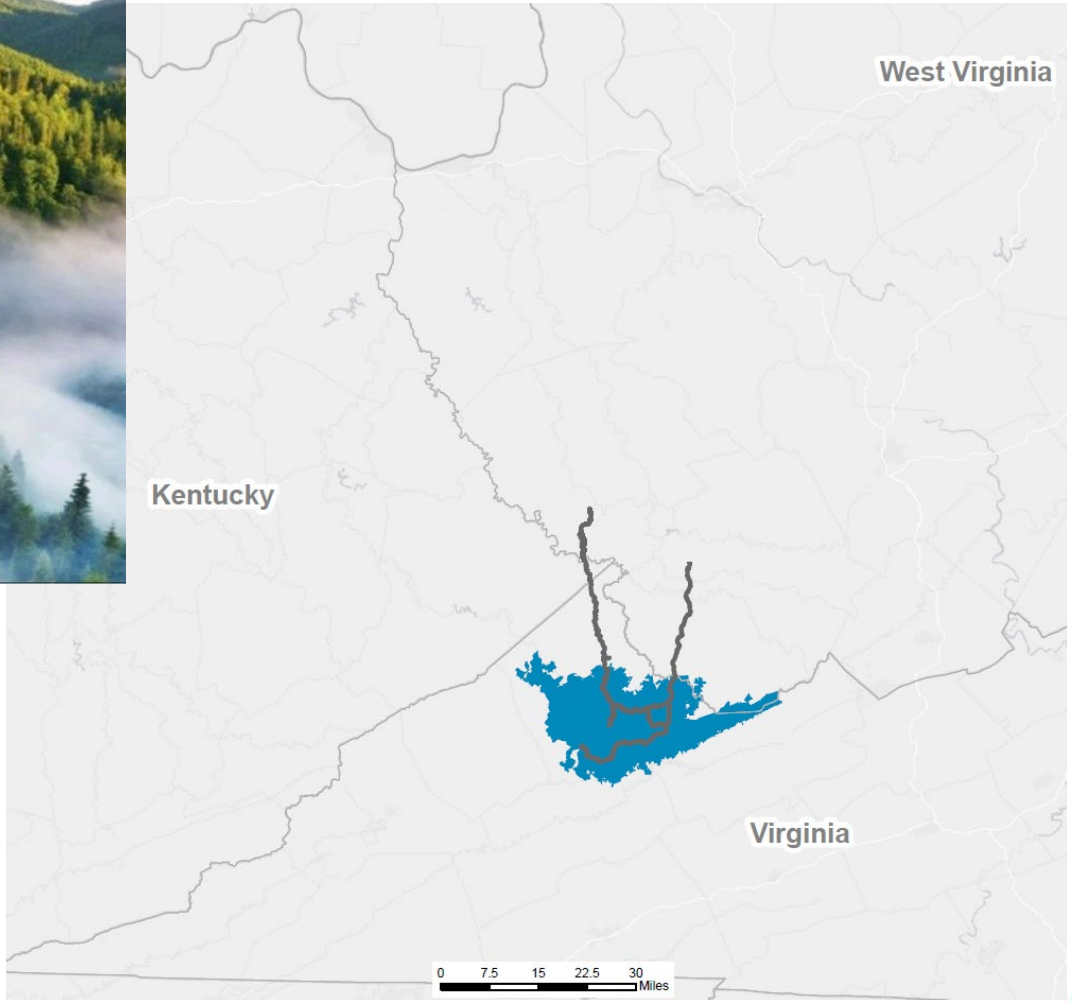
Jumpstarting Coal Mine Methane capture projects for beneficial end use

March, 20, 2024

Tangible and Impactful benefits

CNX uses a data driven approach to develop new capture projects from new sources of waste methane, investing millions of dollars every year.



Examples of data use within our operation include facility telemetry (volume, pressure, composition, temperature), design, customer transparency and policy stakeholder education

CMM Counterfactual Scenario: What would happen w/out incentives?

Release of methane from mined coal bed & disturbed surrounding strata, regardless of collection

100% of CMM released in counterfactual scenario based on [Schatzel et al., 2017] , [Mucho et al.]

Released methane must be removed from the mine for health and safety purposes

100% of CMM liberated from mine in counterfactual scenario, based on 30 CFR 57.8520

Today's analyzed capture activities are far below a level that could be considered standard industry practice

Based on multiple govt. sources and peer-reviewed studies, incl. [CARB, 2014]

Beneficial use is limited to less than 2% of active coal mines

As shown previously, beneficial use is not a viable counterfactual scenario for most projects.

Majority of capture projects today do not involve beneficial use

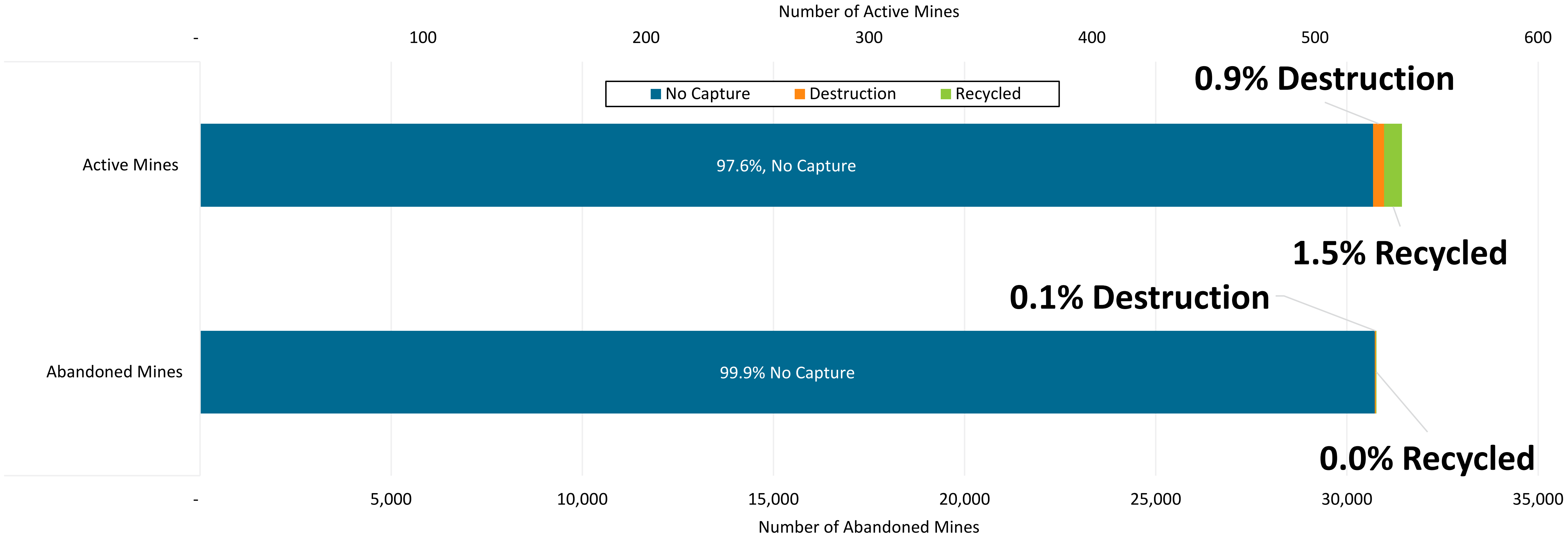
With very few, localized exceptions, capture that does occur today is based on voluntary GHG reduction commitments & CA cap-and-trade

No mandate for capture of liberated methane exists

Lack of legal requirements points to 0% capture in counterfactual scenario

Methane Capture by Mine Type

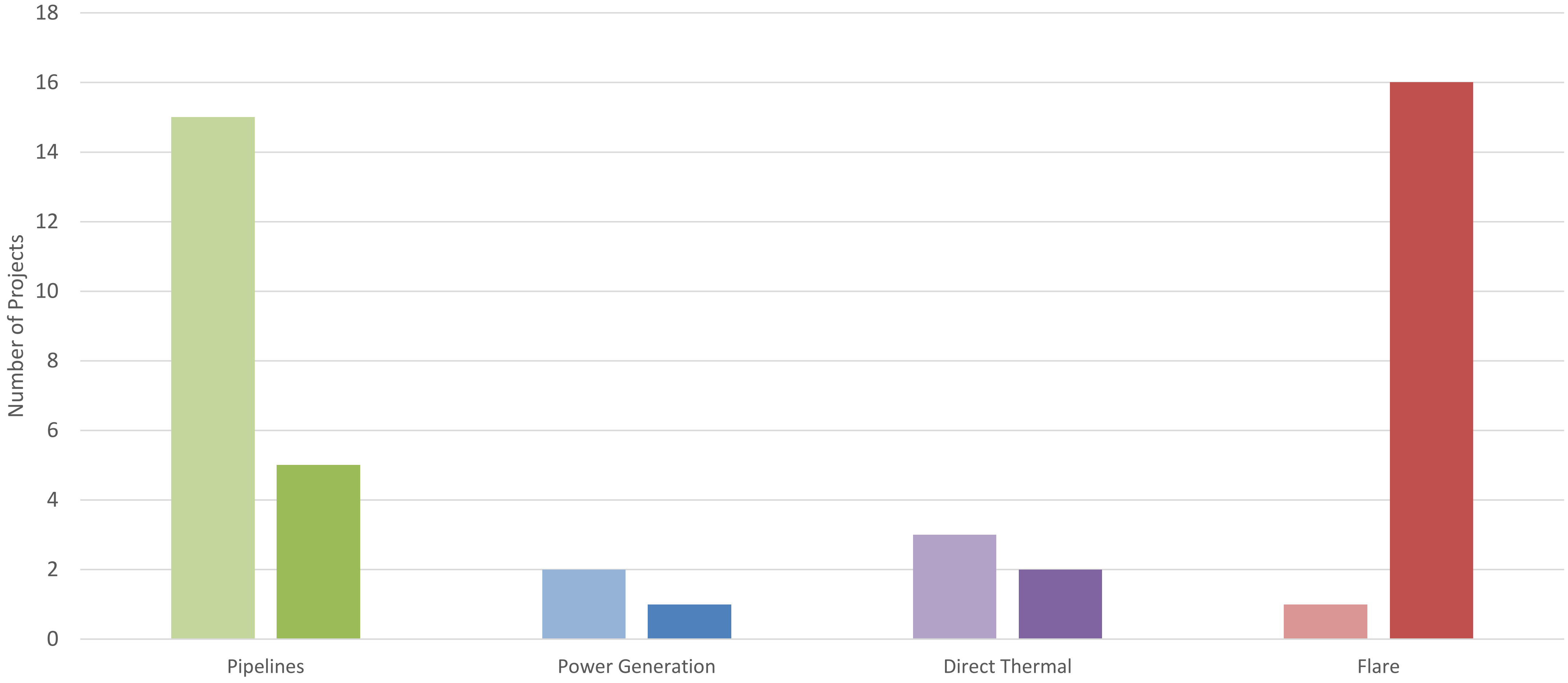
- Per EIA, there were 539 active US coal mines in 2022. In 2022, 13 active US coal mines in the US reported capture devices to GHGRP; 2.4% capture rate. [U.S. EIA],[U.S. EPA,U]
- Per MSHA, the US has 30,771 abandoned coal mines. Carbon registries show 41 abandoned mines with capture projects, less than 0.1% of total. [MSHA],[ACR, 2023]



Graphic 1.1: Active and Abandoned Mine Capture Breakdown *[U.S. EPA,U] [MSHA] [U.S. EIA] [ACR, 2023]*

Pivot from Beneficial Use to Flaring

Graphic 1.2: Drained Gas Projects: 2010 vs. 2022, all of US [GMI, 2022]



Data sources cited by author: U.S. EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2020; American Carbon Registry, Public Registry of CARB Offset Projects

CMM global forecasted pollution worsening

- Abandoned mines are not required to report emissions
- EPA's IA study estimates abandoned mines emitted 6.4 million MT CO2e of uncaptured methane, which is excluded from the 44.7 million MT shown on previous slide.
- Estimated methane emissions from abandoned mines will increase **8x** by the end of the century.[Rickey, T]
- 2020 research study estimates that global abandoned mine methane emissions were 418.9 million MT CO2e in 2010 [Kholod et al.]
  - Expected to increase to 1.4 billion MT CO2e in 2050.

N. Kholod et al. / Journal of Cleaner Production 256 (2020) 120489

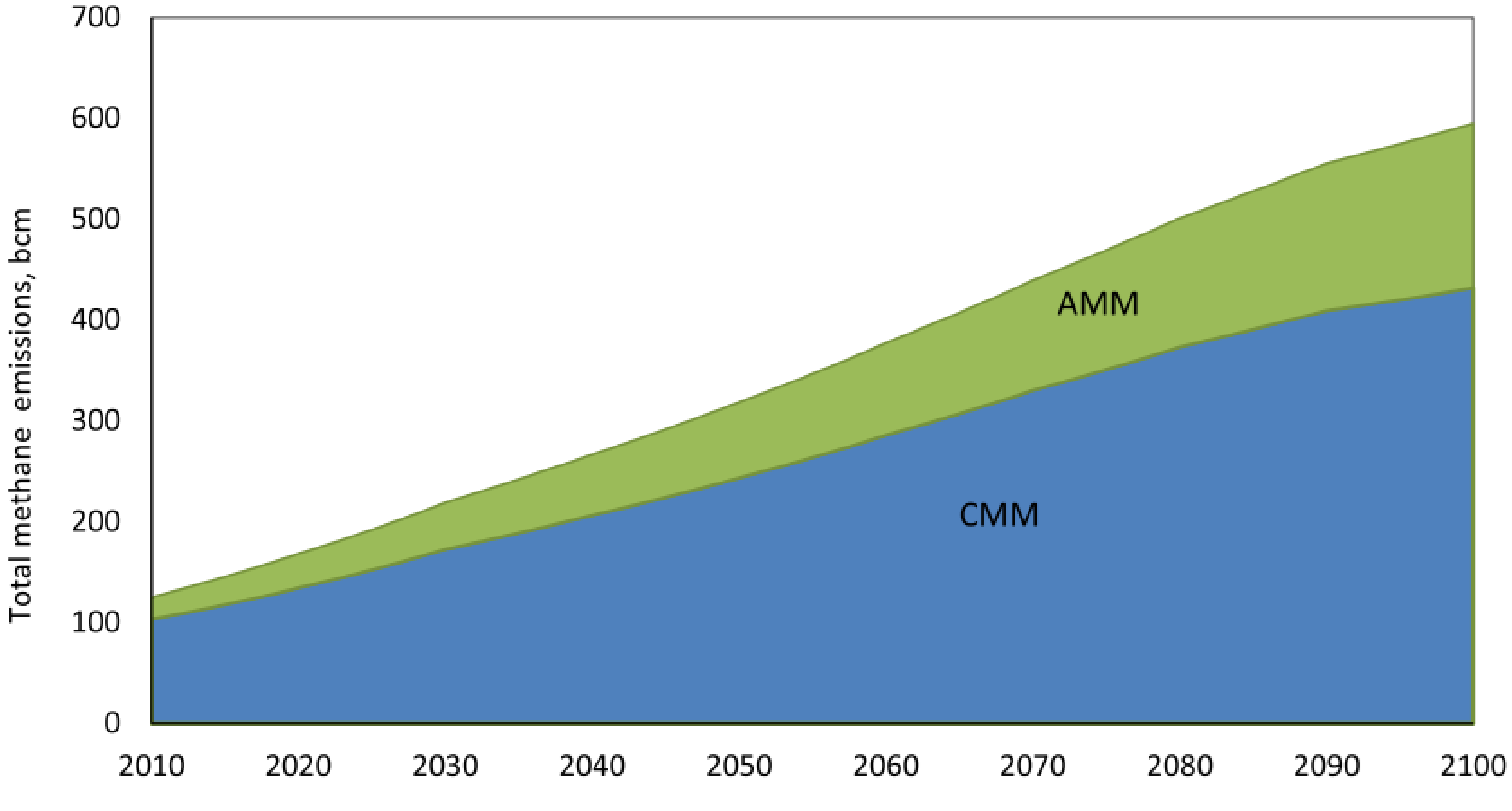
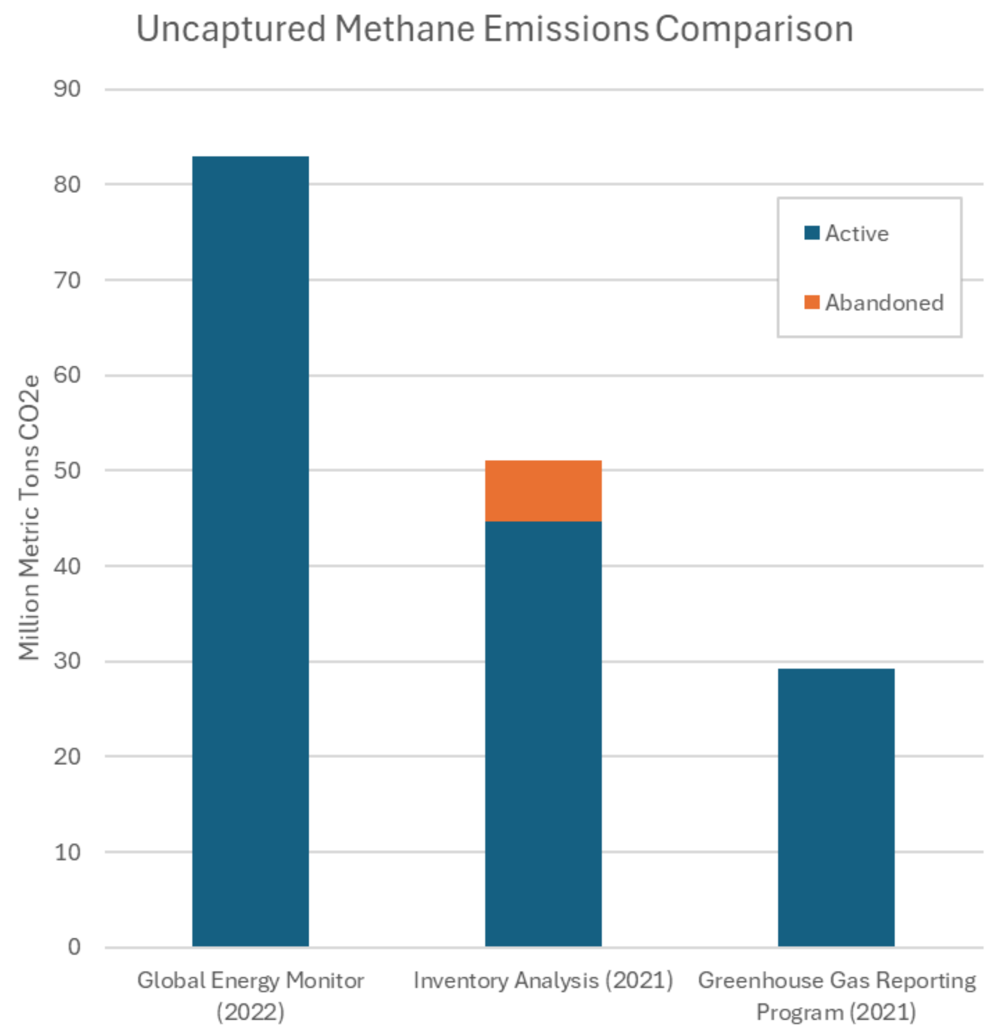


Fig. 4. Global methane emissions from coal mining, 2010 to 2100, bcm.

Comparison of Emissions estimates in the US

- Global Energy Monitor
  - Methane released from US active underground and surface coal mines in 2022 = 82.9 million MT CO_2e [GEM]
- EPA Inventory Analysis (IA)
  - Methane released in 2021 from US active underground and surface mines = 44.7 million MT CO_2e, 8% of total US methane emissions. [U.S. EPA,I]
- EPA – Greenhouse Gas Reporting Program (GHGRP)
  - Active underground coal mines reported 29.3 million MT CO_2e of methane emissions, which represents 14.8% of total US methane emissions reported to GHGRP. [U.S. EPA,U], [U.S. EPA,2]



Graphic 1.4: Comparing Methane Emission estimates by Data Source [U.S. EPA,U], [U.S. EPA,I] ,[GEM]

Carbon Markets: What makes a high quality environmental attribute (EA)?

- Real, Tangible, and Permanent GHG avoidance or removal
- Thoroughly measured, Independently verified, Conservatively estimated, Uniquely tracked, Transparently determined and accounted
- Causality - GHG reductions would not have occurred in the absence of an EA market
- 3-prong additionality test:
  1) exceed all currently effective laws and regulations
  2) goes beyond business as usual
  3) faces a financial, technical, or institutional barrier to implementation
- Carbon Intensity Life Cycle Assessment: Measurement, tracking, independent review & Verification, conservative risking applied in cases of uncertainty.
  - Methane Avoidance accounting – Market Adoption of Capture, Business as Usual, Counterfactual Scenario, Trends of Industry, Regulatory requirements.
  - Project Emissions accounting - GHG generation (Scope 1-3) of process

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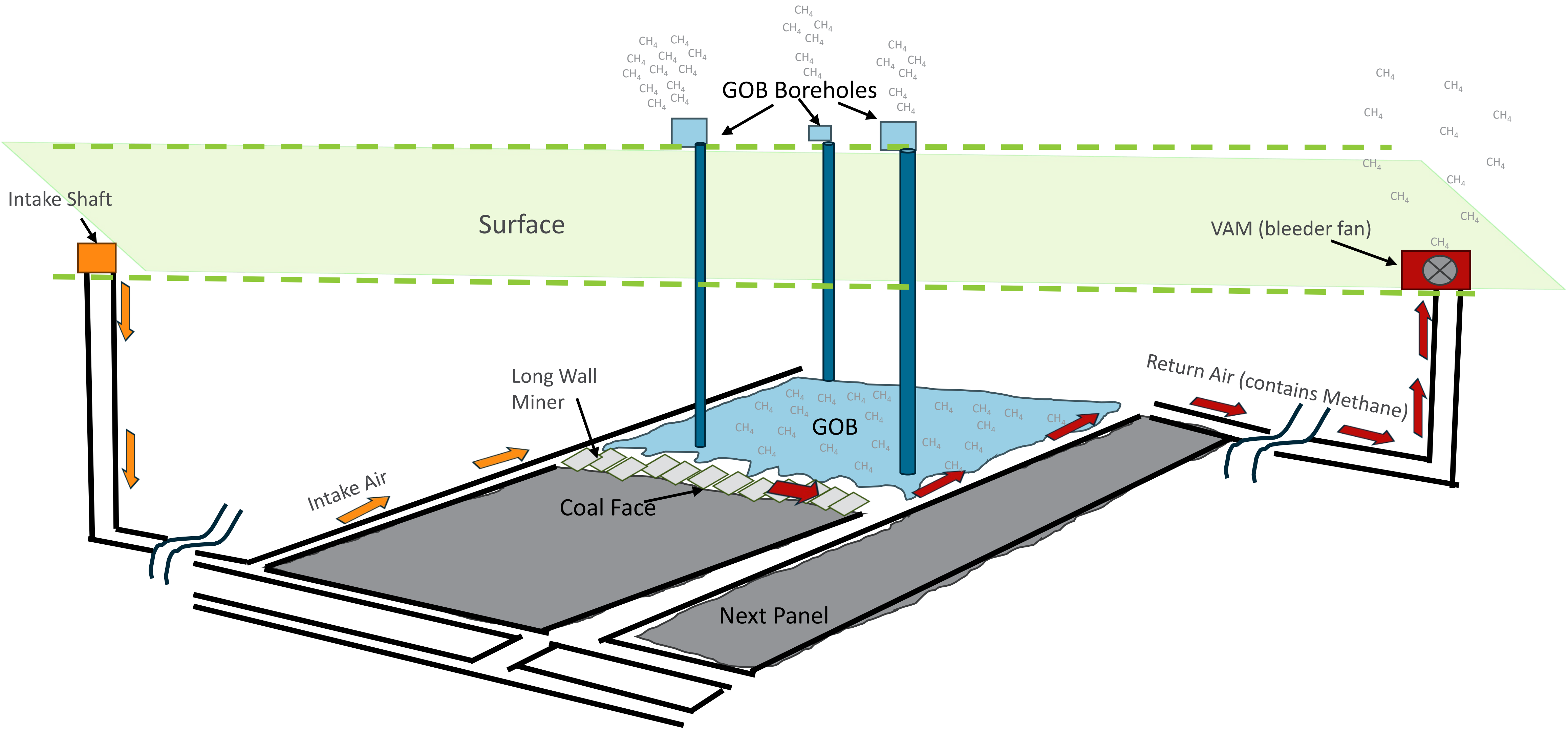
Using data for policy and methane reduction

- US DOE has established a granular, data-based assessment of methane emissions from US coal mines and the emission reduction impacts of pipeline-injected CMM in Argonne Lab's R&D GREET model.
- There is an opportunity to build on EPA's reporting foundation to create a more well-rounded picture; additional data sources can include:
  - Remote sensing-derived macro data
  - Emissions modeling based on mining activity
- Despite public assumption, methane liberated from active underground mines is expected to increase 4X by the end of the century. [Rickey, T]
  - Driven by coal mine industry fundamentals and emissions from abandoned mines
  - Develop a consolidated accounting of future CMM emissions trajectory
- Need clear communication of the reality of the challenge:
  - Determining the true magnitude of methane emissions now and in the coming years
  - Address causality misconception between methane abatement incentives and mining activities
- Lower VAM Emissions through installation of additional Gob Vent Boreholes

Typical coal mine degasification system



Efficiencies of Recovering CMM through Boreholes

- Reviewing a specific mine (Buchanan #1), which incorporates an advanced degasification system with GOB boreholes, the mine liberated 88% of total methane through GOB boreholes in 2022.
- CNX has identified opportunities to install additional boreholes and enhance hydraulic conditions to capture even more than the 88% of methane emissions through boreholes.
- With additional boreholes and degasification system design enhancements, other mines can also shift methane away from the VAM and towards boreholes where it can be captured more efficiently. The methane from the boreholes can then be put to beneficial use.

Year	2017	2018	2019	2020	2021	2022
US Borehole Liberated CO2e, MT*	5.4	5.6	5.6	3.6	4.1	4.4
US* VAM Liberated CO2e, MT	32.6	29.7	28.4	26.4	24.9	22.1
US Total Liberated CO2e, MT*	38.0	35.3	34.0	30.0	29.0	26.5
US* Total Captured CO2e, MT	1.6	1.3	1.0	0.9	1.1	1.2
US Percentage Borehole Drainage System*	14%	16%	16%	12%	14%	17%
Buchanan Borehole Liberated CO2e, MT	7.0	6.9	7.4	6.1	8.2	8.0
Buchanan VAM Liberated CO2e, MT	1.5	1.8	1.9	1.7	1.3	1.1
Buchanan Total Liberated CO2e, MT	8.5	8.7	9.3	7.8	9.6	9.1
Buchanan Total Captured CO2e, MT	7.0	6.9	7.4	6.1	8.2	8.1
Buchanan Percentage Borehole Drainage System	82%	79%	79%	79%	86%	88%

High potential for increasing beneficial use of methane captured

Table 1.2: GHGRP reported Liberated CO_2e by US mines and Buchanan #1 [U.S. EPA,U]

**Excludes Buchanan #1*

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Tracer Studies Confirm VAM and Borehole Connection

- Multiple studies used gas chemical tracer monitoring to confirm the interconnected nature of boreholes and VAM components:
  - Graphic 9: *“The recovery of tracer gas at the bleeder fan is probably directly associated with venthole G2 going off production 5 days before the arrival of tracer gas at BF2 (Bleeder Fan 2).”* [Mucho et al. 2000]
  - Table 1: *“The findings from the tracer gas portion of this study showed that there was interaction between the three GGVs closest to the face — 30 to 170 m (100 to 570 ft) — and face ventilation airflow.”* [Schatzel et al., 2017]
  - Graphic 10: *“It is evident from Figure 10 that gas production variations at G1 were reflected in the gas production rates at G2 and the shut-in pressure at G3, i.e., when G1 was offline, the gas production at G2 increased and the shut-in pressure at G3 rose (became less negative). Similar influences are evident when G2 was offline, i.e., a slight increase in gas production at G1, and the shut-in pressure at G3 rose.”* [Mucho et al. 2000]

Borehole Name	Tracer Migration Rate (ft/min)	SF6 monitoring picked up tracers after release (hours)
GGV 6	1.3 ft/min	47 minutes
GGV 5	.7 ft/min	3 hours 48 minutes
GGV 4	.2 ft/min	38 hours

Table 1: Tracer Migration rates from release in the mine to appearing at GOB well.

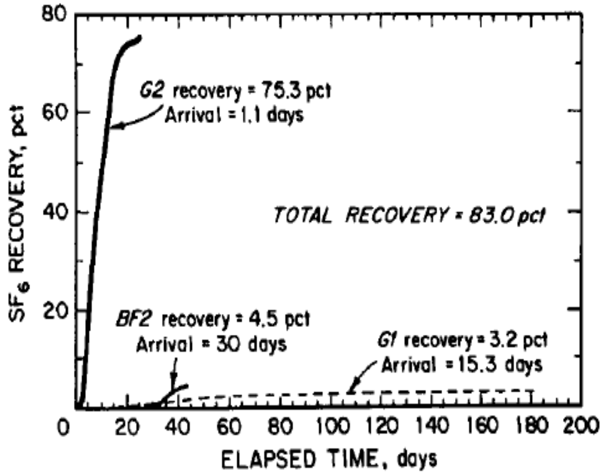

Figure 9. SF_6 tracer gas cumulative recoveries from gob gas venthole injection Test 3-1.

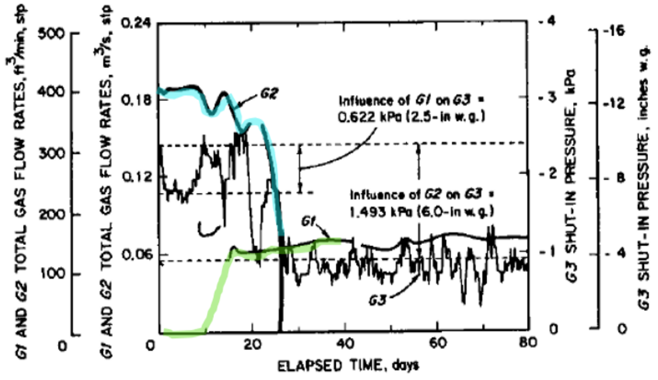

Figure 10. Influence of gob gas venthole production on G3 shut-in pressure.

Key Takeaways

- There is no legal requirement in the US to destroy the CMM that must be liberated for health and safety purposes.
- Current CMM destruction activities are primarily motivated by the valuation of GHG emission reductions in carbon markets.
  - Beneficial use of CMM is decreasing due to high expenses and lack of incentives
  - Observed increase in flaring projects is not material due to small volumes, temporary nature, and low adoption rate.
- CMM emissions in GHGRP are lower than other assesments, and analysis supports that 100% of the methane would be released in the business-as-usual scenario.
  - Methane emissions from coal mines are expected to increase over this century.
- CMM captured for beneficial use can help the US decarbonize and meet GHG reduction targets.
- Direct connection between Gob Vent Boreholes and Ventilation Air Methane.
  - Additional Gob Vent Boreholes will lower Ventilation Air Methane

Appendix

Data Sources

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Data Sources

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Terminology

- **VAM (Ventilation Air Methane)** is defined for the purposes of this presentation as the system that is used to control the concentration of methane within mine working area. The system contains powerful fans that move large volumes of air through the mine workings across the working coal face and out through a bleeder/ventilation shaft.
  - Greenhouse Gas Reporting Program's classifies VAM emission data under subpart FF (underground coal mines) as liberated CH4 from Ventilation Systems.
  - EPA's definition on CMOP's website has VAM listed as a ventilation system. VAM refers to the very dilute methane that is released from underground mine ventilation shafts.
- **Boreholes (GOB Borehole Drainage)** is defined for the purposes of this presentation as a system that drains methane from the GOB (collapsed coal seams and/or surrounding rock strata behind the coal face) through collection of vertical ventilation wells.
  - Greenhouse Gas Reporting Program's classifies borehole emission data under subpart FF (underground coal mines) as liberated CH4 from degasification monitoring points.
  - EPA's definition on CMOP's website has boreholes defined as the degasification system and commonly referred to as drainage systems. These systems employ vertical wells to recover methane during mining activities to help the ventilation system keep in-mine methane concentrations sufficiently low (i.e., well below the explosive limit) to protect miners.