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

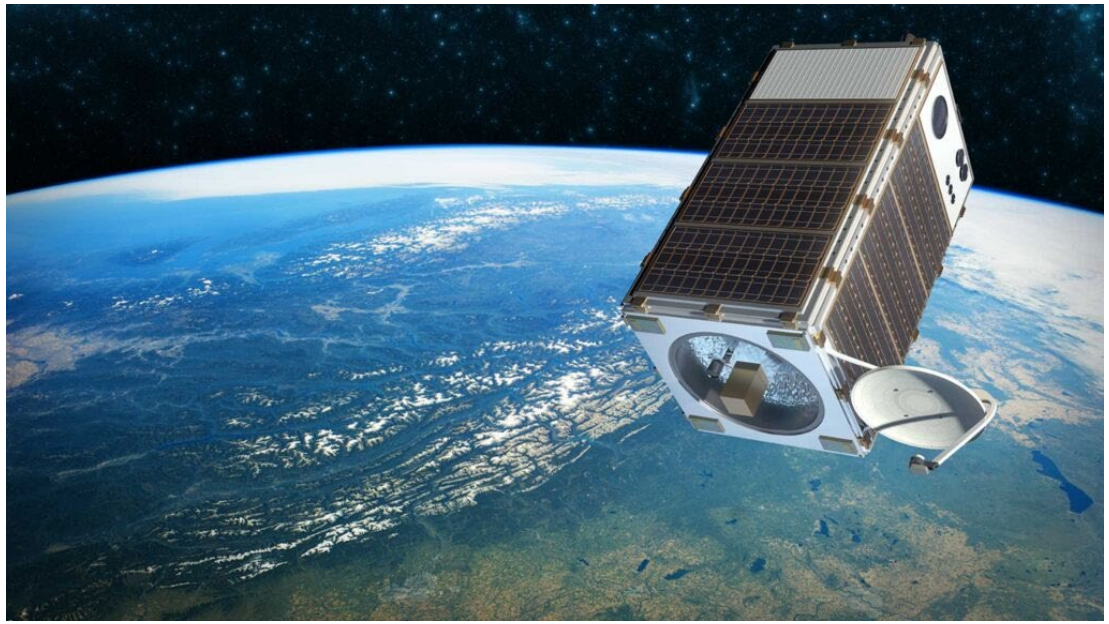
- **In 2023, we launched a Harvard-wide "Initiative on Reducing Global Methane Emissions"**
  - Sponsored by Harvard's Salata Institute on Climate and Sustainability
- **Goal is to achieve *meaningful and sustained* progress in methane emissions reductions …**
  - … through *research and effective engagement* 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

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

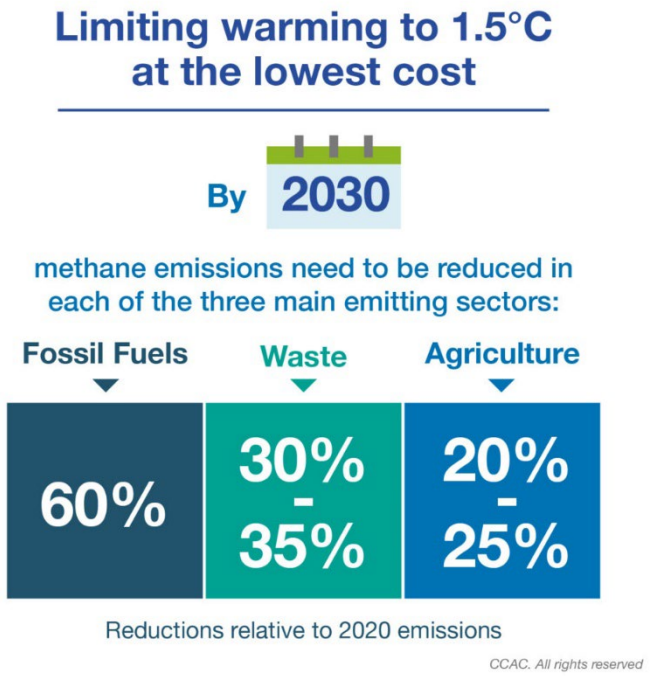
- **Goal:**
  - Increase *value of satellite observations* of atmospheric methane for reporting & regulation of methane emissions in the United States
- **Specifically:**
  - Improve *reporting* of methane emissions from landfills under U.S. EPA's Greenhouse Gas Reporting Program
  - Develop a *near-real-time 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

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 early in of 2025 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.

Methane & Markets: Firm Incentives to Emit

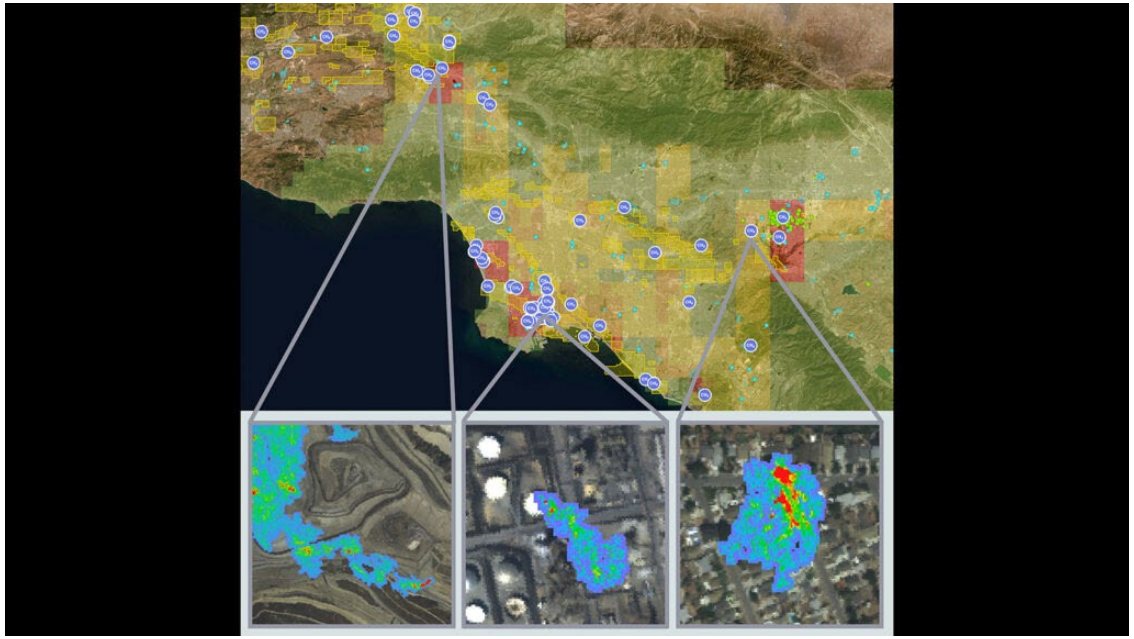
- **Goal:**
  - Explore economic factors that influence firms' decisions to emit methane rather than sell additional natural gas
- **Specifically:**
  - Analyze firm production and emissions decisions in response to oil & gas prices, and costs of capturing & transporting gas
- **Leaders:**
  - *Coly 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

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

Fifteen Additional Projects in Year 2 of the Initiative

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

- Launching 15 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:

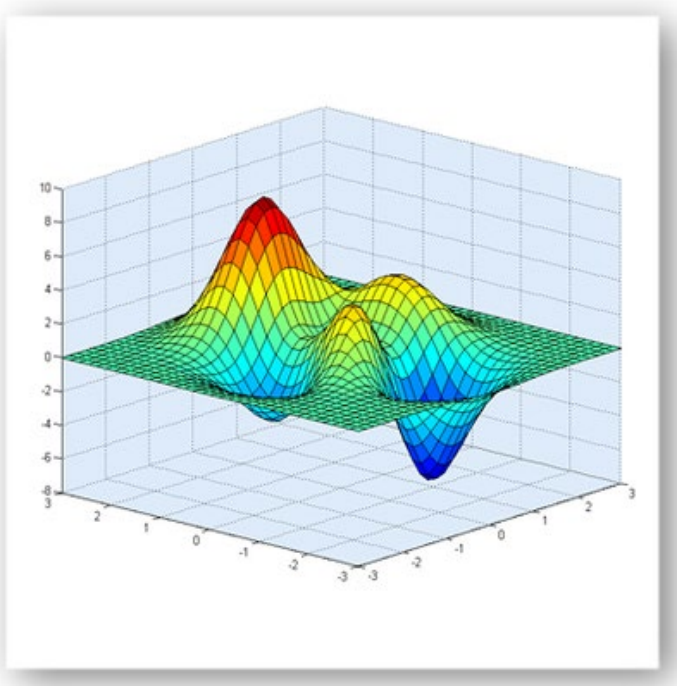
- **Agriculture:**
  - Intelligent Nature-Inspired Olfactory Sensors Engineered to Sniff (iNOSES) for Real-Time Methane Monitoring
  - Policy for and Regulation of Agricultural Methane Emissions in the United States
  - Methane Abatement in Livestock: Making Markets for Feed Additives in the Global North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

Fifteen 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
  - Advancing Methane Entrepreneurship

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 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

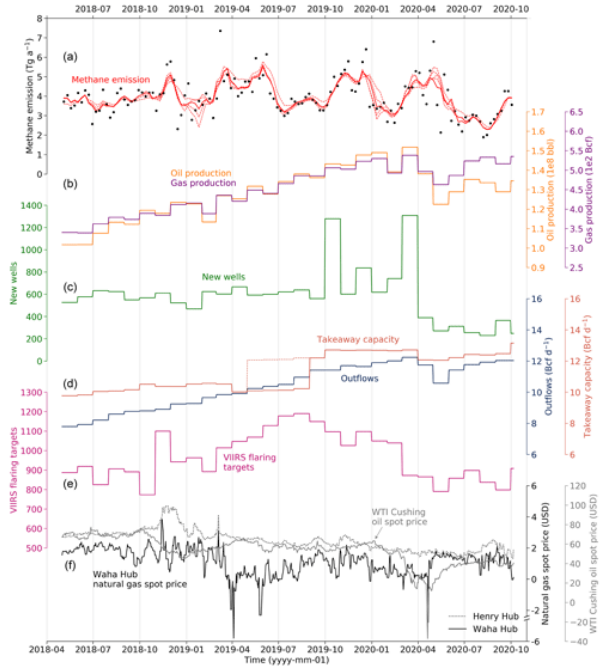
The Market and Climate Implications of U.S. LNG Exports

- **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

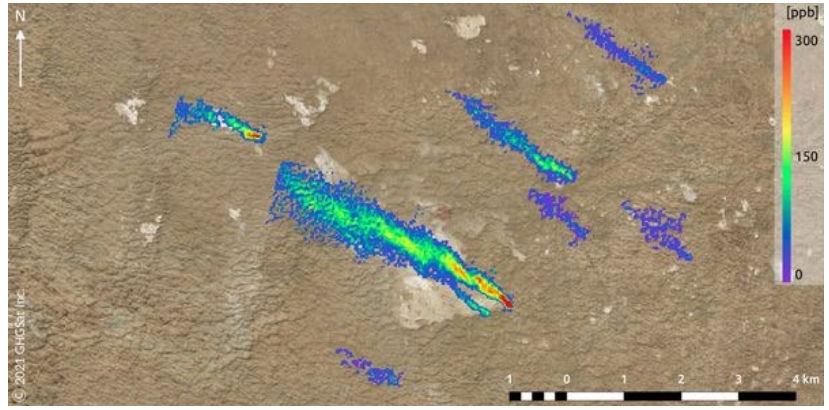
- **Goal:**
  - Based on research from first year, explore how natural-gas producers may react to a range of policy options targeting midstream congestion and changes in natural gas prices
- **Specifically:**
  - Assess effectiveness of flaring restrictions, given limited enforcement capacity
  - Consider 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

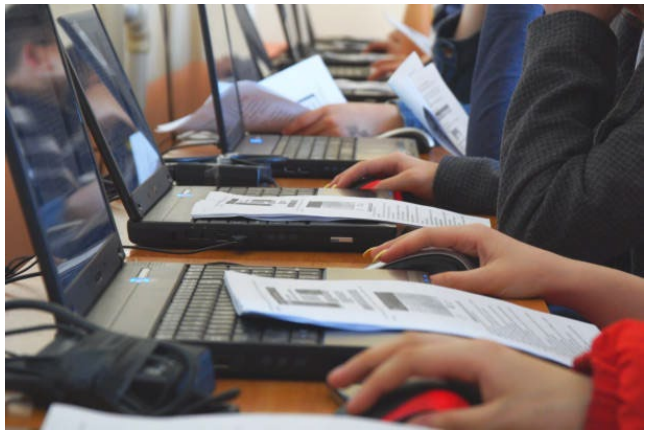
- **Goal:**
  - Develop modes of collaboration with O&G industry in Appalachian region to develop reproducible steps for detecting and mitigating methane emissions
- **Specifically:**
  - Notify companies of emissions detected in remote sensing observations by the project team using MethaneAIR
  - Compare 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 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

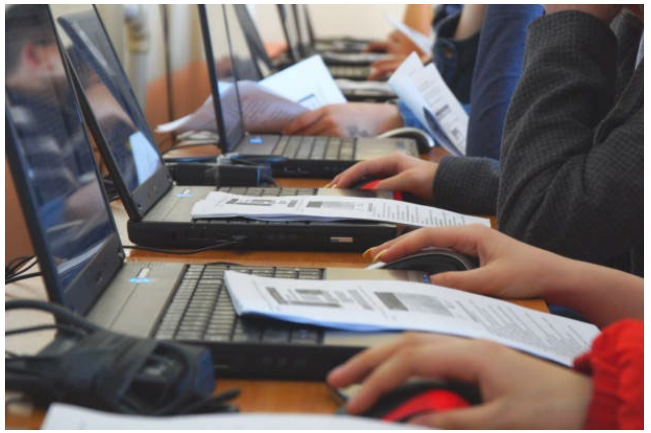
- **Goal:**
  - Execute (remote) workshops to enable users to infer methane emissions from satellite data
- **Specifically:**
  - User-friendly, open-code Integrated Methane Inversion (IMI) tool on Amazon Web Services (AWS) will enable stakeholders with no prior expertise to conduct inversions, visualization, 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**
  - First on-line workshop held in 2024; video made available; planning more workshops

Advancing Methane Entrepreneurship

- **Goal:**
  - Advance entrepreneurship as well as research by bringing together entrepreneurs and academic researchers
- **Specifically:**
  - Convene a one-day workshop at Harvard for exchanges between leading entrepreneurs in the methane space and researchers at Harvard
  - Identify challenges, opportunities, and open questions that shape the business case at start-ups/companies
  - Mutual learning among entrepreneurs, and between entrepreneurs and academics that can enable innovation and commercialization of products, techniques, and equipment, while also serving to inform future research on methane emissions reductions



- **Leaders:**
  - *Peter Tufano* – Harvard Business School
  - *James Matheson* – Harvard Business School
- **Activity & Progress**
  - First workshop to be held in Fall 2025

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/

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