Methane Capture: Options for Greenhouse Gas Emission Reduction

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Summary

Research on climate change has identified a wide array of sources that emit greenhouse gases (GHGs). Among the six gases that have generally been the primary focus of concern, methane is the second-most abundant, accounting for approximately 8% of total U.S. GHG emissions in 2008. Methane is emitted from a number of sources. The most significant are agriculture (both animal digestive systems and manure management); landfills; oil and gas production, refining, and distribution; and coal mining.

As policymakers consider options to reduce GHG emissions, methane capture projects offer an array of possible reduction opportunities, many of which utilize proven technologies. Methane capture projects (e.g., landfill gas projects, anaerobic digestion systems) restrict the release of methane into the atmosphere. The methane captured can be used for energy or flared. Methane capture challenges differ depending on the source. Most methane capture technologies face obstacles to implementation, including marginal economics in many cases, restricted pipeline access, and various legal issues.

Some of the leading methane capture options under discussion include market-based emission control programs, carbon offsets, emission performance standards, and maintaining existing programs and incentives. At present, methane capture technologies are supported by tax incentives in some cases, by research and demonstration programs in others, by regulation in the case of the largest landfills, and by voluntary programs. Congress could decide to address methane capture in a number of different ways, including (1) determining the role of methane capture in energy and environmental legislation; (2) determining whether methane capture should be addressed on an industry-by-industry basis; and (3) determining if current methane capture initiatives will be further advanced with legislative action regardless of other facets of the environmental policy debate. What role methane capture would play in prospective regulations to control GHGs is among the issues that Congress faces.

A few government programs have supported the capture of methane to mitigate climate change. The Methane-to-Markets Partnership, administered by the Environmental Protection Agency (EPA), is an international initiative to reduce global methane emissions. EPA also oversees a variety of voluntary programs related to the Methane-to-Markets initiative (e.g., Coalbed Methane Outreach Program, Natural Gas STAR Program, Landfill Methane Outreach Program, AgSTAR Program).

This report discusses alternatives for addressing methane capture, sources of methane, opportunities and challenges for methane capture, and current federal programs that support methane recovery.

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Introduction

In the climate change policy debate, methane capture projects have garnered attention for their ability to mitigate greenhouse gas emissions. Methane capture projects prevent the release of methane, a potent greenhouse gas (GHG), into the atmosphere. The captured methane is generally flared or used for energy purposes.[1] The U.S. Environmental Protection Agency (EPA) has identified four sources of methane with the greatest potential for capture in the near term: landfills, coal mines, agriculture, and oil and gas systems. The amount of methane captured from each will depend on legislative developments, regulations, economics, technology, and outreach.

Methane (CH_4) constituted approximately 8% of U.S. GHG emissions in 2008.[2] Anthropogenic (human-related) sources of methane in the United States include enteric fermentation,[3] landfills, natural gas systems, coal mines, and manure management. Efforts to reduce emissions of methane—the second-most important GHG after carbon dioxide (CO_2)—could play a significant role in climate change mitigation.

This report will discuss the policy options for addressing methane capture (and their implications), legislative proposals for methane capture, domestic and international sources of methane, opportunities and challenges for methane capture, and federal programs that support methane capture.

Policy Options for Addressing Methane Capture

If policymakers decide to address methane emissions, multiple strategies are available that would either encourage or require methane capture: market-based legislative approaches, such as a cap-and-trade program or emissions fees; carbon offsets or credits as a complementary design element of a market-based approach; emission performance standards; and/or maintaining existing programs and incentives.[4] Policymakers may consider using different strategies for different methane emission sources. These strategies and related issues are discussed below.

Market-Based Emission Control Programs

One option for policymakers is to include methane emission sources as covered entities in a market-based greenhouse gas (GHG) emission control program. Market-based mechanisms that limit GHG emissions can be divided into two types: those that focus on quantity control (e.g., a cap-and-trade program) and those that focus on price control (e.g., emissions fees, often called a

[1] Flaring is the combustion of the gas without commercial purposes. Flaring produces carbon dioxide, which is a less potent greenhouse gas than methane.

[2] U.S. Environmental Protection Agency, *2010 U.S. Greenhouse Gas Inventory Report*, EPA 430-R-10-006, April 2010, http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

[3] Enteric fermentation is the production and release of methane via eructation (burping) and flatulence as ruminant animals digest their feed.

[4] The climate-changing impact of multiple greenhouse gases is commonly measured and compared using their global warming potential as expressed in units of carbon dioxide equivalent. Therefore, many concepts and actions are preceded with the word carbon which may actually account for an assortment of greenhouse gases in both quantity and quality (e.g., carbon tax, carbon offset).

carbon tax). Although each approach has its own set of advantages and disadvantages,[5] both would place a price on methane emissions from covered sources. To the extent that they are able, covered entities (those subject to the cap or fee) would likely pass the emissions price through to consumers. For example, if solid waste landfills were subject to a cap or fee based on methane emissions, the landfill operators would likely raise the price of waste disposal to account for the new cost of emissions. Economic theory suggests that a higher waste disposal price would provide a market incentive for consumers to generate less waste, thus decreasing landfill methane emissions.

Cap-and-trade and carbon tax proposals[6] in the 111th Congress generally did not apply to methane emissions from the primary sources of such emissions. The main rationale for excluding some of these groups involved the administrative costs of covering them under an emissions program. As **Table 1** indicates, the number of methane emission sources is relatively large compared to their total contribution to U.S. GHG emissions. This is particularly the case for methane emissions from the agriculture sector.

Table 1. Selected Sources of U.S. Methane Emissions and Potential Number of Entities Subject to Emission Control Program

Methane Emission Source	Percentage of U.S. GHG Emissions (2008 data)	Potential Applications	
		Entity	**Number**
CH_4 from livestock (enteric fermentation)	2.0	Cattle operations[a]	967,440
CH_4 from landfills	1.8	Landfills[b]	1,831
CH_4 from natural gas systems	1.4	Natural gas processors	530
CH_4 from coal mines	0.9	Active coal mines[c]	1,374
CH_4 from manure management	0.6	Cattle operations; Swine operations[d]	967,440 65,640

Source: CRS analysis of data from USDA and EPA.

a. U.S. Department of Agriculture, *Farms, Land in Farms, and Livestock Operations: 2007 Summary* (2008).

b. U.S. Environmental Protection Agency, *2010 U.S. Greenhouse Gas Inventory Report*, EPA 430-R-10-006, April 2010, http://www.epa.gov/climatechange/emissions/usinventoryreport.html, citing *16th Annual BioCycle Nationwide Survey: The State of Garbage in America* (2008).

c. Methane from underground mines, which accounts for about 61% of coal mine methane, is removed through ventilation systems for safety reasons. These emissions would be easier to monitor under an emission control program than aboveground coal mine methane emissions. Number of active coal mines from Energy Information Administration (EIA), "Coal Production and Number of Mines by State and Mine Type," at http://www.eia.gov.

d. U.S. Department of Agriculture, *Farms, Land in Farms, and Livestock Operations: 2007 Summary* (2008). Other animals—chickens, horses, and sheep—contribute approximately 10% of the total emissions from manure (EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006* (April 2008), table 6-6).

[5] See CRS Report R40242, *Carbon Tax and Greenhouse Gas Control: Options and Considerations for Congress*, by Jonathan L. Ramseur and Larry Parker.

[6] See CRS Report R40556, *Market-Based Greenhouse Gas Control: Selected Proposals in the 111th Congress*, by Larry Parker, Brent D. Yacobucci, and Jonathan L. Ramseur.

Although an even larger number of sources (e.g., industries, automobiles, buildings) generate CO_2 emissions, the vast majority of CO_2 emissions can be addressed by subjecting a relatively small number of entities to an emissions cap. This opportunity exists for CO_2 emissions, because policymakers could apply the emissions cap *upstream* of the actual emissions, typically where the emission inputs are produced or enter the U.S. economy.[7] Under this approach, policymakers could address CO_2 emissions from fossil fuel combustion and non-energy uses—in aggregate 82% of U.S. GHG emissions—by covering fewer than 2,500 entities.[8] For most methane sources, particularly in the agriculture sector, an analogous opportunity does not exist.

In addition, some of the source categories identified in **Table 1** may be more amenable to emissions coverage than others. For example, roughly 25% of the methane emissions from natural gas systems comes from field production,[9] which may be impractical to monitor and measure accurately.[10] The remaining 75% primarily involves accidental releases sometimes referred to as fugitive emissions.[11] Landfill methane may offer fewer challenges in terms of measurement, but the largest landfills are already reducing methane emissions pursuant to landfill gas reduction requirements established by the Clean Air Act (42 U.S.C. 7401 *et seq*.).[12]

Carbon Offsets

Within the framework of a cap-and-trade or carbon tax system, policymakers could encourage methane mitigation activities by allowing methane capture as an eligible offset project or as an emission (or tax) credit. A carbon offset is a measurable reduction, avoidance, or sequestration of GHG emissions from an emission source not covered by a cap-and-trade system. Most of the cap-and-trade proposals offered in the 111th Congress allowed offsets (under varying conditions) as a compliance alternative.[13]

Offsets would likely make an emissions program more cost-effective by (1) providing an incentive for non-regulated sources to generate emission reductions and (2) expanding emission compliance opportunities for regulated entities. The main concern with offset projects is whether or not they represent real emission reductions. For offsets to be real, a ton of CO_2-equivalent

[7] An upstream approach would apply the cap to fossil fuels when they enter the U.S. economy, either at the mine, wellhead, or another practical "chokepoint" in the production chain. Imported fuels would be addressed at their point of entry into the United States.

[8] For more on these issues, see CRS Report R40242, *Carbon Tax and Greenhouse Gas Control: Options and Considerations for Congress*, by Jonathan L. Ramseur and Larry Parker.

[9] As described by EPA, "wells are used to withdraw raw gas from underground formations. Emissions arise from the wells themselves, gathering pipelines, and well-site gas treatment facilities such as dehydrators and separators. Fugitive emissions and emissions from pneumatic devices account for the majority of CH_4 emissions. Flaring emissions account for the majority of the non-combustion CO2 emissions." EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006* (April 2008).

[10] See, for example, Gilbert Metcalf and David Weisbach, *The Design of a Carbon Tax* (June 2008), Tufts University and the University of Chicago.

[11] U.S. Environmental Protection Agency, *2010 U.S. Greenhouse Gas Inventory Report*, EPA 430-R-10-006, April 2010, http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

[12] Landfill gas New Source Performance Standards (NSPS) went into effect in 1996. See U.S. Environmental Protection Agency, "Standards of Performance for New Stationary Sources and Guidelines for Control of Existing Sources: Municipal Solid Waste Landfills," 61 *Federal Register* 9914, March 12, 1996.

[13] For more information pertaining to carbon offsets, see CRS Report RL34436, *The Role of Offsets in a Greenhouse Gas Emissions Cap-and-Trade Program: Potential Benefits and Concerns*, by Jonathan L. Ramseur.

emissions reduced from an offset project should equate to a ton emitted from a capped source, such as a smokestack or exhaust pipe, and would not have occurred without the regulatory incentive. This objective presents challenges because some offset projects are difficult to measure.

However, some methane capture projects, such as those from landfills or coal mines, are generally considered to be of higher quality (more credible) than other offset types. These projects are relatively easy to measure and verify, and in many cases would likely not occur if not for the financing provided by an offset market. Therefore, the challenge of proving "additionality" is easier to overcome.[14]

The advantage some methane capture projects have over other GHG mitigation activities may spur policymakers to control these methane releases directly (via some of the options discussed), instead of encouraging abatement through an offset market. Moreover, allowing certain activities as offsets, while imposing emission controls or caps on others, may raise issues of fairness. For example, why should specific GHG emission sources, such as electricity generators, be capped while other sources, such as landfill or animal feedlot methane, have the potential to generate financial gain for owners and/or operators through the offset market?

Emission Performance Standards

Another option for policymakers is to require emission performance standards for particular methane emission sources. This approach has historically represented the core of U.S. federal air pollution policy. New legislation would not be required to pursue the standards approach. The ability to limit methane emissions already exists under various Clean Air Act authorities that Congress has enacted, a point underlined by the Supreme Court in an April 2007 decision, *Massachusetts v. EPA*. Although the current EPA Administrator has stated a preference for controlling GHG emissions through new legislation, the agency has begun to take actions that could lead to GHG emission performance standards from particular sources.[15]

Pursuant to Clean Air Act authority, EPA would achieve emission reductions by setting emission performance standards on each source of pollution, or requiring that sources use a particular type of technology, such as the "best available control technology." Although emission performance standards have proven to be effective through decades of experience, source-by-source regulation often cannot achieve, by itself, a desired emission reduction target at the least collective cost. Moreover, performance standards can be difficult to adjust as circumstances (e.g., technologies) change. On the other hand, they may be less expensive where measurement, administrative, or transaction costs are high relative to emission control costs. This approach may be a practical option for certain specific sources of methane emissions.

[14] Additionality refers to whether the offset project represents an activity that is beyond what would have occurred under a business-as-usual scenario. In other words, would the emission reductions or sequestration have happened anyway? Additionality is generally considered to be the most significant factor that determines the integrity of the offset.

[15] For more information on these developments, see CRS Report R40585, *Climate Change: Potential Regulation of Stationary Greenhouse Gas Sources Under the Clean Air Act*, by Larry Parker and James E. McCarthy; Environmental Protection Agency, "EPA Finds Greenhouse Gases Pose Threat to Public Health, Welfare / Proposed Finding Comes in Response to 2007 Supreme Court Ruling ," press release, April 17, 2009, http://yosemite.epa.gov/opa/admpress.nsf/0/0EF7DF675805295D8525759B00566924.

Maintain Existing Programs/Incentives

As discussed later in this report, the federal government currently supports several programs that stimulate methane capture. In addition to these initiatives, which are generally voluntary in nature, since 1996 the Clean Air Act has imposed air emission standards on large solid waste landfills. However, as discussed below, the vast majority of landfills are not covered under the 1996 standards, and there is room to increase the amount of methane captured from solid waste landfills. Moreover, the primary objective of these standards is to reduce the hazardous air pollutants and non-methane organic compounds contained in landfill gas, not to reduce methane emissions for climate-related reasons. Regardless, as mentioned above, the existing Clean Air Act authorities could be used to address a wider universe of methane sources, for the express purpose of controlling GHG emissions, or, as in the case of landfills, for multiple purposes.

Because methane can be used as an energy source, the existing marketplace provides some incentive to capture methane for this purpose. If a GHG emission control program were implemented, such a program would increase this incentive by raising the price of traditional high-carbon energy sources (e.g., coal) relative to captured methane. The strength of the incentive would depend on the stringency of the emission control program.

Legislative Proposals Concerning Methane Capture

The 111th Congress introduced numerous bills related to methane emissions. One group of bills specified methane as a GHG, promoted biogas production, supported landfill gas recovery projects, and addressed or promoted methane capture.[16] Another set of bills not related to methane capture prohibited permit issuance under the Clean Air Act for methane emissions from biological processes associated with livestock operations, among other provisions, and expanded methane hydrate research.[17]

H.R. 2454, which passed the House on June 26, 2009,[18] contained numerous energy provisions, including a GHG emission cap-and-trade system. If enacted, the cap-and-trade program would have allowed some methane capture activities to generate offsets. However, some methane sources might have been subject to emission performance standards. One enacted piece of legislation (P.L. 111-5, the American Recovery and Reinvestment Act of 2009) extended and expanded existing incentives for open-loop biomass and landfill gas electricity production and created a new incentive for the same activities.

Methane: A Primer

Methane—a colorless, odorless gas with the molecular formula CH_4—is produced by "methanogenic" bacteria that decompose organic matter in the absence of oxygen. Sometimes referred to as "marsh gas," methane is flammable, can cause suffocation, and can be explosive in

[16] Biogas consists of 60%-70% methane, 30%-40% carbon dioxide, and trace amounts of other gases.

[17] Methane hydrates—a mixture of water and natural gas—are a potentially huge global energy resource.

[18] See CRS Report R40643, *Greenhouse Gas Legislation: Summary and Analysis of H.R. 2454 as Passed by the House of Representatives* , coordinated by Mark Holt and Gene Whitney.

low concentrations in air. It is the primary component (70%-90%) of natural gas fuel. Roughly 27% of total U.S. energy consumed in 2009 was natural gas.[19] Consumption is spread across a wide array of economic sectors, with electric power generation and industrial consumption accounting for roughly 62% of total volume delivered to consumers; residential use, 23%; and commercial use, 15%, in 2009.[20]

Global Warming Potential

Global warming potential (GWP) is an estimate of how much a GHG affects climate change over a quantity of time relative to CO_2, which has a GWP value of 1. Methane is a potent GHG with a global warming potential of 21.[21] Over a 100-year timeframe, methane is 21 times more effective than CO_2 at trapping heat in the atmosphere. In other words, it takes 21 tons of CO_2 to equal the effect of 1 ton of CH_4. Methane has a relatively short atmospheric lifetime (approximately 12 years) when compared to the atmospheric lifetime of carbon dioxide; thus efforts to capture methane from anthropogenic sources provide more near-term climate change abatement than capturing or reducing comparable amounts of CO_2, but less multi-decadal abatement.

Once methane or other GHGs are converted, using GWP or other methods, they can be expressed in a common unit of measurement: carbon dioxide-equivalent (CO_2-eq. or CO_2e). CO_2e both takes into account the potency of each gas and expresses the quantity of the gas. Carbon dioxide-equivalent has been adopted as a principal unit of measurement to aggregate or make comparisons across GHGs. CO_2e expresses the tons of a greenhouse gas in the equivalent effect of tons of CO_2 on climate change (more specifically, on "radiative forcing").[22] Once all gases are converted to CO_2e, they can be compared or added together.

Sources of Methane

Domestic

The top three anthropogenic sources of the roughly 567 million metric tons CO_2e of methane emitted in 2008 were enteric fermentation, landfills, and natural gas systems.[23] These three sources combined were responsible for about 64% of total U.S. methane emissions (see **Figure 1**). There are also natural sources of methane emissions, such as wetlands and releases of natural

[19] BP, *BP Statistical Review of World Energy*, June 2010.

[20] For more information on market conditions for natural gas, see CRS Report R40487, *Natural Gas Markets: An Overview of 2008*, by Robert Pirog; and the Energy Information Administration, *Natural Gas Consumption by End Use*, December 2010 http://www.eia.doe.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm ,

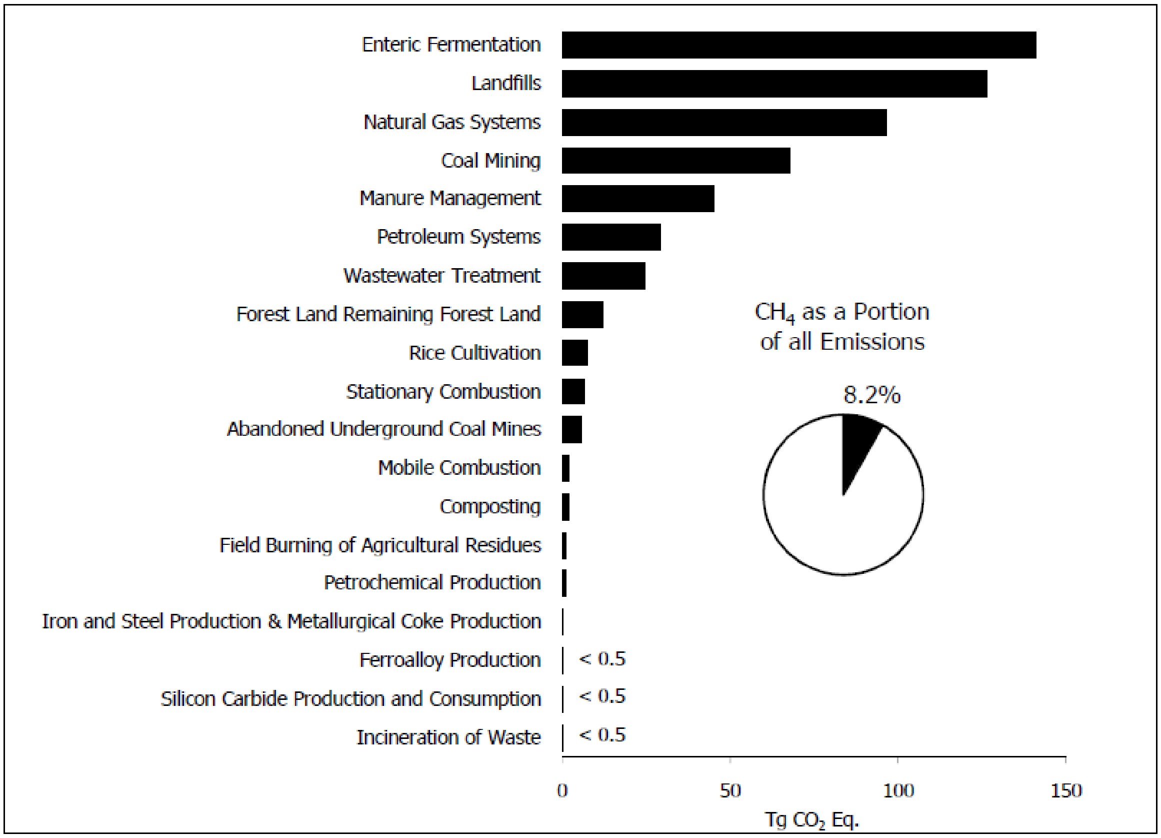
[21] The Intergovernmental Panel on Climate Change (IPCC) assigns methane a carbon dioxide equivalent, or global warming potential, of 21. Intergovernmental Panel on Climate Change, Climate Change 2007: The Physical Science Basis (2007), p. 212.

[22] "Radiative forcing" is defined as the change in the difference between incoming and outgoing radiation at the top of the troposphere. CO_2e is not exactly equivalent to radiative forcing, but it is similar and easier to understand for policy purposes than the main alternative, watts per square meter (W/m^2).

[23] 1 teragram = 1 million metric tons. A Tg CO_2e (teragram of carbon dioxide equivalent) is a principal unit of measurement across greenhouse gases. See footnote 3 for the definition of enteric fermentation. U.S. Environmental Protection Agency, *2010 U.S. Greenhouse Gas Inventory Report*, EPA 430-R-10-006, April 2010, http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

gas from geologic formations. Natural sources of methane are generally assumed to account for 30% of an annual methane emissions inventory that includes natural and anthropogenic sources.[24]

Figure 1. 2008 U.S. Sources of Anthropogenic Methane Emissions



Source: U.S. Environmental Protection Agency, *2010 U.S. Greenhouse Gas Inventory Report*, EPA 430-R-10-006, April 2010, http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

Note: The "forest land remaining forest land" category contains forest land that stays forest land based on IPCC guidance for defining inventory categories. Methane emissions from the category "forest land remaining forest land" are attributed to wildfires and prescribed fires on managed forest land.

International

Methane accounted for nearly 17% of global greenhouse gas emissions in 2005.[25] Asia is reported as having emitted the most methane on a regional basis. China, India, the United States, the European Union, and Brazil are the top five methane-emitting countries (see **Table 2**). The agriculture sector is the leading source of methane emissions for the world (see **Appendix**).[26]

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[24] Kathleen Hogan, *Current and Future Methane Emissions from Natural Sources*, United States Environmental Protection Agency, EPA 430-R-93-011, Washington , DC, August 1993.

[25] World Resources Institute, *Climate Analysis Indicators Tool (CAIT) Version 6.0.*, Washington, DC, 2009. Data quality for the global methane emission estimates reported varies due to uncertainty and possible inconsistency depending on reporting agencies adherence to data collection and interpretation for standardized definitions and measurements for each sector and territory.

[26] The World Resources Institute includes methane emissions from the following activities for the agriculture sector: (continued...)

One analysis of global average atmospheric concentrations for methane indicates that, while growth leveled off for approximately a 15-year period beginning in the early 1990s, methane concentrations may have begun to increase again in 2007, possibly due to warmer temperatures in the Arctic and increased precipitation in the tropics.[27] Global methane emissions from natural sources are estimated at approximately 208 million metric tons of methane per year.[28]

Table 2. Top Five Methane-Emitting Countries in 2005

Country	Million MT (Tg) CO_2e	% of World Total
China	853	13
India	548	9
United States	521	8
European Union	449	7
Brazil	389	6

Source: Climate Analysis Indicators Tool (CAIT) Version 6.0 (Washington, DC: World Resources Institute, 2009).

Notes: Excludes land use change.

Methane Use and Storage

Methane may be captured in its pure form or as a component of biogas, depending on the source.[29] The methane captured can be "flared" (combusted without commercial purpose) or used to generate heat or electricity. Flaring the gas destroys the methane and yields carbon dioxide (CO_2) and water.[30] The release of carbon dioxide as a result of flaring is less risky in terms of climate forcing than releasing the methane or biogas as is into the atmosphere.

Captured methane is stored chiefly underground as a constituent of natural gas. Underground storage options include depleted gas or oil fields, aquifers, or salt cavern formations (see **Figure 2**). A less common option is the storage of natural gas in liquid form. Liquefied natural gas (LNG) is roughly one six-hundredth the volume of gaseous natural gas, allowing for transport by ship to areas that are inaccessible via a natural gas pipeline.[31]

(...continued)

enteric fermentation from livestock, livestock manure management, rice cultivation, and other agricultural sources. The sole exception, according to CAIT data compiled for 2005, is the United States, where the greatest sources of methane—the fugitive emission sector and the waste sector (e.g., landfills, wastewater treatment)—surpass the agriculture sector slightly. However, 2007 data from EPA shown in **Figure 1** depicts the agriculture sector as the largest U.S. methane emission source. The World Resources Institute includes methane emissions from the following activities for the fugitive emission sector: oil and natural gas systems, and coal mining.

[27] For more information, see CRS Report RL34266, *Climate Change: Science Highlights*, by Jane A. Leggett, and E.J. Dlugokencky, L. Bruhwiler, and J.W.C. White, et al., "Observational Constraints on Recent Increases in the Atmospheric CH_4 Burden," *Geophysical Research Letters*, August 18, 2009.

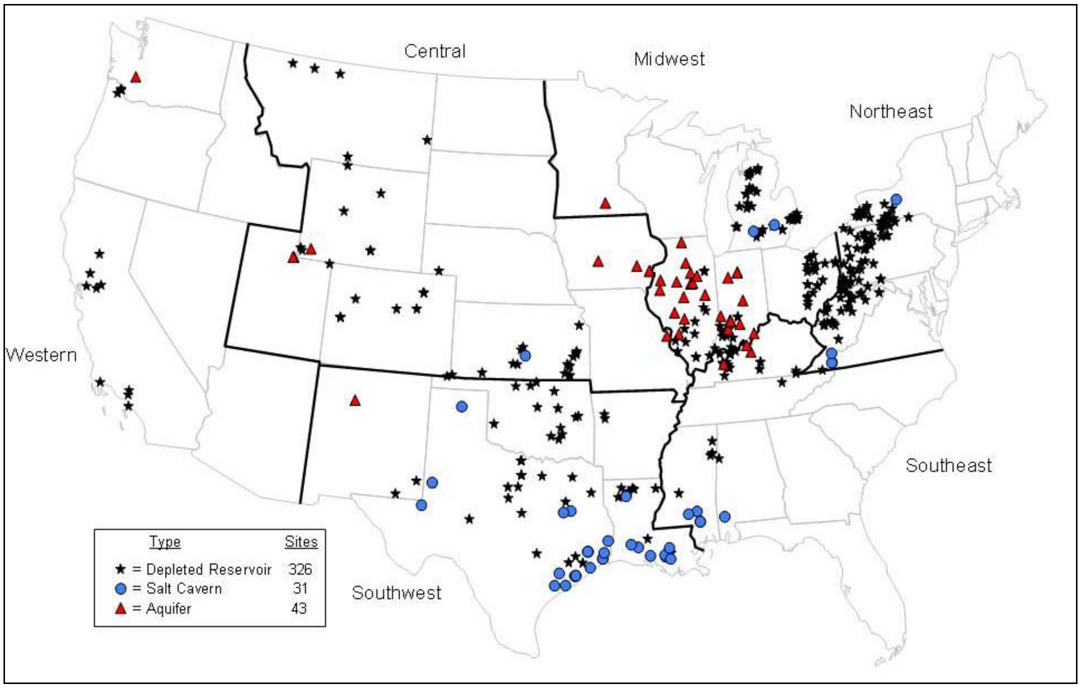
[28] Environmental Protection Agency, *Methane and Nitrous Oxide Emissions from Natural Sources*, EPA-430-R-10-001, Washington, DC, April 2010, http://epa.gov/methane/pdfs/Methane-and-Nitrous-Oxide-Emissions-From-Natural-Sources.pdf.

[29] Biogas consists of 60%-70% methane, 30%-40% carbon dioxide, and trace amounts of other gases.

[30] Stoichiometric equation for biogas combustion: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$.

[31] Energy Information Administration, Department of Energy, *The Global Liquefied Natural Gas Market: Status &* (continued...)

Figure 2. U.S. Underground Natural Gas Storage Facilities, Close of 2007



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System, December 2008.

Notes: There are no natural gas storage facilities in Alaska or Hawaii.

Opportunities and Challenges for Methane Capture

Capturing methane from various sectors of the U.S. economy requires different strategies because some strategies may be more economically feasible for specific emission sources or locations. Policy laid out in forthcoming energy and environmental proposals may further provide technical and economic incentives to overcome barriers—past and present—to methane capture. The following section summarizes opportunities and challenges for methane capture from the top four sources of methane: agriculture, landfills, oil and natural gas systems, and coalbed methane (see **Table 3**).

Table 3. U.S. Methane Emissions by Source

(million metric tons CO_2e)

Source	2000	2006	2007	2008
Agriculture—Enteric Fermentation	136.8	139.0	141.2	140.8
Landfills	120.7	127.1	126.5	126.3
Natural Gas Systems	130.7	103.1	99.5	96.4

(...continued)

Outlook, DOE/EIA-0637, December 2003.

Source	2000	2006	2007	2008
Coal Mining	60.4	58.3	58.1	67.6
Agriculture—Manure Management	38.6	42.3	45.9	45.0

Source: U.S. Environmental Protection Agency, *2010 U.S. Greenhouse Gas Inventory Report*, EPA 430-R-10-006, April 2010, http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

Agriculture

Methane emissions from the U.S. agriculture sector are mostly attributable to enteric fermentation and manure management, the largest and fifth-largest sources of methane emissions in 2008, respectively.[32] Ruminant animals (e.g., cattle, sheep) are the major emitters of methane via enteric fermentation, a non-point source of methane emissions. The amount of methane emitted from enteric fermentation depends on the feed quality and amount of feed ingested by the animal. Options to reduce methane emissions from enteric fermentation include improved animal productivity and feed management.[33]

Some manure management systems (e.g., storage of liquid or slurry manure in a waste storage structure) are a point-source of methane emissions. Methane released from the anaerobic decomposition of manure depends mainly on the storage temperature, storage time, and manure composition. Methane emissions from some manure management systems may be captured with an anaerobic digestion system (AD system) that flares the gas or uses it for energy purposes.[34] Barriers to methane capture from manure management include limited technology and information exchange between agricultural producers and the technology transfer community, high up-front capital costs for AD systems, unsatisfactory technology reliability, and low rates paid by some utilities for the electricity generated.

Landfill Gas

Landfills were the second-largest U.S. source of methane emissions in 2008.[35] Landfill gas—a mixture of roughly 50% methane and 50% carbon dioxide, but including small amounts of other gases—is released into the atmosphere if not captured. The amount of gas produced at any given landfill depends on the amount of organic material in the waste, the landfill's design, the climate at the site of the landfill, and the operating practices used by the site's operator. In general, large amounts of organic waste and high levels of moisture in a landfill lead to greater gas production.

[32] In other parts of the world methane emissions from rice cultivation are a major concern because rice is grown on flooded fields that produce anaerobic conditions to release methane. U.S. methane emissions from rice cultivation are minimal because the United States is not a major producer of rice.

[33] L. E. Chase, "Methane Emissions from Dairy Cattle," Mitigating Air Emissions from Animal Feeding Operations Conference, IA, May 2008, http://www.ag.iastate.edu/wastemgmt/Mitigation_Conference_proceedings/CD_proceedings/Animal_Housing_Diet/Chase-Methane_Emissions.pdf.

[34] For more information on anaerobic digestion systems, see CRS Report R40667, *Anaerobic Digestion: Greenhouse Gas Emission Reduction and Energy Generation*, by Kelsi Bracmort.

[35] U.S. Environmental Protection Agency, *2010 U.S. Greenhouse Gas Inventory Report*, EPA 430-R-10-006, April 2010, http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

Landfill gas is captured at the nation's largest landfills.[36] A 1996 Clean Air Act regulation known as the "Landfill Gas Rule" established New Source Performance Standards and Guidelines that require landfills with a 2.5 million metric ton design capacity that accepted waste after November 8, 1987, to capture and burn the gas. The gas can either be flared or used for energy production—often it is used as fuel for electricity generation. As mentioned above, flaring is less damaging to the atmosphere than release of the methane.

In promulgating the 1996 rule, EPA said that the 2.5 million metric ton minimum "corresponds to cities greater than 100,000 people." The agency also stated that the regulations "will only affect less than 5 percent of all landfills" but would reduce emissions of methane by 37% at new landfills, and by 39% at existing facilities.

In fact, partly as a result of tax incentives and voluntary programs, there are 541 operational projects at landfills as of January 2011.[37] This represents roughly 30% of the 1,812 municipal solid waste landfills reported in operation in 2008.[38]

Whatever success existing regulations, tax incentives, and voluntary programs may be having, a significant amount of methane continues to be emitted even at landfills subject to the Landfill Gas Rule. In addition, there are few methane capture projects at smaller landfills and at landfills that ceased operation before November 1987 (those not covered under the Clean Air Act). The latter group, numbering in the tens of thousands of sites, poses a particular challenge. Often, there is no responsible party who might implement a methane collection system if the site's original owner is no longer in business. At other sites (e.g., sites owned by local governments), there may be no continuing stream of revenue to support installation and operation of the necessary equipment, since the landfill has closed. Further barriers to additional landfill gas capture may include high capital costs for equipment, low rates paid for the gas captured and/or electricity generated, permitting requirements, and liability concerns.[39]

Oil and Natural Gas

Natural gas systems were the third-largest U.S. source of methane emissions in 2008. Methane can be released from natural gas systems during normal operations, maintenance, and unexpected system disorder. An array of technologies and suggested strategies to reduce methane emissions from various stages of natural gas system production is available.[40]

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[36] A common landfill gas capture system consist of an arrangement of vertical wells and horizontal collectors usually installed after a landfill cell has been capped. Without a gas collection system, the landfill gas would escape into the atmosphere.

[37] Environmental Protection Agency, *Landfill Methane Outreach Program* , Energy Projects and Candidate Landfills, http://www.epa.gov/lmop/projects-candidates/index.html.

[38] Environmental Protection Agency, *Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2008,* November 2009, http://www.epa.gov/osw/nonhaz/municipal/pubs/msw2008data.pdf.

[39] Lenders may hesitate to provide funding for landfill gas capture projects due to unease about possibly having to remediate a landfill under CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act; 42 USC 9607).

[40] Environmental Protection Agency, *Natural Gas STAR Program: Cost-Effective Opportunities to Recover Methane,* http://www.epa.gov/gasstar/basic-information/index.html#sources.

Additionally, methane is emitted during oil production, transportation, and refining. Options to reduce methane emissions from the oil sector include flaring, direct use, and reinjection of methane into oil fields. Offshore oil operations (oil platforms) tend to use captured methane directly because flaring is economically unattractive. Onshore oil operations usually inject the captured methane into a pipeline. Captured methane can also be injected into an oil production field to enhance future oil recovery. One analysis estimated the reduction efficiency (which is the percentage reduction achieved with adoption of a mitigation option) for flaring, direct use, and reinjection of methane to be 98%, 90%, and 95%, respectively.[41] The equipment used for abatement has a technical lifetime of 15 years.[42] Barriers to methane capture from oil and natural gas systems include federal and state economic regulations, financial constraints, abatement technology cost, and abatement technology availability.

Coalbed Methane

The coal mining sector was the fourth-largest source of U.S. methane emissions in 2008.[43] Most methane emissions from coal mining occur during the mining process in underground mining operations. The amount of methane released depends chiefly on the coal mine type (e.g., underground mine, surface mine, abandoned mine) and the mining operation type. Two techniques are available to capture methane emissions from coal mines: degasification (including enhanced degasification) and ventilation air methane systems.

A degasification system facilitates the removal of methane gas from a mine by ventilation and/or by drainage. Methane is captured through a series of vertical wells, horizontal boreholes, or gob wells drilled into the mine before or after mining operations.[44] A sizeable portion of the methane captured from degasification systems can be injected into a pipeline directly for energy purposes. Enhanced degasification uses the same approach as degasification systems, but has the capacity to extract lower-quality methane that must be cleaned and upgraded to meet "pipeline quality" gas criteria. Ventilation air methane (VAM) systems flush air into underground mines to keep methane concentration levels at or below 1%. VAM systems are necessary to provide safe working environments for miners because methane can be explosive in low concentrations in air. Methane captured from degasification systems has a higher methane concentration (30%-90%) than methane captured from ventilation air systems.

Methane captured from coal mines using the methods described above can be used to generate electricity on-site or for sale to utility companies. Of the estimated 9,294 coal mines (active underground, active surface, and abandoned underground) in the United States, about 580 are currently active underground coal mines, of which 50 have methane capture projects.[45] Barriers to methane capture from coal mines include legal issues, economic circumstances (e.g., high capital costs for equipment, low electricity prices), restricted pipeline capacity for transporting coalbed

[41] Environmental Protection Agency, *Global Mitigation of Non-CO_2 Greenhouse Gases*, EPA 430-R-06-005, June 2006.

[42] Technical lifetime is the length of time the equipment is expected to perform as intended.

[43] U.S. Environmental Protection Agency, *2010 U.S. Greenhouse Gas Inventory Report*, EPA 430-R-10-006, April 2010, http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

[44] A gob well allows for the extraction of methane from the gob area of a mine.

[45] Environmental Protection Agency, *Methane to Markets Partnership Country Specific Strategy for the United States*, October 2008, http://www.methanetomarkets.org/resources/coalmines/docs/coal_stratplan_us.pdf. Most of these coal mines have been abandoned (8,000).

methane from the mines to natural gas markets, and difficulties with technology development. A primary barrier to methane recovery from coal mines is uncertainty regarding coalbed methane ownership, which exists in part because coalbed methane is located in the same stratum as the coal reserves, making a clear distinction for ownership difficult.[46] Older leases may not clearly specify whether the owner of the coal rights is also the owner of the coalbed methane. Ownership may lie with the owner(s) of the coal rights, owner(s) of the oil and gas rights, or surface owner(s). Ownership may also be an issue for federal lands in the West because developers of federally owned coalbed methane must apply for a gas lease to implement a coal mine methane project via competitive leasing procedures open to all.

Concerns Applicable to All Sources

Two impediments to methane capture cross-cut the top four anthropogenic sources of methane emissions: pipeline capacity, and the price offered by the electric power industry for electricity generated by captured methane. In addition to capacity, another issue is pipeline access for those wanting to purchase captured methane but not immediately adjacent to the methane capture source. In addition to price, other electricity industry issues of concern are competitiveness and the sale of excess power generated from captured methane.

Federal Support for Methane Capture

Periodic reports to Congress from the executive branch, as well as hearing testimony, have conveyed the significance of methane capture since the early 1990s.[47] Congress and the executive branch have supported methane capture projects through voluntary programs, energy management programs, and research and development programs. This section highlights existing efforts.

Methane-to-Markets Partnership

The Methane-to-Markets Partnership is an international initiative for methane capture and reuse from four sources: oil and gas, coal mines, landfills, and agriculture.[48] The partnership is administered by the U.S. Environmental Protection Agency (EPA), which supports the voluntary efforts of the 38 country partners. National governments, research institutions, and the private sector have collaborated since 2004 to develop cost-effective, near-term methane capture projects globally. The partnership receives its legal authority from the Clean Air Act, Section 103 (42 U.S.C. § 7403), and the National Environmental Policy Act (NEPA, 42 U.S.C. §§ 4321-4347).

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[46] Environmental Protection Agency, *Coalbed Methane Extra: Coal Mine Methane Ownership Issues*, EPA-430-N-00-004, 2007, http://www.epa.gov/cmop/docs/fall_2007.pdf.

[47] Environmental Protection Agency, *Options for Reducing Methane Emissions Internationally, Volume 1: Technological Options for Reducing Methane Emissions*, EPA 430-R-93-006, July 1993; Environmental Protection Agency, *Opportunities to Reduce Methane Emissions in the United States Report to Congress*, EPA 430-R-93-012, October 1993. Nineteen hearings pertaining to methane have been held since 1990 including U.S. Congress, Senate Committee on Environment and Public Works, hearing on S. 1772, *Gas Petroleum Refiner Improvement and Community Empowerment Act*, 109th Cong., 1st sess., October 18, 2005, S.Hrg. 109-1001; and U.S. Congress, House Committee on Science, *Energy Research, Development, Demonstration, and Commercial Application Act of 2006*, 109th Cong., 2nd sess., July 28, 2006, H.Rept. 109-611.

[48] For more information on the Methane-to-Markets Partnership, visit http://www.globalmethane.org.

Approximately $4.6 million was appropriated to the partnership for FY2010. Supplemental funding for the partnership is received from the U.S. Department of State. Other U.S. government partners—the Department of Energy, the Department of Agriculture, the Agency for International Development, and the Trade and Development Agency—have the discretion to provide funds to support the partnership. Financial support from government partners varies in amount and by fiscal year.

Voluntary Methane Programs

EPA facilitates a number of voluntary programs related to the Methane-to-Markets initiative that seek to reduce domestic methane emissions from different sectors. Many of these programs receive broad legislative authority from the Clean Air Act, Section 103 (42 U.S.C. § 7403). EPA provides some technical assistance and educational material. The AgSTAR Program supports biogas capture and use at livestock operations managing liquid and slurry manures.[49] The Coalbed Methane Outreach Program (CMOP) works with the coalbed methane industry to reduce coal mine methane emissions via methane capture and reuse.[50] The Natural Gas STAR Program specializes in promoting the reduction of methane emissions from the oil production and natural gas sector.[51] The Landfill Methane Outreach Program (LMOP) encourages landfill gas energy projects.[52] EPA's domestic methane programs avoided the release of more than 20.3 million metric tons of CO_2e into the atmosphere in 2008, out of the roughly 308 million metric tons of CO_2e of the methane emissions reported for the landfills, natural gas systems, petroleum systems, and coal mining categories.[53]

Federal Energy Management Program

The Department of Energy's (DOE's) Federal Energy Management Program (FEMP) addresses energy management at federal facilities and DOE, as well as fleet and transportation management.[54] One component of the program is converting landfill gas to energy for use at federal facilities. DOE has implemented three landfill gas recovery projects. FEMP receives its legislative authority from the Energy Independence and Security Act of 2007 (P.L. 110-140) and was appropriated $32 million for FY2010.

Tax Incentives

Several federal tax incentives subsidize methane capture from landfill and agriculture sources. These tax incentives are broadly broken down into three categories: (1) incentives to produce

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[49] For more information on the AgSTAR Program, see http://www.epa.gov/agstar.

[50] For more information on the Coalbed Methane Outreach Program, see http://www.epa.gov/cmop/index.html.

[51] For more information on the Natural Gas STAR Program, see http://www.epa.gov/gasstar/index.html.

[52] For more information on the Landfill Methane Outreach program, see http://www.epa.gov/lmop.

[53] AgSTAR Program reduced methane emissions—not available. However, the program has provided technical assistance for over 150 operational anaerobic digestion systems. Environmental Protection Agency, *ENERGY STAR and Other Climate Protection Partnerships 2008 Annual Report*, December 2009, http://www.epa.gov/appdstar/pdf/2008AnnualReportFinal.pdf; U.S. Environmental Protection Agency, *2010 U.S. Greenhouse Gas Inventory Report*, EPA 430-R-10-006, April 2010, http://www.epa.gov/climatechange/emissions/usinventoryreport.html..

[54] For more information on the Federal Energy Management Program, see http://www1.eere.energy.gov/femp.

electricity from captured methane gas; (2) incentives to build facilities that produce electricity from captured methane gas; and (3) incentives to produce alternative fuels using captured methane gas.

Two federal tax incentives subsidize the production of electricity from methane. The production tax credit is allowed for the production of electricity from qualified energy resources at qualified facilities, including open-loop biomass and municipal solid waste facilities.[55] In general, open-loop biomass and municipal solid waste facilities placed in service after August 8, 2005, and before December 31, 2013, may claim a tax credit equal to 1 cent per kilowatt-hour of electricity generated during the first 10 years of production.[56] In addition, a one-time investment tax credit equal to 30% of eligible investment costs is available, in lieu of the production tax credit, for open-loop biomass and municipal solid waste facilities placed in service after December 31, 2008.[57] In addition, the American Recovery and Reinvestment Act of 2009 (ARRA, P.L. 111-5) allowed a grant in lieu of tax credits for property placed in service in 2009 and 2010.

Three tax-preferred bond finance options exist to help finance methane capture facilities used to produce electricity. Qualified Energy Conservation Bonds (QECBs), Clean Renewable Energy Bonds (CREBs), and New Clean Renewable Energy Bonds (New CREBs) are a type of bond instrument, tax credit bonds, that offers the holder a federal tax credit instead of interest.[58] The rate of credit for CREBs is intended to be set such that the bonds need not be sold at a discount (for a price less than the face value) or with interest costs to the issuer, while the credit rate for QECBs and New CREBs is set for a credit rate of 70%. All three bond options are available to finance qualified energy production projects, including open-loop biomass facilities and landfill gas facilities. QECBs, CREBs, and New CREBs are all subject to national limits, $2.4 billion, $1.2 billion, and $2.4 billion, respectively. CREBs and New CREBs are allocated by the Secretary of the Treasury to eligible projects in inverse to their size, while QECBs are allocated to the states based upon their share of total U.S. population. Issuing authority for QECBs is without expiration, while CREB and New CREB authority expired at the end of 2009.

In addition, two tax incentives are available where methane gas is used to as a production input for alternative fuels. Facilities with binding construction contracts in place before December 31, 2010, and placed in service before January 1, 2014, are eligible to expense one-half of the cost of qualified property in the facilities first year of service.[59] The remaining 50% of the cost is depreciated under an accelerated five-year depreciation period. Further, compressed or liquefied gas and liquid fuel derived from biomass is eligible for the $1.00 per gallon alternative fuel tax credit for fuel produced through December 31, 2011.[60]

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[55] Internal Revenue Code (I.R.C.) Section 45. Municipal solid waste covers two types of power facilities: trash combustion facilities that burn trash directly to generate power, and landfill gas facilities that first produce methane, which is then burned to generate electricity. Anaerobic digestion systems are an example of an open-loop biomass system.

[56] The credit rate is adjusted each year for inflation. In addition, facilities placed in service prior to August 8, 2005, may claim the credit for the first five years of production. Further, the date in service break-point for certain open-loop biomass facilities is October 22, 2004.

[57] I.R.C. Section 48.

[58] Qualified Energy Conservation Bonds (QECBs), Clean Renewable Energy Bonds (CREBs) and New Clean Renewable Energy Bonds (New CREBs) are defined in I.R.C. Sections 54D, 54C and 54, respectively. See CRS Report R40523, *Tax Credit Bonds: Overview and Analysis*, by Steven Maguire, for more information on tax credit bonds.

[59] I.R.C. Section 179C.

[60] I.R.C. Section 45K.

DOE Methane Hydrate Research and Development

Methane is not captured from naturally occurring gas hydrates because it is bound in the gas and not released. However, recent attention has been directed toward the extraction of methane from gas hydrates as a potential source of energy.[61] The objective of the DOE methane hydrate research and development program is to develop knowledge and technology to allow commercial production of methane from gas hydrates by 2015. The DOE program completed a Gulf of Mexico offshore expedition in May 2009 aimed at validating techniques for locating and assessing commercially viable gas hydrate deposits.[62] The program is planning a two-year production test in Alaska that is expected to provide critical information about methane flow rates and sediment stability during gas hydrate dissociation. Both projects have international and industry partners. Methane hydrate research by DOE was initially authorized by the Methane Hydrate Research and Development Act of 2000 (P.L. 106-193). The Energy Policy Act of 2005 (P.L. 109-58, Subtitle F, § 968) extended the authorization through FY2010 and authorized total appropriations of $155 million over a five-year period. The Omnibus Appropriations Act, 2009 (P.L. 111-8), provided $20 million in FY2009 for natural gas technologies R&D, to include no less than $15 million for gas hydrates R&D. Congress appropriated $15 million for the gas hydrate R&D program in FY2009. The Obama Administration requested $25 million for the natural gas technologies program for FY2010, which includes gas hydrate R&D. Congress appropriated $17.8 million for the program in FY2010, which would also fund research and development into unconventional gas production from basins containing tight gas sands, shale gas, and coal bed methane, as well as for gas hydrates.

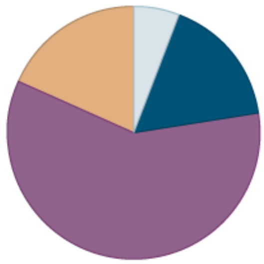
[61] Methane hydrates—a mixture of water and natural gas—are a potentially huge global energy resource. For more information on the DOE methane hydrate R&D program, see CRS Report RS22990, *Gas Hydrates: Resource and Hazard*, by Peter Folger; and http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/rd-program/rd-program.htm.

[62] On May 6, 2009, DOE announced it had completed a 21-day drilling expedition in the Gulf of Mexico in collaboration with the USGS and the Minerals Management Service. A preliminary announcement of the expedition results is available at http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/2009GOMJIP/GOMJIP_Leg2Announcement.html.

Appendix. World Methane Emissions by Sector in 2005

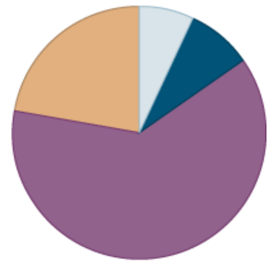
China

Sector	MtCO2e	%
Other Fuel Combustion	50.8	6.0
Fugitive Emissions	141.9	16.6
Industrial Processes	—	—
Agriculture	506.4	59.4
Waste	154.1	18.1
Total	**853.3**	



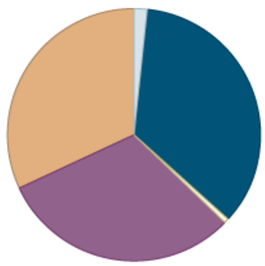
India

Sector	MtCO2e	%
Other Fuel Combustion	39.0	7.1
Fugitive Emissions	45.5	8.3
Industrial Processes	0.0	0.0
Agriculture	341.9	62.4
Waste	121.3	22.1
Total	**547.7**	



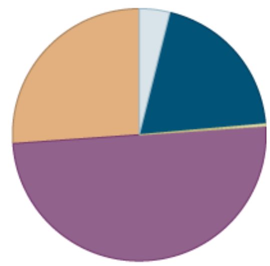
United States of America

Sector	MtCO2e	%
Other Fuel Combustion	9.2	1.8
Fugitive Emissions	182.9	35.1
Industrial Processes	2.6	0.5
Agriculture	160.5	30.8
Waste	165.8	31.8
Total	**521.0**	



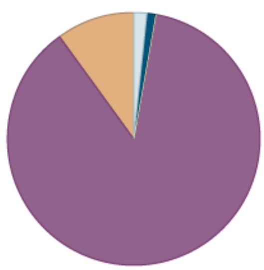
European Union (27)

Sector	MtCO2e	%
Other Fuel Combustion	17.9	4.0
Fugitive Emissions	88.2	19.7
Industrial Processes	1.3	0.3
Agriculture	224.9	50.2
Waste	116.2	25.9
Total	**448.5**	



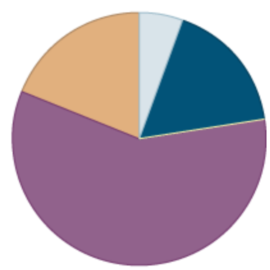
Brazil

Sector	MtCO2e	%
Other Fuel Combustion	6.8	1.8
Fugitive Emissions	4.9	1.3
Industrial Processes	0.1	0.0
Agriculture	338.7	87.1
Waste	38.5	9.9
Total	**389.1**	



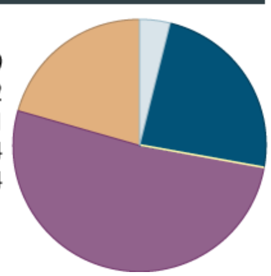
Asia

Sector	MtCO2e	%
Other Fuel Combustion	129.3	5.6
Fugitive Emissions	396.6	17.1
Industrial Processes	0.6	0.0
Agriculture	1,359.0	58.6
Waste	431.6	18.6
Total	**2,317.2**	



World

Sector	MtCO2e	%
Other Fuel Combustion	250.1	3.9
Fugitive Emissions	1,533.2	24.2
Industrial Processes	6.2	0.1
Agriculture	3,290.8	51.4
Waste	1,307.2	20.4
Total	**6,407.5**	



Source: Climate Analysis Indicators Tool (CAIT) Version 6.0 (Washington, DC: World Resources Institute, 2009).

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