The Global Methane Initiative (GMI) Coal Subcommittee released the first edition of this white paper in November 2011 following the GMI Steering Committee charge to examine methane abatement in each sector. The Coal Subcommittee has decided to update the flaring policy white paper to address the changes in a dynamic and rapidly evolving market. In the 2 years since the November 2011 release, much has changed with respect to the availability of carbon finance and this in turn has affected the viability of some CMM utilization projects. At the same time, there is growing acceptance of flaring as a safe and reliable emission reduction technology option and the number of CMM flaring projects is growing.

Flaring of Coal Mine Methane: Assessing Appropriate Opportunities

Executive Summary

In September 2010, the Global Methane Initiative (GMI) was formally launched as a successor to the successful Methane to Markets Partnership that was originally chartered in 2004.[1] GMI is a public-private international partnership that now includes 41 Partner countries and the European Commission. GMI aims to reduce methane emissions from key sectors including landfills, coal mines, oil and natural gas production, agriculture, and wastewater. Historically, the Partnership focused primarily on methane capture and use, rather than emphasizing abatement-only projects that destroy methane without any energy recovery benefit. The newly-anointed GMI Steering Committee formally adopted revised Terms of Reference (TOR) language to expand the Initiative's scope to explicitly include methane abatement in addition to recovery and use. The Steering Committee charged each Subcommittee to evaluate the role of methane abatement within their sector and to update the sector Action Plan accordingly.

This white paper summarizes the approach of the Global Methane Initiative Coal Subcommittee towards coal mine methane (CMM) and abandoned mine methane (AMM) projects that involve mitigation-only of drained gas through flaring. Although flaring-only projects should be the option of last resort for drained gas CMM projects, flaring projects would be preferred to venting methane gas to the atmosphere, and may be appropriate in a number of cases where it is infeasible or impractical to recover the drained gas for energy use.

I. Global Methane Initiative: New Emphasis on Methane Abatement

Methane (CH_4) is a hydrocarbon and the primary component of natural gas. Methane is also a potent and abundant greenhouse gas (GHG), which makes it a significant contributor to climate change, especially in the near term. Methane is the second most abundant GHG after carbon dioxide (CO_2), accounting for 14 percent of global GHG emissions in 2005[2]. Though methane is emitted into the atmosphere in smaller quantities than CO_2, its global warming potential (GWP, the ability of the gas to trap heat in the atmosphere) is 21 times greater.[3] As a result, methane emissions currently contribute to more than one-third of today's anthropogenic warming.

Globally, methane from coal mining accounts for 6 percent of total methane emissions resulting from human activities. In 2012, estimated worldwide coal mine methane (CMM) emissions

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[1] See the Global Methane Initiative website: www.globalmethane.org
[2] A 100-year time frame. Based on IPCC Fourth Assessment Report (AR4), IPCC 2007 – (http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm)
[3] IPCC 2007

totaled nearly 605 million metric tons of carbon dioxide equivalent ($MMTCO_2E$), or about 42.4 billion cubic meters (BCM). By 2020, the world's coal mines are expected to produce annual emissions of 671 $MMTCO_2E$ (46.9 BCM).[4]

Historically, CMM has been, and continues to be considered primarily a safety hazard and an impediment to coal production. As a result, CMM was typically vented to the atmosphere through ventilation and drainage systems. However, in recent decades, awareness of methane's environmental impact as a GHG, in conjunction with higher energy prices and the advent of carbon markets, has encouraged the development of a number of technologies for beneficially using CMM, including for town gas and long distance natural gas trunklines, for electric power production, for industrial boiler fuel and even for vehicle fuel. Furthermore, the potential efficacy of technologies for oxidizing the very low methane concentrations (typically below one percent) contained in ventilation air exhausts from gassy underground coal mines has been demonstrated, and other ventilation air methane (VAM) mitigation technologies are in the research and development pipeline.

Besides VAM, the other principal type of abatement-only project applicable to the mine methane sector is flaring. Methane collected from boreholes in advance of or during mining (e.g., from gob holes or in-mine drainage) is destroyed by combustion in a flare. Through oxidation, the methane is converted to carbon dioxide (CO2), a far less potent GHG. Although flaring projects have used both open (candle stick) and enclosed (ground) flares, enclosed flares are preferred for aesthetics and their 99% destruction efficiency versus 50% for candlestick flares.

The principal concern associated with flaring CMM at or near a coal mine has been the safety of doing so. Flaring itself has been a long-standing global practice in industries handling combustible materials such as oil and gas production, petroleum refining, municipal solid waste landfills, and chemical manufacturing. At the very least, safe flaring requires rigorous design incorporating flame and detonation arrestors, seals, sensors, and others safety devices. Conceptually, the safety risk of flaring is no different from that of a CMM boiler, a well-established CMM application[5]. An accepted design of a safe flare can be found in the U.S. Environmental Protection Agency document, *Conceptual Design for a Gob Well Flare*.[6]

However, the coal mining industry and regulators in certain countries, such as the United States, have been traditionally reluctant to encourage flaring projects at coal mines. In contrast, CMM flares have operated successfully in a number of countries. The GMI International Coal Mine Methane Project Database identifies 40 CMM projects that are using, or have used, flares, either in conjunction with energy recovery technologies, or as a stand-alone mitigation technology. As of July 2013, a total of 20 projects in 7 countries have operating flares including: Australia (6), China (3), Mexico (3), Russia (2), South Africa (1), Ukraine (3), and USA (2). Section V includes a summary of selected flaring projects around the world.

[4] Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990 – 2030 http://www.epa.gov/climatechange/Downloads/EPAactivities/EPA_Global_NonCO2_Projections_Dec2012.pdf

[5] United Nations Economic Commission For Europe and Methane to Markets Partnership, *Best Practice Guidance for Effective Methane Drainage and Use in Coal Mines*, ISBN 978-92-1-117018-4, ISSN 1014-7225, 2010 http://www.unece.org/energy/se/pdfs/cmm/pub/BestPractGuide_MethDrain_es31.pdf

[6] http://epa.gov/coalbed/docs/red009.pdf

In the past, the Coal Subcommittee has only briefly addressed the issue of flaring in the CMM sector. At the May 2006 Subcommittee meeting, Project Network members offered a memorandum[7] proposing a policy that flaring CMM should only be considered as a secondary option if CMM utilization is not technically or economically viable. Subsequently, the Subcommittee has not discussed an official position on flaring-only projects.

Based on the directive from the GMI Steering Committee to specifically address abatement-only opportunities in each sector, the Coal Subcommittee agreed at its 2010 meeting in Beijing, China to develop a draft position paper on flaring using information from the 2006 memorandum as appropriate. This paper briefly summarizes the key issues involved with flaring-only CMM projects and proposes a framework for guiding decisions about when flaring may be viewed as an acceptable CMM abatement option from a best practice perspective. This paper specifically focuses on flaring of drained CMM and does not address the VAM abatement-only projects.

II. Project Considerations and Economic Feasibility: Comparison of CMM Use and Flaring

The recovery of CMM's energy value generally offsets the need for an equal quantity of fossil fuel and its associated GHG emissions. However, on many occasions there are economic or technical barriers to installing CMM end-use projects, and in these cases flaring (abatement-only) projects should be considered for mitigation of part or all of the gas, especially where there is "stranded" gas, remote from either electric or natural gas transmission lines.

Economic and Technical Considerations

Available data suggests that there are several hundred CMM end use projects around the globe, but there are a limited number of projects that flare CMM for a portion or all of the drained gas. Out of 320 projects listed in the GMI International Coal Mine Methane Project Database, 18 projects are flaring-only projects and 22 are energy recovery projects which include flares for destruction of gas that cannot be used in the energy recovery equipment.

In some cases, a flaring-only project may prove to be a more economical and technically feasible option compared to an energy recovery project, based on a combination of one or more of the following factors:

- Proximity to an electrical connection
- Price of electricity or fuel being replaced
- Existence of a local heat demand
- Price of heat
- Proximity of a natural gas pipeline
- Gas quality
- Gas flow variability
- Local administrative regulation (e.g., environmental, ownership, safety)
- Unfavorable topography for a utilization project

[7] Schultz, Karl and Schultz, Lee. *Flaring Coal Mine Methane: When Does It Contribute to Sustainable Development?* May 2006 http://www.climate-mitigation.com/Flaring%20paper%20review10%20Aug%2006.pdf

Flares also offer the potential advantage of shorter planning, design and installation schedules, in conjunction with much lower capital and operating costs than many energy recovery project types. In addition, carbon emission reduction credits may be available in certain cases for flaring projects. The US EPA's Coal Mine Methane Project Cash Flow Model[8] estimates the capital cost of a typical CMM drainage flaring project to be 5 to 10 percent of the cost of a CMM electricity generation project. The operating and maintenance costs of a CMM flaring project may be similarly proportionate to those of an energy recovery project. Of course, energy recovery projects have income directly associated with the recovered energy, thereby offsetting the higher costs. In contrast, flaring projects may only have an income stream associated with carbon reduction credits.

Flaring can also serve as an important initial CMM recovery stage leading up to an energy project (i.e., flaring CMM prior to an energy project becoming operational). Flares are often an integral component of an energy project, used for the destruction of CMM during periods of unacceptable CMM quality, excessive CMM flows or maintenance of the energy recovery equipment. As such, flaring can serve as an interim measure, destroying CMM and earning carbon credits, while a more full-fledged energy project is being implemented.

Greenhouse Gas Emission Reductions

In terms of GHG emissions, flaring CMM significantly reduces methane emissions that would have been otherwise vented to the atmosphere. Flaring alone, when utilization options are viable, wastes a valuable energy resource by emitting CO_2 without recovering any beneficial energy. The following is a GHG emission reductions comparison of CMM flaring and energy recovery:

- Flaring CMM drainage has the GHG benefit of destroying 1 kg of methane with a GWP of 21 kg CO_2e, to 2.75 kg of CO_2, thereby providing a net equivalent benefit of avoiding the release of 18.25 kg CO_2e.
- A similar sized energy recovery project that off-sets an equivalent amount of fossil fuel combustion would result in a benefit of 18.25 kg CO_2e, just like the flare project, but would have an additional benefit of offsetting 2.75 kg CO_2 that would have been emitted from a power plant, for a net benefit of 21 kg CO_2e.

Thus, energy recovery projects conserve energy and result in approximately 15 percent fewer GHG emissions.

[8] http://www.epa.gov/cmop/resources/cashflow_model.html

III. When to Flare?

Because flaring-only does not provide the same level of energy and environmental benefits of energy capture for drained CMM, flaring-only projects should not be the first option considered when planning methane emission mitigation or abatement unless it is clear that no other reasonable options exist. Project stakeholders should conduct a preliminary project scoping analysis to evaluate the costs and benefits of all technologically viable mitigation options.

There is a hierarchy of optimal end use options for CMM based on site-specific economic and market demands (Table 1). Projects using and recovering energy from the highest quality (highest methane concentration) drained CMM would be at one end of the spectrum, and mitigation-only projects (i.e., flaring) would be at the other. Drainage gas with high methane concentrations, such as over 85 percent, presents the most project options since the fuel can replace natural gas with minimal effort. Drainage gas with methane concentrations between 40 to 85 percent can be used in direct combustion applications such as engine-generator sets, dryers, and boilers with little treatment or combustor modifications. Low methane concentrations, such as below 40 percent, have more limited utility (without significant treatment to increase the heating value).

Table 1:
Technically Suitable Uses for CMM Based on Methane Concentration of Drainage Gas

Methane Concentration of Drainage Gas	Natural Gas Pipeline	On-site Combustion Applications	Flaring
High methane concentrations **(over 85 percent)**	✓✓	✓✓	✓✓
Medium methane concentrations **(40 to 85 percent)**	✓	✓✓	✓✓
Low methane concentrations **(below 40 percent)**	–	✓	✓✓
Potential Revenues where infrastructure and demand is available	High	Intermediate	Lower

✓✓ Highly suitable use in proven commercial-scale projects; CMM requires little or no treatment
✓ Suitable use in proven commercial-scale projects; CMM will likely require some treatment

The feasibility of any energy recovery project is significantly impacted by a number of factors such as local energy prices, onsite energy demands and accessibility to energy markets. To assure that sustainability is adequately factored into the project planning, selection, and approval process, projects should consider the technical and economic viability of a wide range of technologies that exploit methane's energy content in some manner.

This process is not intended to be an "all or nothing" approach. In some cases, a mine site will not be able to utilize all of the available CMM in an energy recovery project and should consider an integrated energy recovery and flaring project to mitigate all of the captured methane. When project stakeholders are contemplating such a mixed recovery and flaring option, a stepwise process can be used to first determine what portion of methane emissions meets the investment thresholds for energy recovery. Ideally, only the CMM exceeding reasonable investment thresholds due to fluctuations in methane quantities or qualities would be considered for flaring or, as noted earlier, as an interim option to achieve emission reductions in the early stage of project development. Combined use and mitigation projects are highly desirous as they would mitigate all (or nearly all) methane emissions rather than venting the methane that cannot be economically recovered for energy use.

As an illustrative example, the following is one possible stepwise decision process for evaluating project options:

- ☑ Conduct a preliminary project scoping analysis to identify project-site features and any major impediments to developing CMM energy recovery projects.
- ☑ Identify all technically feasible CMM use options.
- ☑ Eliminate any options for which site-specific markets do not exist or could not be created.
- ☑ Assess capital investment, cash flow, and expected revenues, including sale of carbon credits and any other available economic incentives.
- ☑ Evaluate key economic parameters such as internal rate of return (IRR), return on investment (ROI), capital investment per unit output ($/MW), cash flow profile, etc.
- ☑ Select CMM energy recovery projects for which the project would be technically viable and could be justified based on project economics.
- ☑ Select CMM flaring-only projects for cases in which CMM energy recovery projects would not be technically feasible or could not pass economic hurdles.

IV. Conclusions

The GMI Coal Subcommittee understands and appreciates the potential benefits that CMM flaring as methane abatement can provide when applied in an appropriate setting, including as part of an overall integrated CMM project. From an environmental perspective, it is better to flare excess or stranded CMM rather than to vent it to the atmosphere, as it reduces the overall greenhouse gas emissions. In conclusion, the following considerations should guide CMM flaring methane abatement projects:

- The implementation of 40 flaring projects worldwide over time in most major coal mining countries suggests that flaring of CMM is deemed to be a generally accepted, proven and safe technology that does not pose an intrinsic risk when employing well-designed and operated equipment and sound operating practices. Safety concerns must be evaluated and addressed in every case, and all applicable regulations strictly followed.

- Flaring-only of drained CMM is most appropriate where energy recovery is infeasible because it is not economic to utilize the gas on site or where the gas is not accessible to energy markets.

- Flaring of CMM should be the option of last resort for drained CMM, as CMM energy recovery end-uses are more desirable methods of methane abatement where technically and economically feasible. Flaring of high-quality CMM (above 85%) is not encouraged.

- Flaring is ideal as a component of an integrated overall end-use project to mitigate excess methane that would not otherwise be used.

V. Selected Examples of Mine Methane Flaring Projects

Below are selected examples of operational mine methane flaring projects, including one trona mine project.

Mine Methane Flaring Projects	
Location	**Duerping Mine, Shanxi, China**
Year	2008
Flare	1 x 5,000 m^3/hour enclosed flare
Project Summary	The Duerping Mine, operated by Xishan Coal & Electricity company, drains methane post-mining and exhausts VAM. An enclosed flare was initially used as an interim emission reduction option before gas gensets were installed. The flare is now used to destroy drained gas volumes in excess of those utilized by the gensets, or gas of concentration less than the permitted minimum (currently 30%) but higher than 25%. Approximately 20% of drained gas is expected to be flared.
Location	**Solvay Chemicals Inc., Trona Mine, Green River, Wyoming, USA**
Year	2010
Flare	1 x 2,549 m^3/hour enclosed flare
Project Summary	On July 13, 2012, Solvay Chemicals formally commissioned its complete mine methane recovery, flaring and utilization system at their Green River trona mine in Wyoming. The Methane Recovery System (MaRS) captures methane liberated during the mining process that would otherwise be vented directly into the atmosphere. The captured methane is directed either to be incinerated in an enclosed flare stack or piped, via a 4 mile long 14" pipeline, to the trona processing facility to recover the thermal energy via combustion. The MaRS system is the first in the U.S. to incinerate mine methane above an active longwall. Since its initial testing last year, the project has already removed more than 150,000 metric tons of CO2 equivalent (CO2e) from the atmosphere.
Location	**Sukhodolskaya-Vostochnaya Mine, Luhansk, Ukraine**
Year	2010
Flare	HOFGAS®–CFM4c 25000 (25 MW)
Project Summary	The first commercial successful coal mine methane gas to energy project in the Ukraine. A coal mine methane utilization, flaring and JI project at the Metinvest owned, Krasnodon Coal Company – Sukhodilska-Vostochnaya mine in the Luhansk region of Eastern Ukraine. The flaring project, developed and operated by Green Gas since 2010, has generated 184,850 carbon credits under the Joint Implementation framework, with electricity generation expected to start in 2013.

Mine Methane Flaring Projects	
Location	**Esmeralda Mine and Mine VII, Coahuila, Mexico**
Year	2012
Flare	Biogas Technology Ltd., 2 x 2,000 Nm3/hour
Project Summary	Minera del Norte S.A. de C.V. (MINOSA), a leading coal company in Mexico and a subsidiary of Grupo Acerero del Norte (GAN), began operating the first CMM flares at active coal mines in Mexico in October 2012. The MINOSA flaring project destroys mine methane from gas drainage systems at two of its mines in northern Mexico, Mine VII (Sabinas Basin) and the Esmeralda Mine (Saltillo Basin). The projects are sited at fixed locations and are enclosed flares where the flame is contained within the stack and is not visible. The projects include 9 meter stacks and have a total throughput capacity of 4,000 Nm3/hour (2 x 2,000 Nm3/hour).
Location	**Blakefield South Mine, Bulga Mining Complex, NSW, Australia**
Year	2010
Flare	3 enclosed HOFGAS®- CFM4c 32000/3350 flares
Project Summary	The Bulga Underground Operations actively manage methane drainage through the implementation of a coal seam gas drainage project in the Blakefield South mining activities. The project pre-drains and post-drains the coal seams to provide a safer work environment. The drained methane is flared to lower greenhouse gas emissions resulting from the project. The gas drawn from surface to inseam pre-mining wells is nearly pure methane, with an average gas content between 96% and 99% CH4. At present, this methane is piped to the flaring facility for combustion. The expansion of the flaring facilities completed during 2009 allows the entire draw from the pre-mining gas wells to be combusted and emitted as carbon dioxide. Gas is also captured from goaf/gob wells and piped to the flaring system. Plans are underway to install 9MW of CMM powered electricity generation with the flares destroying any excess.