

Best Practices in CMM Utilization: Achieving Near-Zero Methane Emissions from Coal Mine Mining

Prepared For:

Workshop on Best Practice Guidance for Effective Methane Drainage and Use in Coal Mines

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What is the goal of best practices?

Optimizing the safety, environmental, energy conservation, and financial benefits of the full CMM value chain

- Prediction of underground gas release
  - Efficient mine ventilation
    - Effective gas drainage
      - Optimal use of drained gas (CMM) and ventilation air methane (VAM) for near-zero emission coal mining
        - Management and staff education and training
          - Reinvestment in mine and gas operations

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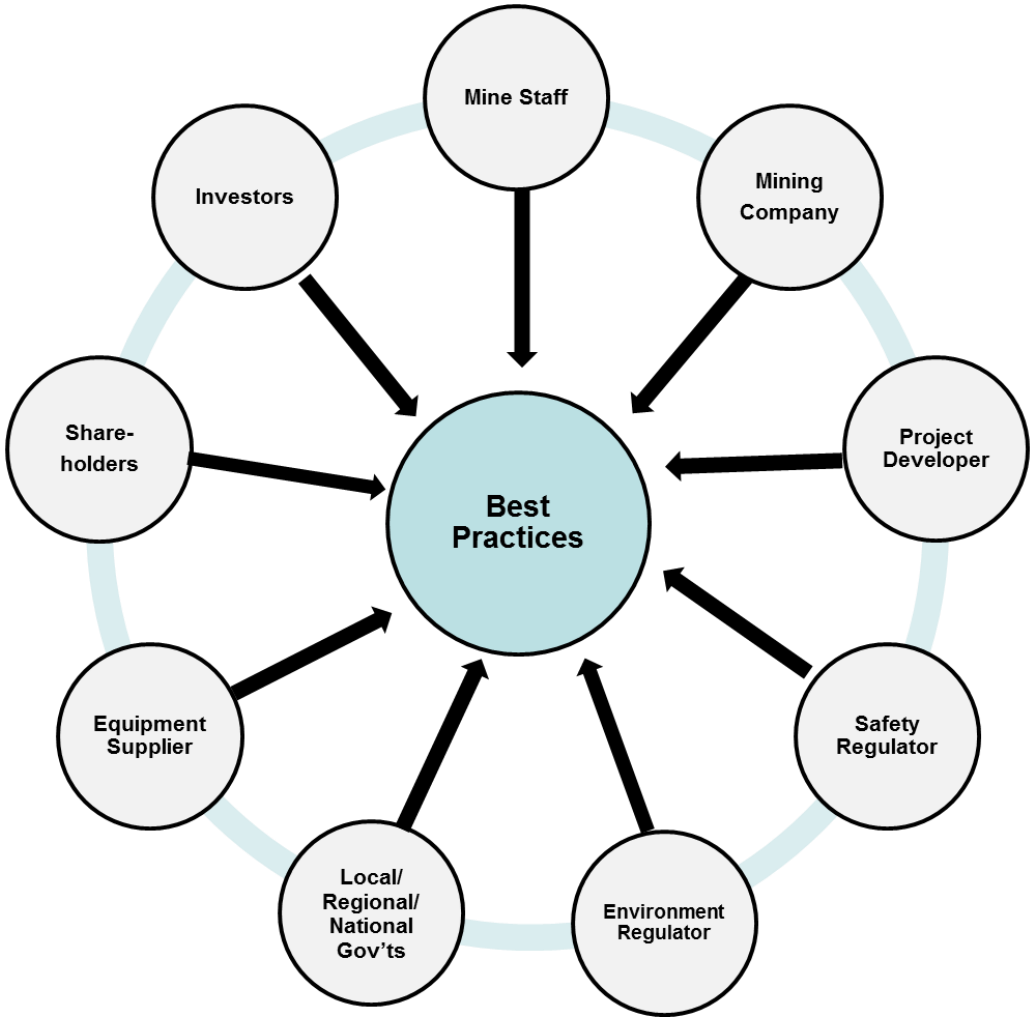
Multiple stakeholders



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Utilization of drained gas

- Technologies that use or destroy CMM are the same as those that use natural gas
- Near-zero emission projects entail a portfolio of technologies to maximize use of gas resources

Technology	Comments
Natural Gas Pipeline Sales	• Requires consistently high gas quality to meet pipeline specifications. • Usually limited to gas produced from inseam boreholes or high concentration gob boreholes where gas conditioning is economic
Power Generation	• Can handle CMM with minimum 25% CH4 and modular construction allows easy resizing of the plant to meet changing conditions at the mine • Most popular use of CMM
Vehicle Fuel – CNG/LNG	• Requires very pure CH4 stream • Expensive but can be economic in countries with high diesel prices , high carbon credit prices , or favorable government policies.
Boiler Fuel	• Not technologically complex and can use mine gas with 30% CH4 concentration. • Very common use – usually involves conversion of a coal-fired boiler
Direct Heating	• Use in industrial burners or industrial flares • Less expensive option. Construction similar to a candlestick flare
Flaring	• Used for stranded gas with no market, as an interim GHG destruction option, or to destroy excess GHGs in an integrated CMM project. • Not technologically complex , and produces large volumes of emission reductions at low cost although results in no energy recovery
Other uses	• CMM has been used in methanol production, glass making, steel manufacturing, desalination plants, green houses, and coal drying.

End-Use Options for CMM

- There is no hierarchy to define the "Best" end-use technology
- A project developer will be guided by
  - Markets
  - Mining company priorities
  - Availability of financing
  - Public policy priorities

Transportation Fuel

CNG Refueling Station

Chemical Feedstock

Methanol Production Plant

Power Generation

Power Plant with 500 kW Gensets

Regional and Export Gas Sales

Flaring

Industrial Use

Cooling

Combined Heat & Power

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Ventilation Air Methane (VAM) abatement

- Thermal and Catalytic Oxidation-Commercially Proven
  - Field-tested with continual refinement in design and control
  - Projects have operated in U.S., Australia and China
  - Destruction-only or energy recovery (heat and/or power)
    - 6MW VAM power plant in Australia since 2007
    - 30MW VAM power plant in China since May 2015

- Other technologies on the horizon
  - Lean-burn turbines
  - Monolithic reactors
  - Rotary kilns
  - Combustion air in small-scale and large-scale power production

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Commercial VAM Projects

Marshall County Mine, West Virginia, USA

- Mine formerly owned by CONSOL and project began under CONSOL
- Mine purchased by Murray Energy in December 2013
- VAM project financed and developed by Sindicatum Sustainable Resources
- 3 2-can RTOs from Durr
- Capacity = 160,000 cfm
- Emission reductions = 197,411 tCO2e

Gaohe Mine, Shanxi Province, China

- Owned by Shanxi LuAn Group
- In development
- 12 RTOs + steam turbine
- Will rely solely on power sales revenue
- Full capacity will be 700,000 cfm and utilize RTOs
- Using drained gas to enrich VAM to 1% CH_4

VAM RTO Manufacturers

- MEGTEC
- Biothermica
- Durr
- HEL-East Ltd
- Gulf Coast Environmental
- Shendong (China)

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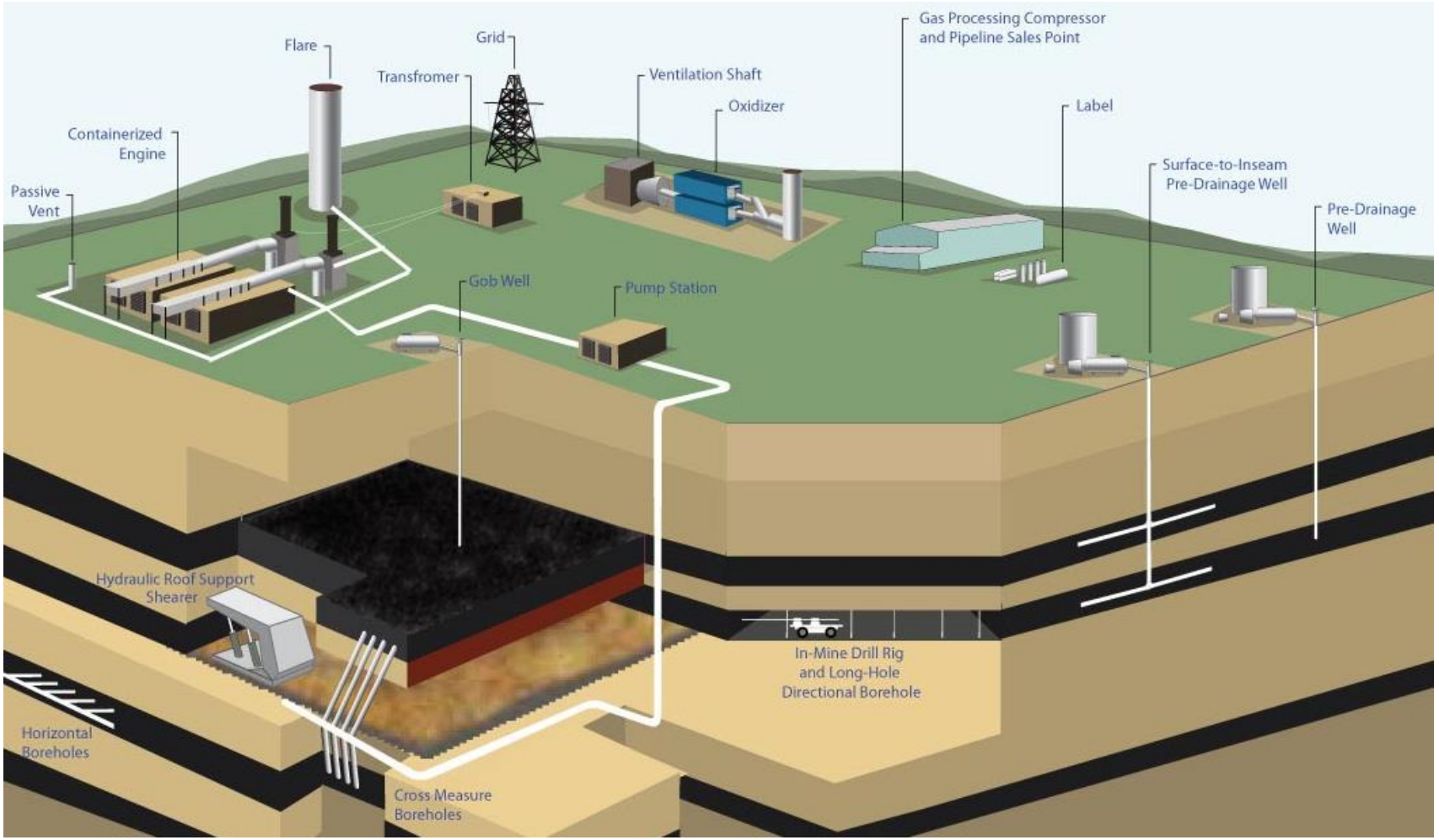
Integrated CMM capture and: Near-zero CH_4 emissions mining



Source: U.S. EPA *CMM Finance Guide (based on original drawing from the UNECE Best Practice Guidance on Effective Methane Drainage in Use in Coal Mines*

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Technology Costs

Drained Gas Utilization*		
Technology	**Capex**	**Opex**
Power generation	$1.5 – 1.75 million per MW installed	2.5 ¢/kWh
Flaring (enclosed stationary flare)	$500K - $1 mil	$25-50K/yr
Natural gas pipeline sales (assume gas conditioning)	$2-4 million	$400-$600K per year
LNG	$3 million per 1 MMcf/d processed	$1.5 - $2 million/yr

* **Costs of surface operations only – gas drainage costs are assumed to be sunk costs already incurred by the mine for safety reasons.**

VAM Destruction and Use		
Technology	**Capex**	**Opex**
Regenerative Thermal Oxidizer (RTO)	$50K-$75K per m^3/s throughput installed (eg. 60 m^3/s unit = $3-4.5 million)	60% of lifecycle project costs for a 10-year project (for 60 m^3/s unit, opex = $675K/yr)

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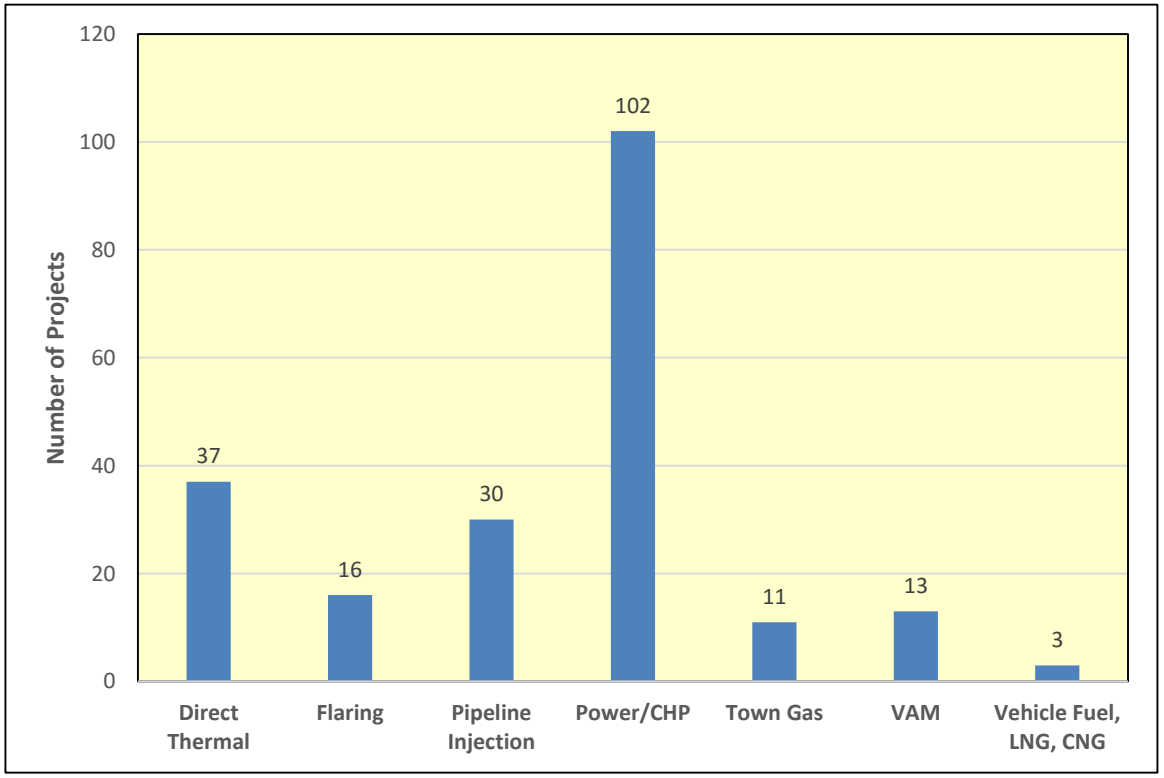
Over 200 CMM/VAM Projects Operational Around the World

The Global Methane Initiative (www.globalmethane.org) has identified more than 200 operational CMM/VAM projects at active and abandoned mines worldwide



Power generation	**709 MW of generation capacity**
Gas sales	**2,716 million m^3 per year**
Annual Emission Reductions	**29.4 million tonnes CO_2 equivalent**

Source: Global Methane Initiative database of CMM projects. Accessed October 2016.
http://projects.erg.com/cmm/

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Implementing & operating a CMM project

- Create a robust data set of flow and CH_4 concentration in VAM and CMM.
- Use a portfolio approach employing VAM destruction and multiple CMM utilization technologies to optimize the use of gas resources.
- Work closely with the mine management to successfully integrate the mine and CMM plant operations.
- Secure all mining, construction, operating, and environmental approvals and established rights to use the gas.
- Design the core project to operate as a baseload plant by sizing the plant at 80% of the average CH_4 flow.
- Establish a reliable emissions monitoring system to measure emissions of greenhouse gases and criteria pollutants.

Implementing & operating a CMM project

- Invest in and implement a quality monitoring, surveillance, and maintenance plan for the plant site. Small problems grow larger and more expensive very quickly.
  - A poorly operated plant not only reduces the value of the investment, but could present health and safety risks to the plant and mine staff
- Establish a continuing education and training program for staff covering plant operation and maintenance, occupational health and safety, and monitoring, reporting, and verification of energy sales and greenhouse gas emission reductions.

Coal Mine Methane Recovery and Use Case Study Duerping Mine, China

Sindicatum Sustainable Resources Duerping CMM Power Plant

Duerping Phase 1

- 12 MW power using IC engines
- Flaring
- Waste heat recovery
- Passive vent

Duerping Phases 1&2

Courtesy of David Creedy, Ph.D. & Sindicatum Sustainable Resources, Inc.

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Lessons learned

- Every project is unique – can systemize general development approach but will need to tailor each CMM project to the unique circumstances at that mine.
- Projects have many moving parts. Be prepared to face range of issues – changes in mine operations, gas quality issues, grid issues, engine maintenance, etc.
- A dedicated, experienced in-house engineering team ensures that technical problems can be resolved quickly.
- Economics are improved significantly if flaring is included in project design and there is a market for carbon offsets or other revenue drivers such as feed-in tariffs.
- Automated data collection and processing increases accuracy, expedites verification, and can save money over the long term.
- When modeling project finances, build adequate contingencies into the model.
- Even at a near-zero emission project, there will be some GHG emissions – it is virtually impossible to eliminate all GHGs

Thank You

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