New Economic Solution for Abating VAM Emissions at Gassy Coal Mines
Ener-Core and Raven Ridge Resources

OTCQB: ENCR
Coal Mine Methane Outreach Program Conference
November 2014
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The Problem:

U.S. Coal Mine Emissions (2012)
Liberated – 137 tcf
  91 tcf was vented
  46 tcf was drained
38 tcf was drained and either used or destroyed
  8 tcf was drained and vented

Largest source of methane emissions is VAM.
Existing solutions **destroy gases**. They do not use them productively.

Ener-Core technology is an alternative, allows coal mines to economically abate emissions of VAM by using it along with CMM as fuel for power generation.
Major Components of the Ener-Core Solution

Source of Low-Quality or Off-Spec Gas

Ener-Core’s Thermal Oxidizer

Thermal Mechanical Digital Interface

Conventional Gas Turbine (modified for external combustion)

Turbine Package

AC Generator

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The dilute gas (input) does not have a high enough energy content for combustion.

Combustion is a rapid reaction that happens in milliseconds and produces pollutants as part of output.

Ener-Core Oxidation is an exothermic chemical reaction. It has no flame, resulting in temperature that avoids the NOx formation temperature. It happens in seconds, it produces heat, and it removes the pollutants in the incoming gas.
Attero Landfill – Schinnen, Netherlands

- Closed landfill with below 30% methane; past problems with reciprocating engines running inconsistently and unable to run on gas
- First Commercially sold unit
- 250kW oxidizer powerstation was successfully installed and is currently operating continuously
- 250 kW oxidizer powerstation generates about 50% more electricity (kWhs) per week than reciprocating engine it replaced
- Has accrued over 1500 hours since commissioning in 2014
Ultra-Low Btu Phase 1 Pilot for Oil & Gas Customer

- Customer is interested in utilizing Ener-Core’s Oxidation technology
  - Generate clean power from a casing gas emitted during a proprietary oil extraction process
  - Reduce CO2 footprint of process
    - Preventing methane venting
    - Avoiding gas blending for destruction (adding natural gas just to destroy methane vent)
  - Maintain air emissions below regulations with Low NOx exhaust (< 1 ppmv @ 15% O2)
  - Results used to permit Phase 2 Field Demonstration

<table>
<thead>
<tr>
<th>Component</th>
<th>1st Condition (%)</th>
<th>2nd Condition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane (CH4)</td>
<td>7.75%</td>
<td>5.80%</td>
</tr>
<tr>
<td>Nitrogen (N2)</td>
<td>84.20%</td>
<td>91.15%</td>
</tr>
<tr>
<td>Carbon Dioxide (CO2)</td>
<td>8.00%</td>
<td>3.00%</td>
</tr>
<tr>
<td>LHV (Btu/scf)</td>
<td>71</td>
<td>53</td>
</tr>
<tr>
<td>Steady run time (hr)</td>
<td>5.5</td>
<td>3</td>
</tr>
</tbody>
</table>

Ener-Core Powerstation at UC Irvine Campus
Robust Reliable Dresser-Rand KG2-3G Gas Turbine

- All Radial; Single Shaft
- Cold End Drive
- Capacity: 2 MW ISO Shaft
- Efficiency: 25%

- KG2-3GEF Off Base Combustor
- Standard Configuration
- Flanges for Oxidizer Interface
Ener-Core Oxidation Expands the Generation Opportunity to Previously Unusable Gases

- KG2-3G with Oxidizer Gas Operating Range
- KG2-3G
- Flares
- Standard Gas Turbines
- Reciprocating Engines

**Oil Fields**
- Tail Gas
- High CO2 Associated Gas
- Natural Gas
- Associated Gas

**Biogas**
- Tail/Perimeter Gas
- Closed Landfills
- Active Landfills
- Digester Gas

**Coal Mine**
- VAM
- Abandoned
- Seams/Beds/Closed/Active

**Industrial Gas/VOC**
- VOC
- Industrial Waste Gases

**Gas Btu/scf**
- 15
- 50
- 100
- 200
- 250
- 350
- 500
- 700
- 1000
- 1200
- 2000+
**KG2-3GEF/GO Configurations: Simple Cycle and Recuperated**

**Simple cycle KG2-3GEF/GO (High Exhaust Heat)**
- Gas Energy Input: 25 MMBtu/hr (7300 kW)
- Electric Output: 1750 kW
- Steam Output: 12,667 lb/hr (3804 kW)
- Overall efficiency: 76% (LHV)

**Recuperated KG2-3GEF/GO (High Electrical Efficiency)**
- Gas Energy Input: 17 MMBtu/hr (5000 kW)
- Electric Output: 1750 kW
- Electrical efficiency: 35% (LHV)
- Overall efficiency: 70% (LHV) (with 6 MMBtu/hr of hot water)
Abandoned Mine Methane (AMM) gas can be used as the primary fuel to operate the powerstation.
AMM Fuel Input Requirements

As the AMM composition fluctuates, the flow required to operate the machine varies.

**KG2-3G w/GO**

- **10% CH4**
  - Energy Content – 3.91 MJ/Nm³
  - Flowrate – 4.600 to 6.400 NM³/hr

- **18.3% CH4**
  - Energy Content – 7.21 MJ/Nm³
  - Flowrate – 2.500 to 3.500 NM³/hr
KG2-3G w/GO Energy Balance

Coal Mine Gas
Energy Input
5000 kW

Energy content of fuel * Flowrate

Electrical Output
1,750 kW

Exhaust Heat
2,700 kW
Ventilation Air Methane (VAM) gas destroyed and GOB gas used to supplement powerstation operation.
VAM Fuel Input Requirements

**FP250**

**VAM**

- Flowrate – 6130 NM³/hr (3615 scfm)
- 5206 MCFD
- Pressure – Atmospheric

**GOB gas**

- Flowrate – 75 NM³/hr (44 scfm)
- 63 MCFD
- Pressure – 517 kPa (75 psig)

**Assuming:**

- 0.8% CH₄ VAM
- 70.0% CH₄ GOB Gas

**KG2-3G w/GO**

**VAM**

- Flowrate – 27001 NM³/hr (15923 scfm)
- 22,929 MCFD
- Pressure – Atmospheric

**GOB gas**

- Flowrate – 463 NM³/hr (273 scfm)
- 393 MCFD
- Pressure – 1103 kPa (160 psig)
KG2-3GEF w/GO CO2 Balance

Energy content of fuel * Flowrate

VAM Gas 38%
Drainage/GOB Gas 62%

POWER INPUT 5,000 kW

Electrical Output 1,750 kW
Exhaust Heat 2,700 kW

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Coal Mine Operations
Costs & Emissions

Electrical Consumption
>80% for Ventilation

Coal Mine Operation

393 MCFD GOB

22929 MCFD VAM

79,379 tons CO2e from VAM & GOB

Source: http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results
Integration into Coal Mine Operations
Offsetting Costs & Emissions

Electrical Consumption
>80% for Ventilation

Coal Mine Operation

393 MCFD GOB

22929 MCFD VAM

14,500 MWh per Year per System
Electricity to Offset Utility Purchases

10,689 tons CO2e

Source: [http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results](http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results)
Integration into Coal Mine Operations
Offsetting Costs & Emissions

Annual Grid Electricity CO2 Savings from 1.75 MW Powerstation: +10000 to 13800 tons (depends on region)
Annual Avoided CO2 from VAM & GOB Utilization: +68690 tons
Annual Avoided CO2 Emissions from VAM Powerstation: +78690 to 82490 tons
Benefit of Low NOx
(Minor NOx Emissions Source)

Electrical Consumption
>80% for Ventilation

Coal Mine Operation

393 MCFD GOB

22929 MCFD VAM

14,500 MWh per Year

Grid Electricity NOx Emissions Rate: +1.38 to 2.3 lb/MWh (depends on region)
Grid Electricity NOx Associated Tons: +10 to 17 tons (depends on region)
Annual Avoided NOx VAM Powerstation: +9.5 to 16.5 tons (depends on region)

0.50 tons NOx
Economics of KG2-3GEF/GO at a Coal Mine
Offsetting Electricity & Emissions

Electrical Consumption >80% for Ventilation

Coal Mine Operation

393 MCFD GOB
Compressed to 115 psig

22929 MCFD VAM
Delivered to system

14,500 MWh per Year per System
Electricity to Offset Utility Purchases

10,689 tons CO2e

Source: [http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results](http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results)
Installation of Ener-Core technology at XYZ Mine

- **Mine parameters**
  - 6 MT of coal mined annually
  - Annual ventilation emissions:
    - 1050 mmcf (or 2.8 mmcmd), 420,000 cfm
    - Concentration ranges from 0.35 to 0.7 percent
  - Annual gob gas drainage:
    - 525 mmcf (or 1.4 mmcmd)
    - Concentration averages 85 percent

## Recent CMM Carbon Credit Prices

<table>
<thead>
<tr>
<th>Emission Reduction</th>
<th>Price ($/tonne)</th>
<th>Credit Type</th>
<th>Includes CMM?</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRT</td>
<td>$1.00 - $3.00</td>
<td>Voluntary</td>
<td>Yes</td>
</tr>
<tr>
<td>VCU</td>
<td>$1.00</td>
<td>Voluntary</td>
<td>Yes</td>
</tr>
<tr>
<td>ARB Offset</td>
<td>$3.00 – 25.00</td>
<td>Compliance</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Source: Cote (2013, 2014)
Average Industrial Electricity Prices by Region

Source: www.eia.gov
Inputs and assumptions

• Ener-Core KG2-3G w/GO units installed at mine site -
• All electricity generated will be used by the mine to supplant power purchased from the grid
• All gob gas is available for use by project at no cost to project
• Drilling costs are not included in economics
• Gas gathering and compression are included
## Economic Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>electricity price (¢)</td>
<td>5.99</td>
</tr>
<tr>
<td>VAM concentration</td>
<td>0.70%</td>
</tr>
<tr>
<td>GOB concentration</td>
<td>85%</td>
</tr>
<tr>
<td>GOB production (mcfd)</td>
<td>1.40</td>
</tr>
<tr>
<td>Installed capacity (MW)</td>
<td>7</td>
</tr>
<tr>
<td>CAPEX ($ x 1,000)</td>
<td>21,592</td>
</tr>
<tr>
<td>OPEX ($ x 1,000)</td>
<td>1,120.8</td>
</tr>
<tr>
<td>ARBOCs</td>
<td>220,951</td>
</tr>
<tr>
<td>IRR (%)</td>
<td>23.08</td>
</tr>
<tr>
<td>NPV ($ x 1,000)</td>
<td>6,891</td>
</tr>
<tr>
<td>Time to Payout (yrs)</td>
<td>4.6</td>
</tr>
</tbody>
</table>

### Assumptions
- **VAM concentration**: 0.70% (constant for all scenarios) and 0.35% (in one scenario).
- **GOB concentration**: 85% (constant for all scenarios).

### Inputs
- **GOB production (mcfd)**: 1.40 (constant for all scenarios) and 1.33 (in one scenario).
- **Installed capacity (MW)**: 7 (constant for all scenarios) and 5.25 (in one scenario).
- **CAPEX ($ x 1,000)**: 21,592 (constant for all scenarios) and 16,194 (in one scenario).
- **OPEX ($ x 1,000)**: 1,120.8 (constant for all scenarios) and 840.6 (in one scenario).

### Results
- **ARBOCs**: 220,951 (constant for all scenarios) and 165,714 (in one scenario).
- **IRR (%)**: 23.08 (constant for all scenarios) and 25.31 (in one scenario).
- **NPV ($ x 1,000)**: 6,891 (constant for all scenarios) and 6,039 (in one scenario).
- **Time to Payout (yrs)**: 4.6 (constant for all scenarios) and 4.3 (in one scenario).
Probability Distribution Plot - NPV
Sensitivity Analysis Tornado Plot

NPV & IRR

- ARBOC_Price: $6.63 to $19.07
- Elec_Price: $0.0621 to $0.0690
- Ventilation Air Methane (VAM): 0.53%
- GOB Gas: 85.0%

Downside Upside

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Raven Ridge Case Study Shows Environmental and Economic Solution Even with $60/MWh (6¢/kWh) Electricity

- **Western Colorado**
  - $72.2/MWh
  - IRR 28%
  - 3.9 yr payback

- **Northern Appalachia / Virginia**
  - $62/MWh to $66.5/MWh
  - 4.3 to 4.6 yr payback

- **Four Corners**
  - $63.2/MWh
  - IRR 25%
  - 4.3 yr payback

- **Black Warrior Basin**
  - $59.9/MWh
  - IRR 23%
  - 4.6 yr payback
Watch our Whiteboard video explaining the gradual oxidation process and its applications

https://www.youtube.com/watch?v=YIwJNOF-SQU