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Methane emissions as energy reservoir: Context, scope, causes and mitigation strategies

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ABSTRACT

Methane (CH_4) is now considered a bridge fuel between present fossil (carbon) economy and desired renewables and this energy molecule is projected to play an important role in the global energy mix well beyond 2035. The atmospheric warming potential of CH_4 is 28–36 times, when averaged over a 100-year period, that of carbon dioxide (CO_2) and this necessitates a close scrutiny of global CH_4 emissions inventory. As the second most abundant greenhouse gas (GHG), the annual global CH_4 emissions were 645 million metric tons (MMT), accounting for 14.3% of the global anthropogenic GHG emissions. Of this, five key anthropogenic sources: agriculture, coal, landfills, oil and gas operations and wastewater together emitted 68% of all CH_4 emissions. Landfills are ranked as the third highest anthropogenic CH_4 emission source, behind agriculture and coal mines, and emissions from the waste sector are expected to reach almost 800 million metric tons CO_2 equivalent ($MMTCO_2e$) in 2015.

The two largest economies spewed out 42% (14% (US) and 28% (China)) of the world's total greenhouse gas (GHG) emissions; these two countries are also the largest producers of municipal solid waste (MSW). The United States averages 250 MMT of MSW annually, of which about 63% enters landfills. In 2015, there were 2434 landfills in the United States and CH_4 from these landfills accounted for 138 $MMTCO_2e$ released into the atmosphere and represents 17.7% of all US CH_4 emissions. China had 580 landfills and treated 105 MMT of MSW in 2013. Methane produced from landfills contributes about 13% of total CH_4 emissions in China. Almost 50% of landfills in China did not install efficient LFG collection and utilization systems to make them manageable so a great deal of CH_4 and CO_2 are emitted without intervention. Recent data show that globally, 45 billion cubic meters (bcm) of CH_4 or 282 million barrels of oil equivalent (boe) was annually released from landfills into the atmosphere. Managing methane emission from landfills is a global challenge, though China lags behind in managed landfills that contribute to adverse health effects on the population. Moreover, the rich organic content of MSW in China indicates that CH_4 emissions there may be underestimated. The China unmanaged landfill scenario is further duplicated in developing as well as in least-developed countries.

This review starts with a dialog on CH_4 emissions and climate change and the chemical changes the CH_4 molecule undergoes in the atmosphere (Section 1). Section 2 deals with identification of global CH_4 emissions from key sources, particularly anthropogenic, among those are agriculture, coal mines, landfills, oil and gas operations and wastewater. Although each of these sources is descriptive on their own, the focus of Section 3 is on landfills with particular emphasis on the United States and China, two largest producers of waste. The quantitative measurement of CH_4 emissions is still uncertain so Section 4 is devoted to various CH_4 estimation models, such as United States Environmental Protection Agency (US EPA) LandGEM, the United Nations Intergovernmental Panel on Climate Change (IPCC) and others that are under development. The key landfill emissions data bases and the collection methodologies such as those used in the United States and recently released by the Chinese government are highlighted. Section 5 describes chemistry of pathways that produce CH_4 from landfills, and how landfills can control those emissions. Section 6 reviews potential of CH_4 as an energy source for combined heat and power (CHP) production

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as well as pathways for conversion of CH_4 into renewable gaseous fuel for use as compressed natural gas (CNG) and clean liquids that could be used as either drop-in replacement (gasoline, diesel, jet fuel hydrocarbons) or advanced oxygenated fuels such as methanol, a versatile precursor to fuels and chemicals, and dimethylether (DME), a clean diesel substitute. Section 7 describes in-place government policies to deal with CH_4 emissions from specific sectors. These policies vary from country to country but the Unites States and the European Union (EU) countries are well ahead in curbing methane emissions while China is now playing close attention to its increasing global share of emissions. The last section (Section 8) identifies science and technology and needed policy challenges to manage fugitive methane; this includes identification of technological intervention that China and other countries would need to capitalize on this wasted resource by efficiently harvesting this energy source, needed government policies and science and technology issues that researchers have to deal with to help combat climate change. The overall review provides a comprehensive description that could lead a coherent picture to harvest global CH_4 emissions for useful energy, a sensible solution.

In 2014, a milestone was reached in US and China relations when the White House announced that the United States intends to achieve an economy-wide target of reducing its emissions by 26%–28% below its 2005 level in 2025 while China intends to achieve the peaking of CO_2 emissions around 2030 and intends to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030. In another 2014 initiative, the United States also identified fugitive methane from oil and gas operations, agriculture, and landfills to maintain respective post-2020 actions on climate change, recognizing that these actions are part of the longer term efforts to transition to low-carbon economies, mindful of containing the global temperature increase goal of 2 °C, also known as two-degree scenario (2DS). These commitments by the United States and China were evident in the successful agreement at the culmination of the recently concluded COP21 event in Paris. This review is written to start a dialog among researchers that tetrahedral CH_4, the simplest among all organic compounds, plays such a complex role in climate change that as its use increases, it will rival carbon dioxide (CO_2) in GHG effect in the coming decades if no attempt is made to contain its emissions.

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