Methane Combustion

Gas Engines	
COMPANY	**DESCRIPTION**
Mines often vent medium quality gob gas instead of using it, because gob gas requires enrichment and treatment prior to pipeline injection. However, fuel for power generators does not require pipeline quality gas. Generally, internal combustion engines can be adapted to generate electricity using coal mine gas with a methane concentration as low as 25%. Regulations in most countries require a minimum of 25% CH_4 concentration for utilization and some require 30% CH_4. While all internal combustion engines powered by CMM are capable of producing electricity, several also have the capability for waste heat recovery and co-generation. There has been considerable consolidation among engine manufacturers in recent years and the list below in some cases includes different brands produced by the same manufacturer.	
Caterpillar http://www.cat.com/power-generation 888-614-4328 toll free in United States and Canada +1 (309) 675-2337 International http://www.cat.com/en_US/support/contact-us.html	Caterpillar has introduced a range of larger, more efficient gas generator sets that can be fueled by CMM, landfill methane, or natural gas. The CMM fueled CAT ™ G3520C Gas Engine produces 2077 kW with an efficiency of about 40% and NOx ratings as low as 0.5 g/bhp-hr. Minimum methane concentration for gas engines may be as low as 25%. Large installed base of CMM power generation, mainly in Australia and China. http://www.cat.com/power-generation
MWM http://www.mwm.net/en/ 49 6 21/3 84-0 info@mwm.net	MWM, formerly Deutz Power Systems, was acquired by Caterpillar in 2011 and manufactures and markets under the name Caterpillar Energy Solutions. MWM's product portfolio manufactured in Germany comprises gas engines (gas generators or gas gensets) and plants in the output range from 400 kWe to 4,500 kWe. MWM can supply open or containerized units. Minimum methane concentration for gas engines may be as low as

Gas Engines	
COMPANY	**DESCRIPTION**
Schaefer Heribert heribert.schaefer@mwm.net Armin Roeseler armin.roeseler@mwm.net	25%. Large installed base of CMM power generation, mainly in Europe, the CIS, and in China. http://www.mwm.net/mwm-chp-gas-engines-gensets-cogeneration/gas-engines-power-generators/
GE Waukesha https://www.ge-distributedpower.com/	Waukesha, a division of GE Distributed Power, manufactures two families of engines. The VHP® and the VGF® include models designed to combust alternative fuels such as bio-gas, landfill, digester gas or CMM in addition to natural gas. Depending upon the model, the engines with attached generators (called Waukesha Enginator®) can produce from 165 to 1400 kW. GE also produces the Waukesha 275GL rated from 2300 to 3500 kW. https://www.ge-distributedpower.com/products/power-generation
GE Jenbacher https://www.ge-distributedpower.com/ Thomas Elsenbruch thomas.elsenbruch@ge.com Barbara Marschik barbara.marschik@ge.com	GE's Jenbacher gas engines manufactured in Austria range in power from 300 kW to 9500 kW and run on either natural gas or a variety of other gases (e.g., biogas, landfill gas, coal mine gas, sewage gas, industrial waste gases and other syngases). Minimum methane concentration for gas engines may be as low as 25%. Jenbacher engines are used in Europe, China, the CIS and Australia. https://www.ge-distributedpower.com/products/power-generation

Gas Engines	
COMPANY	**DESCRIPTION**
IHI Corporation www.ihi.co.jp/en/products/energy_systems/index.html +81-3-6204-7724 https://contact.ihi.co.jp/index.php/ihi_eng/IHI/form_20302	The Nigata Gas Engine AG output ranges from 2,204 to 5,979 kW. This high efficiency gas engine series can combust fuels with low calorific value such as CMM, digester gas and landfill gas. www.niigata-power.com/english/products/gasengines/index.html
Mitsubishi Heavy Industries Ltd. https://www.mhi-global.com/ Power Systems Engine Section Sales Department +81-3-6716-4771 https://www.mhi-global.com/inquiry/index.html	Mitsubishi manufactures the GS16R-PTK and GS16R2-PTK gas engine/generator sets with output of 1000 kW and 1500 kW, respectively. MACH gas engines are being used in CMM fired power generation projects in China. Mitsubishi also produces the MACH-30G series gas engines (KU30GA) that utilize minimum quantities of liquid fuel for ignition and have a generation output range between 3,650 and 5,750 kW. https://www.mhi-global.com/products/detail/product_explanation_gas.html https://www.mhi-global.com/products/pdf/ku30ga_en.pdf
Shengli Power Machinery Group Co., Ltd. http://www.generatorsetscn.com/ http://www.generatorsetscn.com/contact.html Manager Su sdjtsujie@gmail.com +86-15963081356	Shengli Power Machinery Group, the earliest manufacturer of gas engines in China, produces gas engines that are very widely installed across mining regions in China to burn CMM. Shengli gensets come in 500kW and 600kW configurations capable of burning typical CMM gas drainage streams with concentrations above 25%. All CMM projects using Shengli gensets are concentrated in China. http://www.generatorsetscn.com/

Gas Engines	
COMPANY	**DESCRIPTION**
Cummins Engine http://www.cummins.com/cmi/ (763) 574–5000 (800) 888–6626 USA Toll Free ask.powergen@cummins.com http://power.cummins.com/contact-us	Cummins, a United States manufacturer, produces the QSV91 Series ranging from 1500 to 2000 kW through Cummins Power Generation, Inc. The series is designed specifically for lower BTU gas with target industries of landfill gas, CMM and biogas. http://cumminspower.com/www/literature/brochures/F-1523-LowBTUGensets-en.pdf
Dresser Rand Guascor http://www.dresser-rand.com/ (713) 354-6100 +33-156 26 71 71 http://www.dresser-rand.com/company/contact-finder/	Guascor® Low Quality Fuel Engines manufactured in Spain operate on a wide range of waste gases including landfill gas, biogas and coal mine methane. Power output ranges from 315 to 985 kW. Guascor engines are operating at a CMM project in the United States. http://www.dresser-rand.com/products/engines/

Gas Engines	
COMPANY	**DESCRIPTION**
Gas Turbines	
COMPANY	**DESCRIPTION**
A wide variety of gas turbines may be fueled with CMM or AMM. Normally turbines operate over a range of methane concentrations, but best results are achieved with a concentration above 35 % with minimal concentration variability. Large industrial gas turbines can have a generation capacity of 1,000 kW to 50,000 kW. Gas turbines operate by compressing and cooling air drawn into the unit. The compressed air is preheated through an exhaust heat recuperator and then mixed with fuel and combusted. The resulting hot gas expands through the turbine, producing the mechanical energy required to generate electricity and operate the compressor stage of the turbine. Most gas turbines require high inlet pressures, which raise methane's upper explosive limit; therefore, to ensure safe operation, methane concentration should generally be maintained above 40%.	
General Electric (GE) www.gepower.com https://www.gepower.com/contact.html	GE manufactures a wide range of heavy duty, small heavy duty, and aeroderivative gas turbines. Power output ranges from 43 MW to 470 MW. An 88-MW power plant (2 x 44-MW gas turbines) fueled by a mixed stream of coal mine methane and virgin coalbed methane operates in the United States as a peaking plant. https://powergen.gepower.com/plan-build/products/gas-turbines/index.html
Mitsubishi Hitachi Power Systems http://www.mhps.com/en/ https://www.mhps.com/cgi-bin/en/inquiry/index.cgi?code=10001&product=Technology	Mitsubishi Hitachi Power Systems, formerly Hitachi, manufactures the H-25 gas turbine (30 MW class) and the H-15 gas turbine (17MW class), which is a scaled-down model of the H-25 gas turbine. MHPS also offers small to large capacity combined cycle generators that use heavy duty gas turbines, from 6MW class to 300 MW class.

Gas Engines	
COMPANY	**DESCRIPTION**
Kawasaki www.kawasakigasturbines.com http://www.kawasakigasturbines.com/index.php/contact_us/ 1-281-970-3255 Koguchi 1-281-970-3255 ext 25 koguchi_k@khi.co.jp	Kawasaki manufactures a large variety of base load and stand-by gas turbines. The base load models range from 600 kW to 18 MW class while the stand-by turbines range from 600 kW to 4,800 kW class.
Rolls Royce www.rolls-royce.com James Loebig (317)230-3079 jim.loebig@liberty.rolls-royce.com	Rolls Royce manufactures a wide variety of gas turbine engines ranging from 4 to 64 MW in capacity. http://www.rolls-royce.com/about/technology/gas_turbine_tech/index.jsp
Solar Turbines mysolar.cat.com/ (619) 544-5352 https://solarmc.cat.com/ecom/showContactUs.do	Solar Turbines, a Caterpillar company, offers gas turbine engines (rated from 1,590 to 30,000 horsepower), gas compressors, and gas turbine-powered compressor sets, mechanical-drive packages and generator sets (ranging from 1.1 to 22.4 megawatts). https://mysolar.cat.com/cda/layout?m=41100&x=7

Microturbines	
COMPANY/TECHNOLOGY	**DESCRIPTION**
A microturbine consists of a small, air-cooled gas turbine connected to a high- speed generator and compressor on a single shaft. This simple design results in a system with a high power output, minimal noise generation, and efficient operation. Diesel, gasoline or kerosene can be used as alternate fuels to insure continuous electricity production in the event that the methane supply is disrupted. The generation capacity of microturbines can range 30 kW to 2,000 kW and the microturbine's 22-30% efficiency rating improves with the use of exhaust heat for preheating and adsorptive cooling.	
Capstone Turbine Corp. www.capstoneturbine.com 1 866 4 CAPSTONE (818) 734-5300 Marc Rouse mrouse@capstoneturbine.com	Capstone manufactures various sizes of microturbines (i.e., 30kW, 65kW, and 200kW) that are scalable from 30kW to 10MW. Products based on the 200kW turbine are also available in 600kW, 800kW, and 1MW configurations. http://www.capstoneturbine.com/prodsol/products/
Flex Energy www.flexenergy.com http://www.flexenergy.com/flexenergy_contact.html info@flexenergy.com (877) 477-6937	Flex Energy's 250 kW Flex Turbine™ MT250 can operate efficiently on a broad range of gaseous fuels. Its newest 250SV Flex Turbine model will run with very low caloric value fuels such as methane/inert gas mixtures with as little as 30% methane by volume. http://www.flexenergy.com/flexenergy_flex_turbine.html

Microturbines	
COMPANY/TECHNOLOGY	**DESCRIPTION**
Ener-Core www.ener-core.com/ http://ener-core.com/contact-2/ (949) 616-3300 Paul Fukumoto +1 949 636 9746 paul.fukumoto@ener-core.com	Ener-Core has developed the 250kW Ener-Core Powerstation EC250 ("EC250"), and its larger counterpart, the 2MW Ener-Core Powerstation KG2-3GEF/PO, to economically abate emissions of Ventilation Air Methane (VAM) by enriching it with Coal Mine Methane (CMM) to generate electricity with near-zero emissions. The Power stations are specifically engineered for fuel flexibility (≥2.5% Methane Content) and modularity so that low-Btu gas sources can be used as an energy resource instead of wasted through venting and/or flaring. Ener-Core has successfully field tested the FP 250 on landfill gas in the U.S. and is actively targeting the CMM sector.

Co-firing Boilers for CMM and Coal	
COMPANY	**DESCRIPTION**
Co-firing boilers for CMM and coal / low grade coal can be found at mines where coal-fired boilers are partially or completely retrofitted to burn mine methane. There are numerous CMM boiler installations located at mines around the world including in the UK, China, Ukraine, Russia and Kazakhstan.	

Co-firing Boilers for CMM and Coal	
COMPANY	**DESCRIPTION**
IHI Corporation (Energy & Plant Operations) www.ihi.co.jp +81-3-6204-7419	IHI boilers are capable of using a wide variety of fuels, including fuel produced from waste materials, such as petroleum coke, residual oil and organic residues, and biomass in addition to coal, petroleum and natural gas. http://www.ihi.co.jp/en/products/energy_systems/boiler/index.html

Flaring	
COMPANY	**DESCRIPTION**
CMM flaring projects may employ open (a.k.a. "candlestick") or enclosed (a.k.a. "ground") designs. Both open and enclosed flares are designed with multiple redundant safety features such as flame and detonation arrestors to mitigate explosion risk. Open flares are simpler to design, install and maintain, reducing life-cycle costs. Enclosed flares consist of a vertical, refractory lined, combustion chamber which obscures the flame from public view. Enclosing the flame reduces thermal radiation from the flare at ground level, making it safe to work around, while increasing combustion efficiency. In addition, for some in the coal industry an enclosed flare also addresses aesthetic concerns.	

Flaring	
COMPANY	**DESCRIPTION**
A-TEC Anlagentechnik GmbH http://www.atec.de info@atec.de	A-TEC has decades of experience designing and constructing high temperature flares for CMM and lean gas. A-TEC has installed their flaring systems in both Russia and Ukraine, and these plants have successfully operated as UNFCCC emission reduction projects.
Abutec abutec.com/ (512) 836-9473 sales@aereon.com	ABUTEC manufactures and services Low Emission, Low NOx, Mine Gas Incinerators (i.e. Enclosed Flares) for the mine gas industry. ABUTEC specifically sizes and designs its flares to meet each site's unique mine gas needs with flares ranging in size from 10 scfm up to 6000 scfm. All ABUTEC mine gas flares meet United States EPA regulation 40 CFR 60.18 and are BACT approved. ABUTEC installed the first Mine Gas Incinerator in the United States. http://abutec.com/products/other-industries/mine-gas/
Beijing Fairyland Environmental Technology Co., Ltd. http://www.fairyland.com.cn/en/profile.asp +86-10-62975118 fairyland@fairyland.com.cn	Beijing Fairyland Environmental Technology (FET) focuses on the recovery and utilization of low-thermal-value-gas (LTVG) including CMM. FET's flaring systems have been utilized for CMM projects in China. http://www.fairyland.com.cn/en/s_low_calorific_gas.asp?id=39
Biogas Technology Ltd. www.biogas.co.uk +44 (0) 1487 831 701 info@biogas.co.uk	Biogas Technology's Mine Gas Flare system builds upon the company's extensive landfill gas flare expertise. This enclosed flare can safely flare mine gas with 27-50% methane concentrations and is designed for total destruction of methane and associated hydrocarbons. Biogas flares have been used at CMM projects in Mexico and the United Kingdom. www.biogas.co.uk/flare.htm

Flaring	
COMPANY	**DESCRIPTION**
BMF HAASE Energy Technology, Ltd. www.bmf-haase.de/en/ +49 4321 / 878-0 info@bmf-haase.de	BMF HAASE Energy Technology, Ltd., formerly Hasse Engineering, manufactures several low-temperature and high-temperature flare stacks suitable for CMM flaring. http://www.bmf-haase.de/en/products/gas-engineering/flare-stacks/
Hofstetter Umwelttechnik AG http://www.hofstetter-uwt.com/index.php/en/ +31 20 740 09 99 +41 32 580 05 00 info@hofstetter-uwt.com	Hoffstetter's HOFGAS-CFM4c flare is able to burn methane concentrations ranging from 20 vol. % to 95 vol. %. For each specific project, the HOFGAS- CFM4c flare is designed for the defined gas mixture and the burner portion of the flare can be redesigned and modified in short time and at low costs if operating conditions change. The HOFGAS-CFM4c has a destruction efficiency > 99.95% in relation to methane gas achieved with combustion temperatures between 1,000 – 1,200°C and a defined residence time of > 0.3s. http://www.hofstetter-uwt.com/index.php/en/products/coal-mine-gas/cfm4c
MRW Technologies, Inc. www.mrw-tech.com/ Mike Dearinger 918.827.6030 mdearinger@mrw-tech.com	MRW Designs and manufactures a wide variety of elevated/open and enclosed flare systems for all sizes and compositions of waste gas. MRW open flare systems have a destruction-removal efficiency (DRE) of 98%. If higher destruction is required, an enclosed flare system may be utilized if it is economically practical. The VOC Destruction Efficiency for MRW Enclosed Flares is guaranteed up to 99.99%+. http://www.mrw-tech.com/pia_elevated_flares.html http://www.mrw-tech.com/pia_enclosed_flares.html

Flaring	
COMPANY	**DESCRIPTION**
Nanjing Carbon Recycle Biomass Technology Co., Ltd. http://www.rectec.com.cn/html/en/ http://www.rectec.com.cn/html/en/index.php?ac=article&at=list&tid=100 (86-25)84414484 rectec@126.com	Nanjing Carbon Recycle Biomass Technology Co. Ltd. manufactures 3 types of flares—mobile, open, and ground enclosed. The ground enclosed flare has been developed according to UNFCC technical requirements and is mainly used for CDM projects in which methane is destroyed by combustion. The highest capacity ground enclosed flare can process about 5000 Nm^3/h. Nanjing Carbon flares are used at mines in China. http://www.rectec.com.cn/html/en/index.php?ac=article&at=list&tid=91
Perennial Energy, Inc. http://www.perennialenergy.com/ Contact: Scott Cressman +1 417 293 8017 scressman@pernnialenergy.com	Perennial Energy (PEI) designs and manufactures Enclosed Ground Flares which meet current air quality regulatory management agency requirements for maximum by-product of combustion emissions and minimum reduction and destruction efficiencies. PEI also designs and manufactures open Utility Flares with up to 100:1 turndown for optimum utilization with landfill or digester biogas destruction requirements. PEI Utility flares provide excellence in high efficiency combustion and odor control applications. Historically PEI focused on the biogas market but is now targeting CMM projects
Pro2 Anlagentechnik GmbH http://www.pro2-service.com/?page_id=44 Contacts: http://www.pro2-service.com/?page_id=47	Pro2 has decades of experience in the design and construction of high-temperature flares and emergency flares for landfill gas, biogas, sewage gas, and lean gas. Pro2 flares have been deployed in Russia, Ukraine, and Eastern Europe.

Flaring	
COMPANY	**DESCRIPTION**
Questor Technology Inc. www.questortech.com/ http://www.questortech.com/contact/ Ritchie Stagg +1 (780)-978-1608	Questor Technology engineers every incinerator to fit its specific application, based on gas composition and flow rates. Common configuration capacities range from 5 to 5,000 MSCF/D. Questor Incinerators have a combustion efficiency in excess of 99.99%. Questor has traditionally focused on oil field services and is now targeting the CMM and CBM sectors. http://www.questortech.com/wp-content/uploads/2016/04/Questor-Incinerator-Rental-Brochure.pdf

Gas Conditioning Systems	
COMPANY	**DESCRIPTION**
Drained CMM may contain large quantities of water and dust entrained within the gas. Combusting CMM without initial gas clean-up could lead to the combustion process equipment suffering from rapid degradation of the gas train, resulting in poor operational availability. Therefore, gas conditioning systems are sometimes used on the front end of a CMM use or destruction project to remove dirt, water, and control delivery pressure of the CMM. This significantly enhances the availability and reduces the maintenance of the CMM combustion plant.	
A-TEC Anlagentechnik GmbH http://www.atec.de info@atec.de	A-TEC has developed dust removal systems for CMM extraction stations, utilizing low-pressure loss and ease-of-cleaning technologies. In one containerized system, water drops are removed and all other liquids are pumped out.

Gas Conditioning Systems	
COMPANY	**DESCRIPTION**
Beijing Fairyland Environmental Technology Co., Ltd. http://www.fairyland.com.cn/en/profile.asp +86-10-62975118 fairyland@fairyland.com.cn	Beijing Fairyland Environmental Technology (FET) focuses on the recovery and utilization of low-thermal-value-gas (LTVG) including CMM. In particular, its gas pretreatment systems remove impurities such as vapor, particles, and H2S, regulate the gas temperature, pressure, and flow and ensure stable and safety operation. http://www.fairyland.com.cn/en/s_low_calorific_gas.asp?id=42
Hofstetter Umwelttechnik AG http://www.hofstetter-uwt.com/index.php/en/ +31 20 740 09 99 +41 32 580 05 00 info@hofstetter-uwt.com	The HOFGAS-CPM is designed for degasification of coal mines with reliable processing of the methane gas for electricity or heat generation. The system is comprised of one or several blower stations and the necessary components for reliable degassing. Hofstetter gas treatment technology includes gas cooling and drying, filters, and gas compression. http://www.hofstetter-uwt.com/index.php/en/products/coal-mine-gas/cpm
Nanjing Carbon Recycle Biomass Technology Co., Ltd. http://www.sxprice.org.cn/suppliers/nanjing_carbon_recycle_biomass_technology_co_ltd-hzb21853.html	The Dehydrator and Dryer for CMM designed by Biomass Energy & Low Carbon Technology Research Center, Jiangsu and manufactured by Nanjing Carbon Recycle Biomass Technology, removes liquids, moisture, and other contaminants (e.g., sulfur) from CMM using refrigeration and adsorption methods. The Dehydrator and Dryer can achieve lower relative humidity and pressure dew points.
Perennial Energy http://www.perennialenergy.com Scott Cressman +1 417 256 2002 scressman@perennialenergy.com	Perennial Energy (PEI) designs and manufactures Biogas Processing Systems (Compressor Skids, Blower Skids, Chiller Skids) to extract / receive waste gases from landfills, digesters, and coal mines. Systems provide maintainable inlet and discharge pressures to satisfy process requirements as well as gas stream moisture removal and temperature conditioning. Systems range from basic waste gas extraction and combustion to multi-pipeline gas-to-energy projects.

Gas Conditioning Systems	
COMPANY	**DESCRIPTION**
Pro2 Anlagentechnik GmbH http://www.pro2-service.com/ http://www.pro2.com/s/22_123/page/modules/contact/index.php	Pro2 compressor plants and disposal units with energy-saving rotary piston blowers are optimally adapted to disposal conditions and downstream gas utilization and gas disposal plants. Any required gas treatment – e. g. condensate separation, gas cooling/drying or gas purification – is designed for the required gas quality. Containerized plants also provide flexible adaptation capabilities. Pro2 gas conditioning systems are used for biogas treatment in Europe and could be used for conditioning of gob gas.

Fuel Cells	
COMPANY	**DESCRIPTION**
A fuel cell is an electrochemical device that combines hydrogen fuel (can be CMM) and oxygen from the air to produce electricity, useable heat and water. Fuel cells produce Direct Current (DC) electricity without the conventional combustion reaction. A fuel cell is made up of an electrolyte member sandwiched between fuel and oxidant electrodes. A fossil fuel or biogas from which hydrogen is extracted is used for most common applications. The oxidant is typically plain air. The fuel is oxidized at the "anode electrode", releasing electrons that move to the "cathode electrode" via the external circuit. These electrons meet the hydrogen and push charged ions across the electrolyte. The charged ions (positively or negatively charged) move across the ion conducting electrolyte member, completing the electrical circuit. This electrochemical process requires very few moving parts, typically limited to air blowers and fuel/water pumps. Generation capacity is typically 100 kW to 300 kW.	

Fuel Cells	
COMPANY	**DESCRIPTION**
Fuel Cell Energy www.fuelcellenergy.com (203) 825-6000 info@fce.com Ben Toby (203)-825-6114 btoby@fce.com Fuel Cells (general) www.fuelcells.org	Fuel Cell Energy Inc. manufactures the Direct FuelCell® (DFC). DFCs can run on coal mine methane. In addition, DFCs run on biofuels—gases from wastewater treatment, food processing, and landfills. DFCs emit virtually zero nitrogen oxide (NOx), sulfur oxide (SOx) or particulate matter and significantly reduce carbon dioxide (CO_2) emissions. Developed exclusively for use in stationary applications, there are three main Fuel Cell Energy products designed to meet a variety of applications. All are self-contained electrical power generation system capable of providing high-quality baseload power with a range from 300kW to 2.8 MW. Standard efficiency is 47%. Fuel Cell Energy also manufactures a hybrid, multi-megawatt DFC-ERG™ (Direct FuelCell Energy Recovery Generation™) system that combines a Direct FuelCell® power plant with an unfired gas expansion turbine and achieves electrical efficiencies of up to 60%. A 200kW fuel cell plant has previously operated at an abandoned mine in Ohio, U.S.A. http://www.fuelcellenergy.com/products-services/products/

Drainage Gas Purification for Pipeline/Town Gas

Nitrogen Rejection	
TECHNOLOGY/COMPANY	**DESCRIPTION**
There are six basic processes that may be used to reject nitrogen, the major contaminant removed to upgrade CMM to pipeline quality. The technology chosen for removing nitrogen depends largely on a number of variables, including the volume of gas to be processed, the quantity of natural gas liquids present in the methane mix, and the nitrogen level in the gas. For more information, see EPA Publication EPA-430-R08-004 "Upgrading Drained Coal Mine Methane to Pipeline Quality: A Report on the Commercial Status of System Suppliers".	
Solvent Absorption Advanced Extraction Technology http://www.aet.com/home.htm (281) 447-0571 seekinfo@aet.com	The AET nitrogen rejection technology utilizes non-cryogenic absorption to separate methane and heavier hydrocarbons from nitrogen containing natural gases. For CMM, a solvent selectively absorbs methane while rejecting a nitrogen-rich stream in a refrigerated environment. The petroleum industry commonly uses selective absorption to enrich gas streams. http://www.aet.com/nreject.htm
Pressure Swing Adsorption (PSA) CMM Energy LLC http://www.cmmenergy.com/	In most PSA nitrogen rejection systems, wide-pore carbon molecular sieves selectively adsorb nitrogen and methane at different rates in an equilibrium condition. For CMM, nitrogen is removed from low-quality gas by passing the gas mixture under pressure through a vessel containing an adsorbent bed that preferentially adsorbs nitrogen. Therefore, the gas coming out of the vessel is rich in methane. Since nitrogen is

Nitrogen Rejection	
TECHNOLOGY/COMPANY	**DESCRIPTION**
Peet Soot, PhD, PE President (503) 699-9836 cmm@cmmenergy.com TGPE Inc. www.tuckergas.com/nrupg03.htm (217)225-3258 tucker@adams.net	preferentially adsorbed during each pressurization cycle, the process recycles methane-rich gas so that methane proportions increase with each cycle. PSA recovers up to 95 percent of available methane and may operate on a continuous basis with minimal on-site attention. PSA systems have excellent turndown capability so they are able to operate effectively with gas flowing at a fraction of rated capacity.
Molecular Sieve Guild Associates www.moleculargate.com http://www.moleculargate.com/contactus.html (908)752-6420 sales@moleculargate.com	This process removes nitrogen, carbon dioxide, and part of the oxygen from the methane, whereas other processes remove the methane from the nitrogen. The process uses a type of molecular sieve that has the ability to adjust pore size openings within an accuracy of 0.1 angstrom. For CMM, the sieve pore size is set smaller than the molecular diameter of methane and larger than the molecular diameters or nitrogen, oxygen, carbon dioxide, and water. This permits the nitrogen and other contaminants to enter the pore and be adsorbed while excluding the methane, which passes through the fixed bed of adsorbent at essentially the same pressure as the feed. The molecular gate process employs a PSA operation. Guild Associates has installed twelve full-scale plants operating on methane from abandoned mines and gob gas, primarily in the Illinois, Central Appalachian and Northern Appalachian basins of the United States. Guild also has units operating at oil and gas operations, landfills, waste water and agriculture facilities in the United States, UK, Brazil, and the Philippines.
Cryogenic Separation BCCK Engineering, Inc. www.bcck.com	The cryogenic process uses a series of heat exchangers to liquefy the high-pressure feed gas stream. The mixture is then flashed and a nitrogen-rich stream vents from a distillation separator, leaving the methane-rich stream. To avoid the danger of explosion within the plant, designers locate a deoxygenation system at the plant inlet.

Nitrogen Rejection	
TECHNOLOGY/COMPANY	**DESCRIPTION**
1-800-922-2599 (432)685-6095 http://bcck.com/contactus Global Industrial Dynamics http://www.gidynamics.nl/ http://www.gidynamics.nl/#!contact/c3kh +31 (0)174 820 180 info@gidynamics.nl	Cryogenic plants have the highest methane recovery rate (i.e., about 98 percent) of any of the nitrogen rejection technologies. Large-scale cryogenic plants have become a standard and economic solution for upgrading below-specification gas from natural gas fields, but they tend to be much less cost-effective at sizes below 5 mmscfd (142,000 m^3/d). BCCK Engineering is focused on the Americas and has installed three full-sized plants that upgrade CMM to pipeline quality gas in the United States. G.I. Dynamics (GID), a business partner of BCCK Engineering, and represents its cryogenic Nitech™ NRU technology as an integrated part of GID's Gas Processing Group in other areas of the world (Europe, Russia, Asia and Austria). http://bcck.com/nitrogenrejection
Membrane Separation Membrane Technology and Research, Inc. www.mtrinc.com/nitrogen_removal.html Kaaeid Lokhandwala (650) 543 3360 Gas@mtrinc.com ProSep www.prosep.com http://prosep.com/contact-us/ (281) 504 2040 info@prosep.com	The process uses membranes, which are significantly more permeable to methane, ethane and other hydrocarbons than to nitrogen, to selectively pass the hydrocarbons while retaining nitrogen. A simple one-stage membrane unit would be appropriate for feed gas containing about 6 to 8 percent nitrogen, but more commonly (where nitrogen concentrations are higher) a two-stage membrane system is required. Inlet flow rates of between 0.1-20 MMscfd can be processed by MTR's NitroSep™ system with a product BTU recovery of 90%+. ProSep's sweetening membrane skids are modular in design and construction, lending themselves to easy scalability as production volumes and CO_2 concentrations vary. As the produced gas passes across the membrane surface, there is little pressure drop from the inlet to the sales gas stream.

Nitrogen Rejection	
TECHNOLOGY/COMPANY	**DESCRIPTION**
CMM Concentration Technology Osaka Gas Co., Ltd. (Engineering Department) http://www.osakagas.co.jp/en/rd/technical/environment.html	Osaka Gas has two CMM concentration technologies: VPSA process using activated carbon (AC) and PSA process using Carbon Molecular Sieves (CMS). The VPSA process uses AC as adsorbent and can concentrate CMM (20-40% CH_4) to about 50% CH_4. The concentrated CMM can be used as the fuel for the gas engine. The PSA process uses CMS, which can concentrate CMM (50-80% CH_4) to over 90% CH_4. The concentrated CMM can be used as city gas or vehicle fuel. Off-gas can be also available as fuel for gas engine. VPSA using AC as adsorbent is commercially available while PSA using CMS as adsorbent is under development; the field test has been completed and the pilot test is planned. http://www.osakagas.co.jp/en/rd/technical/1198911_6995.html#anchor4

Ventilation Air Methane (VAM) Mitigation and Utilization

Ventilation Air Methane (VAM) Destruction	
COMPANY	**DESCRIPTION/PROJECT INFORMATION**
Ventilation air methane (VAM) refers to the very dilute (<1% methane) ventilation air that is released from underground mine ventilation shafts. To ensure miners' health and safety, large volumes of fresh air are circulated through underground coal mines using ventilation systems to dilute in-mine concentrations of methane to levels well below explosive levels. This ventilation air is commonly vented to the atmosphere. Despite this low methane concentration, VAM is the single largest source of CMM emissions, representing more than half of all coal mining emissions worldwide. The priority for recovered coal mine methane is utilization; however, the very dilute methane concentration in VAM can make utilization very challenging. Absent a cost-effective use, destruction of methane still presents significant environmental benefit due to the reduction of greenhouse gases. The technologies listed below are regenerative thermal oxidizers (RTOs) and regenerative catalytic oxidizers (RCOs). These technologies were developed for use in the pollution control industry to destroy volatile organic compounds, odors, and other pollutants. Today there are thousands of RTOs and RCOs operating around the world in these applications. RTO and RCO technology have now been adapted successfully to the coal industry to destroy VAM emissions. The heat can be recovered for use in mine heating, district heating, power generation and desiccant cooling. However, most current applications at coal mines are destruction only.	
Biothermica www.biothermica.com +1.514.488.3881 biothermica@biothermica.com Dominique Kay 514 488-3881 x228	Biothermica manufactures the VAMOX® RTO. The VAMOX® RTO converts VAM into carbon dioxide and water vapor. VAMOX® systems are tailored to meet site's specific needs. VAMOX® specifications include: • Unit capacity up to 140 000 scfm (238 000 Nm^3/h) • Methane concentration ranging from 0.2% to 1.2% • Up to 98% destruction efficiency http://www.biothermica.com/content/coal-mine-methane

Ventilation Air Methane (VAM) Destruction	
COMPANY	**DESCRIPTION/PROJECT INFORMATION**
dominique.kay@biothermica.com	
CSIRO Energy www.csiro.au Dr. Shi Su +61 7 3327 4679 Shi.su@csiro.au	CSIRO has developed the VAMMIT™, a novel VAM mitigator that is a compact flow reversal reactor with a newly-structured honeycomb regenerative bed, resulting in less pressure drop/energy consumption and a smaller footprint. Moreover, it incorporates an innovative flow diverting section located at the bed center with connections to gas burners for easy start-up, as well as bursting discs for safety management. Dust deposition and sintering issues which occur in conventional packed beds are also avoided. It can be operated with VAM concentrations of ≥0.3 vol %CH_4. Through the Australian Coal Association Research Program (ACARP) project c19055, a VAMMIT prototype unit was designed, constructed, commissioned and tested at CSIRO laboratories in 2013. Site trial results with VAM obtained in 2017 at a mine site in Australia show that the VAMMIT unit operation is self-sustainable, with a range of VAM concentrations between 0.3 and 1.0 vol. %CH_4. The pressure drop across the regenerative bed is 300-1,000 Pa, much lower than that (3,000-6,000 Pa) for existing packed bed mitigators, demonstrating much lower power consumption. On average, over 96% of methane can be oxidized through the novel regenerative bed with <0.02% CH_4 residual present in the flue gas. Through a continuous two-week site trial using only VAM, the presence of dust in the ventilation air was found to have a negligible effect on the VAMMIT's performance. To date, all necessary operational data, engineering and safety management experience have been obtained for scaling the VAMMIT technology.
CSIRO Energy www.csiro.au Dr. Yonggang Jin +61 7 3327 4146 Yonggang.jin@csiro.au	CSIRO has been developing emerging technologies for ultra-low concentration VAM abatement, e.g. photocatalytic oxidation destruction under ambient temperature and pressure conditions. The photocatalytic oxidation is very promising in destructing ventilation air flows with a very low concentrations of methane (e.g. less than 0.3 vol %CH_4 and even at hundreds ppm levels). Another advantage of photocatalytic oxidation over thermal oxidation is that photocatalytic oxidation occurs at ambient temperature, thereby imposing fewer risks to mining operations. Through the ACARP project c24061, photocatalytic tests have demonstrated that almost 100% of CH_4 can be eliminated in the

Ventilation Air Methane (VAM) Destruction	
COMPANY	**DESCRIPTION/PROJECT INFORMATION**
	simulated VAM containing hundreds of ppm CH_4 under ambient conditions. In particular, this technology has the potential to be applied for open cut fugitive methane abatement for which no technology is currently available and for destruction of atmospheric methane to offset fugitive emissions from coal mining.
Dürr http://www.durr.com/ Jason Schroeder jason.schroeder@durrusa.com Dürr Clean Technology Systems http://www.durr-northamerica.com/products/environmental-and-energy-systems-products/ Greg Thompson +1 248 450-2314 greg.thompson@durrusa.com	Dürr manufactures several thermal oxidation (regenerative thermal, compact thermal, thermal exhaust) and catalytic oxidation (high-pressure, low-pressure, regenerative, and selective) air/exhaust purifier systems, as well as energy generation and combined heat/power systems (micro gas turbines and ORC units). For VAM destruction, Dürr has developed the Ecopure® RTO. Installed Ecopure® RTOs are treating roughly 1,000,000 scfm (470 m^3/s) of mine ventilation air in the United States and China. http://www.durr-cleantechnology.com/environmental-and-energy-systems-products/exhaust-air-purification/thermal-exhaust-air-purification/ecopurer-rto/

Ventilation Air Methane (VAM) Destruction	
COMPANY	**DESCRIPTION/PROJECT INFORMATION**
Gulf Coast Environmental (GCE) www.gcesystems.com Chad Clark, Technical Director + 1 773 572 5992 Email: cclark@gcesystems.com +1 (832)476-9024 sales@gcesystems.com	Gulf Coast Environmental manufactures the VAM CH_4 RTO. GCE uses a shipping container as the oxidizer shell, thereby reducing manufacturing costs. http://www.gcesystems.com/thermal-oxidizers.html
Babcock & Wilcox MEGTEC www.megtec.com http://www.megtec.com/rfqform Ken Zak +1 920 337 1479 kzak@megtec.com	MEGTEC is a manufacturer of pollution control equipment including RTOs and RCOs. The MEGTEC VOCSIDIZER® is a compact and flameless regenerative single chamber thermal oxidizer (RTO) that generates high grade, super-heated steam from ventilation air with less than 1% methane. The unit has a flow capacity of 1,000 to 70,000 Nm3/h and destruction efficiency of 95 to 98%. MEGTEC equipment is in use at active mines in China and Australia and, previously, at an abandoned mine in the United States. Most VAM projects with MEGTEC equipment use the Vocsidizer®; however, MEGTEC also manufacturers a "2-can" RTO for VAM using a gas burner to pre-heat the oxidation chamber. http://www.megtec.com/oxidizers
Shengdong New Energy Group Co., Ltd. http://shengdong-new-energy-technology-co-ltd.imexbb.com/ +86-769-86728867	Shengdong New Energy Group Co., Ltd. offers a VAM oxidizer that has been field tested for energy recovery (i.e., steam production) at several Chinese mines.
Canada's Centre for Mineral and Energy Technology (CANMET)	CANMET has designed the CH_4MIN ®, a regenerative catalytic oxidation (RCO) unit, specifically for VAM applications. The RCO (or Catalytic Flow Reversal Reactor (CFRR)) has the same basic design and

Ventilation Air Methane (VAM) Destruction	
COMPANY	**DESCRIPTION/PROJECT INFORMATION**
www.canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/ Eric Soucy Director, Industrial Systems Optimization Group (450) 652-4299 eric.soucy@canada.ca Sindicatum Sustainable Resources http://www.sindicatum.com/ http://www.sindicatum.com/contacts/ David Creedy, Ph.D. david.creedy@sindicatum.com	operation as the RTO except that oxidation takes place in the presence of a catalyst at temperatures below the 1000°C needed for an RTO. Currently the design is destruction-only. CANMET pilot-tested a small-scale CH_4MIN reactor. Sindicatum Sustainable Resources (SSR) holds the global license through 2019 for the CH_4MIN technology (except in Japan), and SSR built and laboratory tested a 54,000 Nm^3/h test unit from 2008 to 2009. http://www.sindicatum.com/technology/
HEL East Ltd. http://www.hel-east.com/ info@hel-east.com Neil Butler Design Engineer and Project Technical Development +44(0)1777712764 nbutler@hel-east.com	HEL-East has developed a Regenerative Thermal Oxidiser (RTO) that was designed in-house specifically for the abatement of coal mine VAM emissions. HEL-East designed, constructed, installed, and operated a commercial-scale RTO demonstration unit (90,000 Nm3/hr) for a period of time at a UK Colliery.

VAM Mitigation and Utilization as Combustion Air in Power Equipment	
COMPANY/TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**
M.E.T.T.S – Consulting Engineers http://www.metts.com.au/ Dr. Michael Clarke +61-7-5502 8093 Michael.Clarke@metts.com.au	Fluidized beds suspend solid fuels on upward blowing jets of air during the combustion process. The result is a turbulent mixing of gas and solids. The tumbling action, much like a bubbling fluid, provides for high chemical reaction rates and heat transfer.
Corky's Sustainable Energy http://www.corkys.net.au/ David Cork +61 2 4960 8847 admin@thecorkysgroup.com.au	Corky's VAM RAB® (Regenerative After Burner) unit treats VAM by a process of oxidation. The VAM RAB® is a patented Regenerative Thermal Oxidiser (RTO) coupled to the mine ventilation system via a safe connection duct. This system safely converts methane to carbon dioxide, which reduces the greenhouse gas impact of the fugitive methane emissions from an underground coal mine. A demonstration scale VAM RAB® with a full function safety duct has been constructed at an operating mine in Australia. The demonstration unit has a capacity of 12 m^3/s of VAM processing.

VAM Mitigation and Utilization in Turbines	
COMPANY	**DESCRIPTION/PROJECT INFORMATION**
CSIRO Energy www.csiro.au Dr. Shi Su	CSIRO developed the VAMCAT™, a lean-fuel gas turbine system that employs a catalytic combustor to run on VAM concentrations around 0.8 vol % methane (CH_4). Depending on mine site specifications, supplemental fuel (e.g., drained coal mine methane, or enriched VAM by the VAMCAP™) may be required to increase the concentration of methane entering the turbine to approximately 0.8 vol %CH_4. Under the

VAM Mitigation and Utilization in Turbines	
COMPANY	**DESCRIPTION/PROJECT INFORMATION**
+61 7 3327 4679 Shi.su@csiro.au	Australian Government's Bilateral Climate Change Partnerships Program with the site support from the Huainan Coal Mining Group, and in collaboration with various research institutions and manufacturers, CSIRO developed a 25kWe VAMCAT prototype unit at CSIRO's laboratories. The VAMCAT prototype unit was then trialled at a mine operated by the Huainan Coal Mining Group in China in November 2011. The experimental data confirmed that the unit can operate with 0.8% CH_4 in air (or a heating value of 0.288 MJ/m^3) and 19-21 kWe power output. In November 2017, CSIRO successfully trialled the prototype VAMCAT unit at a coal mine in Australia using ventilation air methane fed through a safe ducting system, which connected the unit to the mine ventilation air shaft. To date, with all necessary operational data both for the ducting system and VAMCAT unit, site construction, engineering and safety management experience, as well as the mechanical and electrical design skills and knowledge, the VAMCAT technology is ready for scale up to 1MWe. http://www.csiro.au/en/Research/EF/Areas/Coal-mining/Mining-safety-and-automation/VAMCAT
Ener-Core www.ener-core.com/ (949)616-3300 info@ener-core.com Michael Leone michael.leone@ener-core.com	Ener-Core has developed the 250kW Ener-Core Powerstation FP250 ("FP250"), and its larger counterpart, the 2MW Ener-Core Powerstation KG2-3G/GO, to transform methane gas, especially "ultra-low Btu gas" from landfills, coal mines, oil fields and other low quality methane sources into continuous clean electricity with near-zero emissions. The Powerstations are specifically engineered for fuel flexibility and modularity, so that these low-Btu gas sources can be used as an energy resource instead of wasted through venting and/or flaring. The FP250 has been field tested on landfill gas. http://ener-core.com/technology/powerstation-kg2-3ggo/
EESTech www.eestechinc.com http://www.eestechinc.com/contact/ +61 (0)7 3832 9883	The Hybrid Coal Gas Turbine, HCGT, a rotary kiln system that burns waste coal with VAM or drained CMM, was jointly developed by Australia's CSIRO and Liquatech Turbine Company Pty in 2002 and was later purchased by EESTech in 2007. In this application, VAM is a supplemental fuel. The mixed fuel is combusted in a rotating kiln and the exhaust gases pass through a specially designed air-to-air heat exchanger. The heated clean air then powers a turbine to produce electricity. The waste coal feed can be adjusted as

VAM Mitigation and Utilization in Turbines	
COMPANY	**DESCRIPTION/PROJECT INFORMATION**
Ian Hutcheson, CFO 61 7 3832 9883 ihutcheson@eestechinc.com	necessary in response to variations in VAM flow or concentration, thereby allowing for a constant energy feed to the turbine to power electricity generation. A 1.2MW gas turbine pilot plant was constructed at CSIRO's laboratory in 2002. The technology rights have now been acquired by EESTech, who is standardizing 10MW and 30MW systems and is seeking to commercialize the technology in China and India.

VAM Enrichment	
COMPANY	**DESCRIPTION/PROJECT INFORMATION**
Australian Coal Association Research Program (ACARP) www.acarp.com.au 07 3225 3600 Mark Bennets, Executive Director markb@acarp.com.au CSIRO Energy www.csiro.com.au Dr. Shi Su +61 7 3327 4679 Shi.Su@csiro.au	Australian Coal Association Research Program (ACARP) and CSIRO have developed the VAMCAP™, an enrichment technology that uses CSIRO-developed carbon composite adsorbents to capture and concentrate VAM into higher concentration levels. This has important implications for the use of ventilation air methane (VAM), because the methane in VAM can be increased to higher concentrations increasing the range of technologies capable of using VAM and thus allowing for a wider range of uses. Various nano-structured carbon composites with a honeycomb monolithic structure have been successfully fabricated from different raw carbon materials including carbon fibres, carbon nanotubes, Macadamia nut shells, and brown coals. These adsorbents exhibit more than four times the maximum methane adsorption capacity of commercial activated carbons at atmospheric pressure and room temperature. Through the ACARP project c19054, the VAMCAP prototype unit test results showed that 0.30%, 0.60% and 0.98% VAM can be enriched up to an average of 3.49%, 6.09% and 9.46% respectively by one-step adsorption, and up to 19.28%, 24.24% and 36.92% methane respectively by two-step adsorption. The VAMCAP unit has been installed at a coal mine in Australia, and is now under commission with VAM.

Safe Ducting	
COMPANY	**DESCRIPTION/PROJECT INFORMATION**
Regardless of whether or not ducting is enclosed, an unplanned event, e.g. gas outburst, could result in an explosive mix of methane and air exiting the mine via the ventilation fan. This methane could then react with an ignition source in the VAM unit, and potentially flame back through the mine. A major concern faced by the coal industry, therefore, is safely connecting VAM units to the VAM shaft.	
CSIRO Energy www.csiro.au Dr. Shi Su +61 7 3327 4679 Shi.su@csiro.au	CSIRO commenced VAM abatement safety research in early 2010 via a CSIRO strategic research project. The ACARP project C21065 studied gas ignition and explosion limits, flame propagations, and extinction mechanisms in narrow channels. Based on CSIRO research outcomes, the principle prevention and suppression mechanism is the development and implementation of a ventilation air ducting system for VAM abatement. This system can prevent an explosion and suppress flame propagation back to the coal mine. Consequently, a safe ducting system has been developed and patented. The main configurations and strategies of this patent have been applied on a pilot-scale ($\leq 1 m^3/s$) safe ventilation ducting system for connecting the VAM prototypes to the ventilation air shaft at a coal mine in Australia to trial three VAM abatement prototype units. Trial results show that the CSIRO safe ducting technology was successfully demonstrated by providing VAM in a safe manner for the units at the mine site.

Modeling and Analysis

Modeling and Analysis	
COMPANY/	**DESCRIPTION/PROJECT INFORMATION**
Prediction of methane liberation and forecasting gas production in underground mines is an important tool in develop effective methane management programs at underground and surface mines. Effective gas prediction supports the health and safety of the miners, the protection of the mine's physical and mechanical assets, and the commercial prospects of the mine. Software is available to forecast gas production and assist mine owner/operators, CMM project developers, and others plan and develop gas drainage and utilization projects.	
Japan Coal Energy Centre (Resources Development Department) www.jcoal.or.jp/index-en.html tomita@jcoal.or.jp [1] Matsuyama@jcoal.or.jp [2] li@jcoal.or.jp [3] Hiroaki Hirasawa (813)6402-6106 jcoal-info@jcoal.or.jp	JCOAL offers three software packages to model gas liberation and methane emissions: [1]MGF – 3D: PC based simulation software for emission and recovery of coal mine methane developed by JCOAL. [2]COSFLOW: Computer simulation software for emission and recovery of coalmine methane developed by CSIRO and JCOAL. [3]KAZEMARU: PC-based simulation system to analyze mine ventilation network, developed by JCOAL. JCOAL also produces portable and compact gas analyzing apparatuses designed to measure gas contents in coal on site.
United States National Institute for Occupational Safety and Health (NIOSH) www.cdc.gov/niosh	The Office of Mine Safety and Health Research (OMSHR) in NIOSH has produced its Methane Control and Prediction (MCP) software to address some of the methane control issues in long wall coal mines in the United States and other countries. The software contains ancillary models that will help predict total, as well as desorbable, gas content of coals and offers two sets of methane prediction models: a) Models for specific United States conditions, which directly relate to specific United States long wall mining conditions

Modeling and Analysis	
COMPANY/	**DESCRIPTION/PROJECT INFORMATION**
	and to the mining operations in specific states; and b) Models for other United States/international conditions, which are applicable to "other United States" conditions and also to international projects. Version 2 has been available for download on the NIOSH website since September 2010 and can be downloaded for free. http://www.cdc.gov/niosh/mining/works/coversheet1805.html
Advanced Resources International, Inc. http://www.adv-res.com/ Anne Oudinot aoudinot@adv-res-hou.com (281) 558-9200	Advanced Resources' COMET3™ reservoir simulator for gas shale, shale oil, and coalbed methane (CBM) reservoirs, including pre-mine drainage, was developed in the early 1980's, and is available today. It has continually evolved to meet the changing needs of the unconventional petroleum industry. Advanced technical features include: (1) a triple-porosity/dual-permeability option for certain gas shale, tight oil, and coalbed methane (CBM) reservoirs, (2) multi-component sorption for enhanced coalbed methane (ECBM) recovery and carbon sequestration (CO_2 sequestration) applications, and (3) a permeability model capable of modeling stress sensitivity. http://www.adv-res.com/COMET3_reservoir_simulator_for_gas_shale_and_coalbed_methane_CBM_reservoirs.php

CMM to LNG

CMM to LNG	
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**
Liquid natural gas (LNG) is formed by lowering the temperature of methane to -162°C. In its liquid form, LNG takes up 1/600th of the volume of methane in gaseous form. By condensing the methane into a high energy density liquid fuel it can be effectively stored and distributed by truck, rail or vessel. The liquefaction process removes the impurities such as carbon dioxide, sulfur compounds, volatile organic compounds, oxygen, nitrogen, and water. LNG is typically composed of over 95% methane, with the remaining 5% being nitrogen and other heavier hydrocarbons.	
LNG – Silesia (a joint venture by Prometheus Energy and CETUS Energetyka Gazowa) http://www.lngsilesia.pl/ 0048 32 324 46 52 office@ingsilesia.pl Prometheus Energy www.prometheusenergy.com (832) 456-6500 info@prometheus-energy.com	The technology developed is applicable to small-scale operations on the order of 8 to 40 metric tons of LNG production per day. The process results in LNG production of > 90% methane. The installations are modified to handle CMM concentrations as low as 40%.

Drilling Techniques

Drilling Techniques	
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**
Effective gas drainage practices are important in CMM projects in order to decrease downtime due to gassy mine conditions, to maintain safer mine conditions, to create the opportunity to utilize more gas, and to reduce mine methane emissions. Methane drainage methods are conventionally classified as involving either pre-drainage or post-drainage techniques. Pre-drilling CMM drainage techniques can be used to reduce the in-situ gas content by reducing the gas content of the coal and adjacent gassy strata before mining occurs. The main methods of pre-mining degasification are: (1) vertical boreholes drilled from the surface, (2) in-seam boreholes drilled from within the mine, (3) superjacent boreholes drilled directionally from within the mine, and (4) in-seam boreholes drilled directionally from the surface. Post-drainage techniques involve capturing methane and other gases released from surrounding seams as a consequence of the strata movement, relaxation, and increased permeability induced by mining. Methane concentrations of 30% and higher should be achievable using post-drainage systems in all but the most challenging mining conditions, and concentrations of 60% and higher should be achievable from pre-drainage methods. For a more detailed discussion of drilling techniques and descriptions of active mine drainage projects in the United States, see USEPA's CMOP documents: "Coal Mine Methane Recovery: A Primer" and "Coal Mine Methane (CMM) Recovery Opportunities Map".	
Vertical pre-drainage wells Atlas Copco Drilling Solutions LLC http://www.atlascopco.com/ http://www.atlascopco.com/us/contactus/ Shane Lein	Coal seam methane (CSM), termed coal bed methane (CBM) in the United States, is drained from virgin coal seams several years (2-10 years) in advance of mining. Vertical wells are drilled from the surface to intercept coal seams. The wells may or may not benefit from stimulation such as hydraulic fracturing. Very high quality gas is produced from CBM wells, often with methane concentrations greater than 90%. Vertical wells are widely used in the United States, Canadian and Australian coal bed methane basins but have proven less successful outside of these countries where less permeable, deeper and more geologically complex coal seams increase drilling costs and decrease hydraulic

Drilling Techniques	
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**
Shane.lein@us.atlascopco.com Schlumberger http://www.slb.com/ Charles M. Boyer II boyer@pittsburgh.oilfield.slb.com Halliburton http://www.halliburton.com/ Weatherford http://www.weatherford.com/	fracturing success. Due to cost, vertical pre-drainage wells are usually drilled where infrastructure exists to use the gas, for example natural gas pipeline injection or power generation. Vertical wells drilled into virgin coal seams often produce large amounts of water and only small amounts of methane during the first several months in operation. As more water is removed, and the pressure in the coal seam is lowered, methane production increases. Produced water must often be treated before it can be disposed. Vertical wells are usually spaced on a regular grid pattern, such that drainage radii overlap, to most efficiently enhance the dewatering process and reduce the coal seam hydrostatic pressure. Operators may also perform multi-seam completions using the same well bore.
Surface to inseam (pre-drainage) (coal seams below the surface) REI Drilling http://www.reidrilling.com/ Daniel Brunner dan@reidrilling.com Valley Longwall http://www.valleylongwall.com.au/ drillingsales@vli.com.au	Directional drilling technology can be used to drill from the surface horizontally through a target coal seam. The horizontal well bore intercepts previously drilled vertical wells, which produce water and gas to the surface. Multiple horizontal legs can be drilled from one well pad in different directions. Within the coal seam, laterals can be drilled from the main boreholes resulting in wide coverage. Similar to vertical pre-drainage wells, multi-seam completions can be drilled using surface to inseam drilling. This type of degasification can be especially valuable in fairly thick, uniform coal seams where folding, faulting and igneous intrusions are absent. Although hydraulic fracturing of surface to inseams wells is common in other formations, fracking of horizontal boreholes is generally not necessary in coal seams. The use of laterals and favorable geology allow for sufficient pre-mine degasification. Surface to inseam drilling of coal seams has been largely practiced in the United States and Australia where

Drilling Techniques	
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**
+ 612 4964 2300 Target Drilling Inc. http://www.targetdrilling.com/ Steve Kravits stevekravits@targetdrilling.com Scientific Drilling http://scientificdrilling.com http://scientificdrilling.com/contact/ Asif Yusifow asif.yusifov@scientificdrilling.com	geologic conditions are very favorable for this type of drilling. Gas quality is very high coming from virgin seams, and wells are drilled where end use options exist.
High-Wall Mining - Horizontal boreholes and surface to inseam drilling Target Drilling Inc. http://www.targetdrilling.com/ Steve Kravits stevekravits@targetdrilling.com REI Drilling http://www.reidrilling.com/ Daniel Brunner	A high wall in a surface mine develops as the mined coal seam drifts deeper below surface and a large wall of overburden sits on top of the seam. In some instances coal seams mined under the high wall hold substantial quantities of gas presenting the possibility of gas and rock outbursts. In these situations, coal seam methane can be drained from exposed high walls with horizontal wells drilled into the mined seam and possibly surrounding strata in advance of coal mining. High wall degasification has been practiced in the United States and Australia.

Drilling Techniques	
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**
dan@reidrilling.com	
In-mine pre-drainage (in seam, underground coal mining) Target Drilling Inc. http://www.targetdrilling.com/ Steve Kravits stevekravits@targetdrilling.com REI Drilling http://www.reidrilling.com/ Daniel Brunner dan@reidrilling.com	In-seam drilling involves drilling a series of methane drainage holes into the coal seam from underground roadways several months or years in advance of mining. Holes may be drilled in a fan formation, in parallel layouts, or directionally drilled and can vary in length from hundreds to over 1,000 meters. The boreholes are connected to an underground drainage pipe network which carries methane to the surface. Methane concentration varies from 60-80% depending on the quality of the borehole seals and drainage system. The most common in-mine pre-drainage methods are short cross-panel horizontal boreholes and in-mine long-hole directionally drilled boreholes. Cross-measure boreholes drilled at an angle above and below the mined seam also produce methane prior to longwall mine-through and then produce gas from the gob. In-mine drilling methods are used around the world.
Surface post-drainage (post mining/goaf, underground coal mining) Atlas Copco Drilling Solutions LLC http://www.atlascopco.com/ http://www.atlascopco.com/us/contactus/ Shane Lein Shane.lein@us.atlas copco.com	Methane is collected from the gob/goaf following long wall operations. Surface gob vent boreholes are drilled vertically from the surface prior to mine-through and are completed with slotted casing above the mined seam. Initial reservoir pressure is usually sufficient to produce gas without supplemental vacuum pressure, but eventually a vacuum pump is attached to the well to draw gas to the surface. This results in drainage gas with a concentration of approximately 25-70% methane, with the well producing gas of high concentrations initially followed by a decline in CH_4 concentration. Six months to two years is a common operational time frame for a gob vent borehole.

Drilling Techniques	
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**
Schlumberger http://www.slb.com/ Charles M. Boyer II boyer@pittsburgh.oilfield.slb.com Halliburton http://www.halliburton.com/ Weatherford http://www.weatherford.com/	Gas produced from surface vent boreholes may be gathered and used for boiler fuel, power generation or other direct use, or processed for gas pipeline sales. In addition, vacuum pumps on gob wells often run on gas produced from the well.
In-mine post-drainage REI Drilling http://www.reidrilling.com/ Daniel Brunner dan@reidrilling.com Target Drilling Inc. http://www.targetdrilling.com/ Steve Kravits stevekravits@targetdrilling.com	In-mine post mining drainage involves capturing methane released into the gob after the longwall passes. There are several methods practiced around the world, and in-mine post drainage is the most common form of degasification worldwide. Cross-measure boreholes: Drilled at an angle above and below the mined seam from an adjacent roadway, and cross-measure boreholes draw gas from the gob. Gas is transported to the surface using an in-mine gathering system. Cross-measure boreholes are common in Europe and the Former Soviet Union where mines are very deep, permeability is low and geology is complex, and have also been used in other mining regions. Short and long-hole in-mine directionally drilled gob wells: Horizontal boreholes drilled in-mine that produce gas from the gob and can be drilled cross-panel or along the length of the longwall panel, usually above the mined seam. Directionally drilled gob wells are used in Australia, the United States and China and have been demonstrated in other countries.

Drilling Techniques	
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**
	Drainage galleries (superjacent methods): Galleries that are driven in a coal seam above the mined seam for the purposes of capturing gob gas following longwall mining. Drainage galleries can be new purpose-driven galleries or already existing galleries that had a prior use. The galleries are sealed and connected to the drainage system. Gob gas rises through the strata above the mined seam to the drainage galleries where vacuum pressure pulls the gas into the drainage system. Boreholes drilled between the gob and the drainage galleries may be used to enhance gas recovery. Drainage galleries are used in many countries as a primary and secondary degasification strategy.

For a more detailed discussion of drilling techniques and descriptions of active mine drainage projects in the United States, see USEPA's CMOP documents: "Coal Mine Methane Recovery: A Primer" (https://www.epa.gov/sites/production/files/2016-03/documents/cmm_primer.pdf) and "Coal Mine Methane (CMM) Recovery Opportunities Map" (https://www.epa.gov/cmop/cmm-opportunities-map).