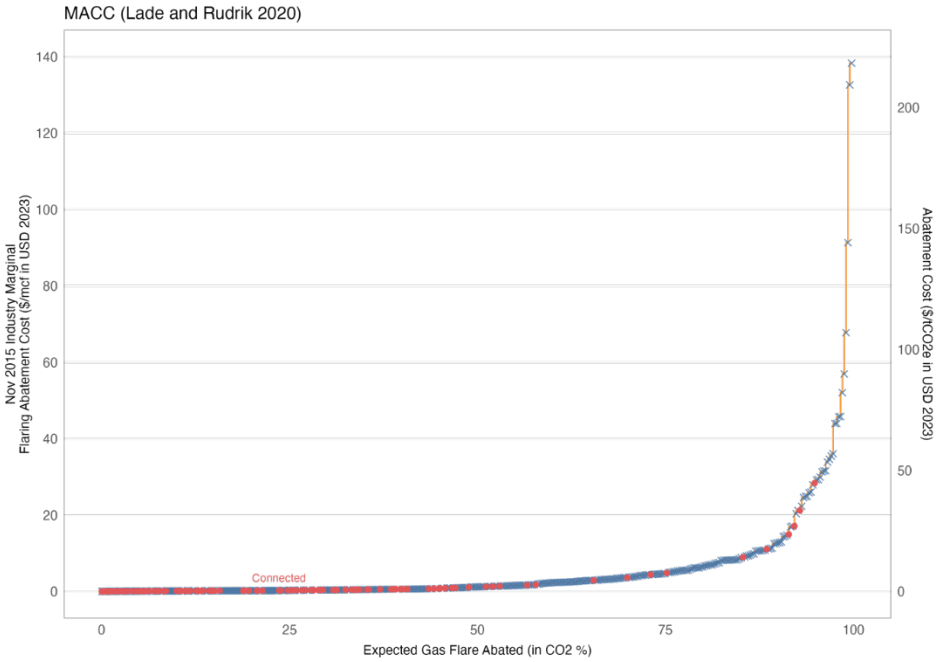


Survey & Synthesis of Methane Emissions Abatement Costs: Retrospective Empirical Cost Estimates #2

- **Inferring Methane Abatement Cost from Variation in Regulations, Flaring, & Emissions**
  - Observe changes in methane flaring when and where subject to regulation, combine with engineering cost estimates to construct marginal abatement cost function
  - Regulation took effect in North Dakota in 2014 (Lade and Rudik 2020)

- **Results**
  - At sufficiently high methane prices, all emissions from flaring could effectively be eliminated.

- **Next Steps for Aldy-Reinhardt-Stavins Project**
  - Build upon approach of Marks (2022), but use *empirical emission estimates*, inferred from concentration observations from TROPOMI (and MethaneSAT) satellites (Jacobs)
  - Combine with panel data on natural gas prices & regulations
  - Develop econometric estimate of supply function, i.e., marginal abatement cost function



Fourteen Additional Projects in Year 2 of the Initiative

The Harvard Methane Initiative, in its second year (began July 2024):

- Launching 14 new projects
- Extending research beyond the oil and gas sector to address sources in agriculture and landfills
- Extending research outside of the USA
- Supporting more doctoral students and postdoctoral researchers

New Research/Outreach Projects:

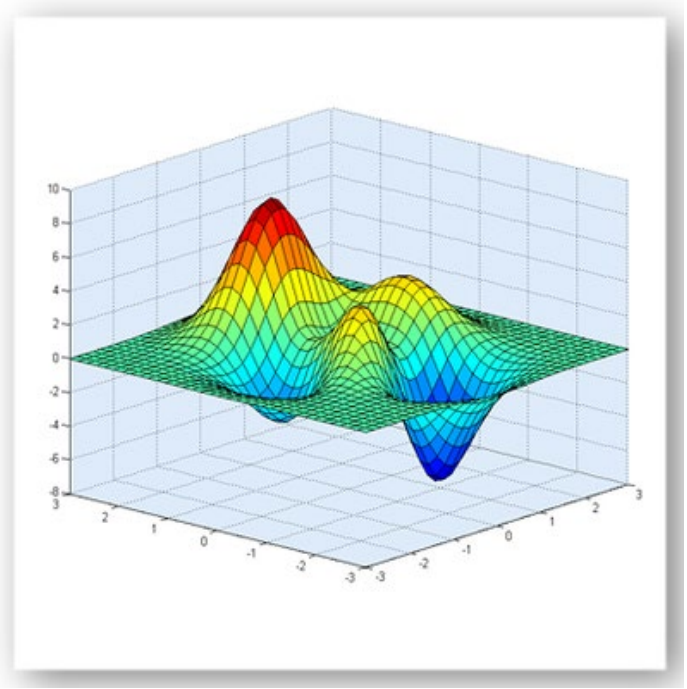
- **Agriculture:**
  - Intelligent Nature-Inspired Olfactory Sensors Engineered to Sniff (iNOSES) for Real-Time Methane Monitoring
  - Policy for and Regulation of Agricultural Methane Emissions in the United States
  - Methane Abatement in Livestock: Making Markets for Feed Additives in the Global North and Global South
  - Methane Mitigation from Dry Cultivation of Rice in China
- **Waste/Landfills**
  - Improved GHGRP Reporting and Reduction of Emissions from US Landfills

Fourteen Additional Projects in Year 2 (continued)

- **Additional Projects Addressing Emissions from the Oil and Gas Sector**
  - The Market and Climate Implications of U.S. LNG Exports
  - Econometric Estimation of Methane Abatement Costs
  - High-frequency Variability of Emissions from U.S. Oil & Gas Production Regions
  - Policy Options for Reducing Methane Emissions
  - Global Climate Impacts of U.S. LNG Exports
  - Establishing the Representativeness of Remote-Sensing Observations of Methane Point Sources
  - Coordinating with Industry on Emissions Monitoring
  - Regulatory Obstacles & Opportunities for Well-Capping in Pennsylvania
- **Cutting Across Sources and Sectors:**
  - Integrated Methane Inversion Training for Stakeholders

Econometric Estimation of Methane Abatement Costs

- **Goal:**
  - Develop and apply empirical framework for estimating costs of reducing methane emissions
- **Specifically:**
  - Focus on U.S. O&G sector to examine market incentives (natural gas prices) and policy incentives (state & federal regulations) to reduce emissions
  - Produce both short-run and long-run methane abatement supply functions
  - Use TROPOMI, MethaneSAT, MethaneAIR emission estimates (time & space)



- **Leaders:**
  - *Joseph Aldy* – Harvard Kennedy School
  - *Forest Reinhardt* – Harvard Business School
  - *Robert Stavins* – Harvard Kennedy School
- **Activity & Progress:**
  - Obtaining data on natural gas nodal prices, O&G fugitive methane emissions, production levels and technologies
  - Working with Daniel Jacob re Integrated Methane Inversion tool; in contact with EDF re MethaneSAT data

Intelligent Nature-Inspired Olfactory Sensors Engineered to Sniff (iNOSES) for Real-Time Methane Monitoring

- **Goal:**
  - Develop and deploy an intelligent, accurate, wearable, nature-inspired olfactory sensor for real-time methane monitoring of livestock (primarily cattle) methane emissions

- **Specifically:**
  - Design, print, and test printed circuit boards to form the hardware foundation of iNOSES
  - Field test device
  - Improve device based on field testing
- **Leaders:**
  - *Joanna Aizenberg*, Materials Science and Chemistry & Chemical Biology (with Postdoc *Anna Shneidman* and PhD student *Haritosh Patel*).
  - *Venkatesh Murthy*, Molecular and Cellular Biology
- **Activity & Progress:**
  - Designing hardware for the device

Regulation of Agricultural Methane Emissions in the United States

- **Goal:**
  - Identify, describe, and evaluate key regulations addressing agricultural methane emissions in the United States
- **Specifically:**
  - Produce a research brief on this topic, to be released by the Harvard Methane Initiative.
  - Summarize and assess existing regulatory frameworks, primarily state level, for livestock
- **Leaders:**
  - *Abby Husselbee*, Harvard Law School
  - *Carrie Jenks*, Harvard Law School
- **Activity & Progress:**
  - Research underway, brief will be delivered in December 2024.

Methane Abatement in Livestock: Markets for Feed Additives in the Global North and Global South

- **Goal:**
  - Elaborate on policy environment needed to speed uptake of feed additives to reduce methane emissions in dairy and beef cattle, comparing the Global North with the Global South
- **Specifically:**
  - Focus on Bovaer as case study, due to regulatory approval in 65 countries, including USA and EU
  - Examine challenges to adoption of Bovaer in Global South
  - In-person interviews
  - Produce a paper presenting results.
- **Leaders:**
  - *Robert Paarlberg*, Harvard Weatherhead Center for International Affairs
- **Activity & Progress:**
  - Research underway, paper will be delivered in late spring 2025

Methane Mitigation from Dry Cultivation of Rice in China

- **Goal:**
  - Using econometric methods, estimate the impact on reduction of methane emissions in China by substituting dry cultivation of rice for paddy rice production
- **Specifically:**
  - Using data from Landsat, GOSAT, and TROPOMI, examine the degree to which dry cultivation reduces methane emissions
  - Examine side effects, including on yield, agricultural revenue, and water use
  - What is the return to government's subsidy for dry cultivation, including as a climate mitigation strategy in terms of $/avoided CO_2e emission?

- **Leaders:**
  - *Xinming Du*, Salata Institute for Climate and Sustainability, on sabbatical leave, National University of Singapore
  - *Charles Taylor*, Harvard Kennedy School (advisory role)
- **Activity & Progress:**
  - Research is underway; paper to be delivered in late summer 2025

Improved Reporting and Reduction of Emissions from U.S. Landfills

- **Goal:**
  - Based on data from the TROPOMI satellite, analyze methane-emission trends for individual landfills
- **Specifically:**
  - Using newly-developed 12x12 km inversion capability to isolate urban landfills
  - Input to U.S. Greenhouse Gas Reporting Program (GHGRP)
- **Leaders:**
  - *Carrie Jenks*, Harvard Law School
  - *Daniel Jacob*, Department of Earth and Planetary Sciences
- **Activity & Progress:**
  - Research is underway

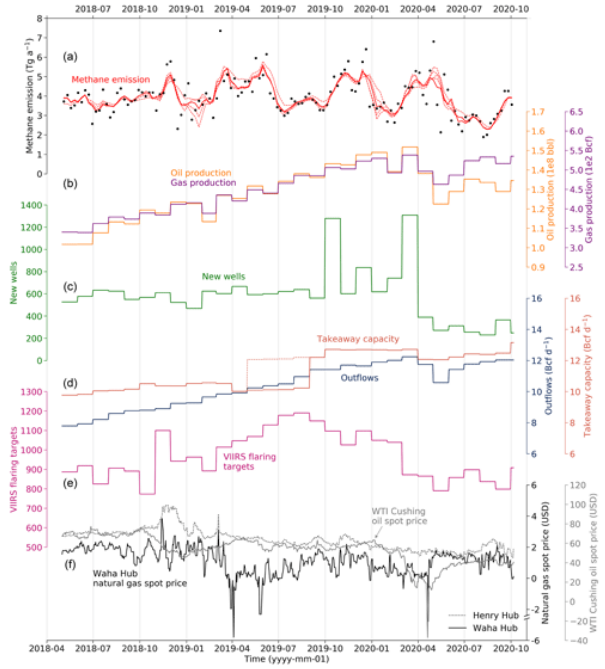
The Market and Climate Implications of U.S. LNG Exports

- **Goal:**
  - Quantify the economic consequences and climate implications of U.S. exports of liquified natural gas
- **Specifically:**
  - Examine how U.S. role as world's largest LNG exporter (2015-2023) reconnected U.S. gas prices to world O&G market prices
  - Analyze effect on domestic gas prices and coal prices in terms of equivalent carbon taxes, and consequent power sector CO_2 emissions reductions
- **Leaders:**
  - *James Stock*, Department of Economics
  - *Matthew Zaragoza-Watkins*, University of California, Davis

- **Activity & Progress:**
  - Working paper (#32228, NBER, March 2024) completed; further work on climate impacts to consider life-cycle emissions associated with LNG exports, including methane leaks

High-Frequency Emissions Variability in US Oil & Gas Production

- **Goal:**
  - Examine implications O&G production of variability for developing policy to reduce methane emissions
- **Specifically:**
  - Quantify emissions from source regions with weekly resolution from TROPOMI data
  - Assess consequences in terms of economic indicators and implications for developing policy to reduce emissions.
- **Leaders:**
  - *Coly Elhai*, Department of Economics (PhD student)
  - *Daniel Jacob*, Department of Earth and Planetary Sciences
  - *Daniel Varon*, Department of Earth and Planetary Sciences (Postdoc)
- **Activity & Progress:**
  - Research is underway



Policy Options for Reducing Methane Emissions

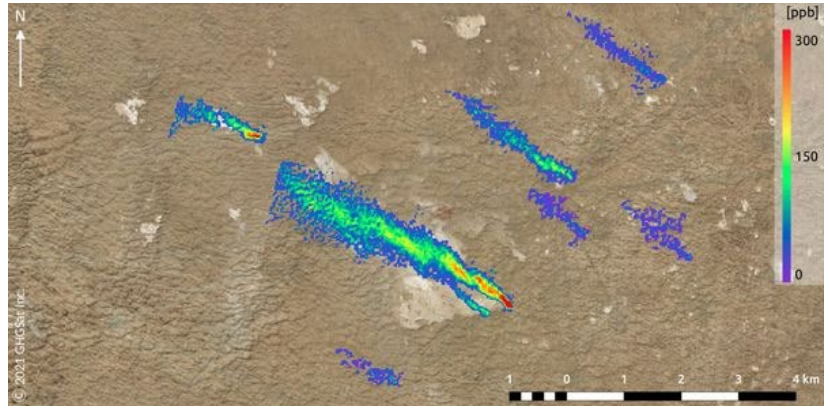
- **Goal:**
  - Based on research from first year, explore how natural-gas producers may react to a range of policy options targeting midstream congestion and changes in natural gas prices
- **Specifically:**
  - Assess effectiveness of flaring restrictions, given limited enforcement capacity
  - Consider how different types of tax policies may affect emissions
  - Examine the emissions impact of policies focused on pipelines
  - Consider the challenge of enforcement throughout
- **Leaders:**
  - *Coly Elhai*, Department of Economics (PhD student)
  - *Toren Fronsdal*, Department of Economics (PhD student)
- **Activity & Progress:**
  - Research is underway.

Global Climate Impacts of U.S. LNG Exports

- **Goal:**
  - Build a quantitative model of global energy markets and electricity investment that can be used to assess the global climate implications of future U.S. LNG capacity expansion
- **Specifically:**
  - Develop dynamic model of global electricity investment, to be combined with a global trade model, where both natural gas and coal prices respond to global demand and supply shocks
  - Estimate model using plant-level data on global electricity generation assets and specialized energy trade infrastructure, complemented by existing estimates of upstream and midstream methane emission intensity
  - Quantify how changes in global energy trade infrastructure affect carbon emissions
- **Leaders:**
  - *Constanza Abuin*, Department of Economics (PhD student)
- **Activity & Progress:**
  - Research is underway

Examining the Representativeness of Remote-Sensing Observations of Methane Point Sources

- **Goal:**
  - Resolve difficulty in interpreting methane point source observations from aircraft and satellites in regard to representative emissions
- **Specifically:**
  - Account for source intermittency, observing precision, and observation repeat time.
  - Will contribute to the Integrated Methane Inversion (IMI) tool developed by the Harvard SEAS/EPS Atmospheric Chemistry Modeling Group to quantify methane emissions with high resolution
- **Leaders:**
  - *Harshil Kamdar*, Harvard Salata Institute; Lead Senior Scientist, Insight M
  - *Daniel Jacob*, Department of Earth and Planetary Sciences
- **Activity & Progress:**
  - Research is underway.



Coordinating with Industry on Emissions Monitoring

- **Goal:**
  - Develop modes of collaboration with O&G industry in Appalachian region to develop reproducible steps for detecting and mitigating methane emissions
- **Specifically:**
  - Notify companies of emissions detected in remote sensing observations by the project team using MethaneAIR
  - Compare these data to data from the Appalachian Methane Initiative on suspected locations of emissions
  - Determine whether the validated data are sufficiently robust to use for reporting to EPA. and use validated data to identify ongoing leaks and choose effective monitoring locations and cadences
- **Leaders:**
  - *Ethan Kyzivat*, Department of Earth and Planetary Sciences (Postdoc)
  - With advice and support from *Dustin Tingley*, Department of Government,
  - … and *Steven Wofsy*, Department of Earth and Planetary Science
- **Activity & Progress:**
  - Research and outreach activities will begin in early spring 2025

Regulatory Obstacles & Opportunities for Well-Capping in Pennsylvania

- **Goal:**
  - Convene major *stakeholders* in western Pennsylvania to examine ways to *address regulatory & economic obstacles* to capping natural gas wells that are no longer producing
- **Specifically:**
  - Develop *blueprint for regulatory & legislative action* by convening regulators, legislators, well owners/operators, land owners, community leaders, & experts in well-capping
- **Leaders:**
  - *Stephen Ansolabehere* – Department of Government
  - *Carrie Jenks* – Harvard Law School
  - *Dustin Tingley* – Department of Government
- **Activity & Progress:**
  - Two-day workshop planned
  - Stakeholders, researchers, including Harvard faculty & staff

Integrated Methane Inversion Training for Stakeholders

- **Goal:**
  - Execute (remote) workshops to enable users to infer methane emissions from satellite data
- **Specifically:**
  - User-friendly, open-code Integrated Methane Inversion (IMI) tool on Amazon Web Services (AWS) will enable stakeholders with no prior expertise to conduct inversions, visualization, and processing of satellite data
  - Half-day workshops to be offered separately for Americas, Europe/Africa, and Asia; Each workshop to include: (1) overview of IMI; (2) tutorial on using IMI; (3) hands-on application by all participants to a common region; and (4) hands-on application by each participant to their region of interest

- **Leaders:**
  - *Daniel Jacob* – Department of Earth and Planetary Sciences
  - *Daniel Varon* – Department of Earth and Planetary Sciences
- **Activity & Progress**
  - In preparation; to begin in November of 2024

Other Participating Faculty and External Collaborators

- **Other Participating Faculty**
  - *Jody Freeman* – Harvard Law School
  - *Meghan O'Sullivan* – Harvard Kennedy School
  - *Michael Toffel* – Harvard Business School
  - *Mark Brownstein* – Environmental Defense Fund
  - *Nathaniel Hendren* – Department of Economics, MIT

- **Collaborating Institutions (partial list)**
  - Clean Air Task Force
  - Climate and Clean Air Coalition
  - Environmental Defense Fund
  - Office of the U.S. Special Presidential Envoy for Climate, U.S. Department of State
  - Oil & Gas Climate Initiative
  - Resources for the Future
  - U.N Environment Programme
  - World Bank Group

Thank You!

For More Information

Harvard Project on Climate Agreements
www.belfercenter.org/climate

Harvard Environmental Economics Program
www.hks.harvard.edu/m-rcbg/heep

Website
www.stavins.com

Blog
http://www.robertstavinsblog.org/

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Salata Institute Initiative on Reducing Global Methane Emissions
https://salatainstitute.harvard.edu/projects/methane/