Inequitable exposures and health burdens of air pollution from the major oil and gas lifecycle stages in the US
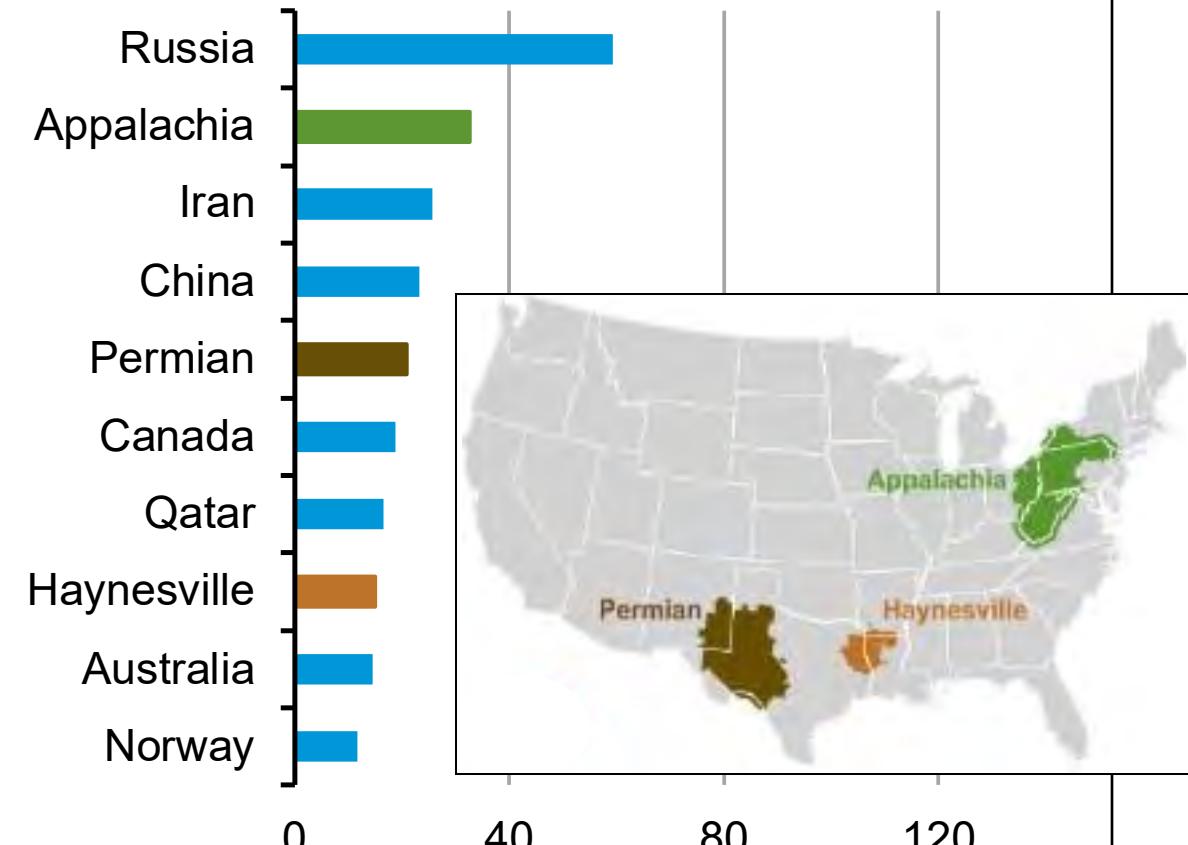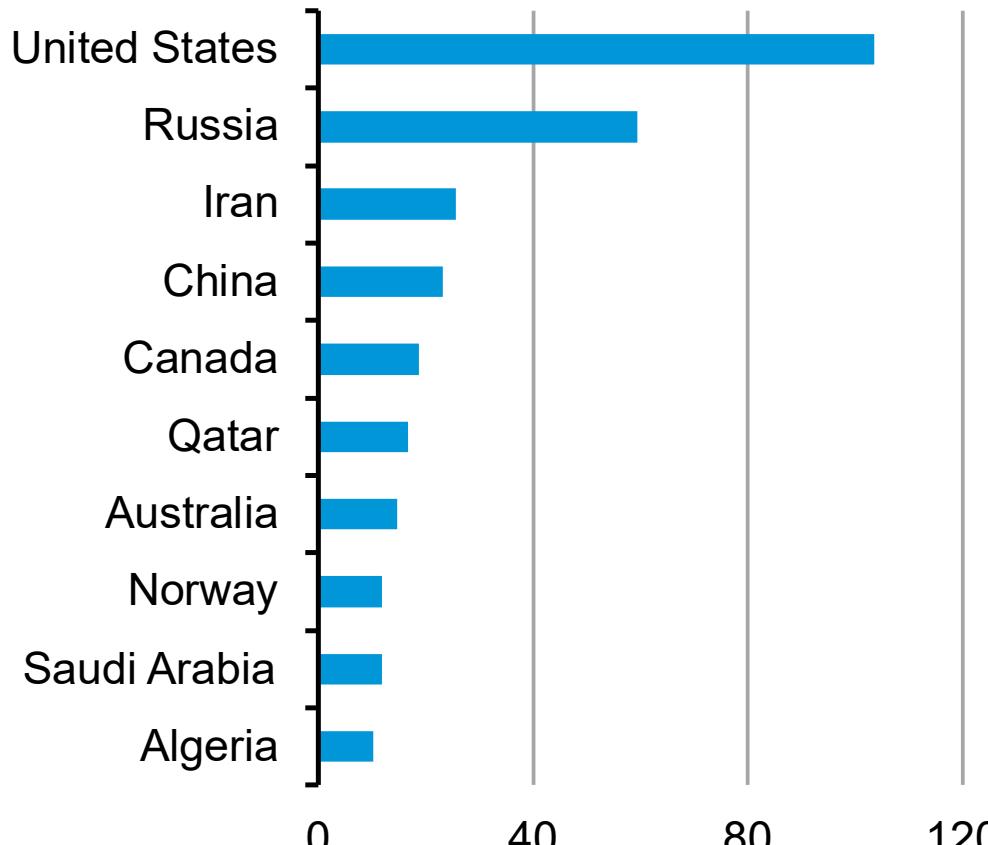

Karn Vohra, **Eloise A. Marais**, Ploy Achakulwisut, Susan Anenberg, Colin Harkins

RSC AQ in the 21st Century Conference   15 December 2025

# National Contributions to Global Natural Gas Production

Top natural gas production countries and regions in 2023
billion cubic feet per day

eia

Chart 1 — Countries:
- United States
- Russia
- Iran
- China
- Canada
- Qatar
- Australia
- Norway
- Saudi Arabia
- Algeria

(x-axis: 0, 40, 80, 120)

Chart 2 — Countries and regions:
- Russia
- Appalachia
- Iran
- China
- Permian
- Canada
- Qatar
- Haynesville
- Australia
- Norway

(x-axis: 0, 40, 80, 120)

Map labels: Appalachia, Permian, Haynesville
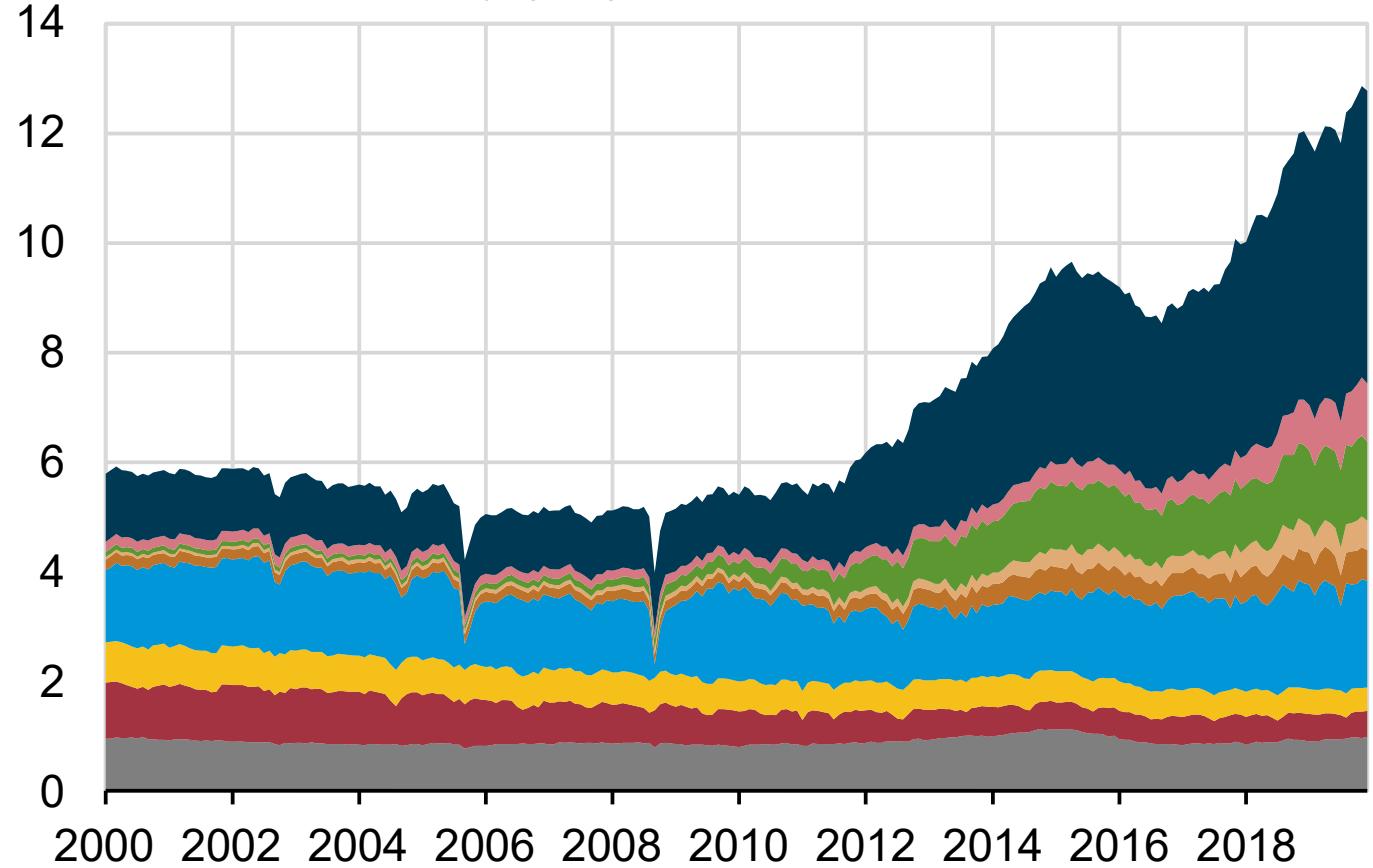
[Energy Information Administration (EIA), https://www.eia.gov/todayinenergy/index.php]

US largest global producer of natural gas (and oil)

Trends in US Crude Oil Production

U.S. crude oil production by state (2010-2019)
million barrels per day (b/d)

Annual change (2018-2019)
thousand barrels per day
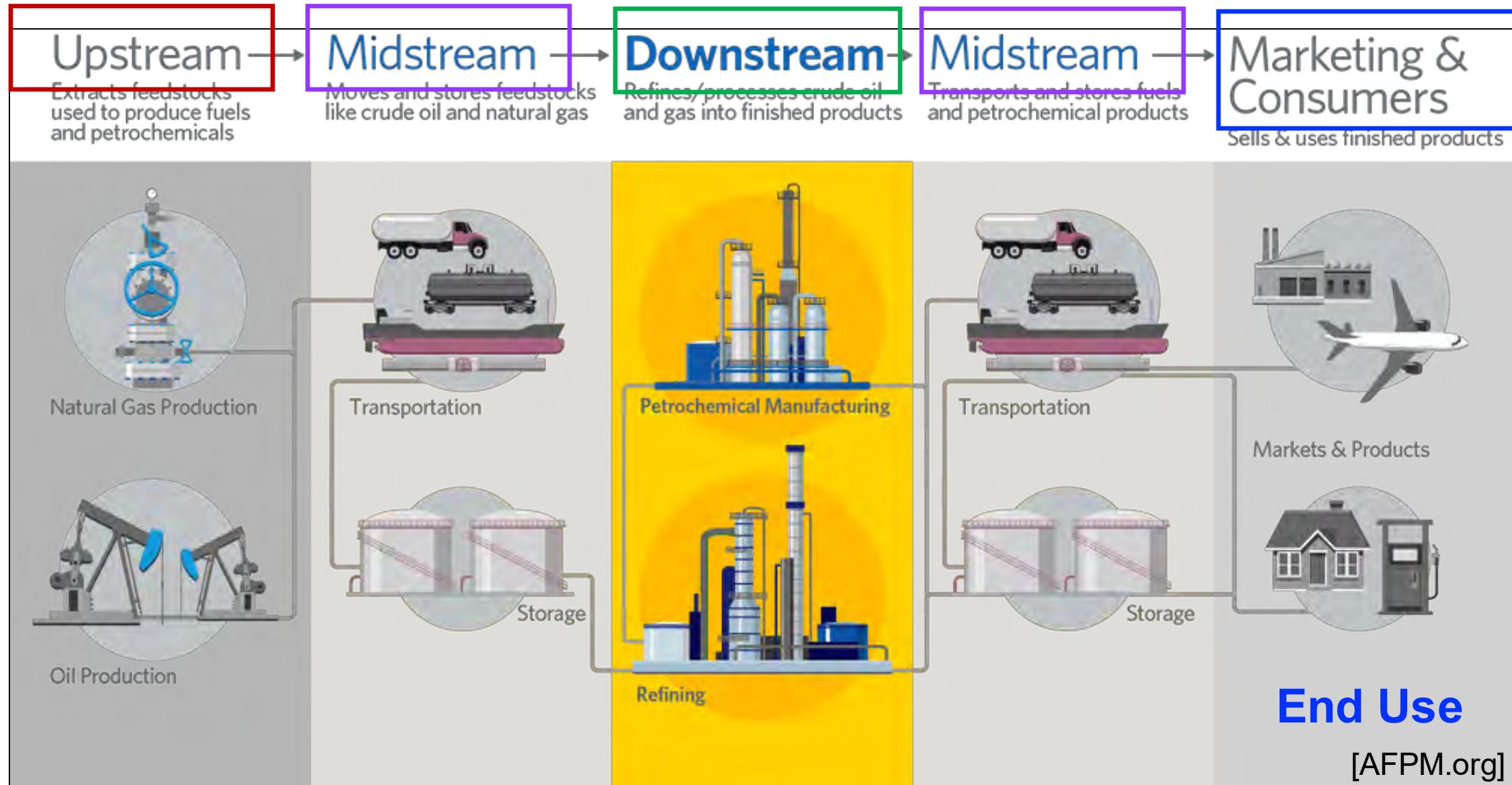
- Texas
- New Mexico
- North Dakota
- Colorado
- Oklahoma
- Offshore Gulf of Mexico
- rest of United States
- California
- Alaska

[EIA, https://www.eia.gov/todayinenergy/detail.php?id=43015]
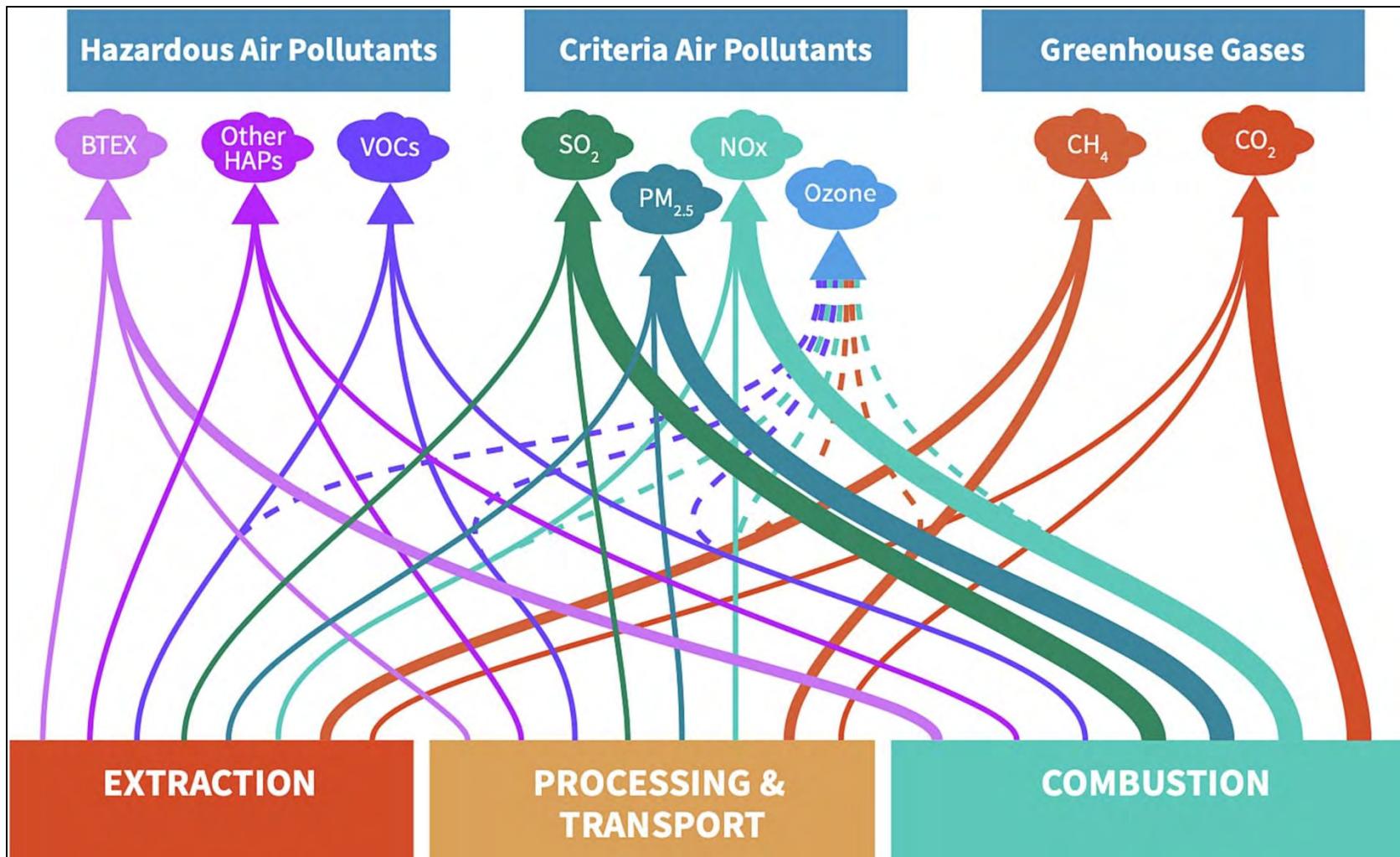
Steep growth since 2011 in oil (and natural gas) production spurred by unconventional oil and gas (O&G) and phase-out of coal

Major Stages of the Oil and Gas Lifecycle

Upstream — Extracts feedstocks used to produce fuels and petrochemicals

Midstream — Moves and stores feedstocks like crude oil and natural gas

Downstream — Refines/processes crude oil and gas into finished products

Midstream — Transports and stores fuels and petrochemical products

Marketing & Consumers — Sells & uses finished products

Natural Gas Production

Oil Production

Transportation

Storage

Petrochemical Manufacturing

Refining

Transportation

Storage

Markets & Products

End Use

[AFPM.org]

End use includes combusted crude and refined fuels and non-energy products (waxes, plastics)

Activities in All Stages Produce Pollutants

BTEX: benzene, toluene, ethylbenzene, xylene

HAPs: Hazardous air pollutants

VOCs: volatile organic compounds

NOₓ: nitrogen oxides (NO + NO₂)

PM₂.₅: Small particles

[Adapted from Donaghy et al. 2023]

A complex mix of primary and secondary pollutants
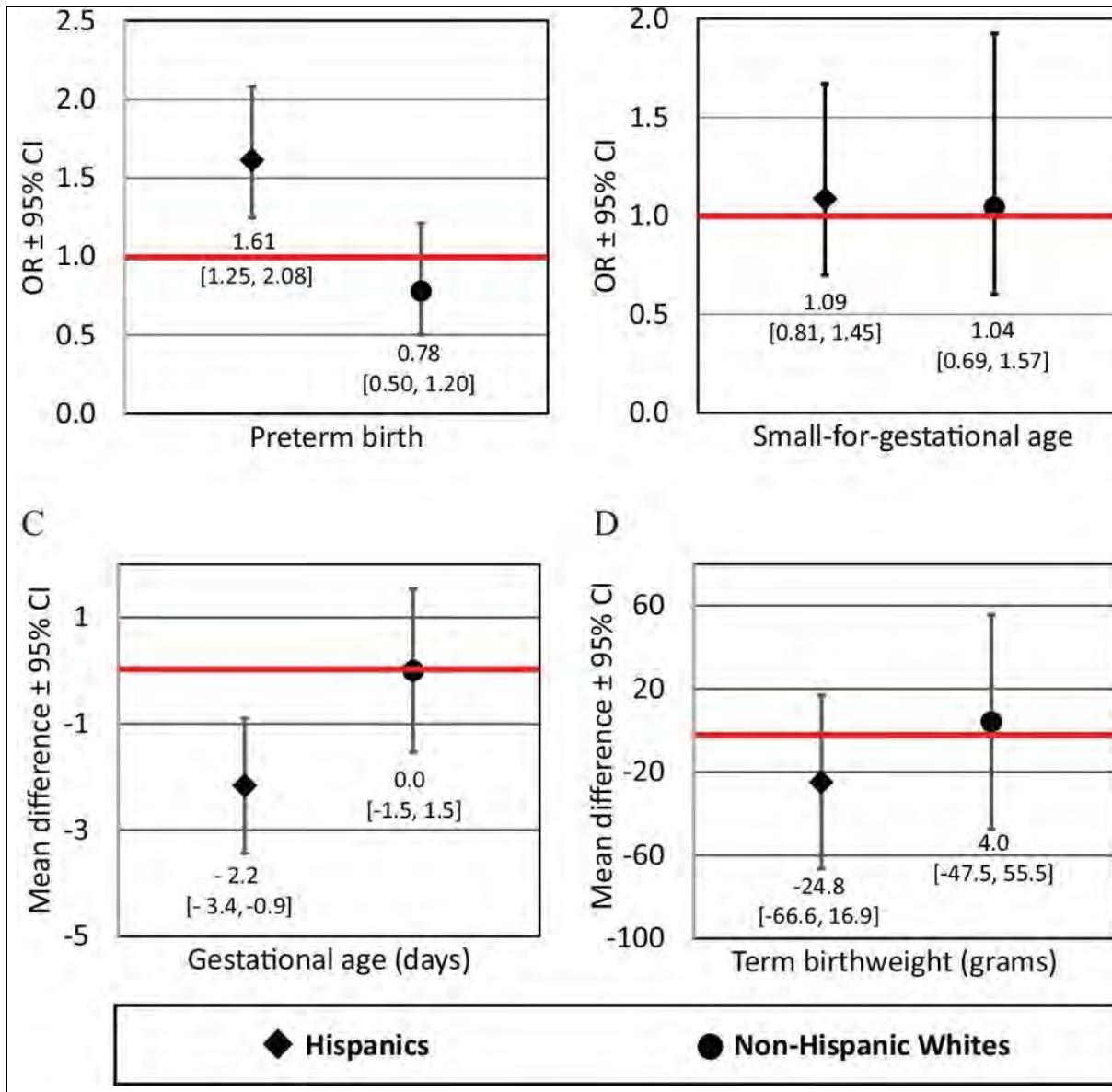
Air pollution health burdens we investigated

- **Premature mortality** from exposure to $PM_{2.5}$ (adult), O_3 (all ages; COPD), and NO_2 (elderly)

- **Preterm births** from exposure to $PM_{2.5}$

- **Childhood asthma** incidences from exposure to NO_2

- **Lifetime cancers** from volatile organic compounds

COPD: chronic obstructive pulmonary disease

Unjust Exposure to O&G Air Pollution

Example past study assessing unjust health burden from natural gas flaring

OR: odds ratio

Hispanic population closer to flaring wells, so greater likelihood than non-Hispanic white population of preterm birth (by 0.9-3.4 days)

Unjust exposure from:
- placement of infrastructure (extraction wells, pipelines, compressor stations, downstream chemical manufacturing plants)
- proximity to intense flaring
- proximity to busy roadways

[Cushing et al., 2020]

Motivation for Our Study

**So much already known about O&G harm to health, so why another study?**
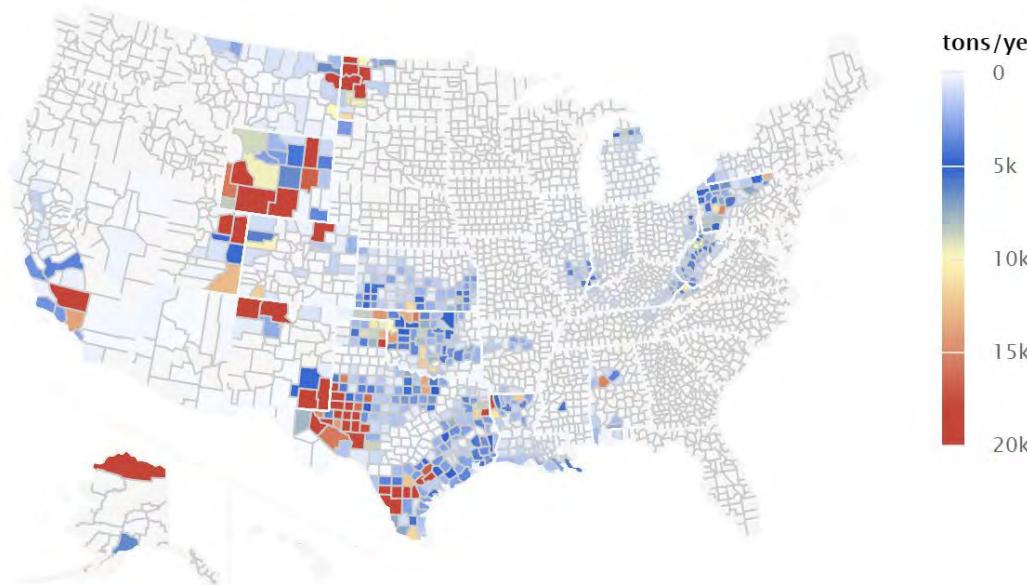
Past studies not sufficiently holistic:

- Focused on single O&G lifecycle stage (mostly production)

- Focused on single pollutant (typically $PM_{2.5}$)

- Focused on specific state or natural gas basin

- Combined O&G with coal for fossil fuel focused analysis

- Used reduced complexity models that do not suitably model secondary pollutants (O_3, $PM_{2.5}$)

- Quantification of inequitable health outcomes in environmental injustice studies is rare

Vital for directing policies that prioritize the most adversely affected communities

We construct a unified air pollutant emission inventory for 2017

US EPA National Emission Inventory (NEI) 2017

tons/year
0
5k
10k
15k
20k

Global Fuel Exploitation Inventory (GFEI) for methane

Oil: 26 Tg a^{-1}

Methane emissions (Mg km^{-2} a^{-1})
0.1   1   10
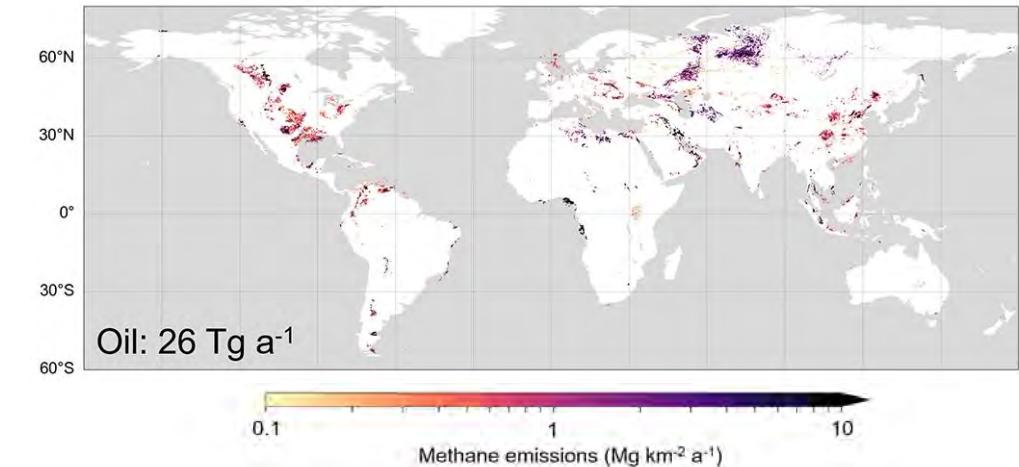
Fuel-based Inventory for Vehicular Emissions (FIVE)

**Aviation Emissions Inventory Code (AEIC)**
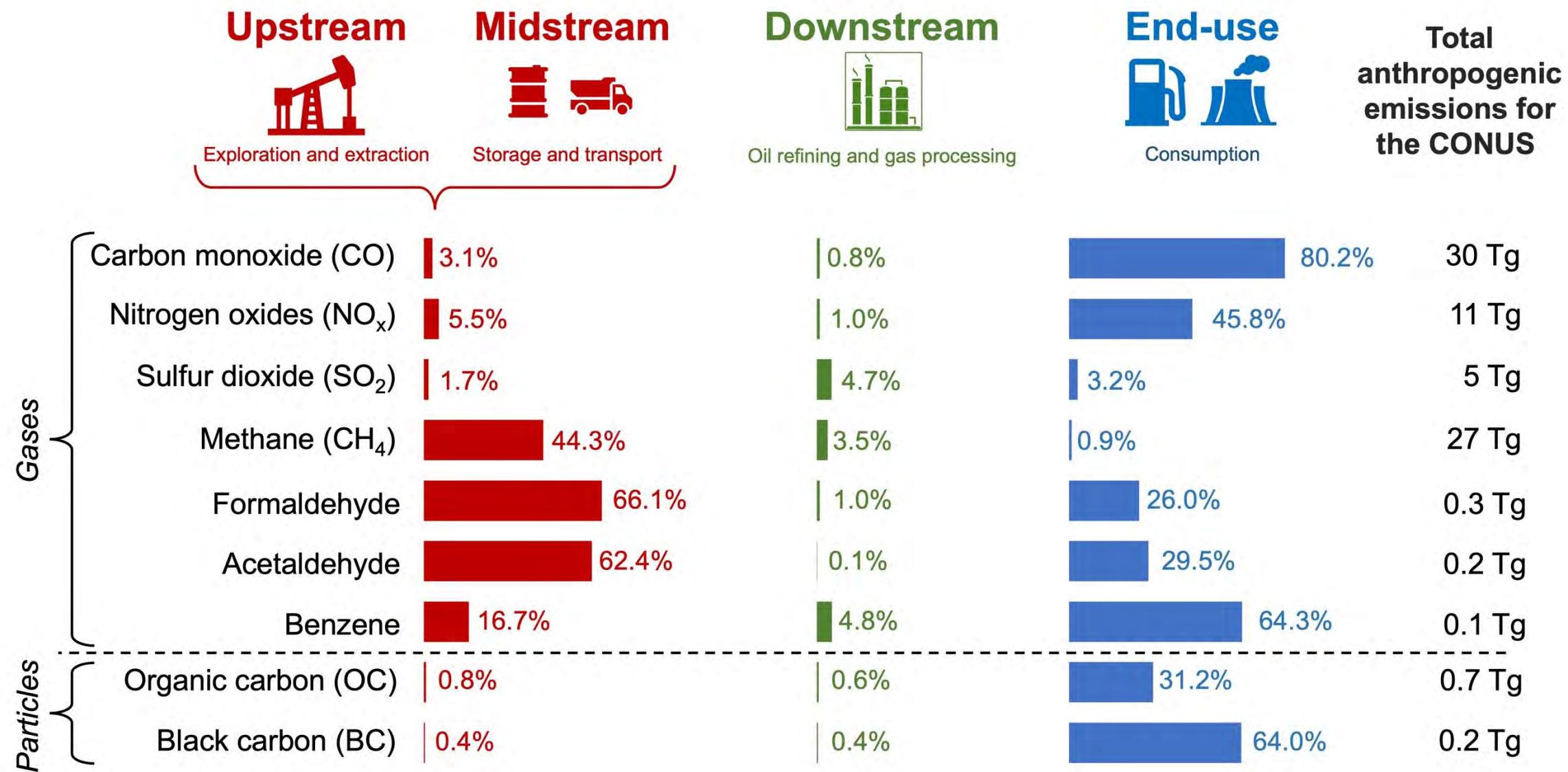
**Community Emissions Data System (CEDS) for shipping and outside US**
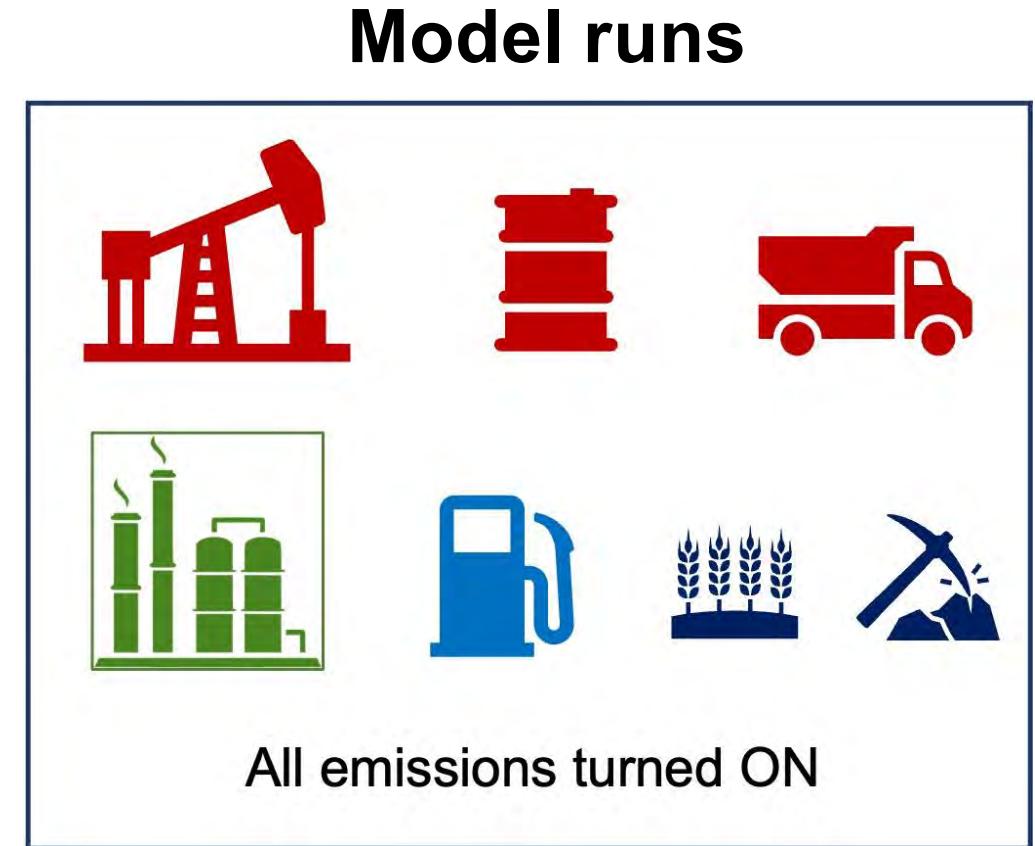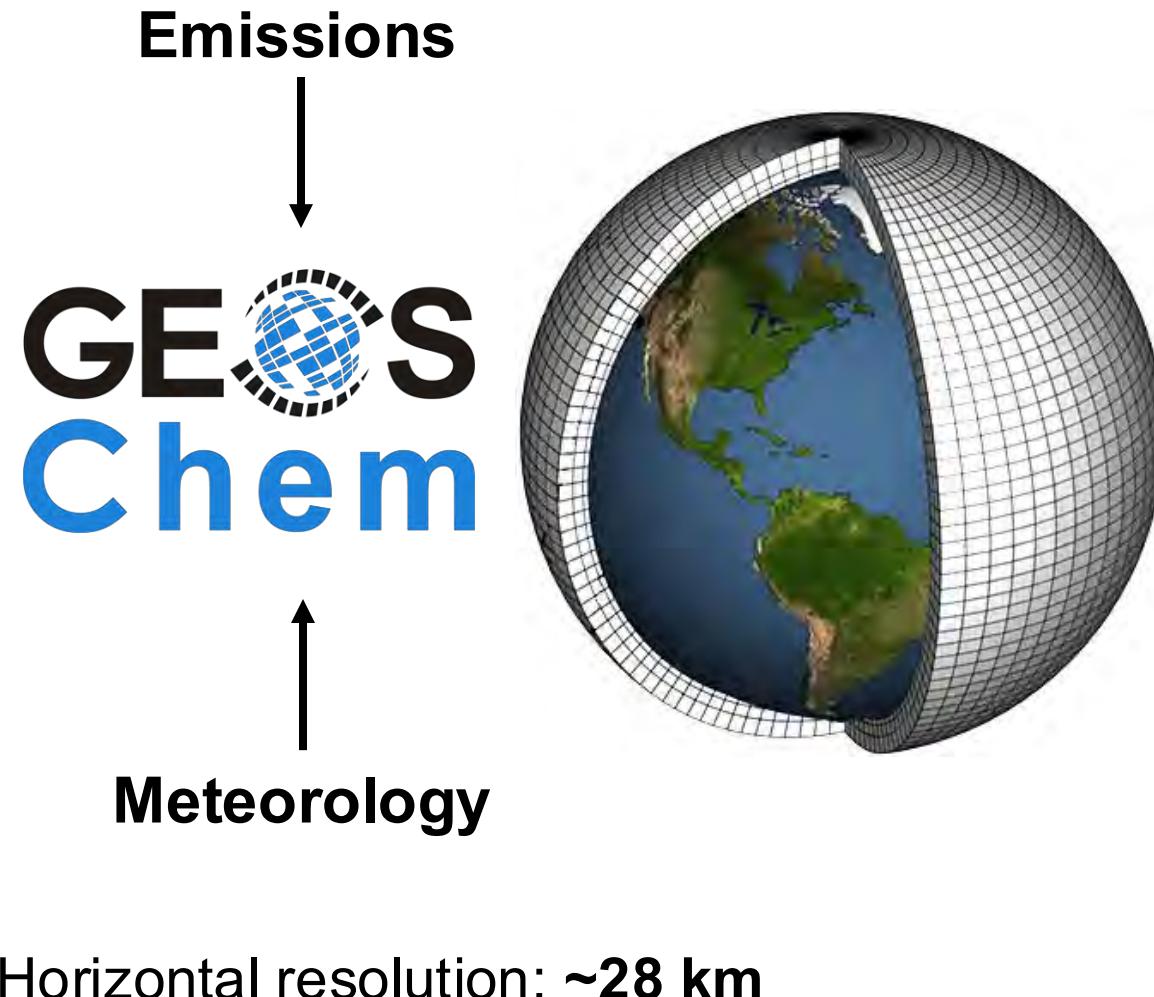
2017 selected, as most current datasets are for this year

# Relative contribution of O&G to total anthropogenic emissions

	Upstream (Exploration and extraction) / Midstream (Storage and transport)	Downstream (Oil refining and gas processing)	End-use (Consumption)	Total anthropogenic emissions for the CONUS
Gases				
Carbon monoxide (CO)	3.1%	0.8%	80.2%	30 Tg
Nitrogen oxides (NO_x)	5.5%	1.0%	45.8%	11 Tg
Sulfur dioxide (SO_2)	1.7%	4.7%	3.2%	5 Tg
Methane (CH_4)	44.3%	3.5%	0.9%	27 Tg
Formaldehyde	66.1%	1.0%	26.0%	0.3 Tg
Acetaldehyde	62.4%	0.1%	29.5%	0.2 Tg
Benzene	16.7%	4.8%	64.3%	0.1 Tg
Particles				
Organic carbon (OC)	0.8%	0.6%	31.2%	0.7 Tg
Black carbon (BC)	0.4%	0.4%	64.0%	0.2 Tg

O&G activities more than half CO, NO_x, formaldehyde, acetaldehyde, benzene, and BC

Use a state-of-science chemical transport model to determine air pollutant concentrations attributable to each O&G lifecycle stage

Emissions

Meteorology

Horizontal resolution: **~28 km**

**Model runs**

All emissions turned ON
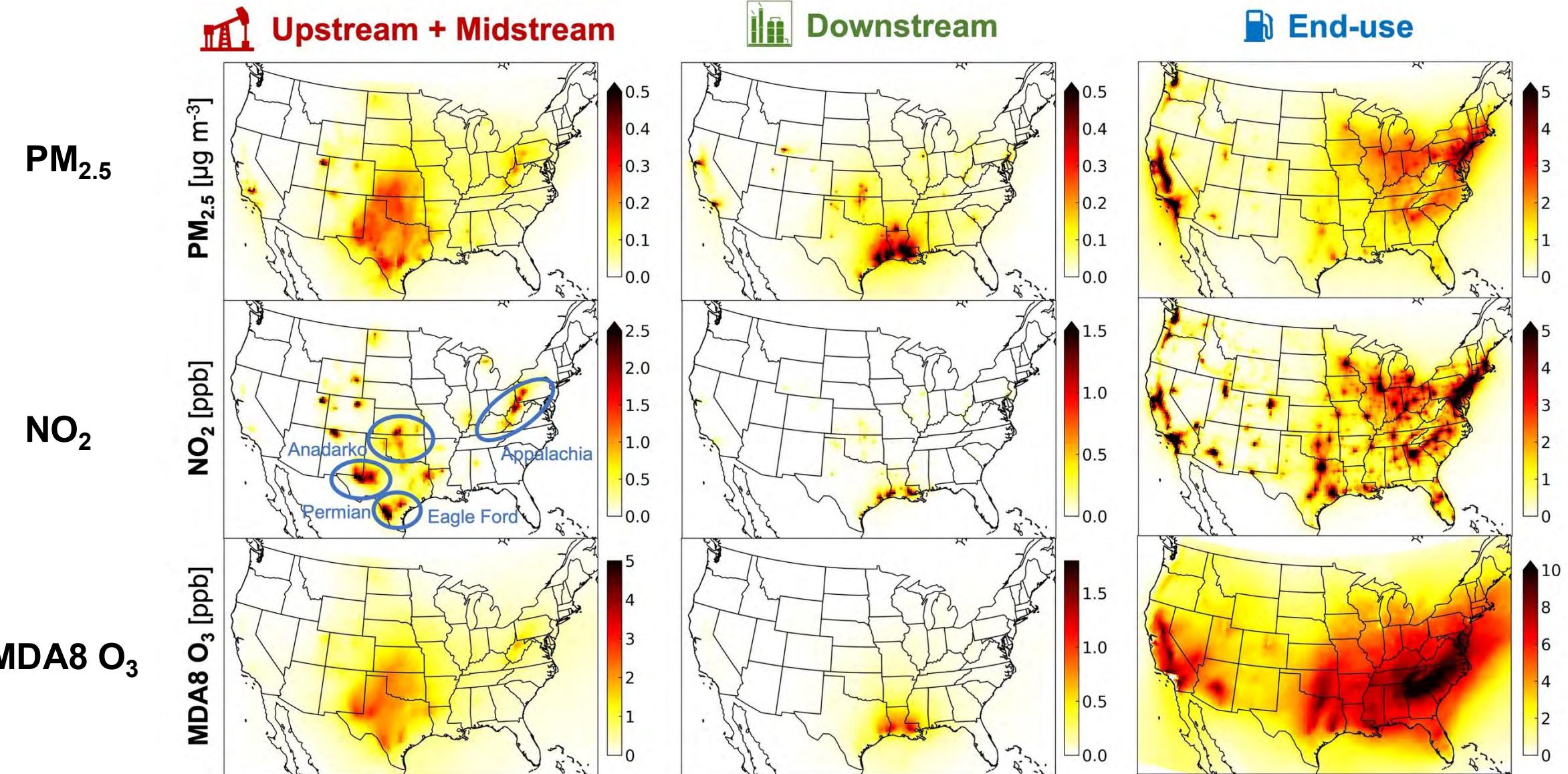
→ **Estimate air pollution baseline**

→ **Validate model**

Use a state-of-science chemical transport model to determine air pollutant concentrations attributable to each O&G lifecycle stage

Emissions

Meteorology

GEOS Chem

Model runs

Upstream and midstream emissions turned OFF

→ **Estimate contribution of lifecycle stage activities**

# Health-harming pollutant concentrations from O&G activities in 2017
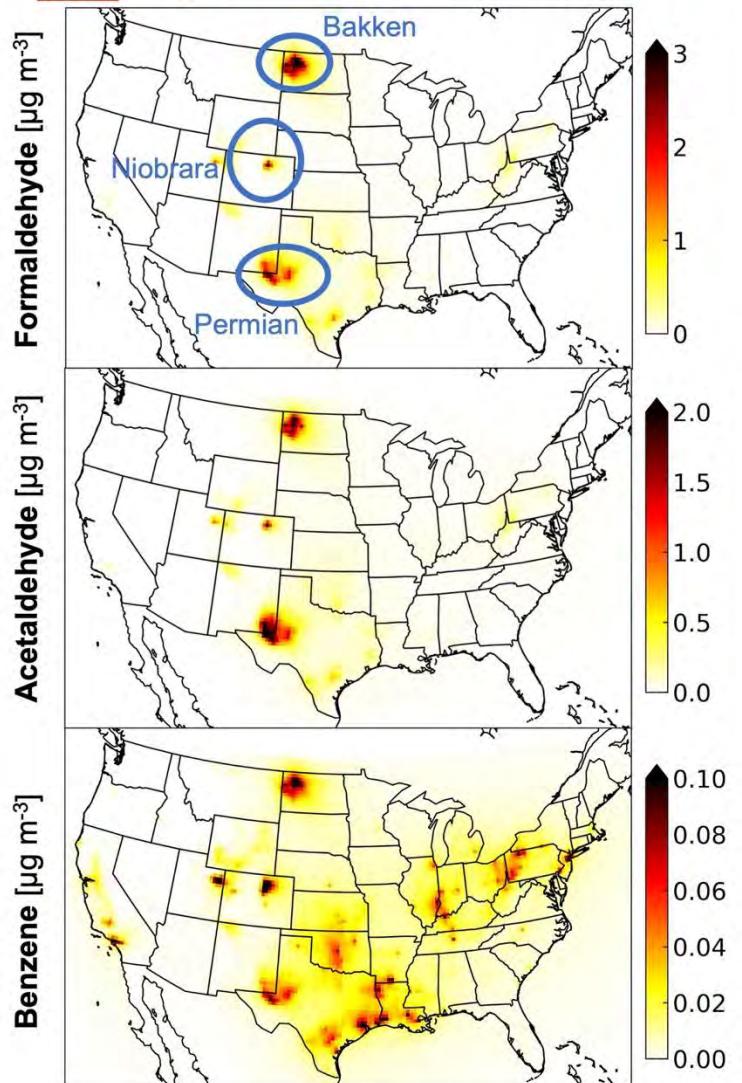
Largest enhancements from end-use and mainly in California and eastern US
Combined upstream/midstream in Texas and neighbouring states, downstream in Texas and Louisiana
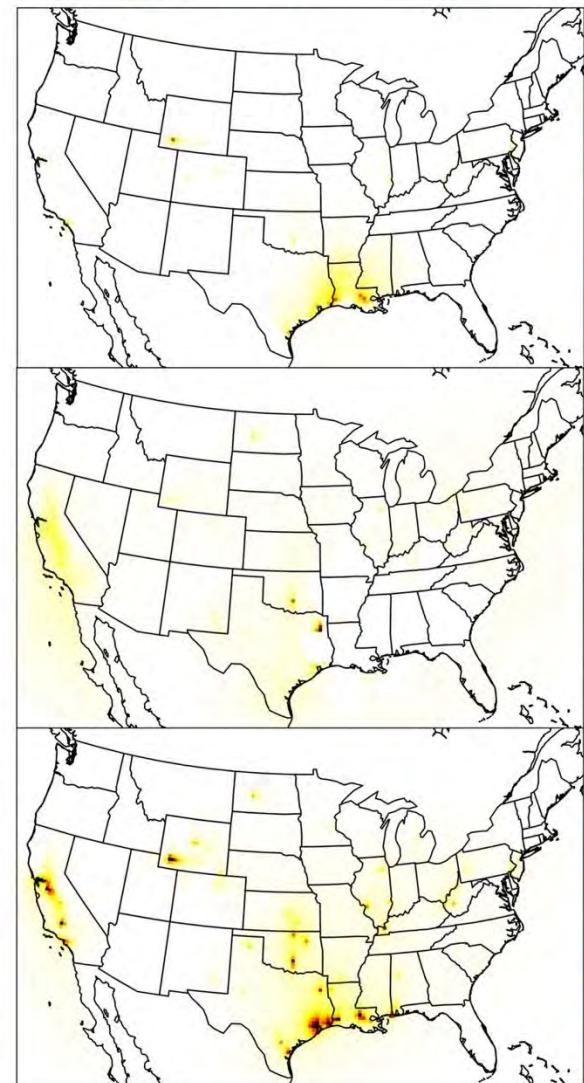
# Annual mean HAPs concentrations linked to oil and gas activities
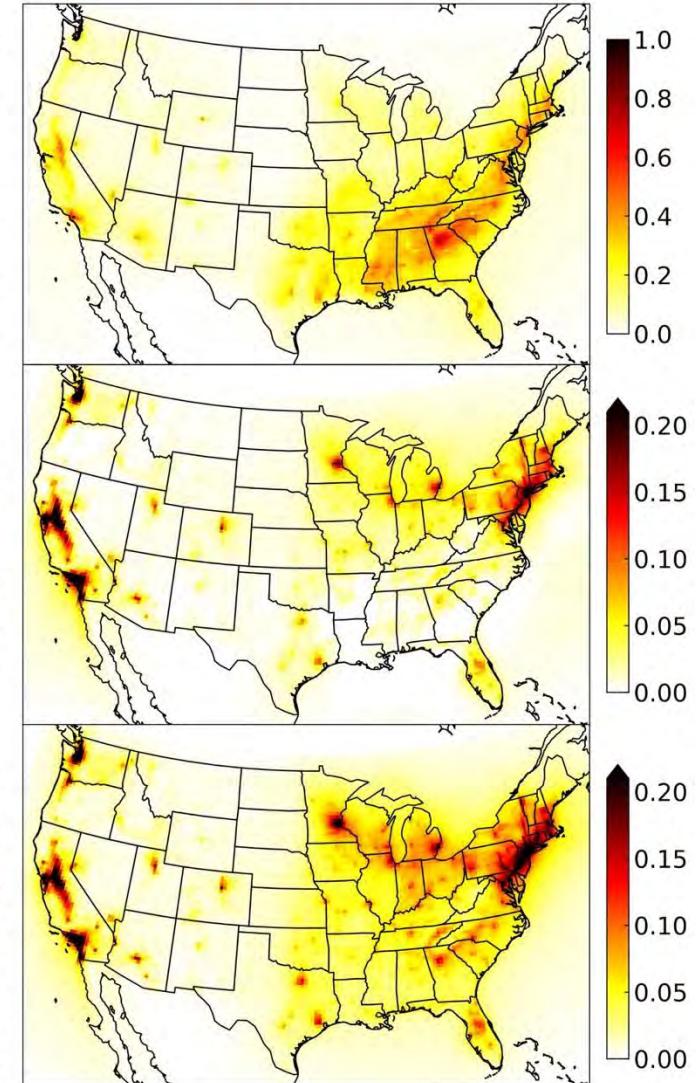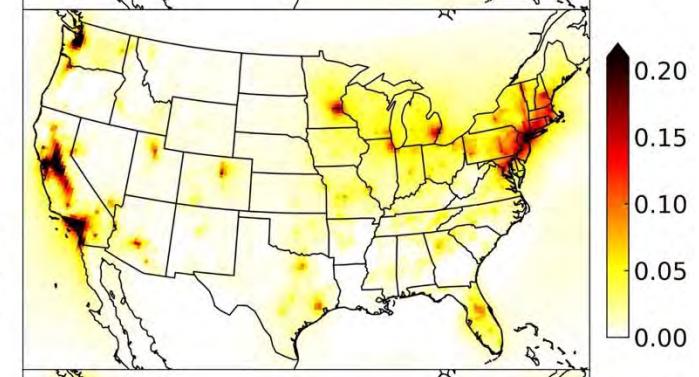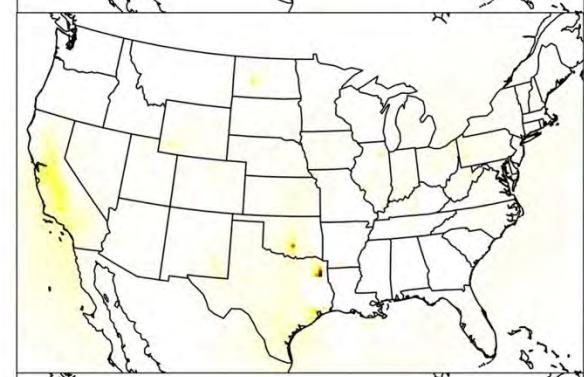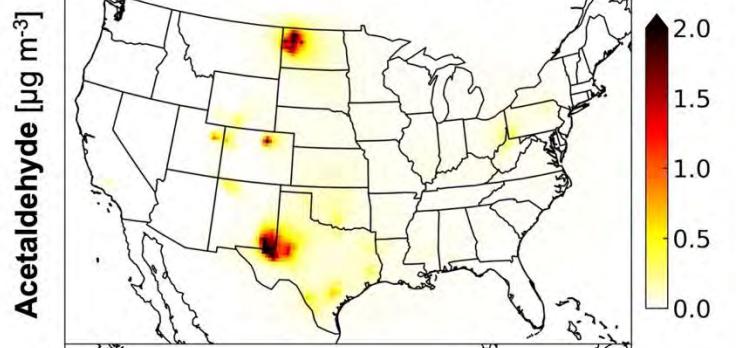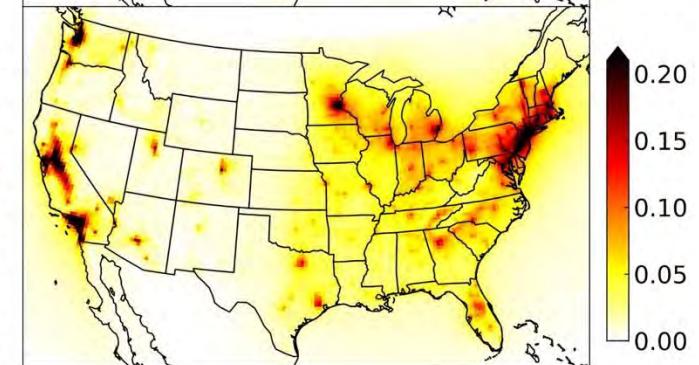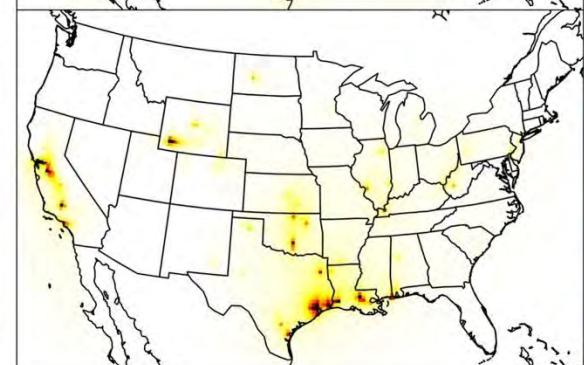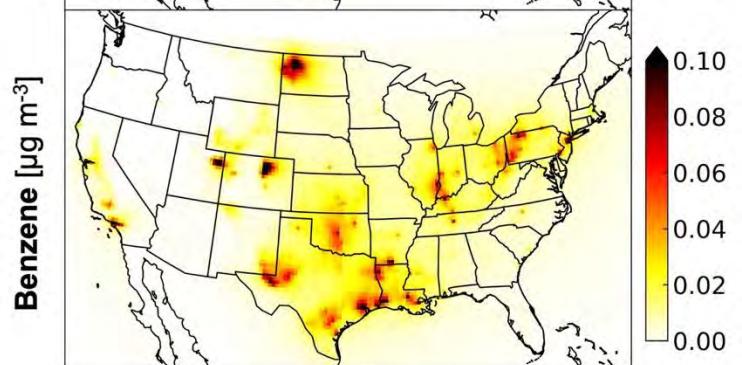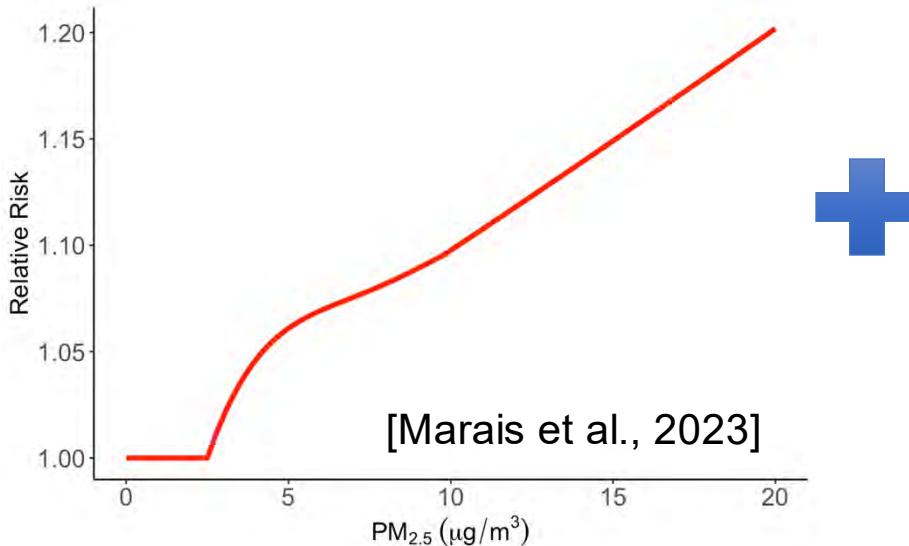
Greater contribution of formaldehyde and acetaldehyde than benzene.
Relatively small benzene emissions and formaldehyde/acetaldehyde from VOC oxidation
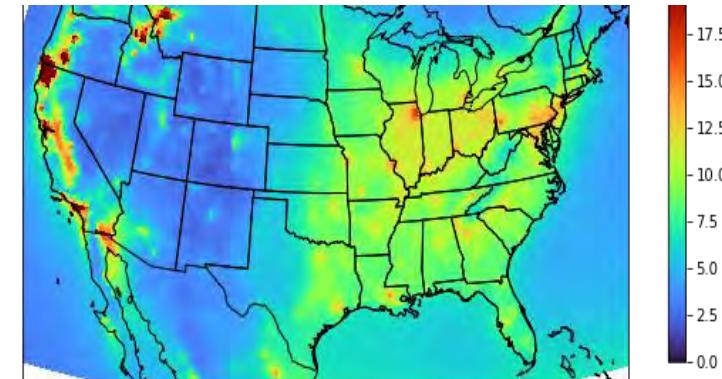
# Estimating health burden of O&G air pollution exposure
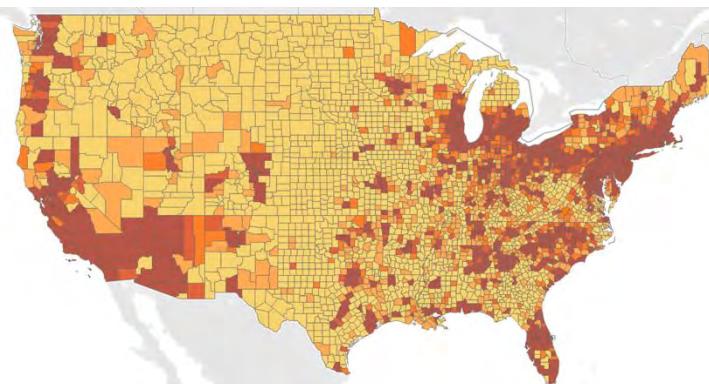
Health-risk assessment models


[Marais et al., 2023]
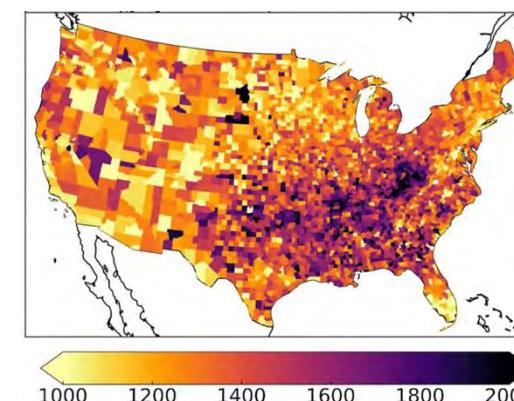
GEOS-Chem air pollutant concentrations
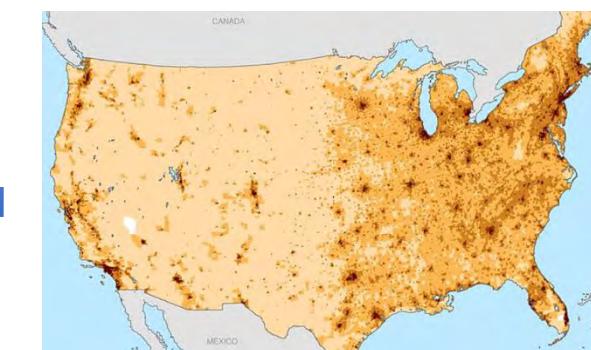
Relative exposure risks

Health burden estimates

US CDC baseline health data
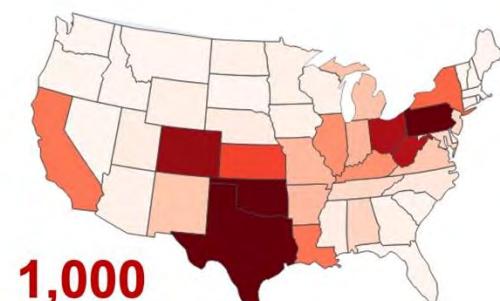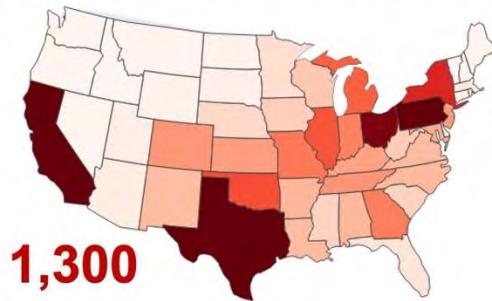
WorldPop Population data
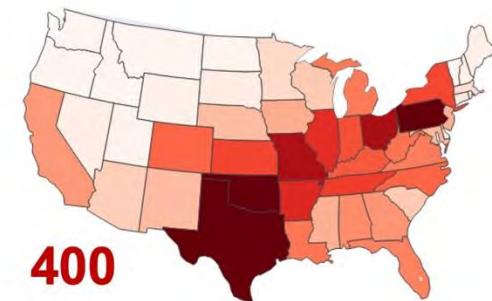
Annual premature mortality linked to O&G O$_3$, NO$_2$, and PM$_{2.5}$
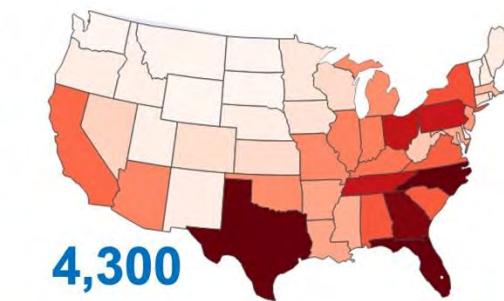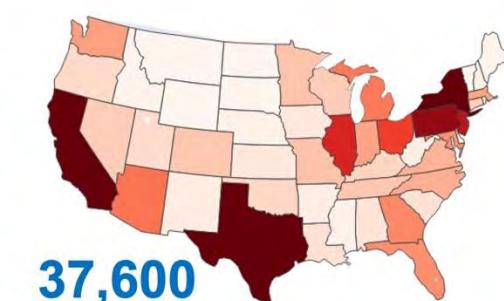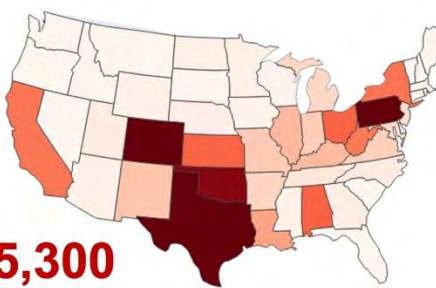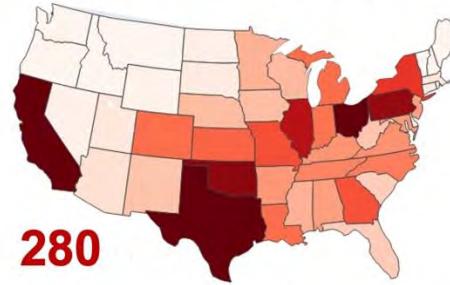

91,000 premature deaths in CONUS linked to oil and gas activities in the US
(2-3% of all early deaths in the US)

Preterm births, asthma and cancer incidences from O&G pollution
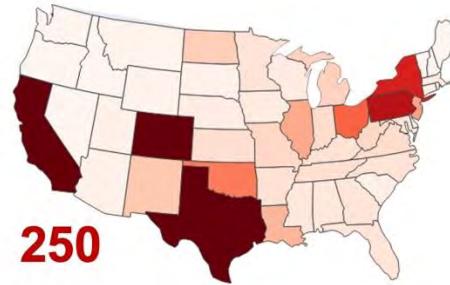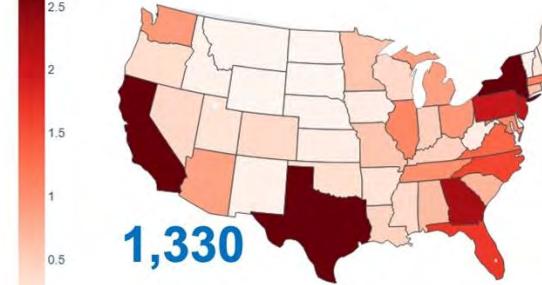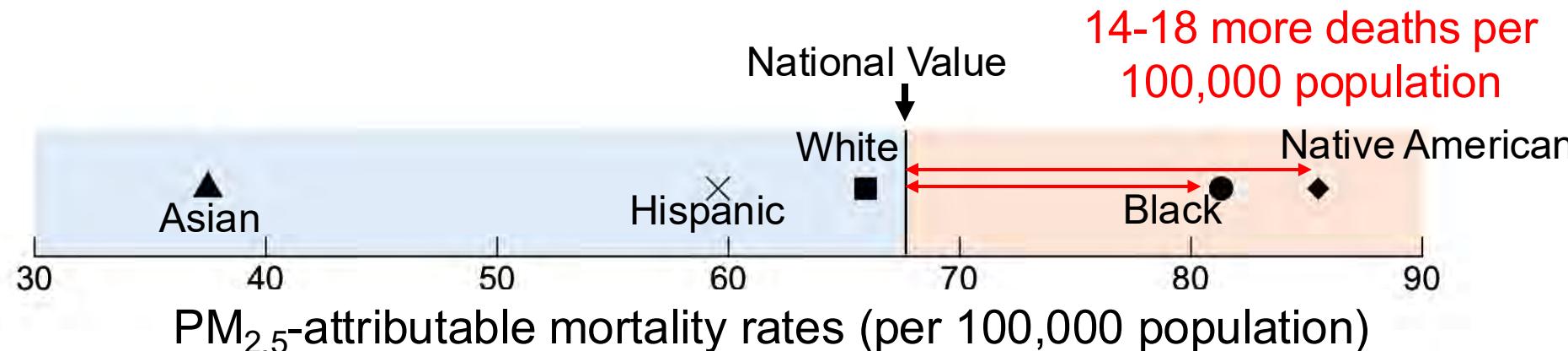
US O&G air pollution linked to 3% of preterm births, 10% of pediatric asthma incidences, and 4% of all respiratory and hematologic cancers in the US

Absolute disparities in O&G air pollution health burden
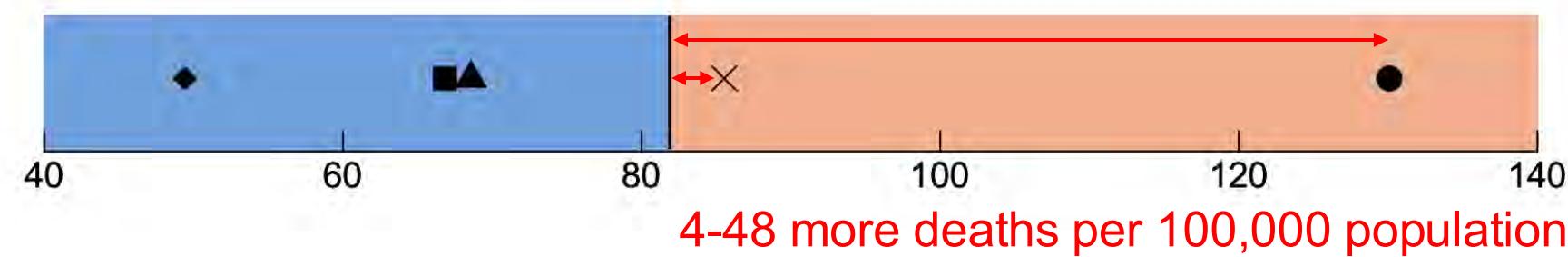
We estimate population-standardized health burdens for each racial and ethnic group. Subgroup population demographic data from American Community Survey (ACS) estimates.

Upstream + Midstream

14-18 more deaths per 100,000 population

National Value

White · Hispanic · Asian · Black · Native American

PM$_{2.5}$-attributable mortality rates (per 100,000 population)

Downstream

4-48 more deaths per 100,000 population

End-use

460 more deaths per 100,000 population
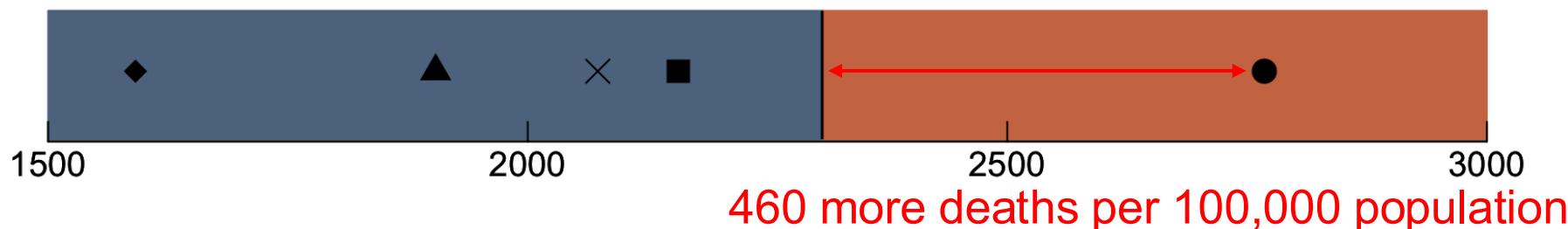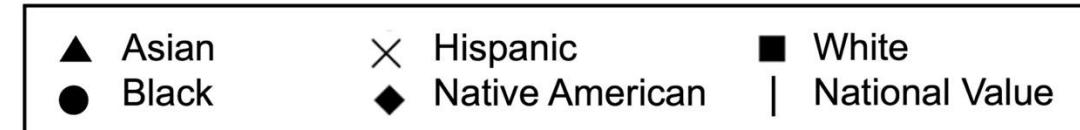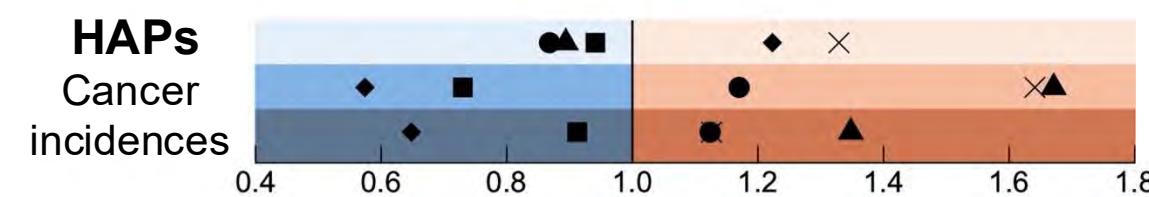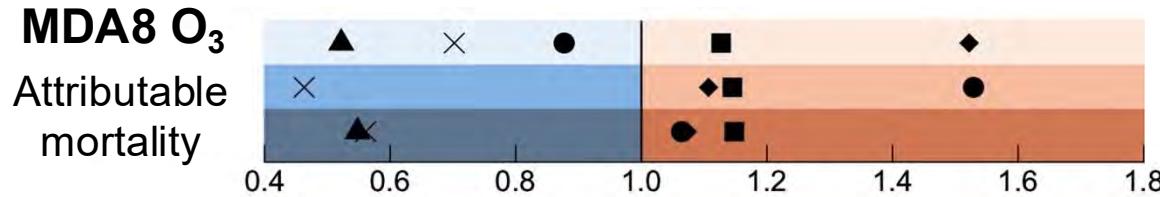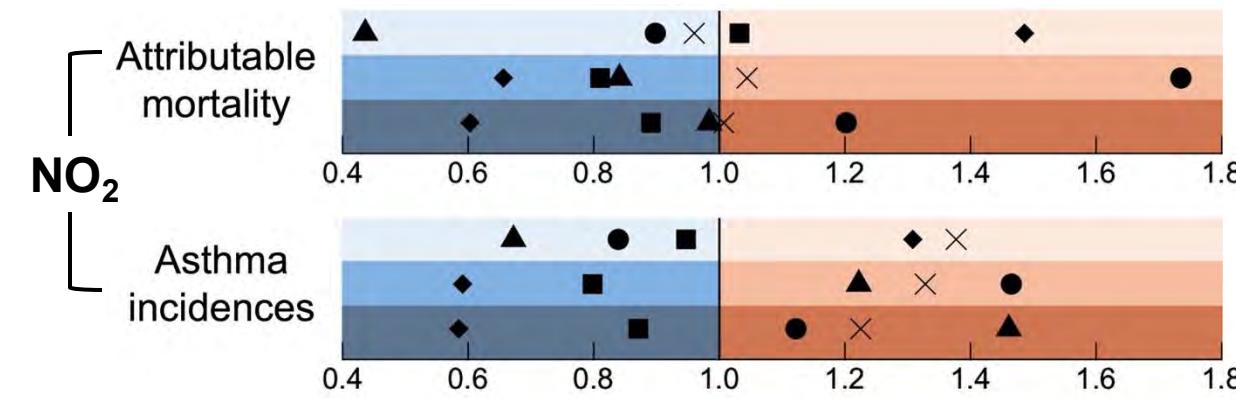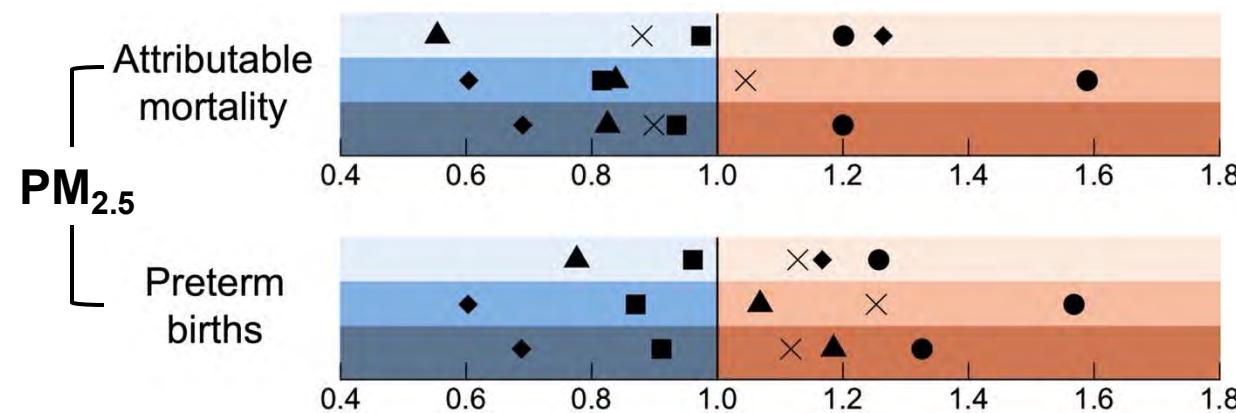
Absolute racial and ethnic disparities for the end-use stage exceed other stages

Relative disparities in O&G air pollution health burden

Population-standardized health burdens for each racial and ethnic group normalized to the national value

Disparities relative to national average:

    20-50% greater mortality rates for Native Americans; almost all health outcomes 20-70% greater for Black population; 35-50% greater asthma and cancer incidences for Asian population.

Greatest **relative disparities** almost all in the downstream stage

Interactive dashboard designed to aid potential beneficiaries of the study

https://bit.ly/US_oilgas_healthburden_dashboard

Severe health burden of air pollution from the US oil and gas sector
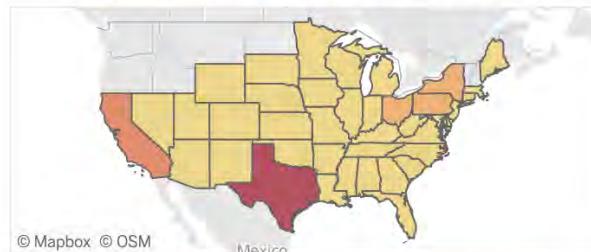
Step 1: Select an adverse health outcome.

Early deaths in adults (25+ years) from annual exposure to fine particles (PM2.5) ▾

Step 2 (Optional): Choose one, more or all states.

(All) ▾

Upstream and midstream activities
(Exploration and production) **Totals: 1,294**

**Downstream activities**
(Processing or refining) **Totals: 1,616**

End-use activities
(Consumption or combustion) **Totals: 44,301**

© Mapbox © OSM   Mexico

State: California
Lifecycle stage: Downstream
Health outcome: Early deaths in adults (25+ years) from annual exposure to fine particles (PM2.5)
Estimate: 375

Estimate 0 ———————— 217   Estimate

Up to 15 worst affected counties

Up to 15 worst affected counties	Up to 15 worst affected counties	Up to 15 worst affected counties
Los Angeles (California)	Los Angeles (California)	Los Angeles (California)
Harris (Texas)	Harris (Texas)	Cook (Illinois)
Dallas (Texas)	Contra Costa (California)	Orange (California)
Tarrant (Texas)	Philadelphia (Pennsylvania)	San Diego (California)
Bexar (Texas)	East Baton Rouge (Louisiana)	Riverside (California)
Allegheny (Pennsylvania)	Orange (California)	San Bernardino (California)

For more information, feel free to contact Dr Karn Vohra or Prof Eloise Marais. Suggested citation: K. Vohra, E. A. Marais, P. Achakulwisut, S. Anenberg, C. Harkins, **The health burden and racial–ethnic disparities of air pollution from the major oil and gas lifecycle stages in the United States,** doi:10.1126/sciadv.adu2241, *Science Advances*, 2025.

OR

SCAN ME

Concluding Remarks

- **Baseline mortality rates** not sufficiently stratified by race or ethnicity, so disparities are conservative.

- **Coarse resolution** doesn't resolve isolated, large sources like cancer-causing HAPs and super-emitters of methane contribution to O_3.

- **Instigator** of further studies with finer resolution models nested over target regions with most severe unjust exposures and burdens.

- **2017** chosen to combine most contemporary, best-available inventories. Growth in activities and faster rates of growth in production (upstream) since 2017, so contributes to conservative burden estimates.

- Health burden of air pollutants treated separately, so risk of **double or triple counting**. Paper includes detailed discussion of potential biases this introduces for specific lifecycle stages and locations.

Acknowledgements

Peer-reviewed Paper:

Science Advances: https://www.science.org/doi/10.1126/sciadv.adu2241