Best Practices for CMM Utilization – End Use Options

GMI Coal Mine Methane and Coalbed Methane Technical Workshop

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Presentation Outline

- Introduction to ARI
- Coal Mine Methane Sources
- Methane Drainage Use Technology Options
- Ventilation Air Methane (VAM) Use Technology Options
- Project Economics
- Developing a CMM Project
- Financing a CMM Project
- Conclusions

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Advanced Resources International

- **A consulting, research and development firm**
- **Principal practice areas**
  - Coal mine methane (CMM)
  - Unconventional gas development (gas shales, coalbed methane and tight sands)
  - Enhanced oil recovery (EOR)
  - Carbon capture, utilization and storage (CCUS).
- **Experience in over 30 other countries**

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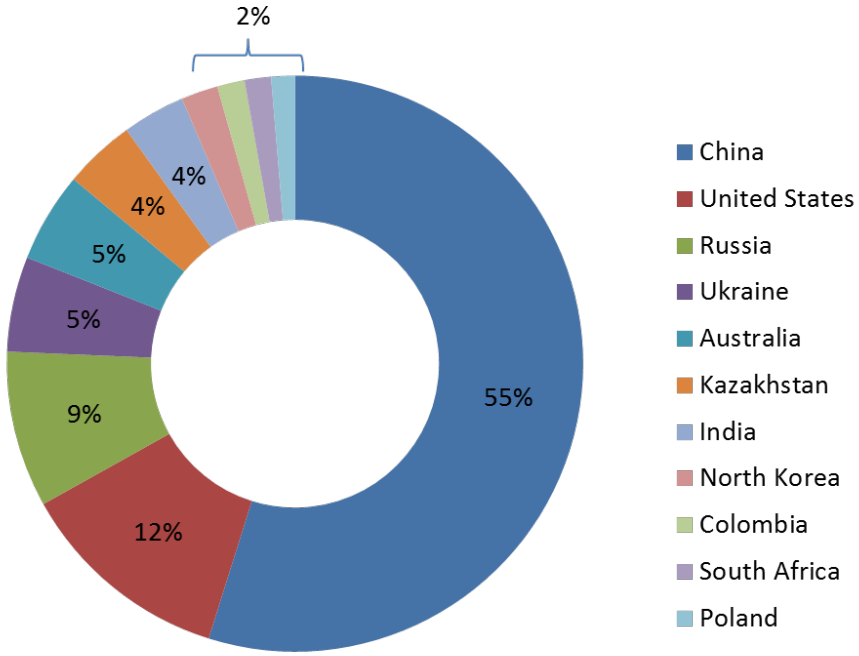
Sources of Coal Mine Methane

- CMM = 8% of Global CH_4 Emissions
- CMM emissions are growing.
  - In 2014, CMM emissions totaled 621MMtCO2e (44 BCM)*
  - By 2030, CMM emissions projected to increase to 784 $MMTCO_2E$ (55 BCM)*



Share of Global CMM Emissions from Major Coal Mining Countries (Million tCO2e)

Source: US EPA 2012

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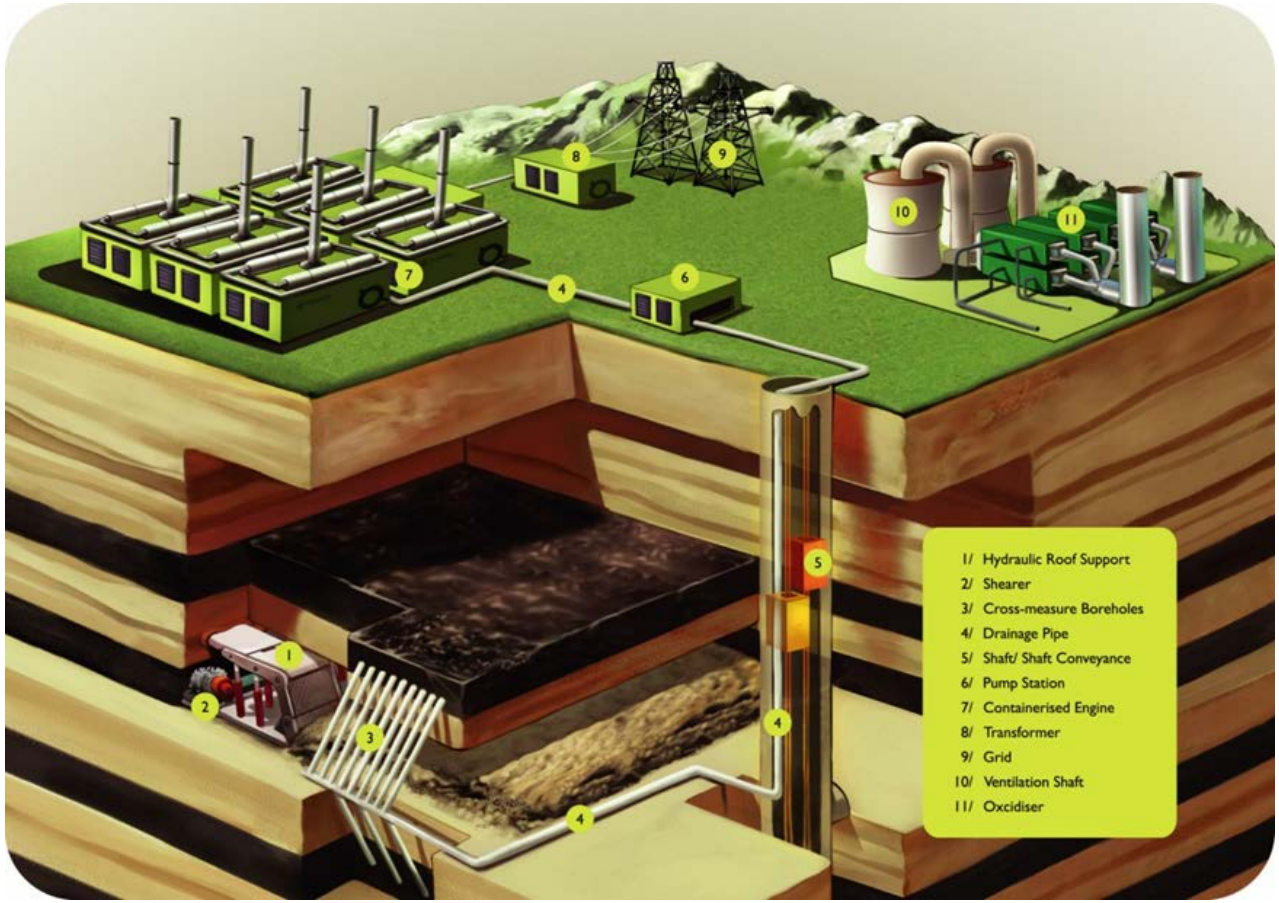
Integrated CMM Capture and Utilization at an Operating Mine



Source: UN Economic Commission for Europe. *Best Practice Guidance on Effective Methane Drainage and Use in Coal Mines*. Schematic courtesy of Green Gas International, Inc.

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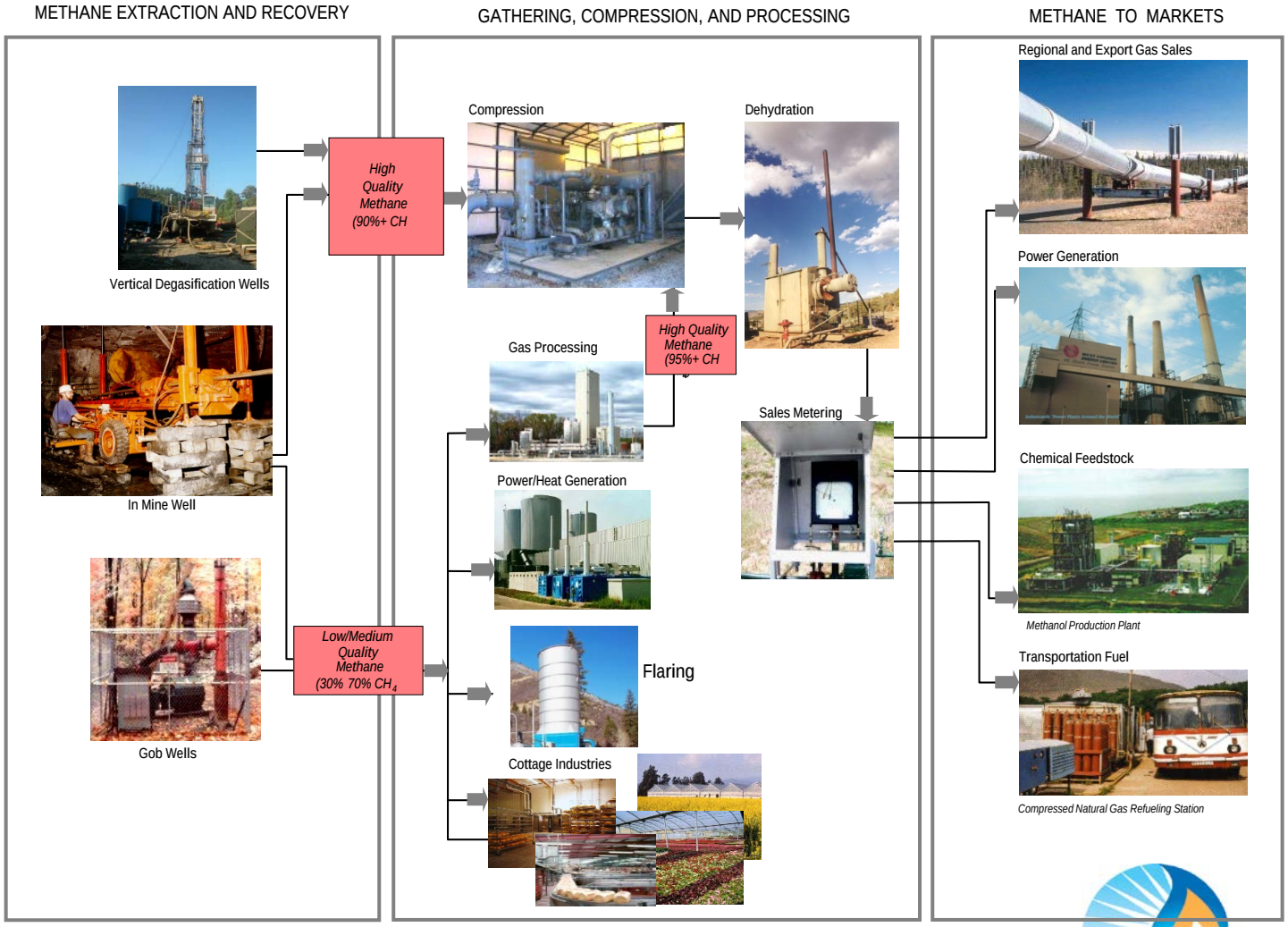
Methane Drainage Value Chain



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Methane Drainage Use and Destruction Technology Options

Technology	Comments
Natural Gas Pipeline Sales	• Economic where extensive gas pipeline network is accessible • Requires consistently high gas quality to meet pipeline specifications.
Power Generation	• Most common use worldwide • Used mostly in internal combustion (IC) engines but can be used in gas turbines. • Modular configuration with small engines (500kW-3 MW) are most common
Vehicle Fuel – CNG/LNG	• Requires a very pure methane stream. • Infrastructure necessary to move CNG/LNG to market or use on-site • Expensive options but becoming more attractive
Boiler Fuel	• Very common • Used to heat water or air for mine buildings (e.g. showers/space heating) and shaft heating. • Not technologically complex and can use mine gas with 30% CH4 concentration.
Direct Heating	• Mine shaft heating in winter • Industrial furnaces
Flaring	• Destruction-only technology. Can use mine gas with concentrations down to 30%. • For stranded gas with no market, as an interim GHG destruction option, or to destroy excess GHGs in an integrated CMM project.
Other uses	• CMM has been used in methanol production, glass making, steel manufacturing, desalination plants, green houses, and coal drying.

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Methane Drainage Key Points

- Technologies to use or destroy CMM are the same as those that use natural gas.
- End use is determined by many factors:
  - Gas quality (CH_4 %)
  - Gas quantity (4.2 m^3/min CH_4 = 1 MW)
  - Access to markets
  - Infrastructure
  - Financial position
  - Staff capacity
  - Mining company priorities
  - Government policy priorities

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Methane Drainage Key Points

- Projects often include a portfolio of technologies to maximize gas use.
- When deciding what technology to use:
  - Power, flaring, boilers, and vacuum pumps require minimal gas treatment
  - LNG, CNG, and pipeline sales require expensive gas treatment
- In order to implement a successful methane drainage project:
  - Improve gas availability (gas quantity and quality) and maintain CH_4 concentrations above the explosive range
  - Size plant properly- 80% of average gas flow
  - Flare gas when not used rather than venting
  - Regular maintenance and overhaul are required to keep the plant operating

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Ventilation Air Methane (VAM) Technology Options

Range of Technologies have been identified

Only 2 have been used commercially

Regenerative Thermal Oxidation

- Oxidizes VAM at 1000°C
- Technology common in manufacturing operations to destroy very low concentrations of VOCs
- Destruction only or energy recovery
- 1 VAM power project in Australia, and 1 under construction in China.

Ancillary Use as Combustion Air

- Successfully used in Australia at a 54 MW CMM power plant use 1 MW internal combustion engines
- Improved efficiency of the gas engines
- Resulted in some corrosion problems

Duerping Mine (China)

Marshall County Mine (USA)

Jim Walter Resources Blue Creek #4 (USA)

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VAM Technologies on the Horizon

- Regenerative Catalytic Oxidation
- Lean- burn turbines and microturbines
- Rotary Kilns

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Ventilation Air Methane (VAM) Key Points

- Success of projects is almost entirely dependent on carbon markets
- Some potential for power generation, but it requires a consistent and high VAM concentration (1% CH_4)
  - One option is to enrich the VAM with supplemental drained gas
- CH_4% is critical – the higher the CH_4% the larger the emission reductions and the more carbon offsets that are generated.
- Proven technologies are available and in operation
- Other technologies close to commercialization

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Project Economics- Gas Drainage

Notional Costs of Gas Drainage Projects		
Technology	Capital Costs	Operating Costs
Flaring Enclosed (ground flare) Open (candlestick flare)	$120,000 - $450,000 (290 - 1,089 mln Colombian Peso) $30,000-130,000 (72 – 314 mln Colombian Peso)	$10,000 - 20,000 per year (24 – 48 mln Colombian Peso) $5,000 -15,000 per year (12,106,250 – 36,318,750 Colombian Peso)
Power generation	$0.75 - 1.5 million per MW installed (1,815 – 3,631 mln Colombian Peso)	$0.015 - 0.03 per kWh (36.319 – 72.638 Colombian Peso)
Natural gas pipeline sales (assume gas conditioning)	$2 - $4 million (4,842 – 9,685 mln Colombian Peso)	$400 - $600K per year (968 – 145 mln Colombian Peso)
LNG	$3 million per 1 MMcf/d processed (7,263 mln Colombian Peso)	$1.5 - $2 million per year (3,631 - 4,842 mln Colombian Peso)

- Projects often include a portfolio of technologies to maximize gas use
- A CMM power project will typically include:
  - Gas engines with generators
  - Flare
  - A passive vent
  - Possibly heat recovery

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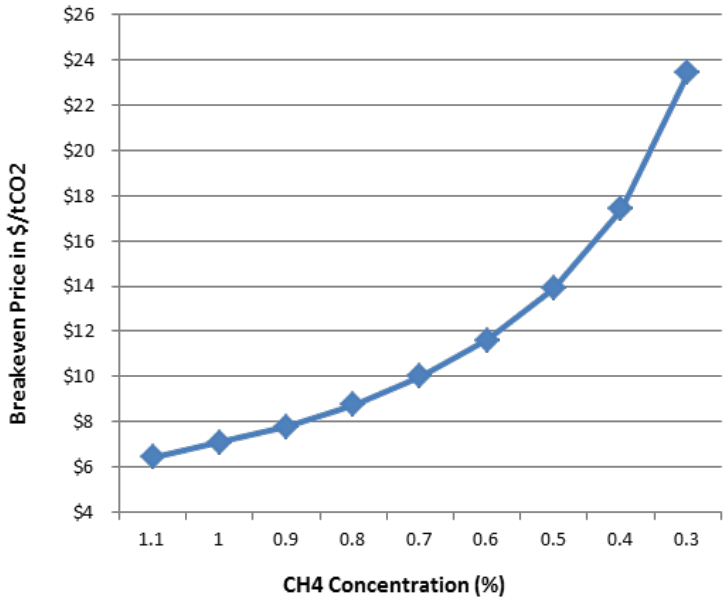
Project Economics- VAM

VAM Destruction and Use		
Technology	Capex	Opex
Regenerative Thermal Oxidizer (RTO)	$50,000-$75,000 per m^3/s throughput installed (eg. 60 m^3/s unit = $3-4.5 million) (121 mln – 181 mln Colombian Peso)	60% of lifecycle project costs for a 10-year project (for 60 m^3/s unit, opex = $675,000/yr)



Breakeven price of an example VAM project at different CH_4 concentrations

- VAM projects are capital intensive
- VAM projects can have high O&M costs
- Can generate significant revenue at attractive carbon prices due to high CH_4 throughput

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Financing a CMM Project

- Available funding
  - Do it yourself- internally financed
  - Private Equity
  - Debt providers- commercial or investment banks
  - Targeted investment funds
  - Developer/ investors
  - Carbon credit buyers or buyers with focus on Corporate Social Responsibility
- Critical to secure financing from 3rd parties
  - Credible gas resource assessment and full feasibility study with financial analysis
  - Off- take agreements with credit- worthy partners
- Secure carbon financing or other environmental finance in addition to internal financing and institutional finance

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Conclusions

- There is a long history of CMM capture and use worldwide and much experience to access
- Recovery of CMM is largely from underground mines but there have been surface mine methane projects
- Power generation, boiler fuel, gas pipeline sales, flaring and local distribution are the most common uses for gas drainage.
- VAM accounts for 70% of methane emissions from underground coal mines.
  - Any sustained effort to reduce Greenhouse Gas emissions from the coal sector must address VAM emissions.
  - Regenerative Thermal Oxidation is a commercially proven technology available currently in use.
  - Other technologies have been field tested and are close to commercialization.

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