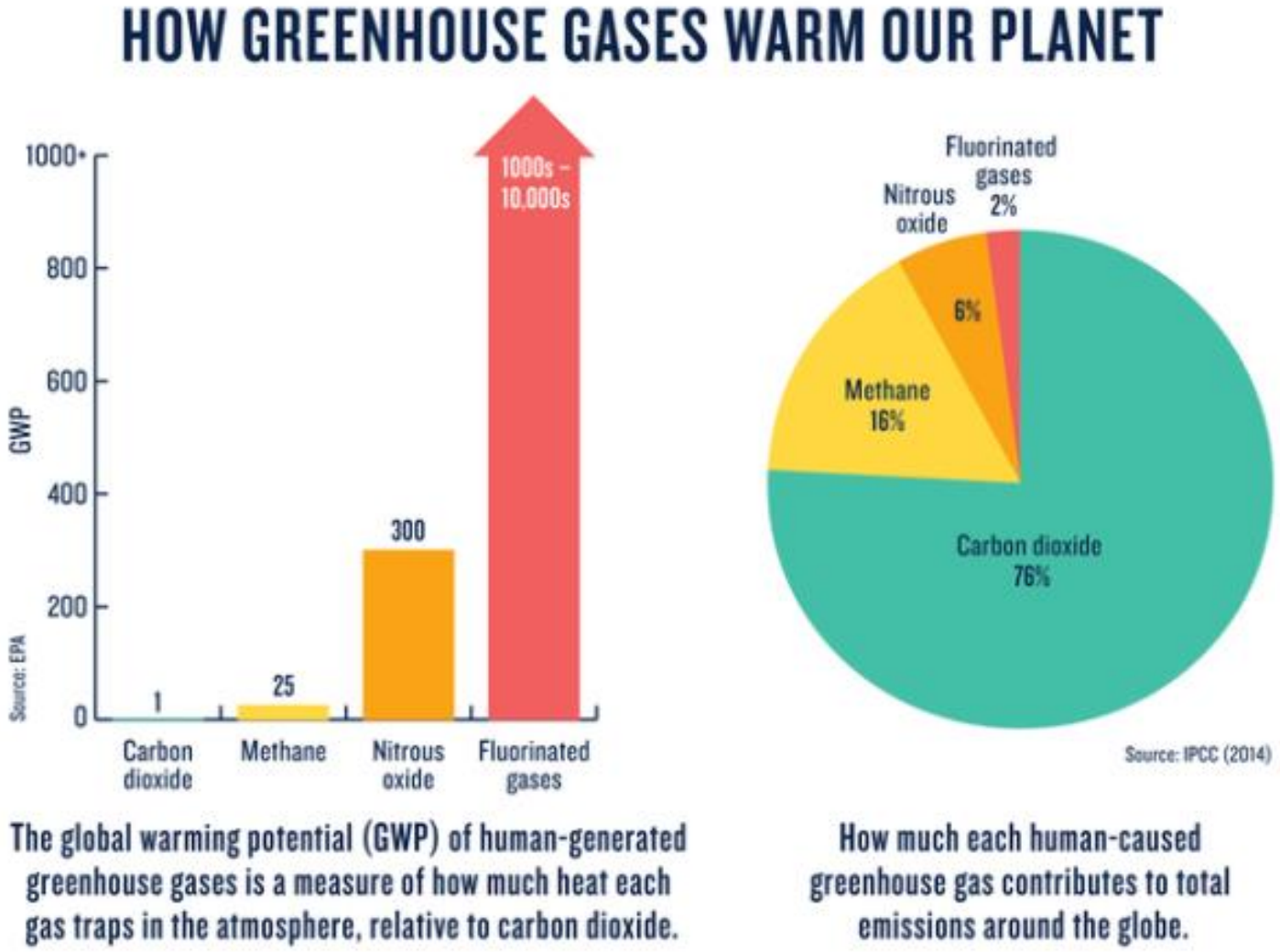


# Methane, the Other Greenhouse Gas: Challenges and Opportunities

# Introducing Performatica

A **non-profit ecosystem framework** for social innovation.

*"Connect and Be Connected" for social good*

Performatica Foundation

*Community/Social Projects*

**Working in teams globally**

- **Technology & Applications**
- **Strategy & Management**
- **Leadership Training**
  - **Webinars**

Performatica Ventures

*Commercial/ Enterprise Projects*

**Two entities working towards Transformation**

**Digital** & **Social** innovation through sustainable projects and leadership development

- ✓ Awareness of ESG issues
- ✓ Access to industry experts
- ✓ Collective thinking on key global issues
- ✓ Purposeful Organization models to create value at individual, business & community levels

visit
www.performatica.net

A **for-profit venture** focused on ESG Consulting, leadership training & digital innovation; serves as a funding source for the Foundation.

*"Aspire and Be Inspired" by industry experts*

# Agenda


| Section | Topic | Speakers |
|---|---|---|
| Introduction | Introduction on Performatica | Murthy Divakaruni |
| Context Setup | Introduction to the Topic and Panelists | Dr Ram Seetharam |
| Methane - Climate Challenge & Solutions | A serious climate problem with achievable solutions | Dr David Lyon |
| Methane - Catalytic Oxidation | Catalytic Oxidation of Methane: Make it a Win-Win | Dr Mike Harold |
| Methane: The Greenest Greenhouse Gas | One Pathway Towards Using it to Advantage | Edan Prabhu |
| Panel Discussion | Discussion and Q&As | Moderated by Dr Ram Seetharam |
| Key Takeaways | Key Digital Solutions | Murthy Divakaruni |

# Methane, the Other Greenhouse Gas – Challenges and Opportunities

**Performatica Webinar Series**

November 16, 2021

PERFORMATICA
STRATEGY · OPERATIONS · TECHNOLOGY · ALLIANCES

**Moderator:**
**Dr. Ram Seetharam**,
Energy Center Officer @
UNIVERSITY of HOUSTON
UH ENERGY

# Focus on Methane

- Climate action efforts focused on Carbon Dioxide ($CO_2$) reduction.
- Methane ($CH_4$), the other greenhouse gas, does not get as much attention.
- Methane likely to be part of energy mix for several more decades as a "bridging" fuel to facilitate the transition to low- to zero-carbon energy world
- Low carbon footprint, high energy content and affordable
- However, Methane Global Warming Potential (GWP) 28–36 times greater than $CO_2$ over 100 years, 80 times in a shorter time scale of 10 years.
- Critical need to reduce anthropogenic methane emissions of ~600 MM ton $CO_2e$,~10 percent of all U.S. greenhouse gas emissions from human activities.
- Critical need to capture and utilize ~35-50 percent of methane generated by natural sources such as wetlands

# Methane Abatement

PERFORMATICA
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UNIVERSITY of HOUSTON
UH ENERGY

## COP26: US and EU announce global pledge to slash methane

## White House announces new methane regulations, kicking off global pledge


We estimate that it is technically possible to avoid around three quarters of today's methane emissions from global oil and gas operations. Moreover, a significant share of these could be avoided at no net cost, as the cost of the abatement measure is less than the market value of the additional gas that is captured. Natural gas prices

Source: IEA

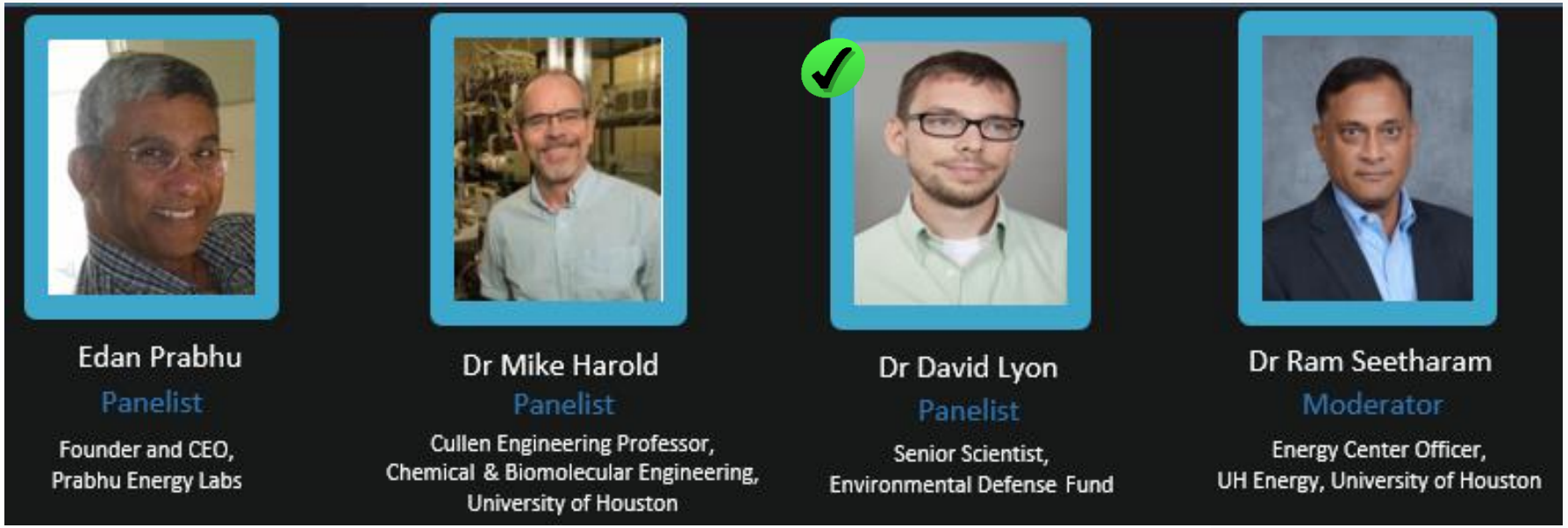
"These emissions are avoidable, the solutions are proven and even profitable in many cases. And the benefits in terms of avoided near-term warming are huge."
- Fatih Birol, IEA Executive Director

*Can we effectively use methane as a "bridge" fuel, while minimizing its impact on global warming ?*

# Our Panelists

- **Dr. David Lyon**, Senior Scientist at the Environmental Defense Fund.
- **Dr. Mike Harold**, Cullen Engineering Professor of Chemical and Biomolecular Engineering at the University of Houston
- **Edan Prabhu**, Founder and CEO of Prabhu Energy Labs

# Agenda

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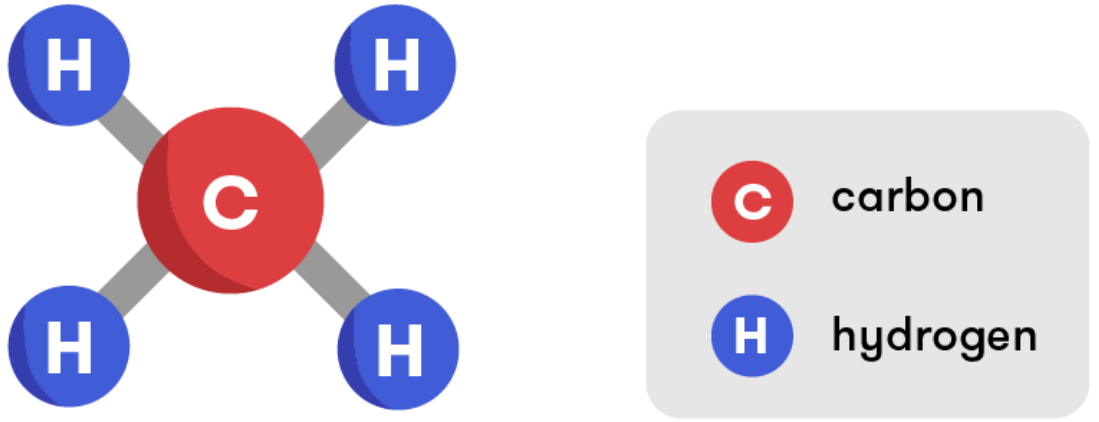
# Methane:
## A serious climate problem with achievable solutions

David Lyon, Ph.D.
Senior Scientist
Environmental Defense Fund
dlyon@edf.org

EDF
ENVIRONMENTAL DEFENSE FUND
Finding the ways that work


- EDF is a non-partisan, non-profit environmental advocacy organization
- Funded by our 2.5 million members and philanthropy
- ~750 staff working in 26 countries
- Guided by science and economics to find solutions to environmental challenges
- Works on diverse issues including climate, energy, oceans, ecosystems, and health

# What is methane?

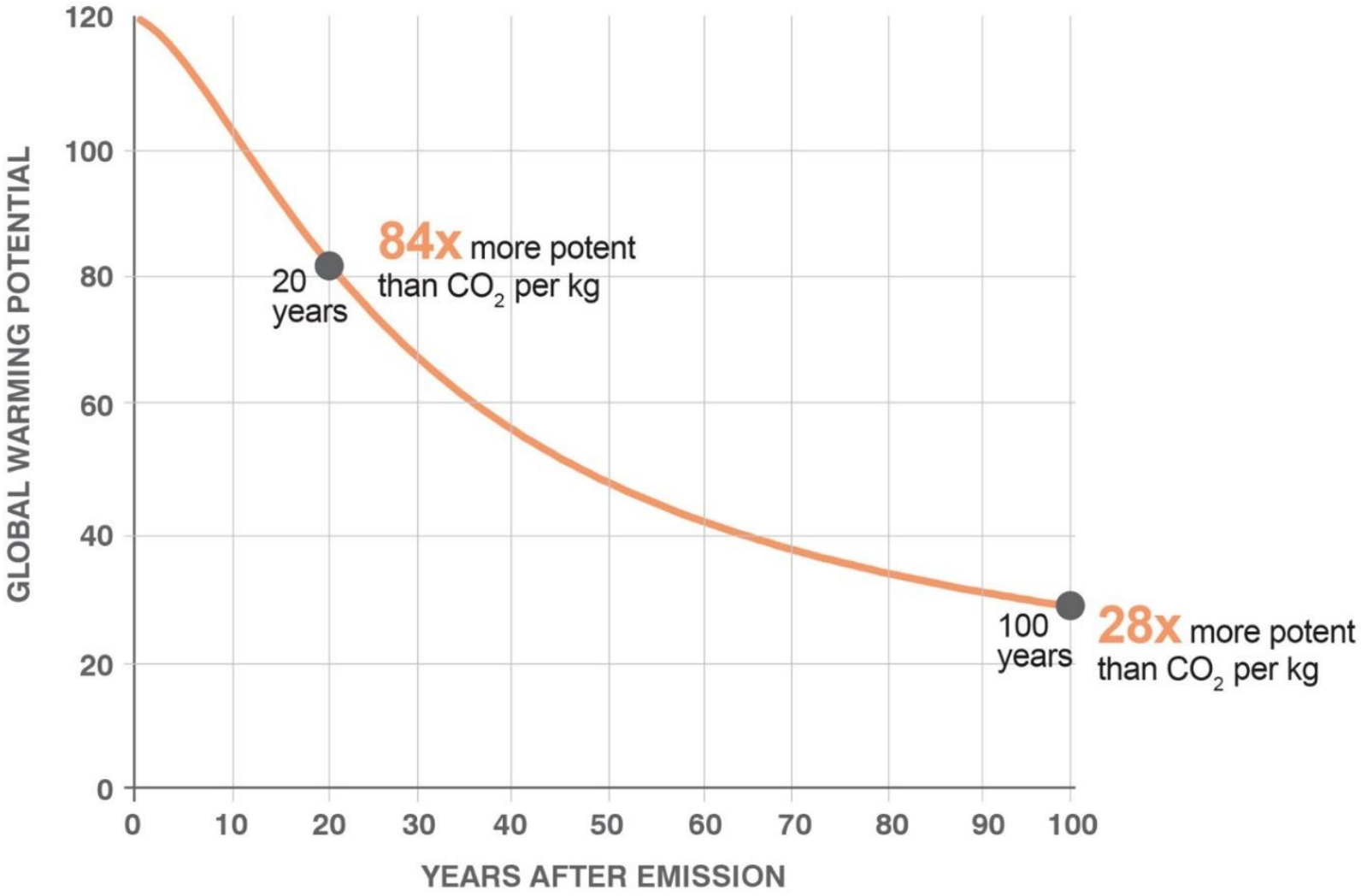



https://www.science.org.au/curious/earth-environment/methane

- Simplest hydrocarbon: $CH_4$
- Main constituent of natural gas
- Produced by microbes in low oxygen environments like wetlands, landfills, and cow stomachs
- Odorless and invisible
- Non-toxic but explosive
- Powerful but short-lived greenhouse gas

https://www.scientificamerican.com/article/how-bad-of-a-greenhouse-gas-is-methane/

# Methane is a powerful greenhouse gas.

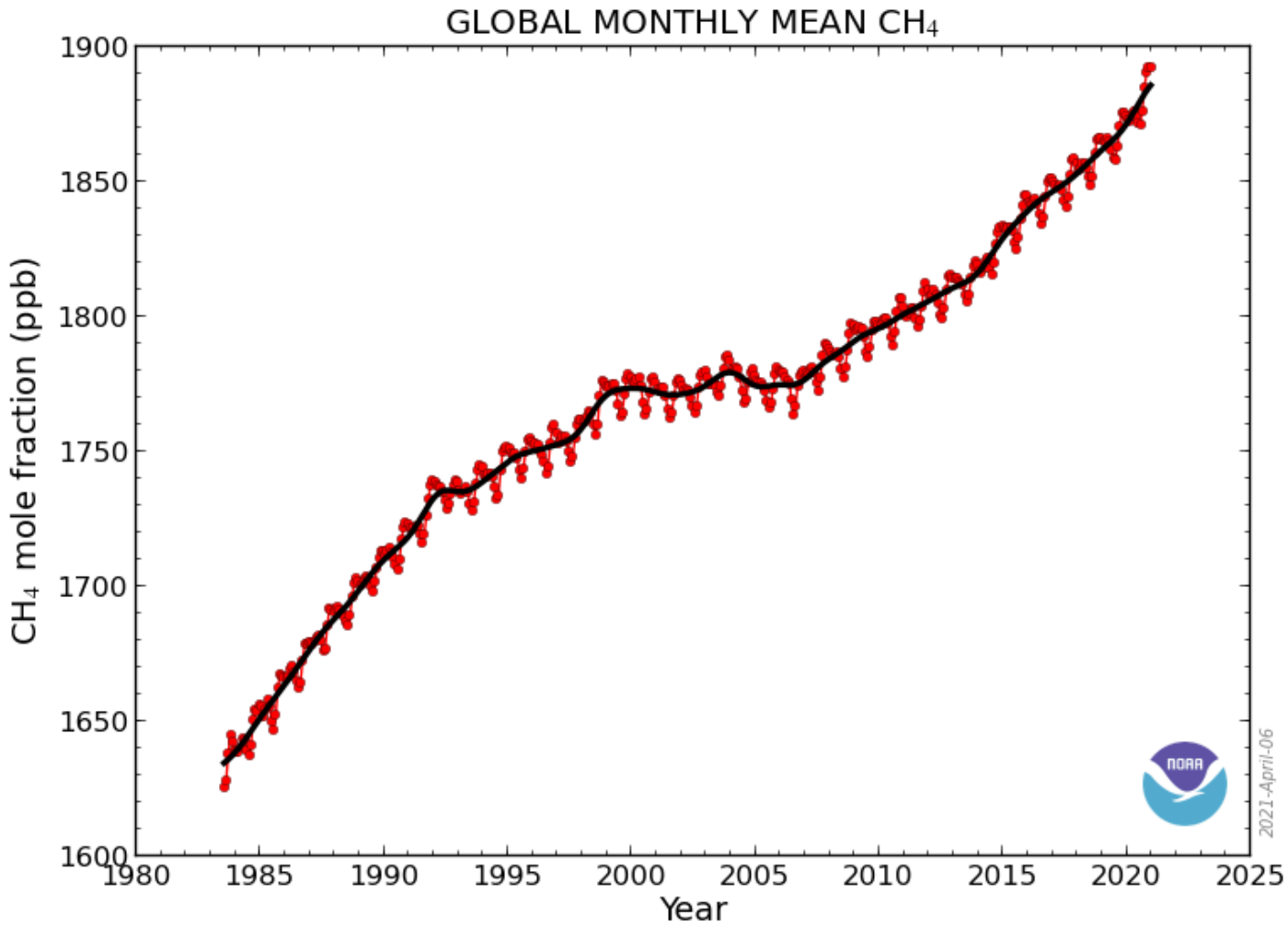



Methane only lasts ~10 years in the atmosphere, but traps 80+ times more heat than carbon dioxide per pound over 20 years.

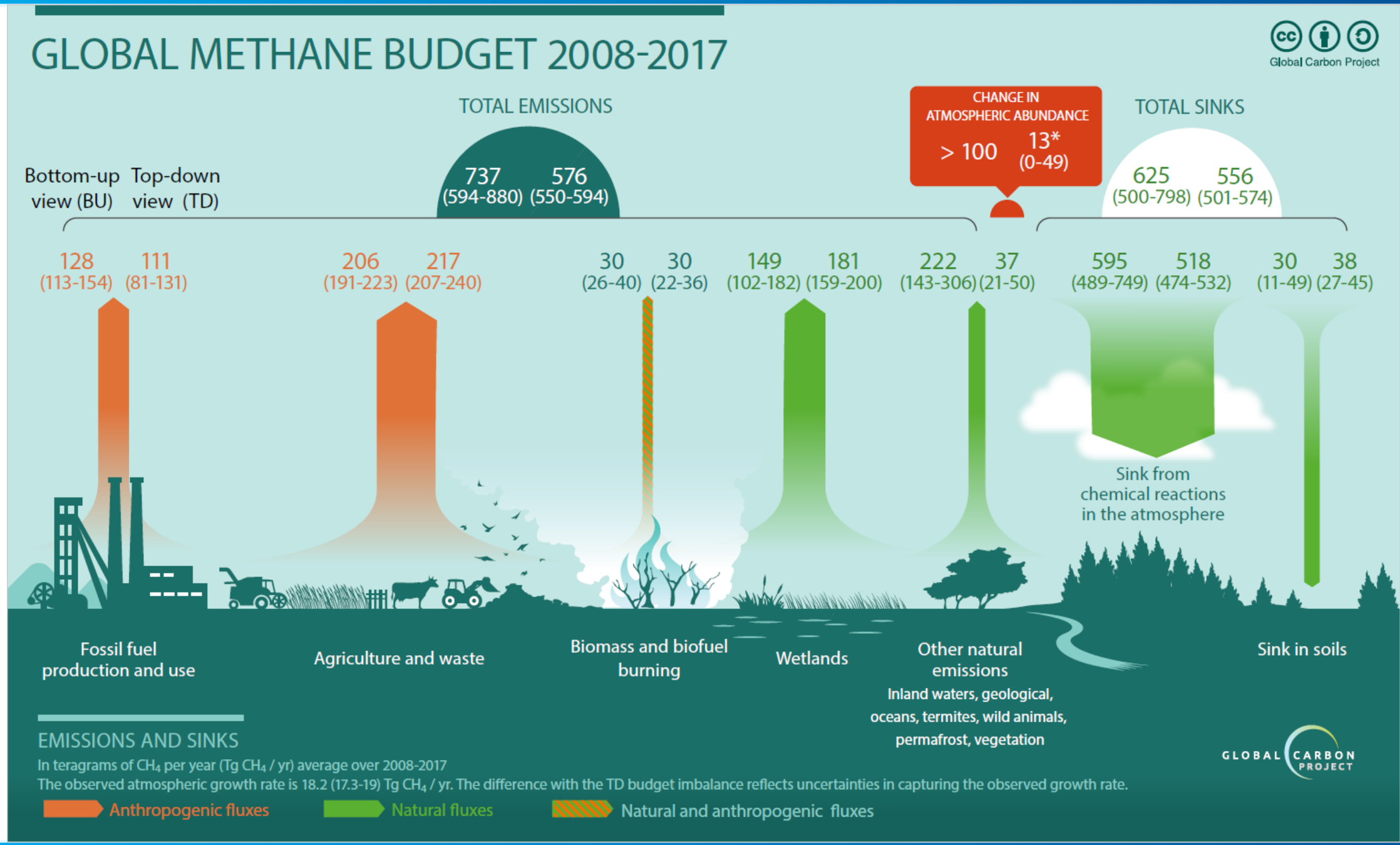
Methane is responsible for ~25% of man-made global warming.

# Atmospheric methane concentration is rising.

- Global methane concentrations have almost tripled since the industrial era
- Concentrations continue to increase ~5 to 15 parts per billion per year




Source: https://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/



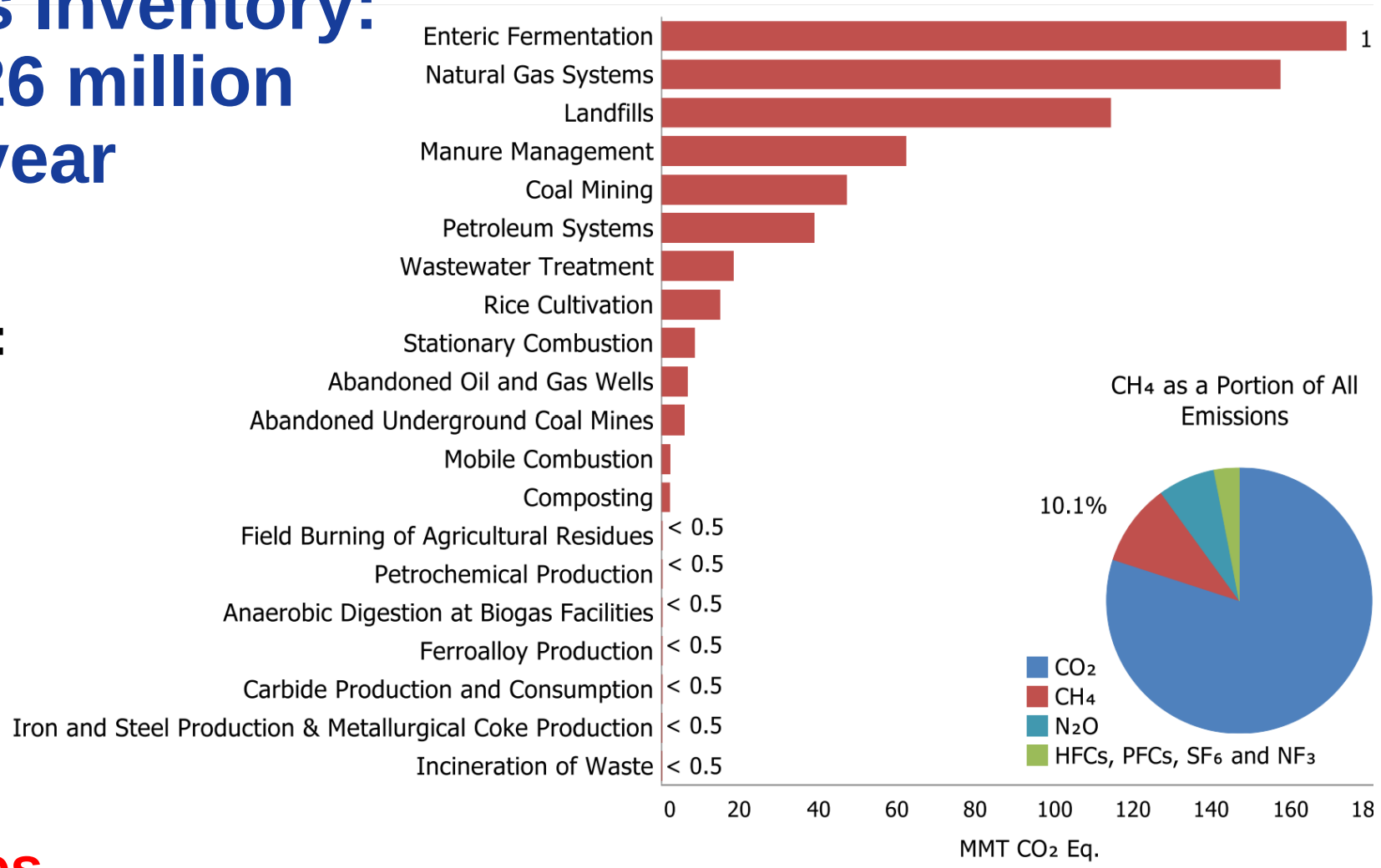

Source: https://www.globalcarbonproject.org/methanebudget/index.htm

# EPA Greenhouse Gas Inventory: United States emits 26 million metric tons $CH_4$ per year

**Human-caused national methane emissions in 2019:**

- 37% livestock (10 MMT)
- 31% oil & gas (8.1 MMT)
- 17% landfills (4.6 MMT)
- 8% coal mines (2.1 MMT)

**Measurement studies find U.S. O&G $CH_4$ emissions are ~70% higher than EPA estimates**



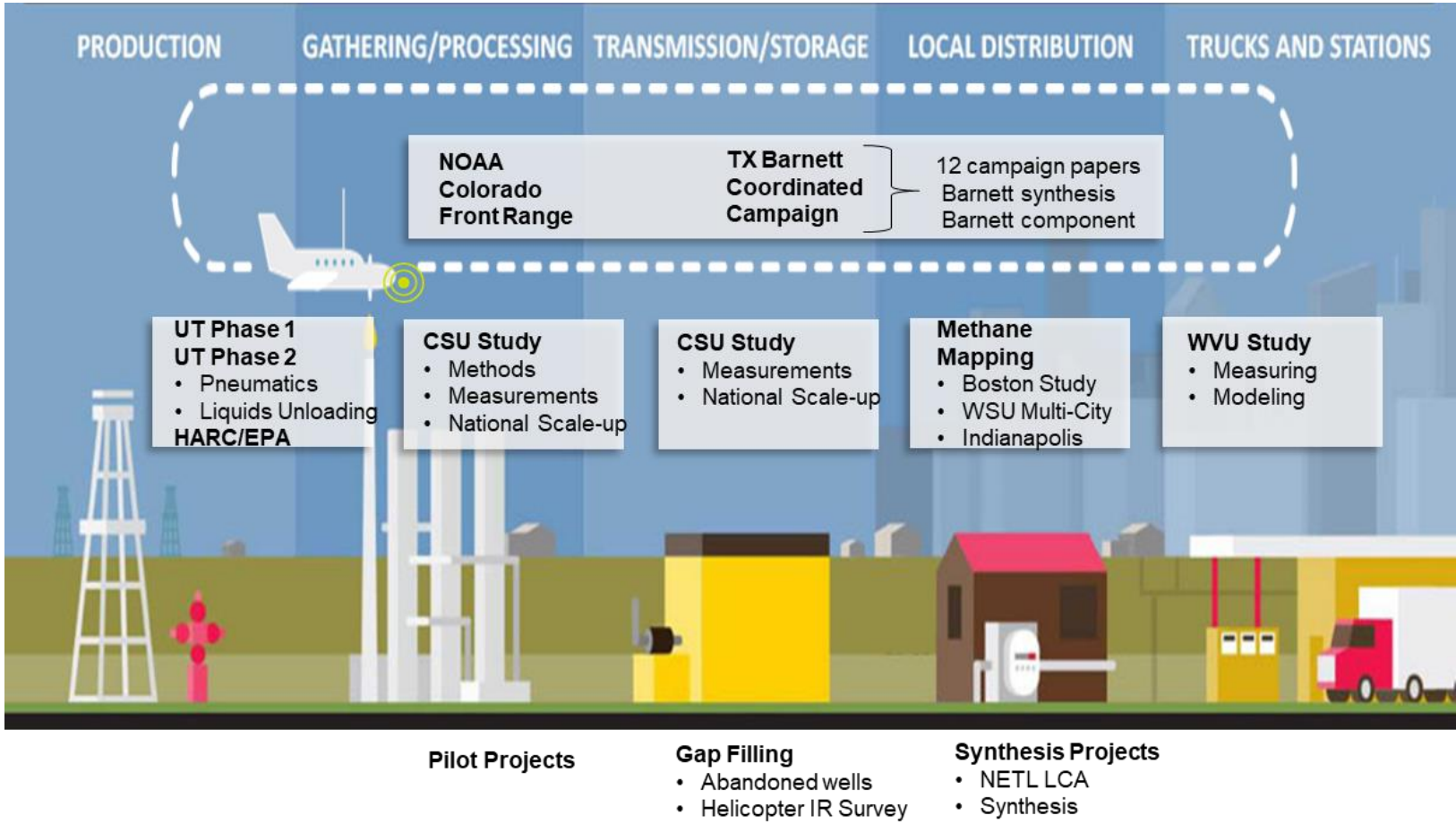

Sources: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks
http://blogs.edf.org/energyexchange/files/2021/04/2019-CH4-Estimate.pdf

# Oil and Gas Methane Emissions

- **Fugitive emissions (unintentional)**
  - Equipment leaks
  - Malfunctions
- **Vented emissions (intentional)**
  - Well completion flowback
  - Pneumatic controllers
  - Tank flashing
  - Liquids unloading
  - Blowdowns
- **Combustion emissions**
  - Flares
  - Compressor engines
  - Heaters and other process equipment

# EDF's Oil and Gas Methane Research

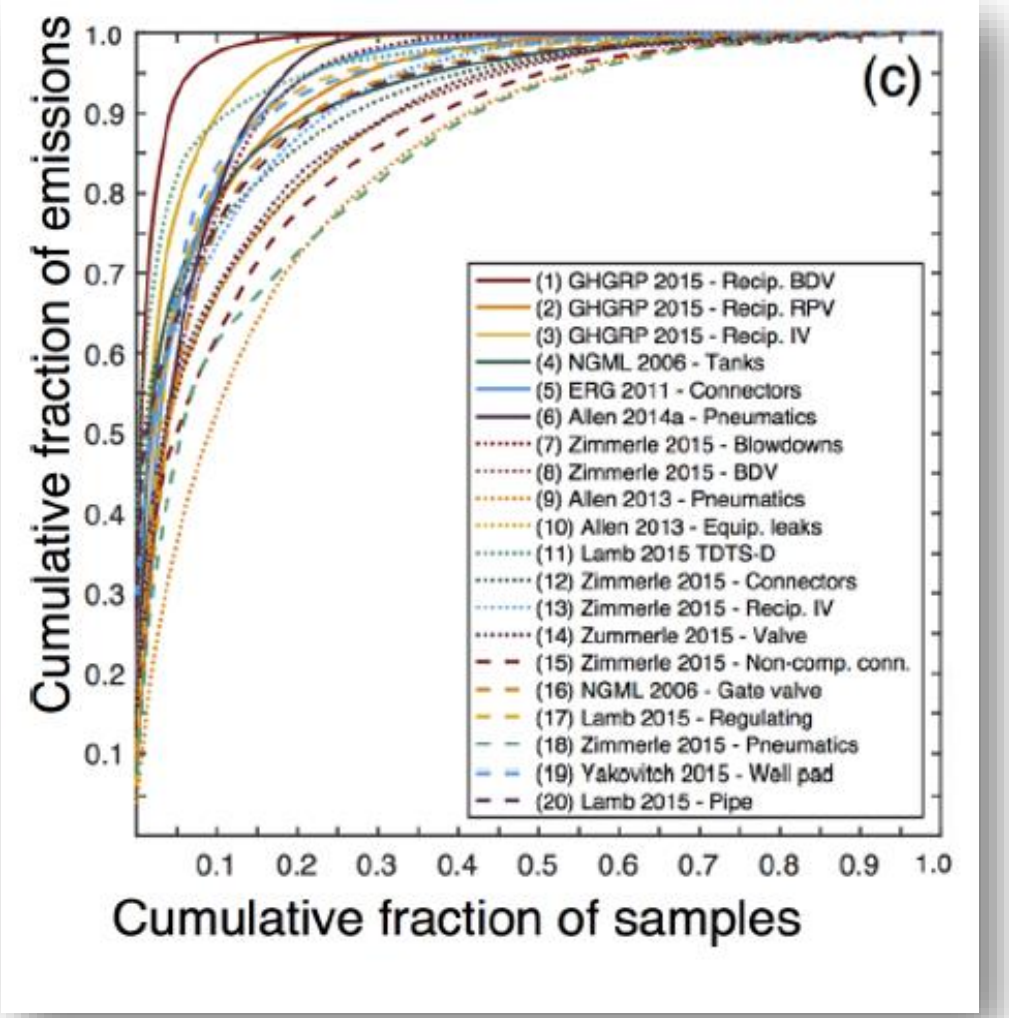
- Sponsored 16+ U.S. O&G methane studies chain since 2012
- Collaboration with 50+ universities and 50+ O&G companies
- 40+ published peer-reviewed studies based on data
- EDF's O&G $CH_4$ research has expanded globally




https://www.edf.org/climate/methane-research-series-16-studies

# Major Findings from EDF Studies

- Emissions occur across the O&G supply chain but are highest from production and gathering infrastructure.
- The highest emitting 5-10% of sources account for the majority of emissions.
- Bottom up inventory methods used by governments and operators tend to underestimate emissions.




https://doi.org/10.1021/acs.est.6b04303

# U.S. O&G $CH_4$ emissions are 2.3% of natural gas production, ~70% higher than EPA estimates

Science REPORTS

10.1126/science.aar7204

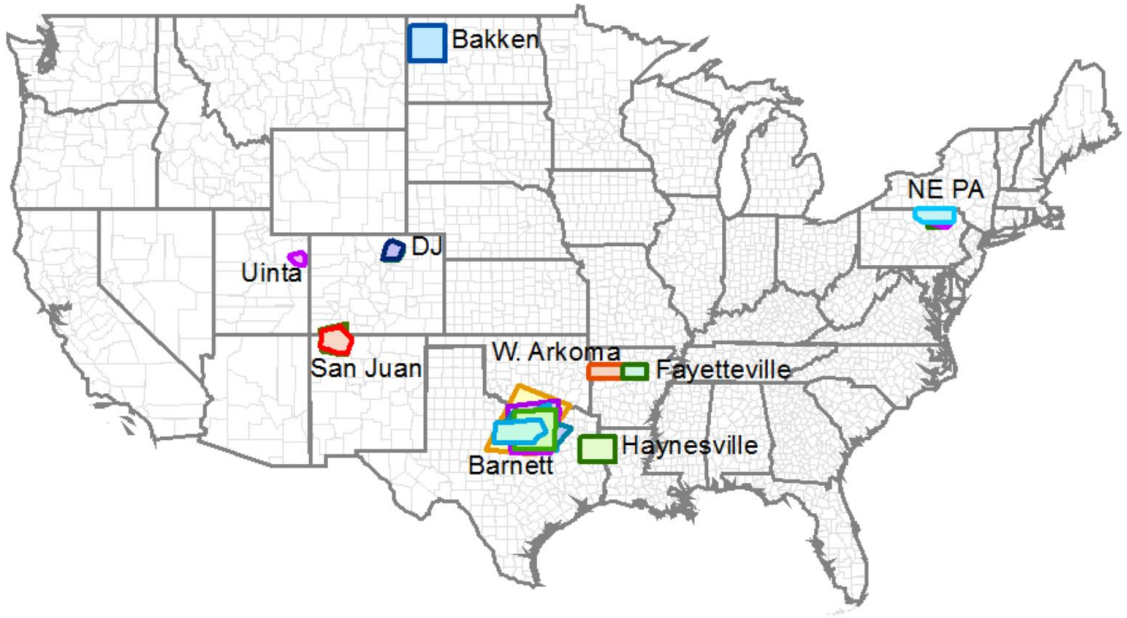
Cite as: R. A. Alvarez *et al.*, *Science* 10.1126/science.aar7204 (2018).

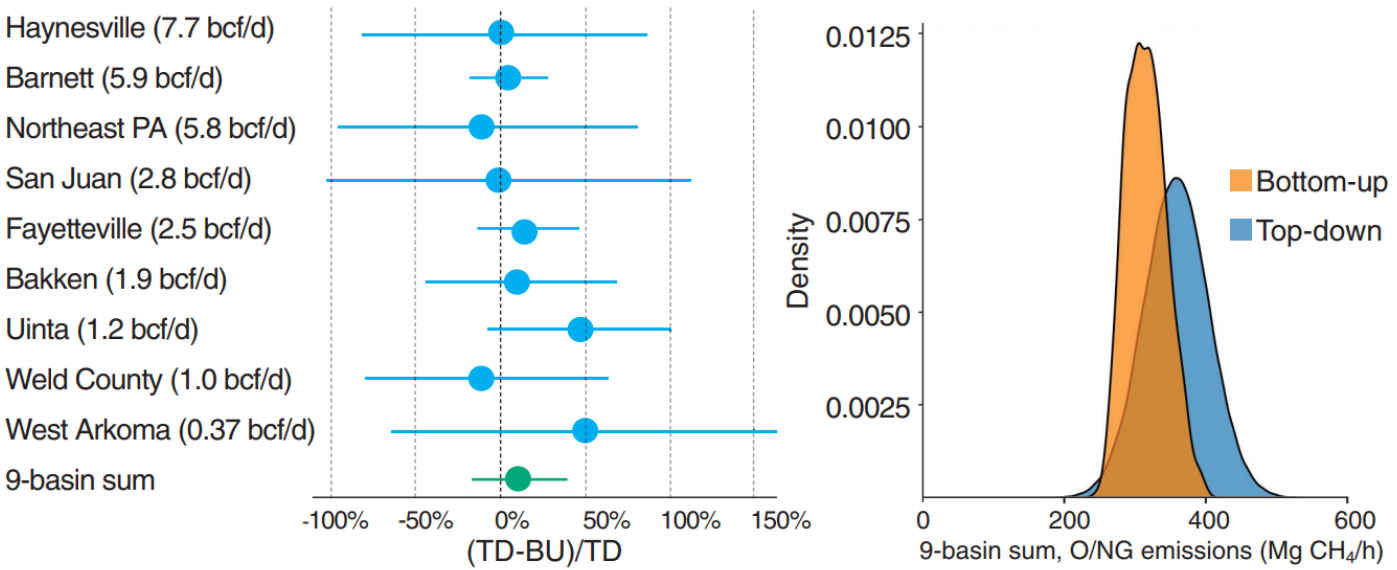
## Assessment of methane emissions from the U.S. oil and gas supply chain

**Ramón A. Alvarez[1]*, Daniel Zavala-Araiza[1], David R. Lyon[1], David T. Allen[2], Zachary R. Barkley[3], Adam R. Brandt[4], Kenneth J. Davis[3], Scott C. Herndon[5], Daniel J. Jacob[6], Anna Karion[7], Eric A. Kort[8], Brian K. Lamb[9], Thomas Lauvaux[3], Joannes D. Maasakkers[6], Anthony J. Marchese[10], Mark Omara[1], Stephen W. Pacala[11], Jeff Peischl[12,13], Allen L. Robinson[14], Paul B. Shepson[15], Colm Sweeney[13], Amy Townsend-Small[16], Steven C. Wofsy[6], Steven P. Hamburg[1]**

[1]Environmental Defense Fund, Austin, TX, USA. [2]University of Texas at Austin, Austin, TX, USA. [3]The Pennsylvania State University, University Park, PA, USA. [4]Stanford University, Stanford, CA, USA. [5]Aerodyne Research Inc., Billerica, MA, USA. [6]Harvard University, Cambridge, MA, USA. [7]National Institute of Standards and Technology, Gaithersburg, MD, USA. [8]University of Michigan, Ann Arbor, MI, USA. [9]Washington State University, Pullman, WA, USA. [10]Colorado State University, Fort Collins, CO, USA. [11]Princeton University, Princeton, NJ, USA. [12]University of Colorado, CIRES, Boulder, CO, USA. [13]NOAA Earth System Research Laboratory, Boulder, CO, USA. [14]Carnegie Mellon University, Pittsburgh, PA, USA. [15]Purdue University, West Lafayette, IN, USA. [16]University of Cincinnati, Cincinnati, OH, USA.

*Corresponding author. E-mail: ralvarez@edf.org



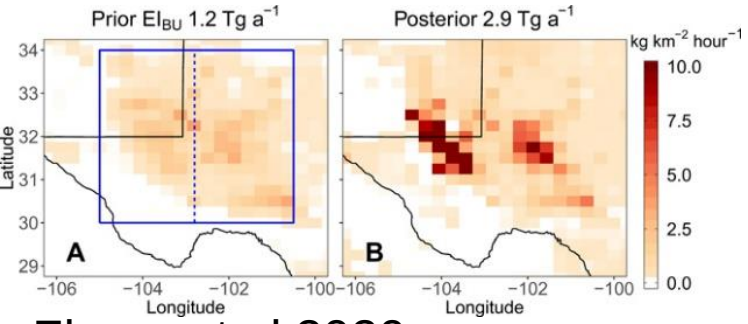



# PermianMAP

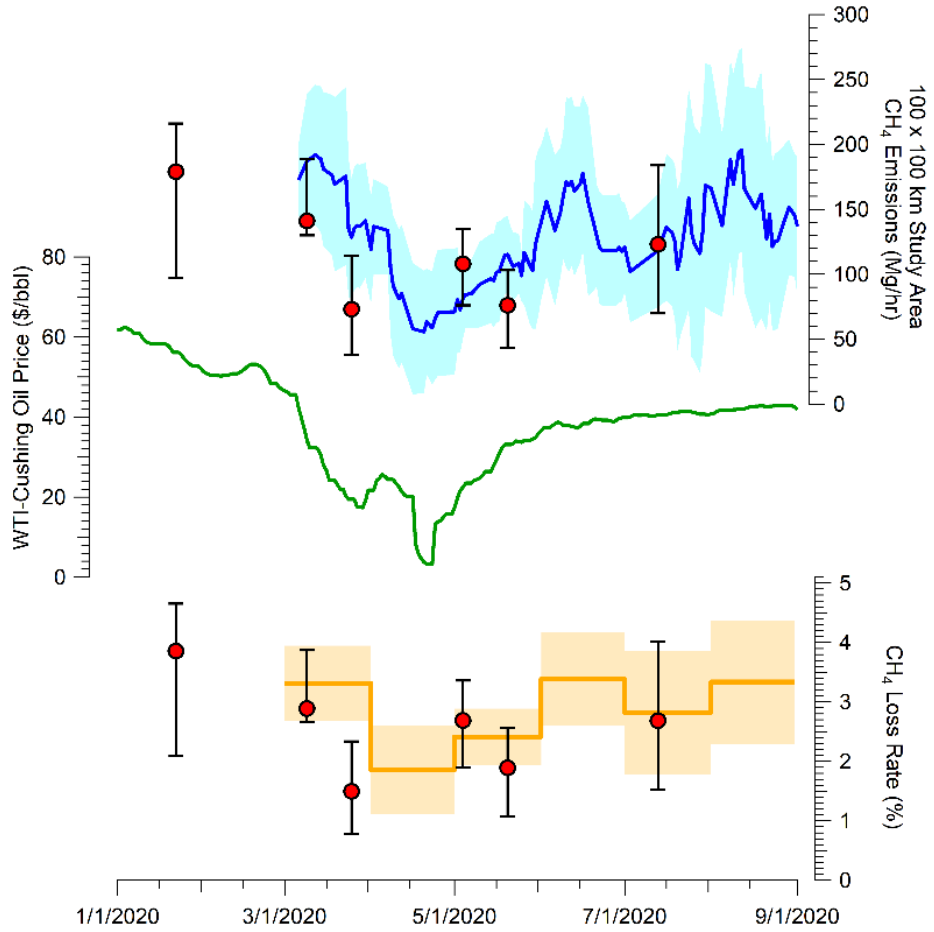
## Methane Analysis Project

## Going deep into the world's largest oilfield to track methane pollution

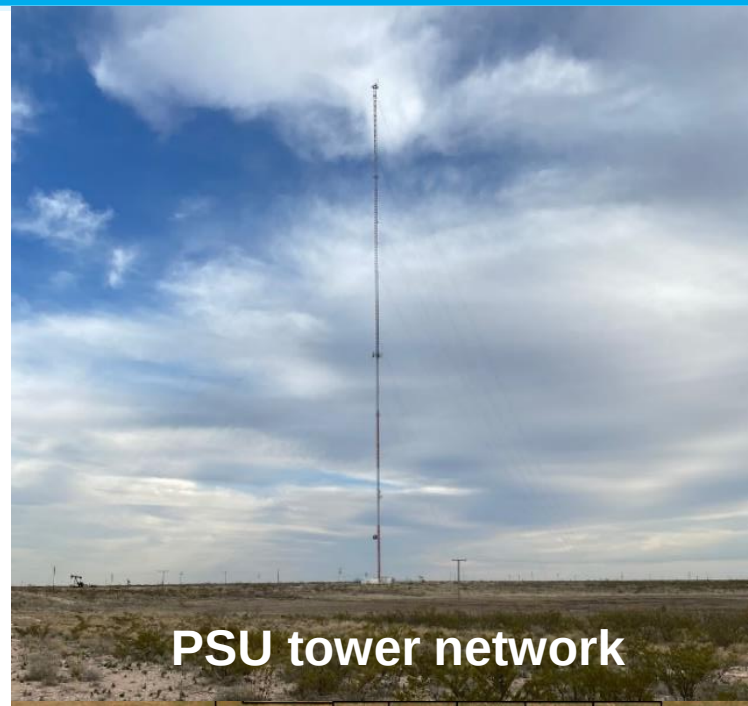
# Regional total methane emissions

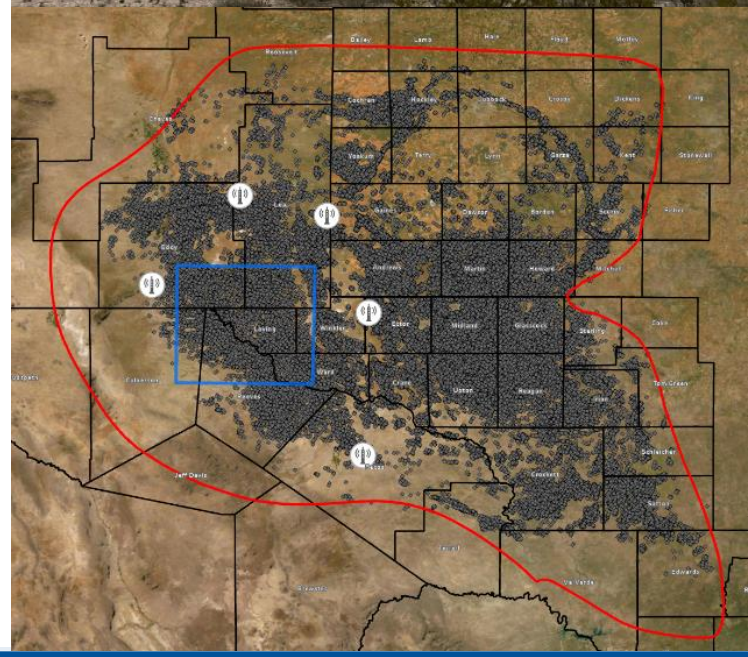




Zhang et al 2020

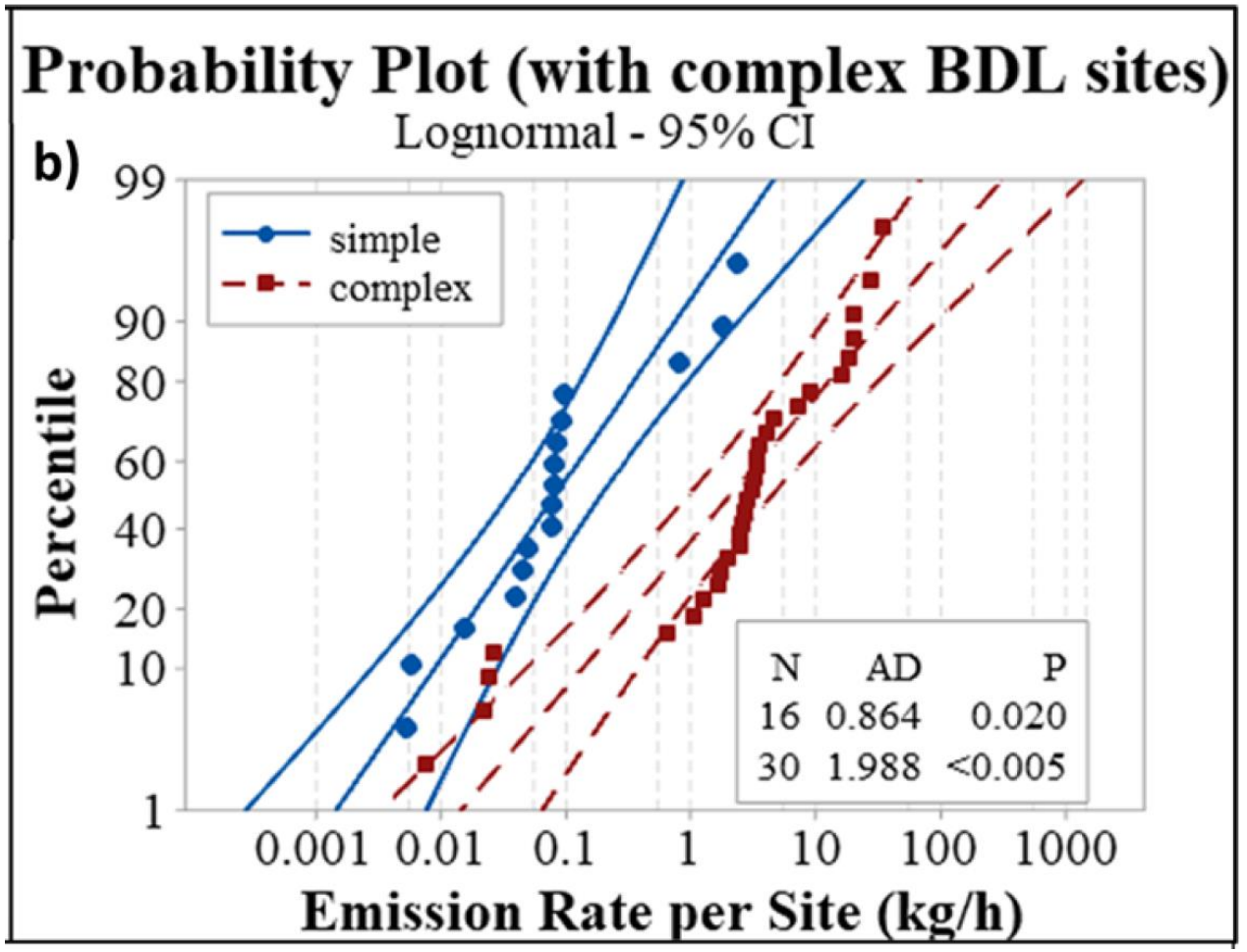

Lyon et al 2021: [10.5194/acp-21-6605-2021](https://doi.org/10.5194/acp-21-6605-2021)



# Vehicle-based, site-level quantification (EPA Other Test Method 33a)



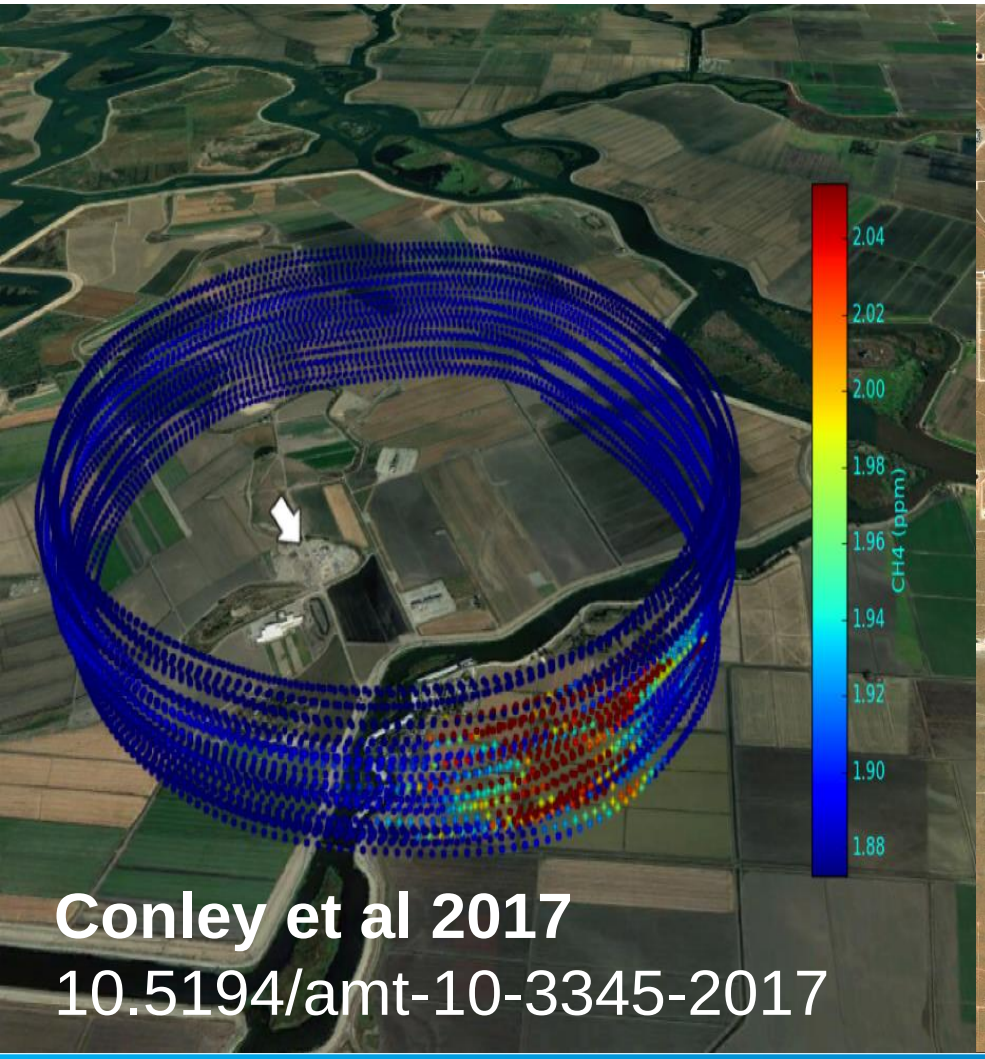



Robertson et al 2021: [10.1021/acs.est.0c02927](https://doi.org/10.1021/acs.est.0c02927)

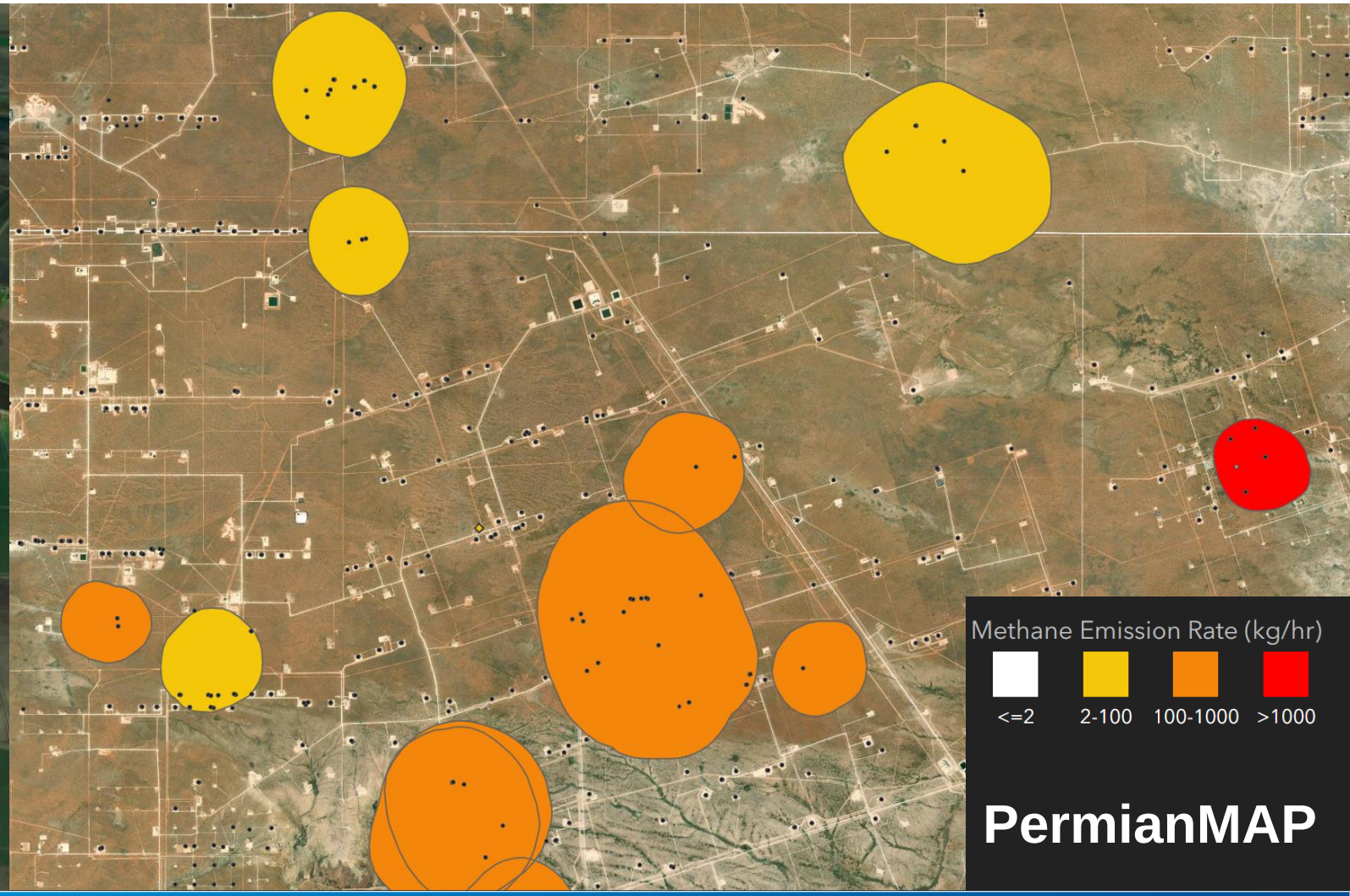
# Optical gas imaging of malfunctioning flares and other large emission sources

Leak Surveys, Inc.

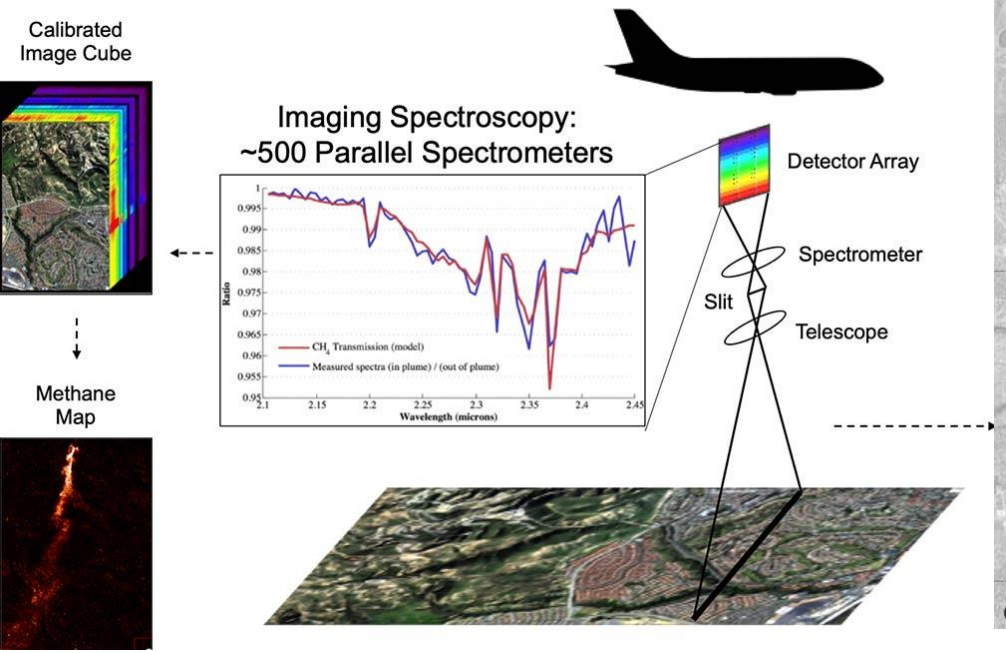
# Aerial mass balance quantification of multi-site areas (~1 - 4 square miles)

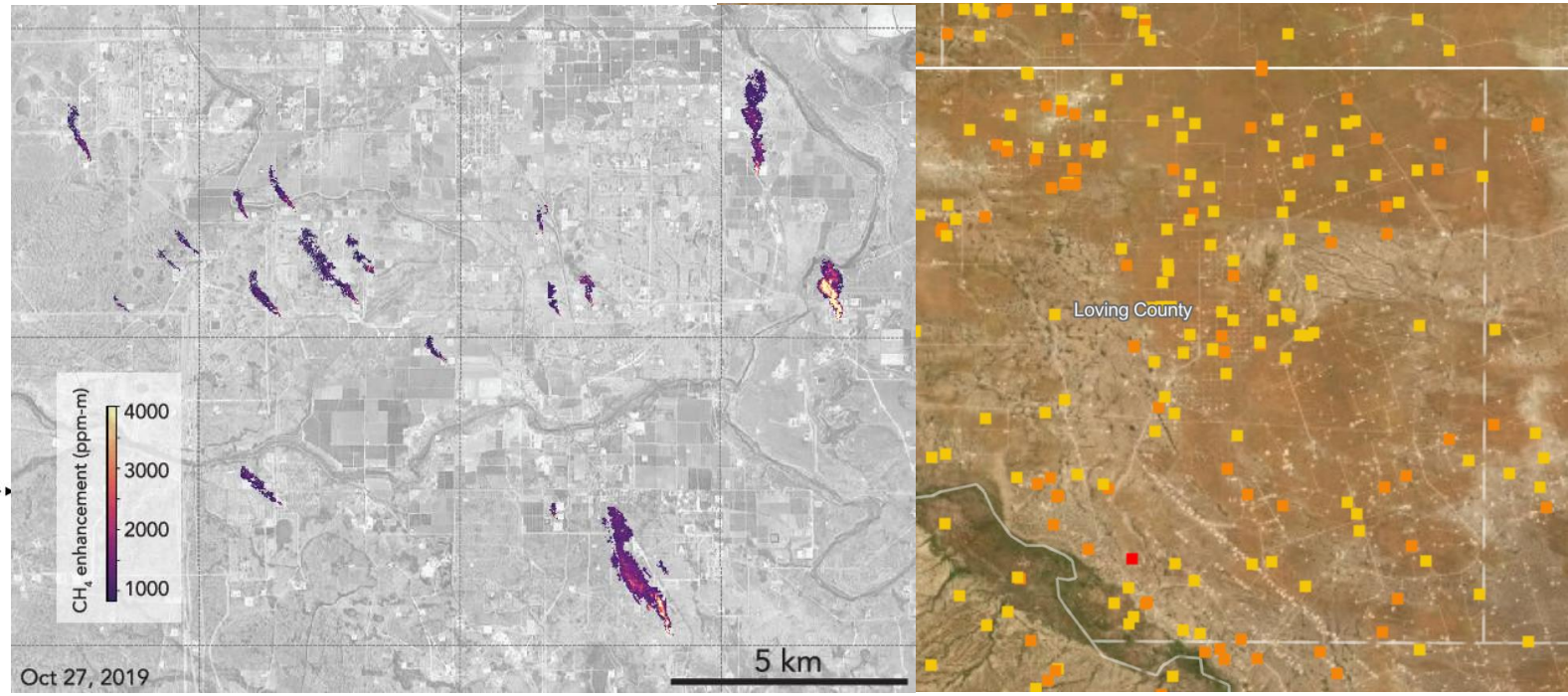



**Conley et al 2017**
10.5194/amt-10-3345-2017



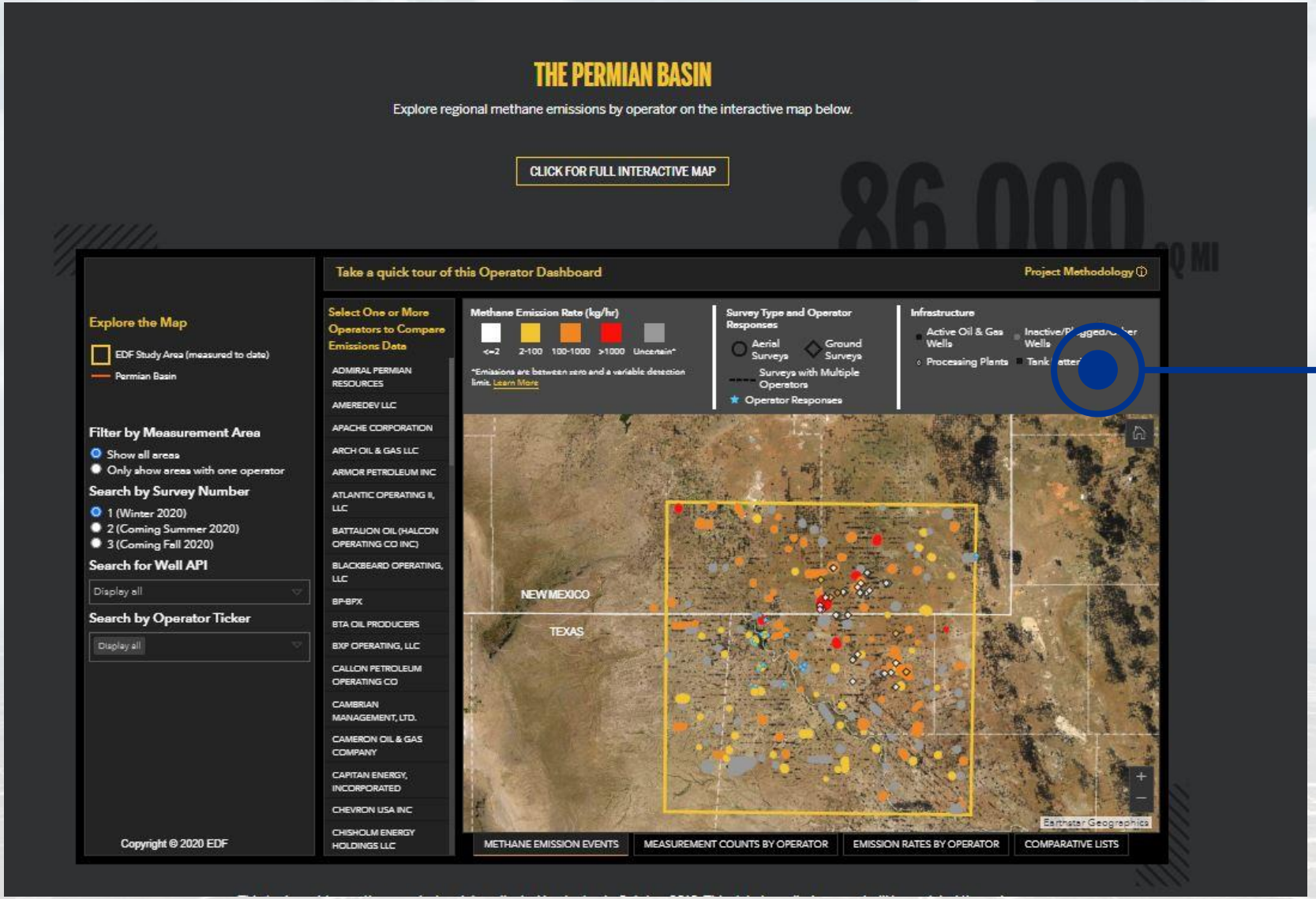
# Aerial remote sensing quantification and plume imaging of >1000 large emission sources




https://carbonmapper.org/our-mission/technology/

Cusworth et al 2021 10.1021/acs.estlett.1c00173 PermianMAP




# Delivering the Data

- **Videos, photos, and emissions data available for viewing and download at permianmap.org**


https://www.methanesat.org

# Summary

- Oil and gas methane emissions are high and underestimated by traditional methods.
- There are numerous cost-effective technologies to detect and mitigate methane emissions.
- Regulations, stakeholder influence, and economics are incentivizing many companies to reduce emissions but more action is needed.

Methane hunters Dr. David Lyon (EDF) and Dr. Anna Robertson (U. of Wyoming)

LESLIE VON PLESS / EDF

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# Catalytic Oxidation of Methane: Make it a Win-Win

Mike Harold

Chemical & Biomolecular Engineering Dept.

UNIVERSITY of HOUSTON

# Takeaways

- Natural gas is a clean, domestically-sourced fuel that can reduce the Carbon footprint from transportation and commerce
- Methane slip must be eliminated from CNG-fueled engine exhaust
- New catalyst technologies show promise to make this happen
- Elimination of methane slip from existing engine fleet  and stationary sources contributes to 0.012 gT CO2e reduction
- Reduction in $CO_2$ emissions would be far greater with implementation of dual-fuel CNG+Diesel technology

# Motivation

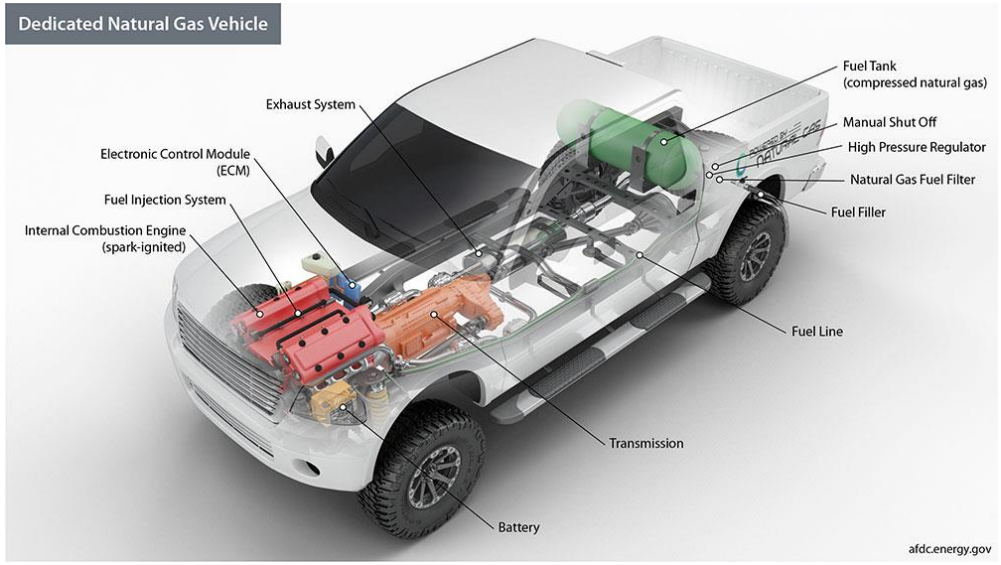
- Natural Gas Vehicles (NGVs) & engines:
  - Significant contributors to $CO_2$ emissions
  - Combusting methane produce less $CO_2$ than diesel or gasoline vehicles
  - $CH_4$ slip is a problem

- Methane is potent Greenhouse Gas
  - $CH_4$ Global Warming Potential ~ 25x that of $CO_2$[1]
  - $CH_4$ emissions >30 mg/mi light-duty vehicle cap count against fuel economy

[1] O. Boucher, P. Friedlingstein, B. Collins, K.P. Shine, The indirect global warming potential and global temperature change potential due to methane oxidation, Environ. Res. Lett. 4 (2009) 044007. doi:10.1088/1748-9326/4/4/044007.

# Motivation, cont.

- Stoichiometric oxidation (spark-ignition) vehicles & engines:
  - Most common in medium/heavy duty applications such as urban buses
  - Utilize Three-way Catalyst (TWC) converter containing Pt+Pd+$CeO_2$
  - TWC converts CO, NOx, NMHCs to $CO_2$, $H_2O$ & $N_2$
  - TWCs are ineffective for $CH_4$ oxidation <400 °C[2]

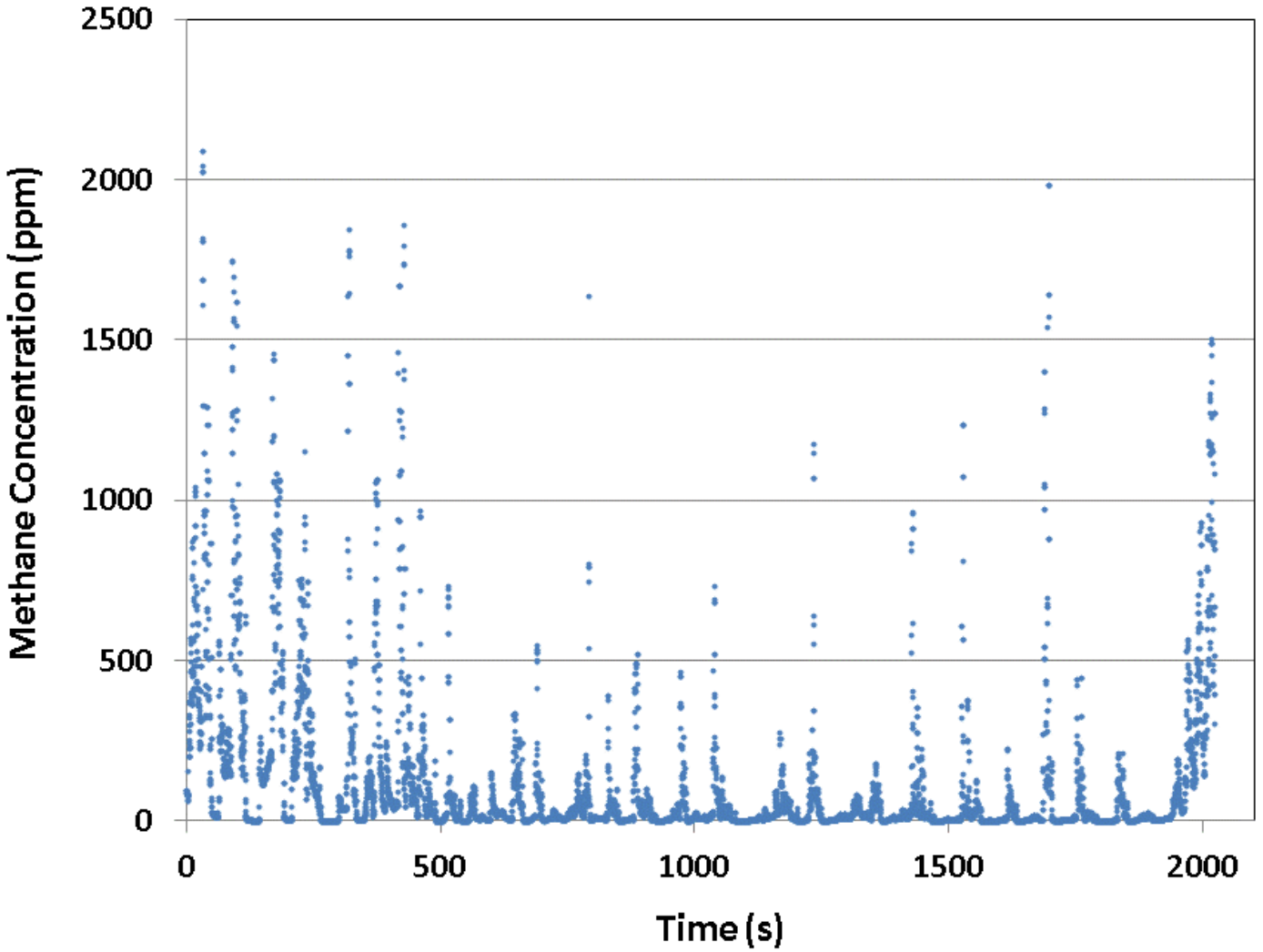



https://afdc.energy.gov/vehicles/how-do-natural-gas-cars-work


https://fmgdesign.com/uds-portfolio/houston-downtown-management-district-greenlink/

[2] P. Gélin, M. Primet, Applied Catalysis B: Environmental, 39 (2002) 1-37.

# Methane Emissions from CNG Bus




Equipped with TWC

Stoichiometric combustion

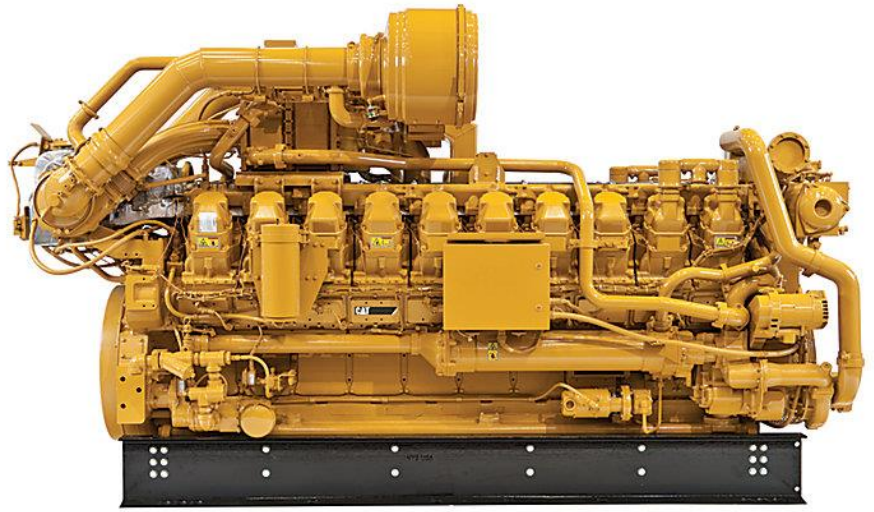
TxCEF

- Data collected on UH heavy-duty chassis dynamometer

# Motivation, cont.

- Lean oxidation (compression ignition) vehicles & engines:
  - Notably energy efficient
  - Most common in heavy duty vehicles and large off-road engines
  - Natural gas effective replacement for diesel; i.e., “dual-fuel” engine
  - Utilize high loading PdO catalyst
  - PdO deactivated by $H_2O$ and poisoned by $SO_2$

https://www.asme.org/topics-resources/content/power-of-dualfuel-diesel-engines



https://www.cat.com/en_US/products/new/power-systems/oil-and-gas/gas-compression-engines/18444291.html

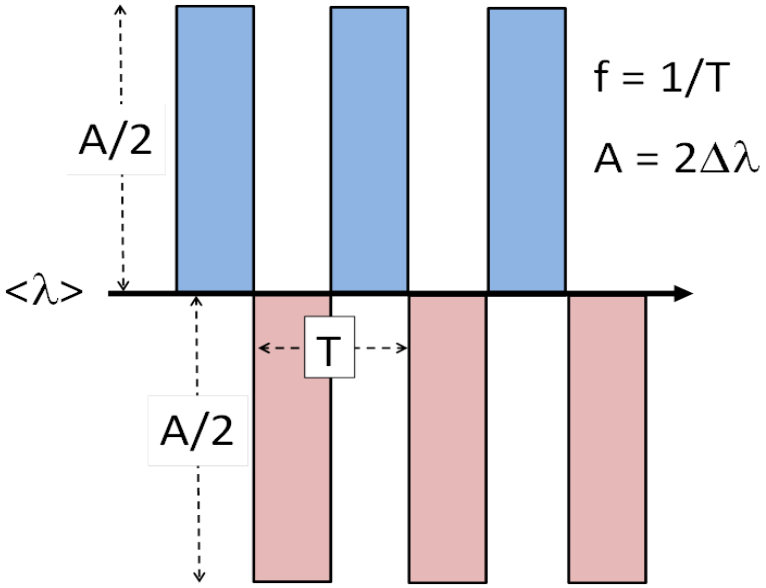
# Challenge & Opportunity

New methane oxidation catalysts with increased activity, better resilience (to temperature & Sulfur), and decreased precious metal content needed in order to exploit the cleaner burning natural gas for the transportation and commerce sectors.

# Stoichiometric Methane Oxidation Technology

***FWC = Four Way Catalytic Converter***

enables reduced emissions of $CH_4$ from stoichiometric NGVs through combination of **feed modulation** and **spinel oxide promoter**

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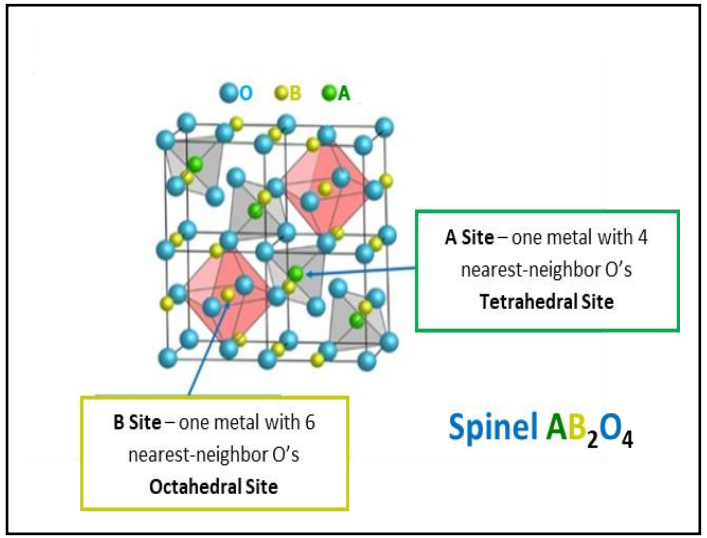
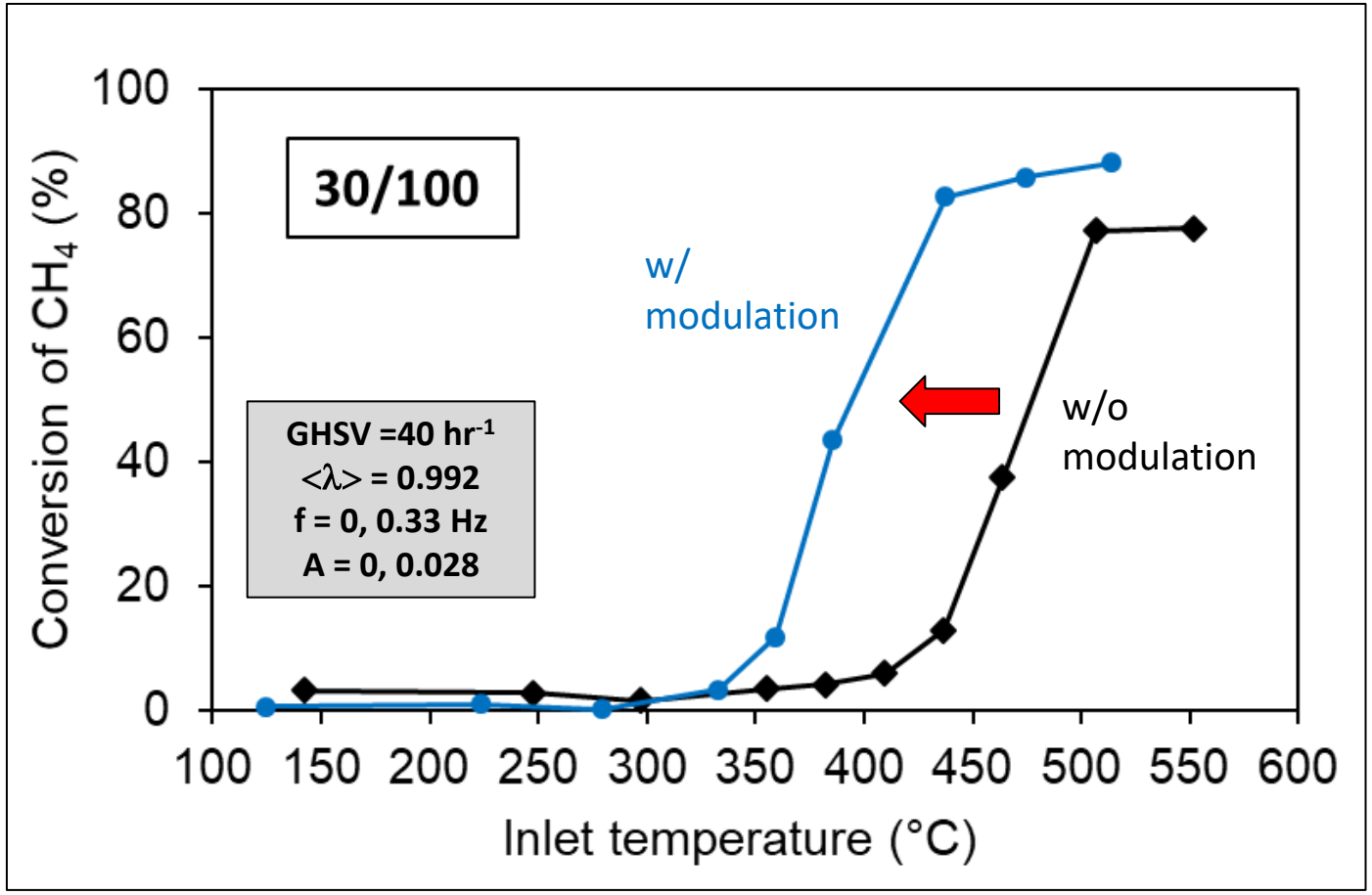



A, B: Mn, Fe, Co, Ni, etc.

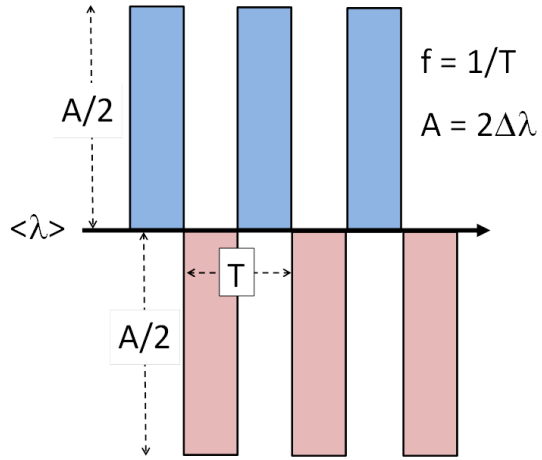
# Lower Light-off Temperature with Modulation




30 g PGM/ft$^3$/100 g Spinel/L

PGM: Pt:Pd = 19:1

Spinel: $Mn_{0.5}Fe_{2.5}O_4$

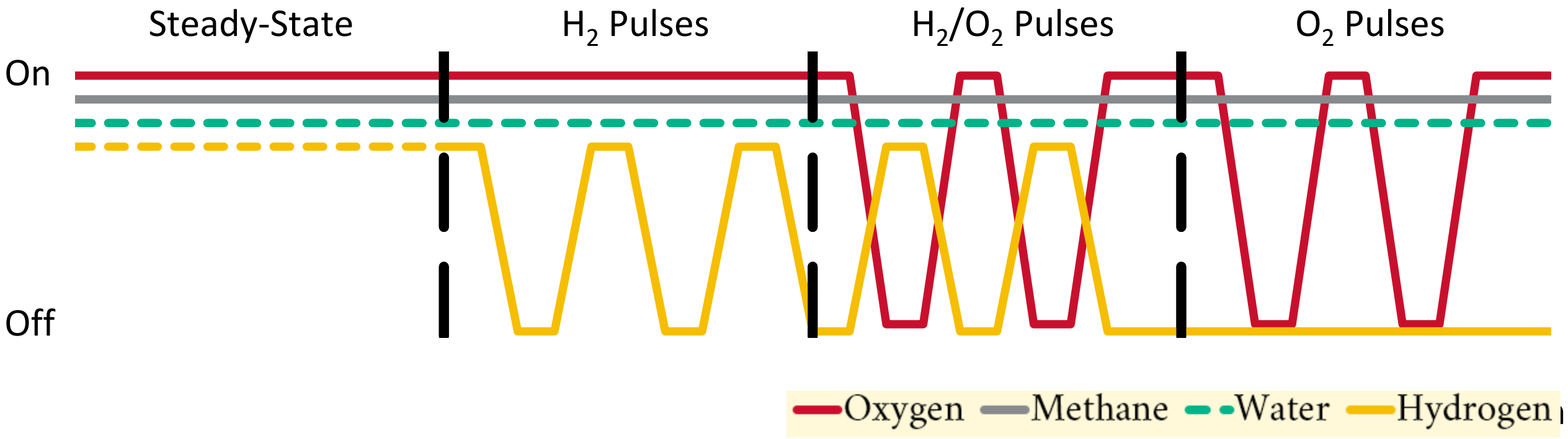



*Modulation of lean-rich ratio enhances catalytic activity for $CH_4$ oxidation*

Kang, S.B. K. Karinshak, P.W. Chen, S. Golden, and M. P. Harold, "Coupled Methane and NOx Conversion on Pt+Pd/$Al_2O_3$ Monolith: Conversion Enhancement Through Feed Modulation and $Mn_{0.5}Fe_{2.5}O_4/Al_2O_3$ Spinel Addition," Catal. Today, **360**, 284-293 (2021).

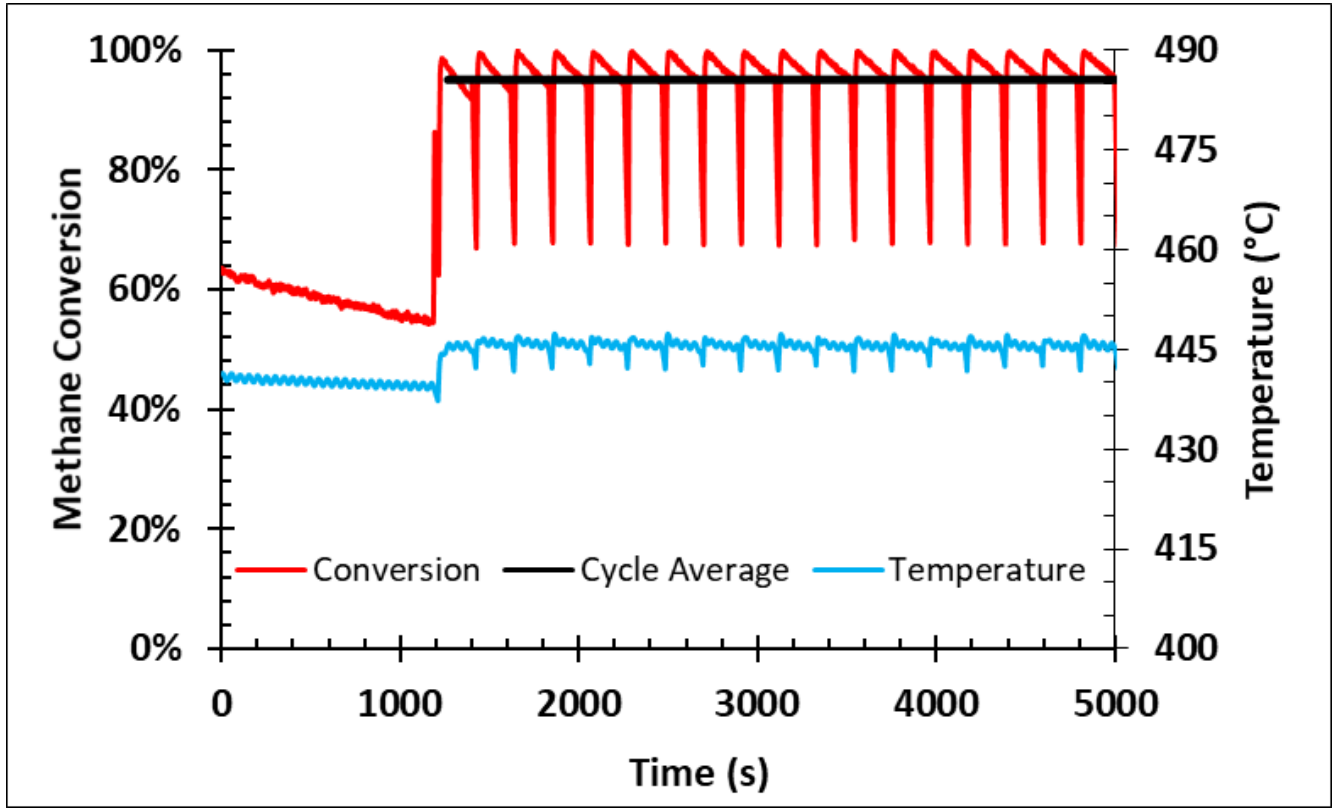
# Lean Methane Oxidation Technology

Intermittent “rich” operation mitigates poisoning by $H_2O$ and $SO_2$




Karinshak, K. A., P. Lott, O. Deutschmann, and M.P. Harold, “In Situ Activation of Bimetallic Pd-Pt Methane Oxidation Catalysts,” ChemCatChem, **12**, 3712 –3720 (2020). https://doi.org/10.1002/cctc.202000603

# Reductant Pulsing Impact in Presence of $H_2O$




- *$H_2O$ in feed leads to progressive activity decline:*

$$PdO + H_2O \rightarrow Pd(OH)_2$$

- *Sustain high cycle average $CH_4$ conversion with $H_2$ pulsing:*

$$Pd(OH)_2 + H_2 \rightarrow Pd + PdO$$

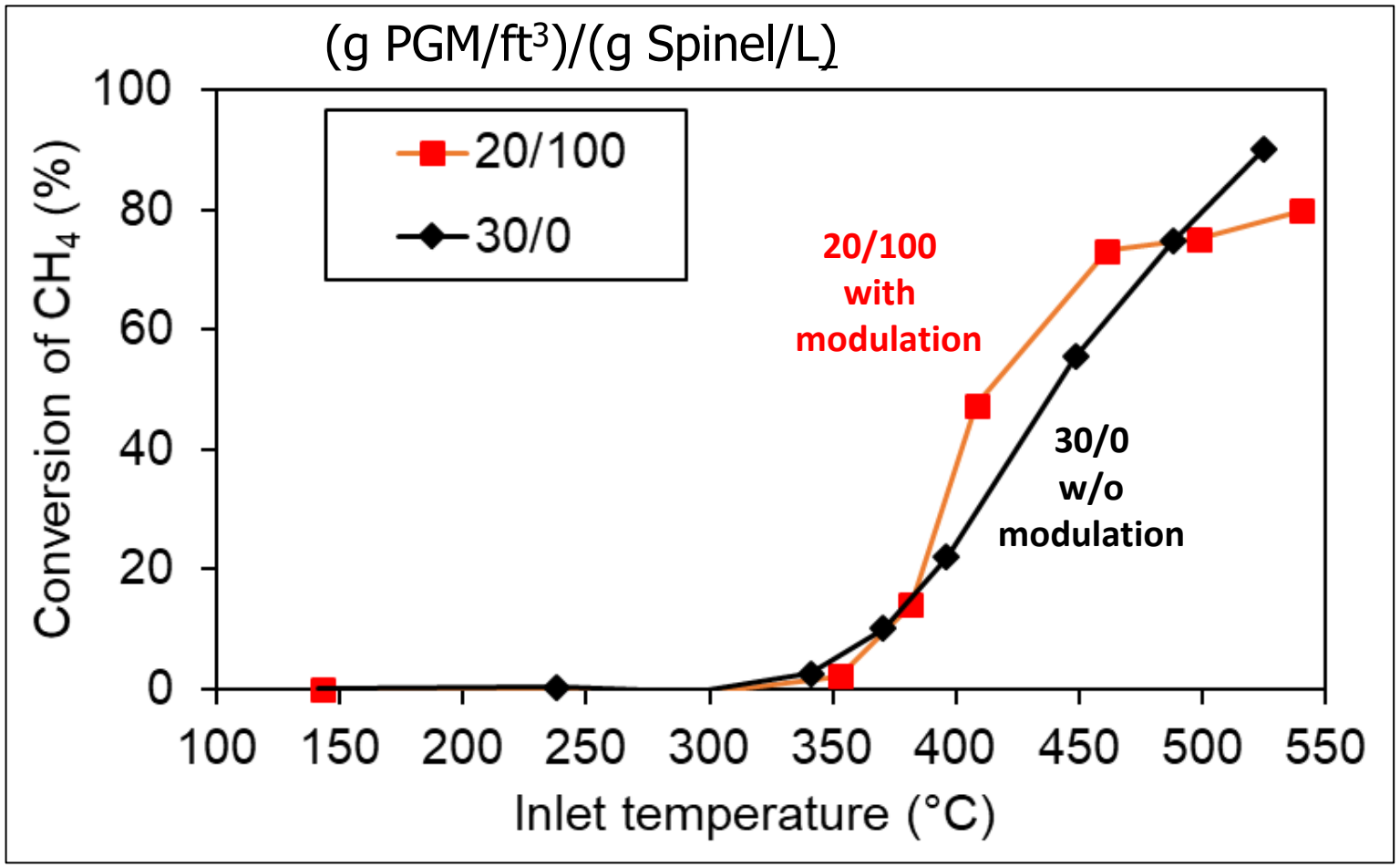
**12% $H_2O$, 2000 ppm $CH_4$, bal. Ar with 30 s/180 s of 1% $H_2$/10% $O_2$**

# Final Remarks

- Natural gas is a clean, domestically-sourced fuel that can reduce the Carbon footprint from transportation and commerce
- Methane slip must be eliminated from CNG-fueled engine exhaust
- New catalyst technologies show promise to make this happen
- Elimination of methane slip from existing engine fleet and stationary sources contributes to 0.012 gT CO2e reduction
- Reduction in $CO_2$ emissions would be far greater with implementation of dual-fuel CNG+Diesel technology

# Backup Slides

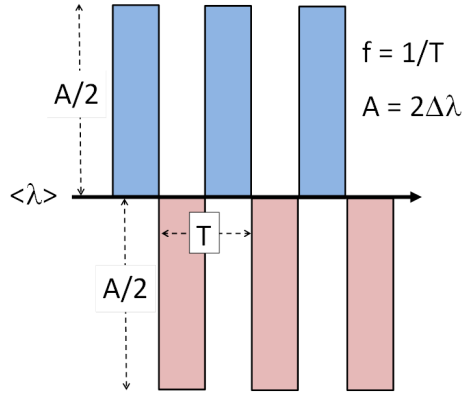
# Reduced PGM Loading with Modulation




PGM: Pt:Pd = 19:1

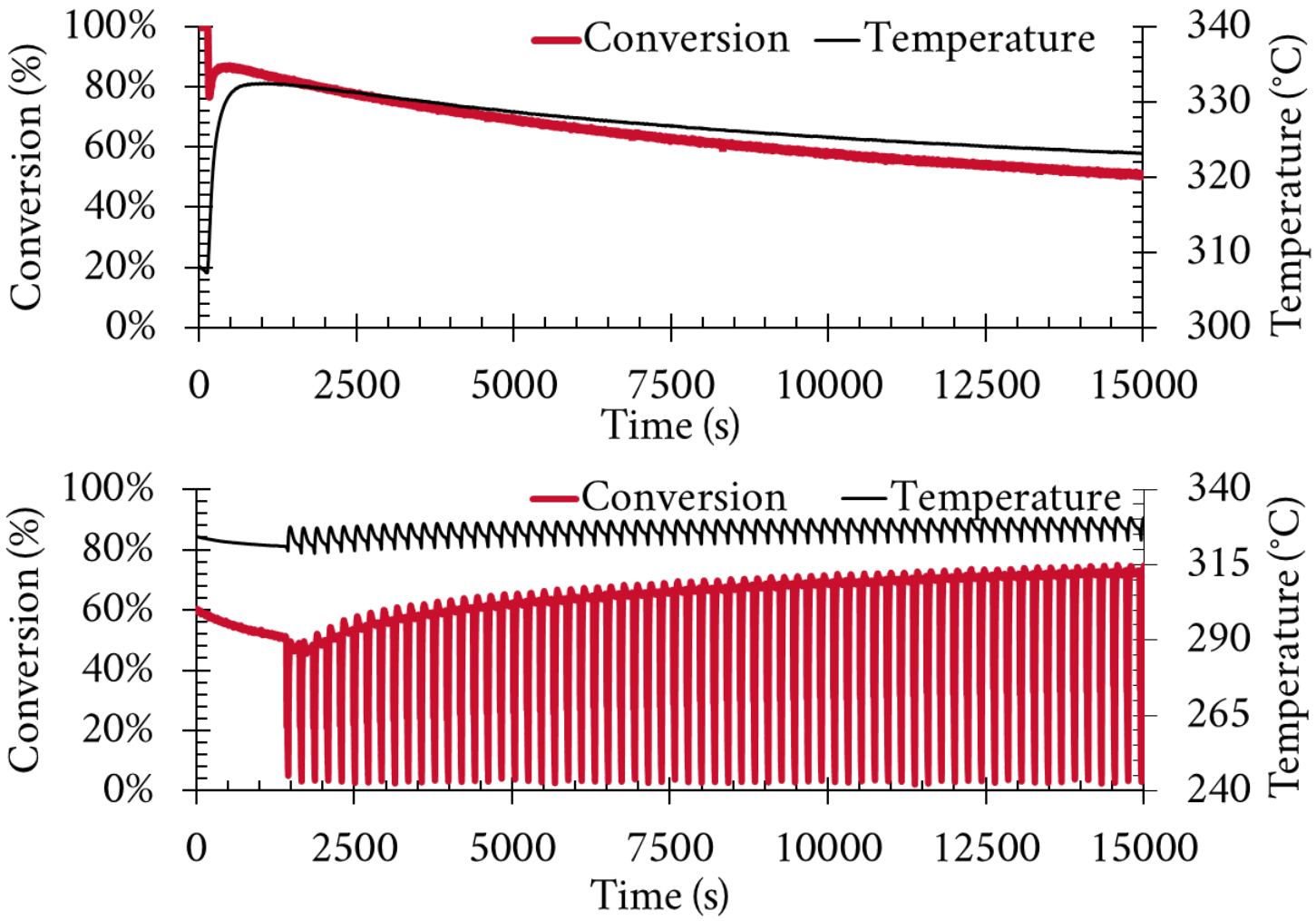
Spinel: $Mn_{0.5}Fe_{2.5}O_4$

**GHSV =40 $hr^{-1}$**
**$\langle\lambda\rangle$ = 0.992**
**f = 0, 0.33 Hz**
**A = 0, 0.028**




*Modulation reduces PGM loading by 10 g/ft³*

# Intermittent Pulsing of $H_2$ Sustains Activity




- $H_2/O_2$ pulses show improved catalytic activity over time
- Pulses result in high catalytic activity on the scale of several hours

Pd-Pt/CZ at 315 °C for dry feed

# Key Reactions

$CH_4 + 2\ O_2 \rightarrow 2\ H_2O + CO_2$ oxidation

$PdO + Pd + 2\ H_2O + ½\ O_2 \leftrightarrow 2\ Pd(OH)_2$ deactivation

$2\ Pd(OH)_2 + H_2 \rightarrow PdO + Pd + 3\ H_2O$ reactivation

$CH_4 + H_2O \rightarrow CO + 3\ H_2$ steam reforming

$PdO + 2\ SO_2 + 1.5\ O_2 \rightarrow Pd(SO_4)_2$ sulfur poisoning

$10\ H_2 + Pd(SO_4)_2 \rightarrow Pd + 8\ H_2O + 2\ H_2S$ desulfation

# Agenda


| Section | Topic | Speakers |
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| Methane: The Greenest Greenhouse Gas | One Pathway Towards Using it to Advantage | Edan Prabhu |
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# Methane: The Greenest Greenhouse Gas

## One Pathway Towards Using it to Advantage

# Methane is the world's best fuel

- Occurs naturally, from organic decomposition, in wetlands
- It is mostly hydrogen, safe, stable, contains no ash or toxins
- Can be converted into heat or electricity
- It is also a big culprit, responsible for 30% of all greenhouse gases from oil and gas, coal, landfills, dairy operations AND natural sources
- If it could be tapped, wetlands methane could generate as much power as solar and wind combined

# PEL Mission

- Methane offers a pathway to reducing greenhouse gases in the next decade
- At the recent COP 26 Climate Change conference in Glasgow, there was a separate booth for just for methane
- The US DOE just announced new regulations governing methane emissions
- PEL's prime focus is to oxidize methane, making power wherever possible
- The Oxiperator can make a difference

# Oxiperator Features:

- At 0.3% concentration in air, oxidize the methane
- At 1.5%, generate electricity in a gas turbine
- No catalyst, no ceramic shells
- No harmful emissions, no NOx, no CO

# The Technology:

- The Oxiperator is a slow cooker. It gradually oxidizes the methane, steeping it in its own sauce
- Slow cooking will fully oxidize very weak streams
- It also keeps temperatures low enough to avoid formation of NOx
- The Oxiperator also works for hydrogen, ammonia and any other weak gas
- We have an Oxiperator running at our California Lab
- We are looking for funds to scale-up and commercialize

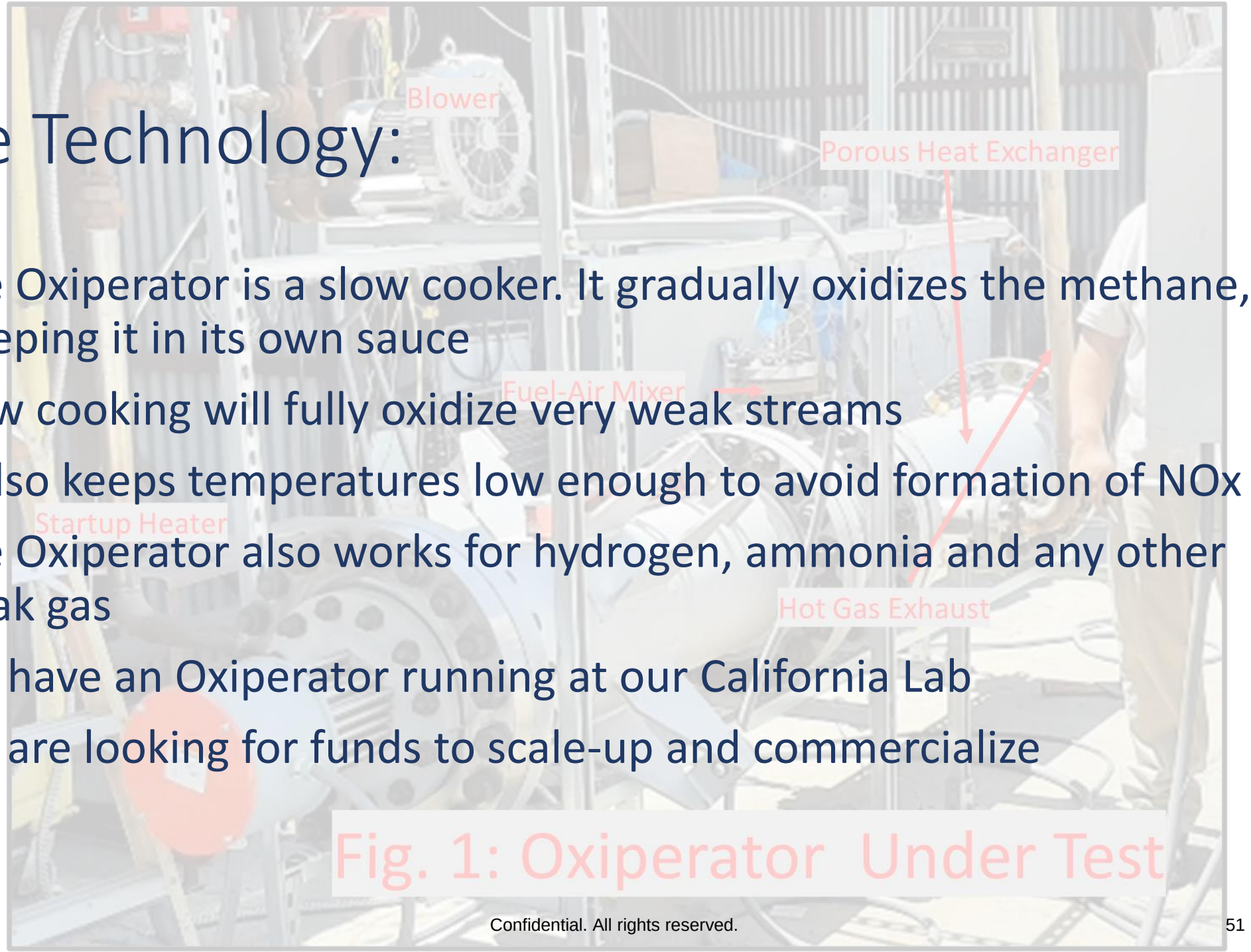
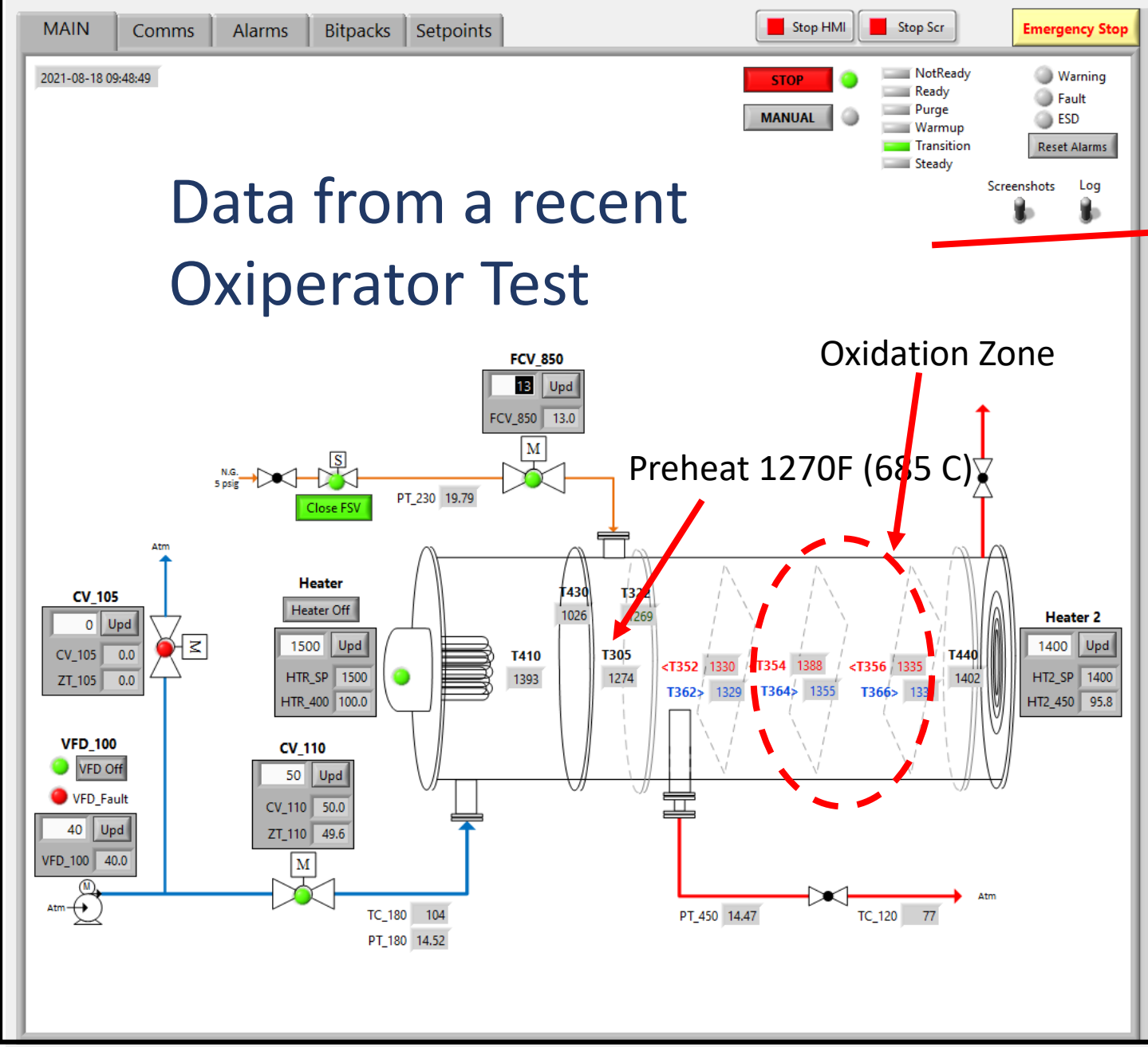
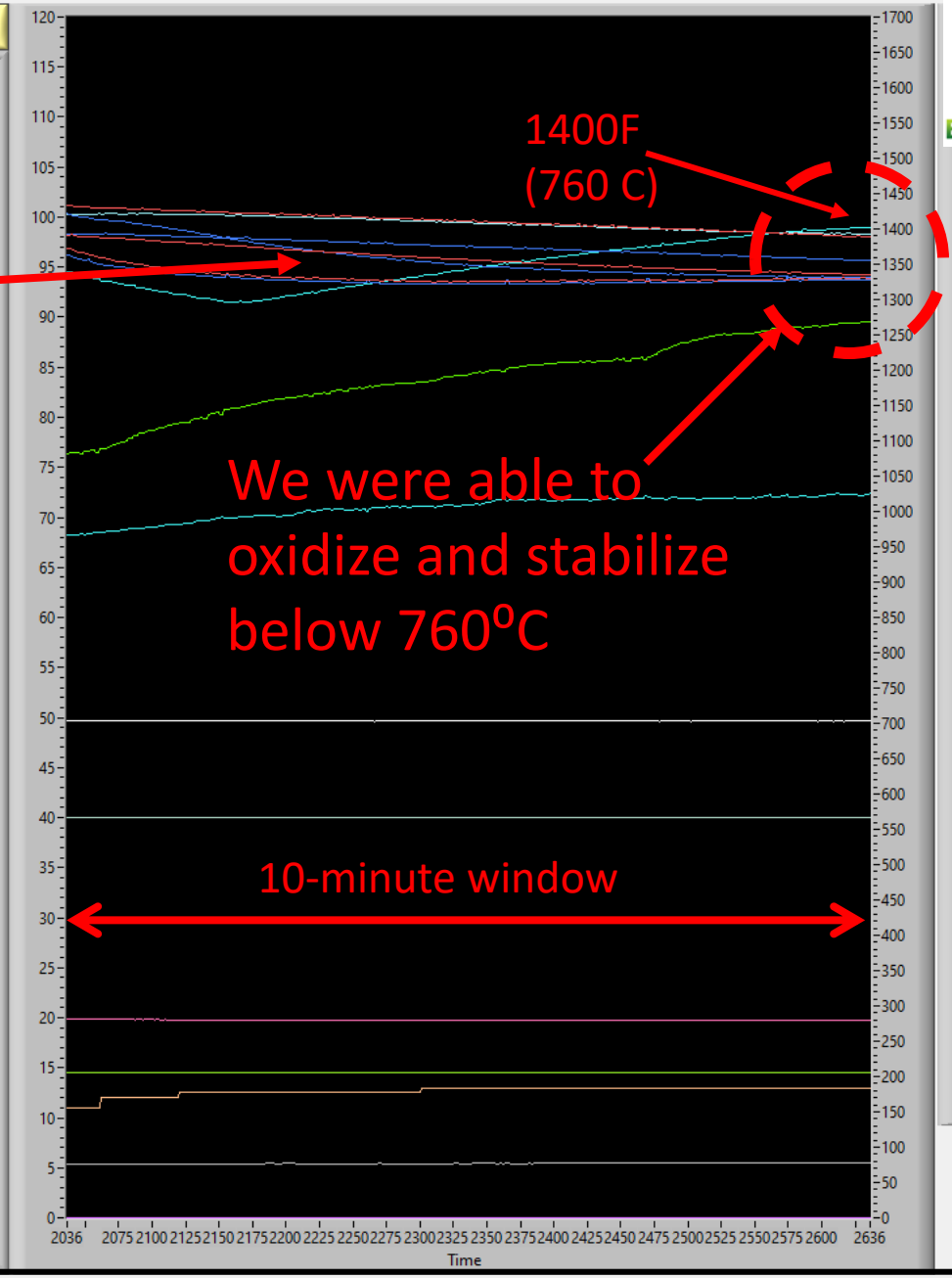



Fig. 1: Oxiperator Under Test

# Data from a recent Oxiperator Test

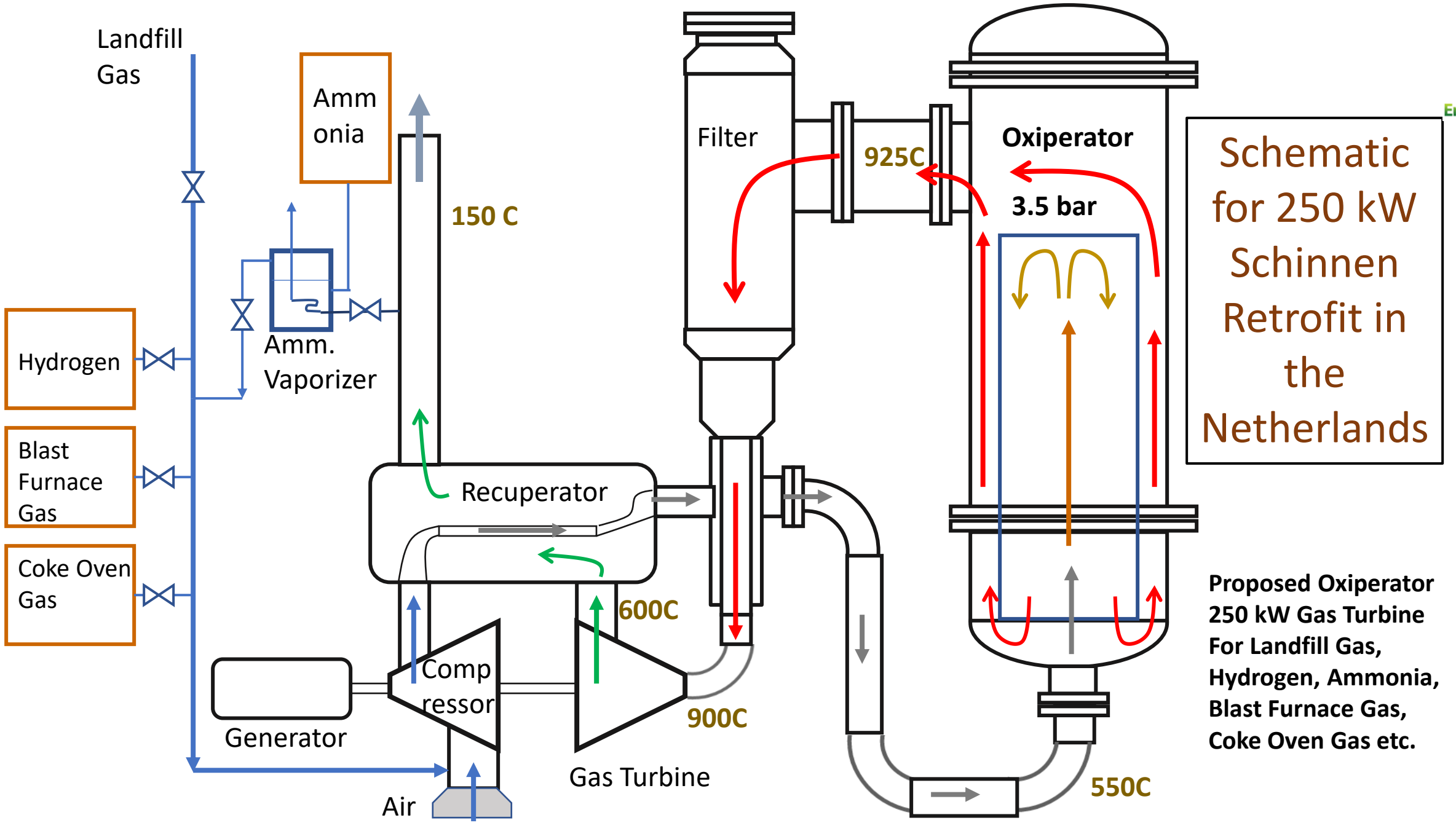



Prabhu Energy Labs

# Next steps

- Upgrade a 250-kW power plant in the Netherlands with an Oxiperator
- Run the plant on methane (landfill gas), hydrogen, ammonia, blast furnace gas and other gases
- Find a coal mine, landfill or oilfield in the US for a Demo
- Team up with gas turbine companies for 1.5% and higher
- Develop systems for fugitive methane below 1.5%




# Schematic for 250 kW Schinnen Retrofit in the Netherlands

**Proposed Oxiperator 250 kW Gas Turbine For Landfill Gas, Hydrogen, Ammonia, Blast Furnace Gas, Coke Oven Gas etc.**

# Our Plans:

- Deploy Oxiperators packaged in shipping containers to handle fugitive methane wherever it is emitted:
  - Oil and gas including flares
  - Landfills
  - Coal mines
  - Dairy digesters
  - Engine exhausts
- Where the gas concentrations are 1.5% or higher, make electricity
- Use Oxiperators as VOC destroyers
- Then we plan to tap natural methane from wetlands…concentrate it to 1.5% and use it to make power

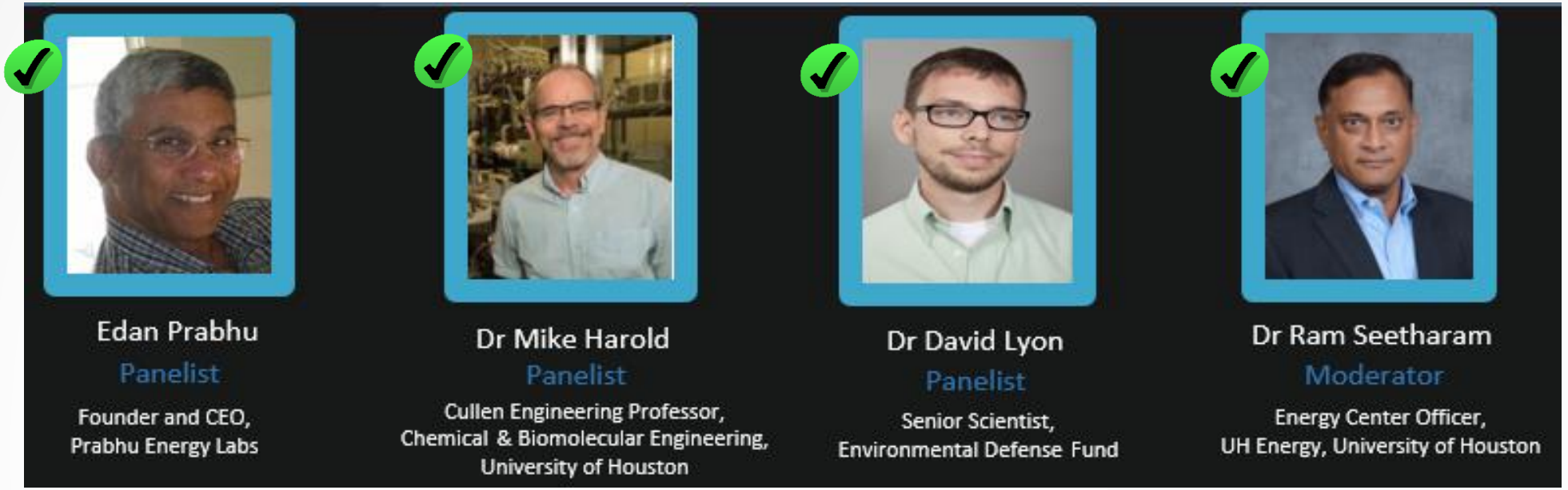
We plan to make methane green again

It will go from bane to boon

Methane will be the new renewable energy, along with solar and wind!

Our goal:  Cut 100 million tons CO2e in ten years

# Panel Discussion

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# Panel Discussion and Q&As

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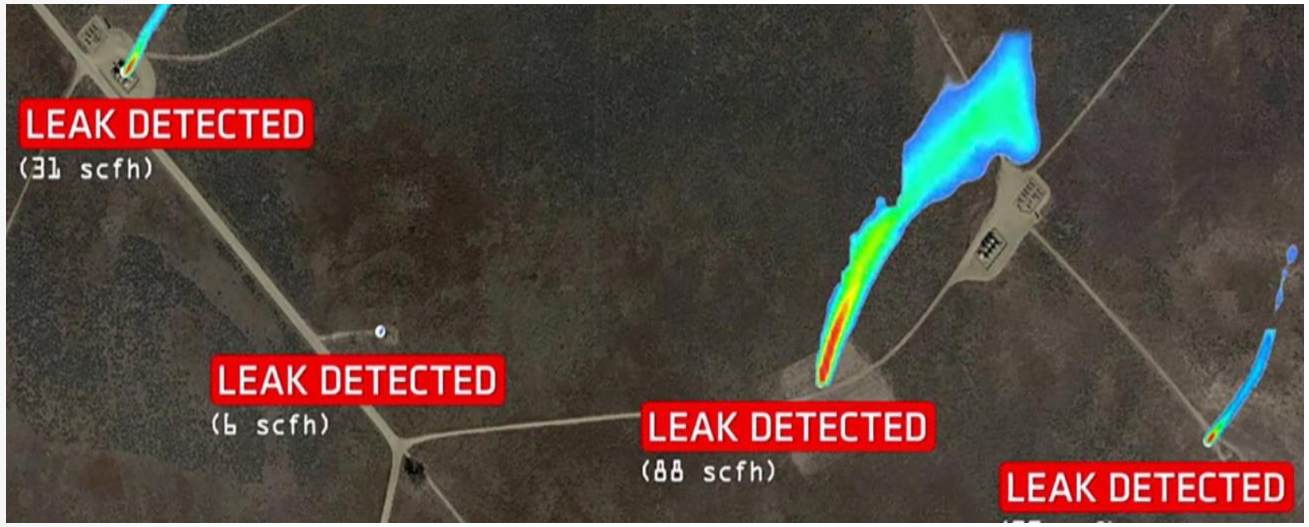
# Digital Solutions Support from Performatica – Computer Vision, Simulation & Augmented Analytics

*Leveraging Open-Source Platforms for Methane Detection*




- Methane leak hotspots detection through Satellite Images
- Pinpoint Methane leak location and identify the cause of the leak
- Estimate emission size and impact from Methane leaks and emissions
- Simulating effectiveness of methane leak detection programs
- Focus in ESG & Reporting through digital platforms

# Thank you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https://performatica.net/