Methane Combustion

Gas Engines

TECHNOLOGY	DESCRIPTION/PROJECT INFORMATION	STATUS
Mines often vent the medium quality gas they drain from gob wells into the atmosphere instead of using it, because gob gas requires enrichment prior to pipeline injection. However, fuel for power generators does not require pipeline quality gas. Generally, IC engines can be adapted to generate electricity using coal mine gas with a methane concentration as low as 20%. However, for safety reasons, mines usually cease production of gob gas if the methane concentration drops below 25%. 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. For more information: http://www.epa.gov/cmop/docs/ic_engine.pdf		
Caterpillar www.cat.com/power-generation/generator-sets/gas-generator-sets	Caterpillar has introduced a range of larger, more efficient gas generator sets which can be fueled by CMM, landfill methane, or natural gas. The CMM fueled CAT ™ G3520 Gas Engine produces 1966 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, including: • Sihe Mine, Jincheng, China (60 gensets - 120 MW) • Jincheng (18 MWe) • Jincheng (38MWe) • Malan (4 MWe) • Huainan Mine, Anhui Province, China (2 x 1.8 MW) • BHP's Appin, Tower and West Cliff mines, Australia: 94 Caterpillar engines generate 97 MW of electricity. • Anglo's Moranbah North and German Creek mines, located in the Bowen Basin coalfields in central Queensland, Australia: Moranbah North (15 x 3 MW), German Creek (16 x 2 MW)	Commercially available and demonstrated using CMM worldwide.

Gas Engines		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
Deutz www.deutz.com Ulrich Sawetzki 49 6213848646 Sawetzki.U@deutz.com	Deutz manufactures gas engine gensets up to 7,400 kW. Minimum methane concentration for gas engines may be as low as 25%. Large installed base of CMM power generation, mainly in Europe.	Commercially available and demonstrated using CMM worldwide.
Dresser Waukesha http://www.waukeshaengine.com	Waukesha manufactures three families of engines the APG™, VHP®, and the VGF® that 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 can have a range 1000 to 1800 rpm and can produce from 280 to 1,100 kW. www.waukeshaengine.com/documents/1079_0610.pdf	Commercially available and demonstrated using CMM worldwide.
GE Jenbacher www.gegasengines.com Gerhard Pirker 43(0)5244 600 2906 gerhard.pirker@ge.com	GE's Jenbacher gas engines range in power from 250 kW to 4,400 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%. Project examples: Harworth Colliery, UK (5 x 1.4 MW) Fenne, Germany (8 x 3MW, 6 x 2.8MW) Oaky Creek, Australia (10 x 1MW, 2 x 3MW) Sasyadko, Ukraine (19 x 3 MW) Tunlan Mine, China (4 x 3MW) Wesola, Poland (2 x 1.4MW) Zernovo, Kuzbass Russia (1x 1MW) Lenina Mine, Kazakhstan (1x 1.4MW)	Commercially available and demonstrated using CMM and AMM on a worldwide base.

Gas Engines		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
IHI Corporation www.ihi.co.jp/en/products/energy_systems/index.html	The Nigata Gas Engine – 12V22AG 400 kW to 5,800 kW 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	Commercially available and demonstrated using CMM worldwide.
Mitsubishi Heavy Industries Ltd. www.mhi.co.jp/en/ Takaaki Furuya 813-6716-2956 takaaki_furuya@mhi.co.jp Nobuhiro Sawaki 81-45-224-9157 nobuhiro_sawaki@mhi.co.jp	MACH gas engines are being used in CMM fired power generation projects in China. The MACH-30G series gas engines utilize minimum quantities of liquid fuel for ignition and have a generation output range between 3,650 and 5,750 kW.	Commercially available and demonstrated using CMM worldwide.
Shengli Oil Field Shengli Power Machinery Group Co., Ltd. http://www.sdxsgs.com/en/ Aaron Xia 86-1-595-466-6035 sdjtfire@gmail.com	Shengdong are a Chinese domestic manufacturer of reciprocating gas engines which are very widely installed across mining regions in China to burn CMM. Their engine offering is the 500GF1-RFm rated at 400kW: http://www.sdxsgs.com/en/disppro.php?id=0000000030	Large installed base of CMM power generation in China.

Gas Turbines		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
A wide variety of gas turbines may be fuelled 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 raises methane's upper explosive limit; therefore to ensure safe operation, generally methane concentration should be maintained above 40%.		
General Electric www.gepower.com Ilene Marto Atiyah (202)637-4065 ilene.atiyah@ge.com	GE manufactures a wide range of heavy duty, small heavy duty, and aeroderivative gas turbines.	Commercially available.
Hitachi www.hitachi.co.jp/products/power/large-generator/index.html	Hitachi's manufactures the H-25gas turbine (30 MW class) and the H-15 gas turbine (17MW class) which is a scaled-down model of the H-25 gas turbine. Hitachi also offers small to large capacity combined cycle generators that use heavy duty gas turbines.	Commercially available.
Kawasaki www.kawasakigasturbines.com Eiichi Harada 81-78-921-1679 harada@ati.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.	Commercially available.

Gas Turbines		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
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 capacity.	Commercially available.
Solar mysolar.cat.com/ David R. Schnaars (858)694-6632 dave.schnaars@solarturbines.com	Solar Turbines' products include 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).	Commercially available.

Microturbines		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
The 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 be from 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	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. Project example: • Five Capstone microturbines operating at the abandoned Akabira Mine in Japan.	Commercially available and field tested on CMM in limited capacity.
Flex Turbine™ Flex Energy www.flexenergy.com (Note: Flex Energy completed the purchase of Ingersoll Rand's Energy Systems business on January 18, 2011.) www.ingersollrandproducts.com	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. Project example: • In 2006, CONSOL Energy partnered with Ingersoll Rand Energy Systems to install this first-of-a-kind microturbine unit. Sited at CONSOL Energy's Bailey Mine, one of the largest underground coal mines in the world, the unit uses coal mine methane liberated directly from the underground workings to generate electricity.	Commercially available.

Microturbines		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
United Technologies www.pw.utc.com www.utc.com/Home	Pratt & Whitney (a United Technologies Corp. company) successfully tested its 400 kW ST5 "miniturbine" for distributed generation in 2001.	Commercially available unknown.

Co-firing boiler for CMM and coal		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
Co-firing boiler for CMM and coal / low grade coal. Most co-firing boilers are found at mines where coal fired boilers are partially or completely retrofitted to burn mine methane. Numerous installations internationally, including the UK, China, Ukraine, Russia and Kazakhstan.		
Ishikawajima-Harima Heavy Industries Co., Ltd. (Power Plant Division) www.ihi.co.jp/en/index.html Ryosuke Tsujimae (813)3543-4374 ryosuke_tsujimae@ihi.co.jp	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.	Commercially available and demonstrated using CMM worldwide.

Co-firing boiler for CMM and coal		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
	The Huainan Coal group has retrofitted 14 boilers at seven coal mines in the Huainan coal field (Anhui Province, SE China). Originally fuelled with coal, the boilers now combust 65.8 million m^3/year of CMM. Emission reductions from the conversion are estimated at 1.67 MTCO2e per year.	Commercially available and demonstrated using CMM worldwide.
	Numerous CMM burners have been installed in modified coal boilers in Russia and Kazakhstan. Packaged specialized boiler for CMM developed by Uglemetan in Russia www.uglemetan.ru/	Commercially available and demonstrated using CMM worldwide.
	Numerous CMM burners have been installed in modified coal boilers in Ukraine.	Commercially available and demonstrated using CMM worldwide.

Flaring		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
Numerous flare manufacturers, including most of those listed here, have practical experience with installations at mines. Flare designs are divided between open and enclosed designs. Open flares are widely used at landfills, sewage treatment works, chemical plants, anaerobic digesters, and refineries around the world. They have an advantage over enclosed flares in being simpler to design and install and requiring lower maintenance, therefore being lower cost. Some designs can be portable. Presence of an open flame has to be considered while positioning open flares on site. With open flares, the flare efficiency cannot be measured in a reliable manner. The UNFCCC Annex 13 Methodological "Tool to determine project emissions from flaring gases containing methane" recommends a default destruction efficiency of 50% and The Climate Action Reserve recommends a default destruction efficiency of 96% for open flares. Also, with open flares, emission monitoring is not practicably possible.		

Flaring		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
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. The enclosed design also reduces noise associated with the combustion process. Enclosed flare designs have reported methane destruction efficiencies of over 99%. Automatic combustion control is a standard feature. Data logging, remote and local process control (flow and pressure) and continuous emission monitoring systems are commonly applied. *Both open and enclosed flares are designed with multiple redundant safety features. Protection may be provided from all potential sources of ignition and from flashback or detonation occurring in the flare stack via an integrated passive safety system (flame arrestors), an active positive pressure system (blower/exhauster) and a monitoring and control system with valve and equipment activation.*		
Abutec abutec.com/ Andy Smith (770) 846-0155 andy.smith@abutec.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 U.S. EPA regulation 40 CFR 60.18 and are BACT approved. ABUTEC installed the first Mine Gas Incinerator in the United States. Project examples: • Chertinskaya Kokovskaya Mine, Russia - Enclosed Pro2 flare stack with electrically driven extraction plant. • Solvay, Wyoming, USA - Enclosed Abutec flare stack coupled to Methane Buster gob well extraction pump (www.solvay.com).	Commercially available and demonstrated using CMM worldwide.

Flaring		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
Beijing Fairyland Environmental Technology Co., Ltd. www.fairyland.com.cn/huoju/tianmaiqihuoju/	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 in more than 60 projects in China and worldwide. Project examples: • 7 enclosed flare stacks on CMM down to 30% CH4 (Duerping 1 unit, Malan 2 units, Tunlun 4 units) manufactured by Beijing Fairyland and Nanjing.	Commercially available and demonstrated using CMM, primarily in China.
Biogas Technology Ltd. www.biogas.co.uk/flare.htm Ian Gadsby 44 1487831701 ian.gadsby@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. Project examples: • 8 x 2000 m3/hr enclosed Biogas Technology flare stacks have been installed at five deep mines in the UK to combust excess mine gas which cannot be fed to generator sets. Gas concentration is 27-60% methane.	Commercially available and demonstrated using CMM worldwide.
Haase Engineering www.haase-energietechnik.de/en/	Hasse manufactures several low-temperature and high-temperature flare stacks suitable for CMM flaring.	Commercially available and demonstrated using CMM worldwide.

Flaring		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
HOFGAS-CFM4c Hofstetter www.hofstetter-uwt.com/web/hofstetter/en.html	HOFGAS-CFM4c flare is able to burn methane concentrations ranging from 20% to 95%. For each specific project, the HOFGASÒ-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 condition 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. Project examples: • Anglo Coal is incorporating two mobile flares into the existing methane drainage system at the company's New Denmark Colliery near Standerton, in Mpumalanga province, South Africa. Costing $1.2 million, the two enclosed flares developed by Swiss company, Hofstetter, will combust gob methane drained from mine workings. The HOFGAS-IPL1c 500 mine degasification and incineration systems were built according to the Anglo's requirements and supplemented with a HOFGAS-Assay Gas Analyzer, combined with data recording. The flare's communication system is solar powered and allows for remote monitoring. The systems, including measurement devices, were each mounted onto a trailer by Anglo.	Commercially available and demonstrated using CMM worldwide.
MET Pro Corporation www.met-prosystems.com/open_enclosed_flare_thermal_oxidizers.htm	Met-Pro Systems open and enclosed flares operate at high temperatures (1500° F to 2500° F) offer high destruction efficiencies that are ideal for use with most VOC applications. They use modular design for flexibility.	Commercially available and demonstrated using CMM worldwide.

Flaring		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
MRW Technologies Inc. www.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 are guaranteed to meet EPA requirements for 40 CFR 60.18 and 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.	Commercially available and demonstrated using CMM worldwide.
Nanjing Carbon Recycle Biomass Technology Co., Ltd. www.rectec.com.cn/en/enprojects_5.html	Nanjing Carbon Recycle Biomass Technology Co. Ltd. manufactures 3 types of flares—mobile, open, and ground enclosed. Ground enclosed flare has been developed according to UNFCC technical requirements and is mainly used for CDM project in which methane is destroyed by combustion.	Commercially available and demonstrated using CMM worldwide.
Pro2 pro2.com/ Ekkard Wick 49 2154488430 e.wick@pro-2.de	As one of the pioneers in landfill gas technology, 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.	Commercially available and demonstrated using CMM worldwide.
Questor Technology Inc. www.questortech.com/ Doug Hollenbeck (403) 539-4377 dhollenbeck@questortech.com	Questor Technology engineers every incinerator to fit its specific application, based on gas composition and flow rates. Configuration capacities typically range from 5 to 5,000 MSCF/D.	Commercially available and demonstrated using CMM worldwide.

Gas conditioning systems		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
Drained CMM contains large quantities of water and dirt entrained within the gas. Combusting CMM without initial gas clean-up would lead to the combustion process equipment suffering from rapid degradation of the gas train, resulting in poor operational availability. Gas conditioning systems are used on the front end of a CMM combustion plant 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.		
Beijing Fairyland Environmental Technology Co., Ltd. www.fairyland.com.cn/huoju/tianmaiqihuoju/	Fairyland Environmental Technology (FET) focuses on the recovery and utilization of low-thermal-value-gas (LTVG) including CMM. Its services include gas pretreatment systems.	Commercially available and demonstrated using CMM worldwide.
Haase Engineering www.haase-energietechnik.de/en/	The HAASE BiogasUpgrader increases the methane percentage of source gas to 90-98% by volume (adjustable values) and at the same time eliminates sulphur and water vapor. The processed gas can be used for power generation or inject as pipeline gas. The BiogasUpgrader use an organic cleaning dilution that bonds carbon dioxide, hydrogen sulphide and water vapor by means of pressure and at low temperatures. The gases are desorbed by relaxation and heating.	Commercially available and demonstrated using CMM worldwide.
Hofstetter www.hofstetter-uwt.com/web/hofstetter/en.html	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.	Commercially available and demonstrated using CMM worldwide.

Gas conditioning systems		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
Nanjing Carbon Recycle Biomass Technology Co., Ltd. www.rectec.com.cn/en/enprojects_5.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.	Commercially available and demonstrated using CMM worldwide.
Pro2 pro2.com/ Ekkard Wick +492154488430 e.wick@pro-2.de	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.	Commercially available and demonstrated using CMM worldwide.

Fuel Cells		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
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. Typically, 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		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
FuelCell Energy info@fce.com www.fuelcellenergy.com Fuel Cells (general) www.fuelcells.org	Direct FuelCells (DFCs) run on biofuels—gases from wastewater treatment, food processing, and landfills—in addition to natural gas, coal gas, and propane. DFCs emit virtually zero nitrogen oxide (NOx), sulfur oxide (SOx) or particulate matter and significantly reduce carbon dioxide (CO2) emissions. Developed exclusively for use in stationary applications, there are four main fuel cell products designed to meet a variety of applications. All are self-contained electrical power generation system capable of providing high-quality baseload power. •DFC300 – capable of providing baseload power up to 300 kW with 47% electrical efficiency. •DFC1500 – capable of providing baseload power of 1.4 MW with 47% electrical efficiency. •DFC3000® – capable of providing baseload power up to 2.8 MW with 47% electrical efficiency. •DFC-ERG™ – 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 with electrical efficiencies of up to 65%. Project examples: • FuelCell Energy (FCE) with support from the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) and Northwest Fuel Development demonstrated in 2003, the use of CMM in a 250kW carbonate Direct FuelCell® power plant at a test site in Hopedale, Ohio, USA. (DOE Contract DE-FC26-00NT40979).	Commercially available. Field tests ongoing.

Drainage Gas Purification for Pipeline/Town Gas

Nitrogen Rejection		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
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" www.epa.gov/cmop/docs/red24.pdf		
Solvent Absorption Advanced Extraction Technology http://www.aet.com/home.htm Tom Gaskin, VP Technology (281) 447-0571 seekinfo@aet.com	This process uses specific solvents that have different absorption capacities with respect to different gas species. 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. Advanced Extraction Technology's (AET) first CMM application began operation at the Aberdeen Mine near Price, Utah in June 2007.	Commercially available and demonstrated using CMM worldwide.
Pressure Swing Adsorption (PSA) Northwest Fuel Development, Inc. www.northwestfuel.com Peet Soot, PhD, President (503)699-9836 nwfuel@northwestfuel.com	In most PSA nitrogen rejection systems, wide-pore carbon molecular sieves selectively adsorb nitrogen and methane at different rates in an equilibrium condition. In a CMM stream containing a mixture of air (nitrogen and oxygen) and methane, methane is 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	Commercially available and demonstrated using CMM worldwide.

Nitrogen Rejection		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
TGPE Inc. www.tuckergas.com/nrupg03.htm (217)752-6420 tucker@adams.net	systems have excellent turndown capability so they are able to operate effectively with gas flowing at a fraction of rated capacity.	
Molecular Gate Guild Associates www.moleculargate.com Michael Mitariten (908)752-6420 mike@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 new type of molecular sieve that has the unique 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 by "swinging" the adsorbent bed pressure from a high-pressure feed step that adsorbs the contaminants to a low-pressure regeneration step to remove the previously adsorbed contaminants. Guild Associates has installed twelve full-scale plants operating on methane from abandoned mines and GOB gas and is approaching 30 projects overall to reject nitrogen and/or carbon dioxide.	Commercially available and demonstrated using CMM worldwide.
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	Commercially available and demonstrated using CMM worldwide.

Nitrogen Rejection		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
R. Clark Butts, P.E., President Greg Hall, Sales Manager greghall@bcck.com Stephens T. Harper, VP – Corporate Development sharper@bcck.com (432)685-6095	plant, designers locate a deoxygenation system at the plant inlet. 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. BCCK Engineering is focused on developing its gas processing business (including CMM utilization) in the Americas and has installed three full-sized plants that upgrade CMM to pipeline quality gas. G.I. Dynamics (GID) 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).	
Membrane Separation Membrane Technology and Research, Inc. www.mtrinc.com/nitrogen_removal.html Kaaeid Lokhandwala (650)543-3360 gas@mtrinc.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 Inc systems.	Commercially available and demonstrated using CMM worldwide.

Nitrogen Rejection		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
Centrifugal Separation Bose Research and Development www.reducingglobalwarming.com Ranendra Bose (703)818-8919 info@reducingglobalwarming.com	The Bose System's Centrifugal Separation process is based on the molecular weight difference of the gas species contained in the CMM/AMM gases recovered. The Bose System has shown gas separation efficiencies of 70-75% in the automobile exhaust application, but no real world tests have been applied to CMM upgrading.	Commercially available, no CMM upgrading field testing.

Ventilation Air Methane (VAM) Mitigation and Utilization

VAM Fact Sheet: http://www.epa.gov/cmop/docs/vam_technologies-12-2010.pdf

Ventilation Air Methane (VAM)

Ventilation air methane (VAM) refers to the very dilute (<1% methane) ventilation air that is released from underground mine ventilation shafts. To ensure mine 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.

VAM Mitigation and Utilization in Thermal/Catalytic Reactors

TECHNOLOGY	DESCRIPTION/PROJECT INFORMATION	STATUS
Hybrid Waste Coal/ Methane (VAM) Combustion in Kiln EESTech www.eestechinc.com Ian Hutcheson, CFO 61 7 3832 9883 ihutcheson@eestechinc.com	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 (2002). 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 necessary in response to variations in VAM flow or concentration, thereby allowing for a constant energy feed to the turbine to power electricity generation. By combusting waste coal and VAM, this technology offers the ability to mitigate methane emissions while also reducing instances of spontaneous combustion and acid runoff from waste coal piles. A	Pilot tested and becoming commercially available soon.

VAM Mitigation and Utilization in Thermal/Catalytic Reactors		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
	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. Because it avoids the water requirements of steam-cycle power generation, the hybrid coal and gas turbine (HCGT) is appropriate for remote locations where waste coal and methane are available but where water is scarce.	
Thermal Flow Reversal Reactor (TFRR), Flameless Thermal Oxidation (FTO), Regenerative Thermal Oxidation (RTO) and Catalytic Flow Reversal Reactor (CFRR) Several companies have developed variations of thermal reactors designed to destroy methane in ventilation air. The general principal is that ventilation air enters the reactor and flows in one direction into a preheated ceramic bed that increases its temperature to above the ignition point of methane (i.e., 1,832°F or 1,000°C). Oxidation of the VAM takes place in the bed, and the hot products of oxidation continue through the bed, losing heat to the far side of the bed in the process. When the far side of the bed is sufficiently hot, the reactor automatically reverses the direction of ventilation airflow to maintain the thermal environment necessary to continue the auto-oxidation process in the oxidizer core. An in depth explanation of the main thermal oxidation systems (in use or being developed), can be found on the ventilation air methane section of USEPA's CMOP website: www.epa.gov/cmop/resources/vam.html and www.epa.gov/cmop/docs/vam-planning-mitigation.pdf		
VAMOX Biothermica www.biothermica.com Nicolas Duplessis Nicolas.duplessis@biothermica.com (514)488-3881	VAMOX® converts VAM into carbon dioxide and water vapor using the principle of regenerative thermal oxidation (RTO). VAMOX® systems are tailored to meet site's specific needs. Vamox specifications include: • Unit capacity up to 170 000 Nm^3/h (100 000 SCFM) • Methane concentration ranging from 0.2% to 1.2% • Up to 98% destruction efficiency • Low parasitic power consumption • Oxidation temperature as low as 800°C	Commercially available and demonstrated using CMM worldwide.

VAM Mitigation and Utilization in Thermal/Catalytic Reactors		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
	Project examples: • Jim Walter Resources No.4 Mine, Alabama, USA – The project employs a single VAMOX™ unit that oxidizes 51,000 m^3/h (30,019 cfm) of 0.8%CH4 VAM. The project was initiated in January 2009 and it is the first to operate at an active mine in the Americas. It also is the first VAM oxidation installation to receive approval from the U.S. Mine Safety and Health Administration (MSHA). As this is an oxidation-only project (i.e., does not include energy capture and use), its revenues derive solely from the sale of carbon offset credits during the planned 4-year operational lifetime. During its initial year of operation, the project generated 25,931 carbon credits (3rd party verified) that will be registered for sale in the North American market. In its second year of operation, it generated 28,222 CRTs—a 9% increase compared to its first year.	
Ecopure® Dürr www.durr.com (734)459-6800 eesales@durrusa.com	Dürr manufactures several thermal oxidation (regenerative thermal, compact thermal, thermal exhaust) and catalytic oxidation (high-pressure, low-pressure, regenerative, selective) air/exhaust purifier systems. These systems come in a range of sizes and include pre-manufactured units designed for quick installation. Project examples: • McElroy Mine, West Virginia, USA – Planned demonstration VAM abatement project using Durr's regenerative thermal oxidation technology. CONSOL Energy will co-develop the project with Verdeo. An estimated 230,000 tonnes of CO2 equivalent (tCO2e) will be destroyed annually by the project.	Planned demonstration project. Commercially available.

VAM Mitigation and Utilization in Thermal/Catalytic Reactors		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
RTO Gulf Coast Environmental (GCE) www.gcesystems.com sales@gcesystems.com Mark Owen, VAM Manager (949) 783-0464 mowen@gcesystems.com	Gulf Coast Environmental Systems, LLC provides a thermal flow-reversal oxidizer, the CH4 RTO (regenerative thermal oxidizer), that uses a shipping container as the oxidizer shell, thereby reducing manufacturing costs.	Commercially available.
MEGTEC VOCSIDIZER™ MEGTEC Systems www.megtec.com Richard Mattus 46 (0)31 65 78 19 rmattus@megtec.se	The MEGTEC VOCSIDIZER® is a compact and flameless regenerative thermal oxidizer (RTO) that generates high grade, super-heated steam from ventilation air with less than 1% methane. Project examples: • Thoresby Mine, Nottinghamshire, England – VOCSIDIZER™ demonstration project (1994). • Appin Colliery, New South Wales, Australia – 12 month VOCSIDIZER™ demonstration project ('01-'02). • West Cliff Colliery, New South Wales, Australia – Full scale VAM to electricity project dubbed WESTVAMP (2007 to present). The project integrates VOCSIDIZER™ units (4) with a conventional steam turbine. The system, running on superheated steam from the TFRR, generates 6 MW of electrical power which is fed to the mine. • Windsor Mine, West Virginia, USA – First U.S. field demonstration project ('07-'08). Sited on an abandoned mine, the project employed a single VOCSIDIZER™ unit to process ~50,000 m3/h (29,430 cfm) of simulated VAM, at a concentration of 0.6% CH4.	Commercially available and demonstrated using CMM worldwide.

VAM Mitigation and Utilization in Thermal/Catalytic Reactors		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
	• Zhengzhou Mining Group, Henan, China – VOCSIDIZER • Datong Mine, Chongqing municipality, China (planned project) – MEGTEC are contracted to build the largest VAM abatement project in the world. The system, comprising six VOCSIDIZER units with a total capacity of 375,000 m3/h of ventilation air, is expected to reduce greenhouse gas emissions by up to 200,000 tons of CO2 equivalent per year. In addition, energy released in the process will be used to heat water for nearby buildings.	
Shengdong Regenerative Thermal Oxidation Technology Shengdong Group www.sdxsgs.com/en/index.php 86 0546 877 1005	Shengdong Group is offering a VAM oxidizer that has been field tested for energy recovery (i.e., steam production) at several Chinese mines. Project examples: • Fuxin, China (2007) – Demonstration pilot unit using Shengdong regenerative thermal oxidation technology, sweetened with CMM, generates steam from waste heat. • Pingdingshan, China (2009) – Full scale unit using Shengdong regenerative thermal oxidation technology, sweetened with CMM, generates steam from waste heat.	Pilot and full-scale tested in China.
Catalytic Flow Reversal Reactor (CFRR) CH4MIN Canada's Centre for Mineral and Energy Technology (CANMET) www.canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/ Hristo Sapoundjiev (450)652-4621	The CFRR has the same basic design and operation as the TFRR, except that oxidation takes place in the presence of a catalyst at temperatures well below the 1000°C needed for the TFRR. As yet there is no design to use the energy released. CANMET has developed and pilot-tested a CFRR design, termed the CH4MIN, which is specifically intended for VAM applications. Their technology has not yet been deployed in VAM mitigation applications, but it is in the process of being commercialized by SCS Americas in countries that signed on to the Kyoto Protocol. SCS built a 15 m^3/s test unit and is in	Pilot tested. Commercially available in the near future.

VAM Mitigation and Utilization in Thermal/Catalytic Reactors		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
Jacques Grau (450) 652-5177 jacques.grou@nrcan.gc.ca	the process of executing design modifications based on the results obtained. They plan to have initial units operating in China in the near future.	

VAM Mitigation and Utilization as Combustion Air in Power Equipment		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
M.E.T.T.S – Consulting Engineers www.metts.com.au/hybrid-vam-and-coal-waste-fired-power-generation.html	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. However the technology is still a proposed concept, with no real development.	Proposed concept.
Catalytic Monolith Reactor Commonwealth Scientific and Industrial Research Organization (CSIRO) Exploration and Mining www.csiro.com.au Dr. Shi Su 61-7-3327 4679 Shi.su@csiro.au	Catalytic monolith reactor technology uses a honeycomb type monolithic reactor, which is a type of reactor in common use due to its outstanding characteristics of very low pressure drop at high mass flows, high geometrical area, and high mechanical strength. Monoliths consist of a structure of parallel channels with walls coated by a porous support containing catalytically active particles.	Field tested, not yet commercially available.

VAM Mitigation and Utilization in Turbines		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
Catalytic lean-burn gas turbines In general, the catalytic turbine intakes a very lean fuel/air mixture, and compresses it, and combusts it in a catalytic combustor. The turbine operates at low temperatures, so does not use combustion air for dilution and internal cooling, thus allowing the air intake to contain methane.		
VAMCAT™ CSIRO Exploration and Mining Dr. Shi Su 61-7-3327 4679 Shi.su@csiro.au	CSIRO developed the VAMCAT™, a lean-fuel gas turbine that employs a catalytic combustor to run on VAM concentrations in the 1% range. In most field applications, this technology will require the availability of supplemental fuel (e.g., drained coal mine methane) that can be blended in to increase the methane concentration entering the turbine to approximately 1 percent methane. CSIRO, with the support of the Australian Greenhouse Office and China's Shanghai Jiaotong University and Huainan Coal Mining Group is planning to test a 30kW demonstration unit at the Panyi coal mine in China. www.globalmethane.org/expo_china07/docs/postexpo/coal_guo.pdf	Commercially available with limited field testing.
FlexEnergy www.flexenergy.com Edan Prabhu (949) 380-4899 edan.prabhu@flexenergy.com	The FlexEnergy Micro turbine, adapted from the commercially available Capstone micro turbine, is designed to accept a wide range of fuels, including VAM. A FlexEnergy unit can achieve full power with fuel as low as 1.5% methane (~ 15 Btu/ft^3) delivered at atmospheric pressure. Even lower concentrations may be used, but will not generate full power. The fuel/air mixture is compressed and then oxidized in a catalytic combustor. The hot compressed gases expand in the turbine to power the generator. The compressor and combustor are contained within a compact turbine module. Project examples: • A FlexEnergy turbine has been installed at the DCOR oilfield near Santa Barbara, California, to consume oilfield gas at concentrations ranging from 1.5 to 4.2 percent, and another is running on coal	Proposed concept.

VAM Mitigation and Utilization in Turbines		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
	process waste gas at the Western Research Institute in Laramie, Wyoming.	
Flex Energy www.flexenergy.com (Note: Flex Energy completed the purchase of Ingersoll Rand's Energy Systems business on January 18, 2011.) www.ingersollrandproducts.com	Ingersoll-Rand (IR) developed a microturbine that will run on 1.0% ventilation air methane (VAM), and as low as 0.86%. It is a lean-fuel version of PowerWorks Micro turbine System. The current prototype is rated at 70 kW and is designed for remote outdoor installations.	Prototype stage.

Enriching VAM		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
Concentration Australian Coal Association Research Program www.acarp.com.au Samantha McCulloch +61 2 6273 6044 samantha.mcculloch@australiancoal.com.au	Concentrators have been applied to several industries to capture volatile organic compounds. A concentrator of this type could be used to enrich methane in mine ventilation air to levels that meet the requirements of lean-burn methane utilization technologies, such as catalytic and recuperative gas turbines. This involves taking the 0.1-0.9 % methane stream and increasing the methane to a concentration of greater than 20%. This technology has been investigated by Environmental C&C, Inc., (www.environmentalcc.com) and is being studied by CSIRO and ACARP.	Emerging/initial research stages.

Enriching VAM		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
CSIRO www.csiro.com.au Dr. Shi Su 61 7 3327 4679 Shi.su@csiro.au Bose Research and Development Inc. www.reducingglobalwarming.com Ranendra Bose (703)818-8919 rkbose@cox.net Lazarus Ude Innocent 234 80 33789633 delphicogroup@yahoo.com	Also see CMOP's Concentrating Coal Mine Methane brochure www.epa.gov/coalbed/docs/concentrating-cmm.pdf	
	A battery of Bose System Gas Turbines using compressed VAM from active coal mines may be able to centrifugally separate methane from 0.1 – 0.9% VAM to a concentration of greater than 20%, for use in micro turbines. This technology is at the concept stage.	Emerging/conceptual stage.
Gas upgrading system Gas and Power Co. Ltd. (Energy and business Development Department) www.gasandpower.co.jp 06 6205 4557 hamaguti@gasnadpower.co.jp	Upgrades low-quality CMM using filtration with activated carbon. The technology has been field tested but little information is publically available.	Emerging/limited field testing.

Modeling and Analysis

Modeling and Analysis		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
Gas simulation software Japan Coal Energy Centre (Resources Development Department) tomita@jcoal.or.jp [1] Matsuyama@jcoal.or.jp [2] li@jcoal.or.jp [3] www.jcoal.or.jp/index-en.html	[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.	Commercially available.
Gas simulation software U.S. National Institute for Occupational Safety and Health (NIOSH) www.cdc.gov/niosh/mining/products/product180.htm Ozgen C. Karacan +1-(412) 386- 4008 cok6@cdc.gov	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 U.S. 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 U.S. conditions, which directly relate to specific U.S. long wall mining conditions and to the mining operations in specific states; and b) Models for other U.S./international conditions, which are applicable to "other U.S." conditions and also to international projects.	Publically available.

Modeling and Analysis		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
Gas contents analysis apparatus Japan Coal Energy Centre (Resources Development Department) www.jcoal.or.jp tomita@jcoal.or.jp Hiroaki Hirasawa (813)6400-5196 hirasawa@jcoal.or.jp U.S. National Institute for Occupational Safety and Health (NIOSH) www.cdc.gov/niosh/mining/pubs/pdfs/mdmsoa.pdf	Portable and compact gas analyzing apparatus to measure gas contents in coal on site.	Commercially available.

CMM to LNG

CMM to LNG		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
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, sulphur compounds, volatile organic compounds, oxygen, nitrogen, and water. LNG is typically composed of over 95% methane, with the remaining 5% typically being made up of nitrogen and other heavier hydrocarbons.		
Purification in CMM to LNG process LNG – Silesia (a joint venture by Prometheus Energy and CETUS Energetyka Gazowa) +48 (0) 32 324 45 52 office@ingsilesia.pl www.lngsilesia.pl/index.php?show=about&lang=en Prometheus Energy www.prometheusenergy.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 an LNG production of 97% methane. The installations are modified to handle CMM concentrations as low as 40%.	Commercially available.
Compact High Efficiency Natural Gas Liquefier Idaho National Laboratory (208)526-9169 https://inlportal.inl.gov/portal/server.pt/community/home	"Free" energy from the pipeline pressure letdown is used to liquefy the natural gas. INL liquefaction technology is designed to draw natural gas from a transmission pipeline at a point where the pressure is dropped to accommodate commercial distribution. The plant is powered mainly by the energy created through this pressure drop. As the gas enters the plant, some of it is allowed to expand, and as it expands, it cools. This allows the process to use the natural gas as a	Emerging/pilot testing.

CMM to LNG		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
	coolant in the liquefaction process. A pilot plant removes contaminants from the methane stream as it progresses through the plant. This significantly decreases the work involved with pre-cleaning the methane. The pilot plant is designed to liquefy 10-20% of the gas entering the plant. No gas is consumed by the plant during the process. The INL technology could be applicable for smaller-volume CMM applications. The liquefier could be expected to produce between 8 and 70 metric tons of LNG per day.	

Drilling Techniques

Coal Mine Methane Recovery: A Primer: www.epa.gov/coalbed/docs/cmm_primer.pdf

Best Practice Guidance for Effective Methane Drainage and Use in Coal Mines: live.unece.org/fileadmin/DAM/energy/se/pdfs/cmm/pub/BestPractGuide_MethDrain_es31.pdf

Vertical Wells		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
Vertical wells	Coal seam methane (CSM), termed coal bed methane (CBM) in the U.S., is drained from virgin coal seams several years in advance of mining. Vertical holes are drilled from the surface to intercept coal seams. After fracturing and dewatering the coal, methane with concentrations greater than 90% is produced up the well.	Common practice and widely implemented worldwide.
Surface to inseam (coal seams below the surface)	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 surface location resulting in a "pinnate" or "turkey-foot" layout of well bores. Project examples: • Buchanan Mine and VP 8 Mine, Virginia, USA • CONSOL Energy • Grasstree Mine, Queensland, Australia • Anglo Coal • Oak Grove Mine, Alabama, USA • Cliffs Natural Resources	Common practice worldwide.

Vertical Wells		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
	• Pinnacle Mine, West Virginia, USA • Pinnacle Mining Company • Wilkie Creek Mine, Queensland, Australia • Peabody Energy Australia	
Surface to inseam (coal seams exposure in highwall mining)	Coal seam methane is drained from exposed high walls with a series of horizontal wells drilled into both highwall and underground seams several years in advance of coal mining. Project examples: • German Creek Mine, Bowen Basin Queensland, Australia Operated by Capcoal www.capcoal.com.au/oview.htm CSM drained from this mine is used to power a 32MW power plant, operated by Environmental Developments Limited. • Meridian Seamgas (formerly Dawson Seamgas) Bowen Basin, Queensland Operated by Westside Corporation www.westsidecorporation.com Coal seam methane is drained from exposed high walls with a series of horizontal wells into both highwall and underground seams several years in advance of coal mining. Over 2.8 Bcf (3 PJ) of CSM per year is supplied from this colliery to the regional transmission line. A gas processing plant located on site dehydrates and compresses the gas before delivering it to the pipeline. Methane concentration is typically greater than 90%.	Common practice worldwide.

Vertical Wells		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
	• North Antelope Rochelle Mine Powder River Basin, Wyoming, USA. Operated by Peabody Energy Corp. www.peabodyenergy.com/Media/factsheets/NARoch.asp This CMM project, at an open-cast mine, involves methane drainage, from 47 vertical, surface wells, in advance of the highwall (mining face). The drained gas is collected, compressed and metered, before being transported to the nearest natural gas pipeline. Before 2002, the methane was passively vented to the atmosphere through the high-wall, or from dewatering wells. The project is estimated to reduce 200,000 tonnes of carbon dioxide equivalent (TCO2e) annually and is registered for carbon credits on the Voluntary Carbon Standard registry.	
Pre drainage (in seam, underground coal mining)	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, parallel layouts or directionally drilled and vary in length from 100's to 1,000's of feet. 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. Project examples: • Appin Mine and West Cliff Mine, New South Wales, Australia BHP Billiton www.bhpbilliton.com Tim Meyer 02 42553388 tim.g.meyer@bhpbilliton.com	Common practice worldwide.

Vertical Wells		
TECHNOLOGY	**DESCRIPTION/PROJECT INFORMATION**	**STATUS**
	• Jim Walter Resources Blue Creek Mines No. 4 and No. 7 Black Warrior Basin, Alabama, USA www.walterenergy.com/operationscenter/jwr.html	
Post drainage (post mining/goaf, underground coal mining)	Methane is collected from the goaf/gob following long wall operations. This results in drainage gas with a concentration of approximately 25-70% methane.	Common practice worldwide.

Note: Conventional technologies, including gas engines, can be used for high concentration drainage gas from the above activities with methane content greater than 25 percent.

For a more detailed discussion of drilling techniques and descriptions of active mine drainage projects in the U.S., see USEPA's CMOP documents: "Coal Mine Methane Recovery: A Primer" and "Identifying Opportunities for Coal Mine Methane Recovery at U.S. Coal Mines: Profiles of Selected Gassy Underground Coal Mines 2002-2006".