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## A short review on Methane Mitigation Methods for reducing Global Warming

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### **Abstract**

*Nowadays global warming effect, in general, is a great concern for the scientific communities of the world. It constitutes the emission of greenhouse gases such as Carbon dioxide, carbon monoxide, nitrous oxide, Methane, and so on. Methane is one of the most important greenhouse gases which contribute to global warming. This mini-review focuses on the different sources of methane emission and its mitigation. The five different emission sources are Land Fills, Rice Paddy Fields, Ruminants, Waste Water, and Coal Mines. Several emission studies and their control treatments had been a discussion of interest. Ultimately to our goodwill, several solutions are coming up that have solved real-life problems regarding the mitigation of methane from the environment. Several of these solutions are specific to their emission specificities. While these provide a narrow genre of solutions, it also cuts down on the decision making of analysis between different solutions. Several of these solutions need a thorough discussion and review to make the least of concern the decision of choosing a bit easier on the readers. Clearance of the pros and cons of every method are discussed give a clear view of the methods of methane mitigation.*

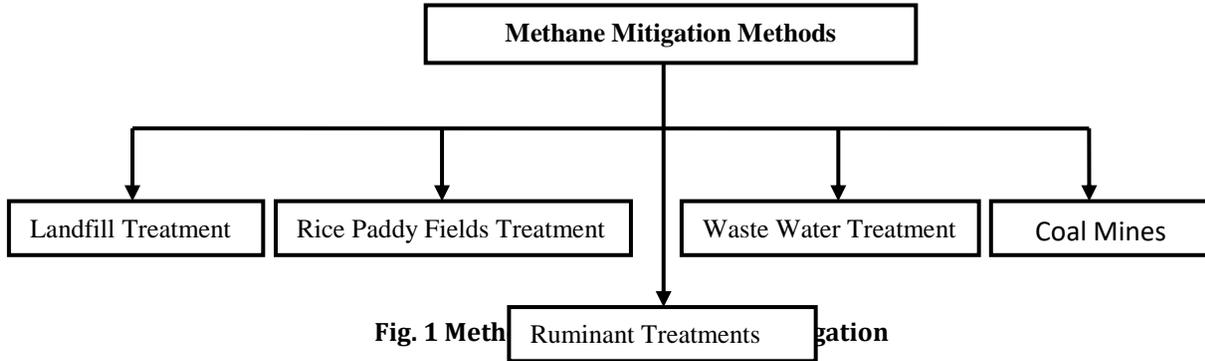
**Keywords:** 1 Global Warming, 2 Landfill Treatment, 3 Methane emissions, 4 Methane mitigation, 5 Rice Paddy Fields

## 1. Introduction

Ensuing several years of the chrysalis of human aptitude and potential, the given development has provided us with diverse and even discrete events as payoffs, unraveling certain problems, while initiating new ones. The initiated including from the moral obligation of diminution of human potential to the real shift in the balance of Earth's climatic pattern. These evident changes, commonly known as Climate Change are driven by, in turn, human-driven factors, such as the greenhouse effect (Shibata, 2010). The Greenhouse effect is exactly, what it sounds like. It makes our atmosphere act as a greenhouse, in turn keeping all the absorbed radiation from the sun inside the atmosphere, while not letting it escape due to the accumulation of gases such CO<sub>2</sub>, CH<sub>4</sub>, CO and so on, interestingly enough these gases are further named greenhouse gases, owing up to its major effects (Margaret, 2016). One of the gases that are severely preceding the phenomenon is CH<sub>4</sub> i.e. methane, with several of its sources, the concentration has doubled over a decade; in fact, it has been six-folds since the arrival of humans on earth (Susan, 2012 ). As the discussion of the sources goes, the numbers might be startling yet mind-numbing obvious. From the natural producer, taking the part in the process from ages that have passed to the human reliant, indigent ones i.e. presenting the worse of presents earth has received, encapsulating the origins such as marshlands, ruminants, volcano eruptions, deep-sea vents, garbage dumps, rice paddy fields and many more, respectively (Achim, 2003 ). As we have known the sources, it'll be a moral as well as an appraised responsibility to focus on the control i.e. mitigation of the product as well as the producers, basing it on the aplenty number of sources, one has to be specific regarding the given conduct driving the process of extenuating. Be it from the agricultural sources one investigates the prevailing elements of instigation influencing the overall process. One will follow the same flow of endeavors in general. Finally following the previously mentioned assessments regarding mitigation, several technologies that have come into place having the potential and characteristics to reach such geographical extents as created by the fellow creator of the problem itself are to be mentioned in this work (Joshuah, 2012). As we further discuss the sources more having yet no solution our highest intention is to study them more, understand them, in turn, having a pinch of a contribution involving the evolvement of certain new technologies working on those specific sources. Certain of those sources which are out of human hand as previously mentioned mud volcanoes, deep-sea reservoirs of methane still provide us an interest in the emission of methane (Izzet, 2012). Fellow releases regarding the failure of human sensibility and concern also reflect the slowly destructive events such as leaking of long term hazardous gas being leak-prone in its nature has been a noticeable problem. All of these concerns are of selfish yet sensible reasons that are basic human health concerns reflecting the problems of the greenhouse effect, and its wrath on quality of human life is indeed a thought to be taken care (Gerhard,1994) This short review will give insight into the methods used to reduce/mitigation of methane emission.

**2. Methods used in methane mitigation**

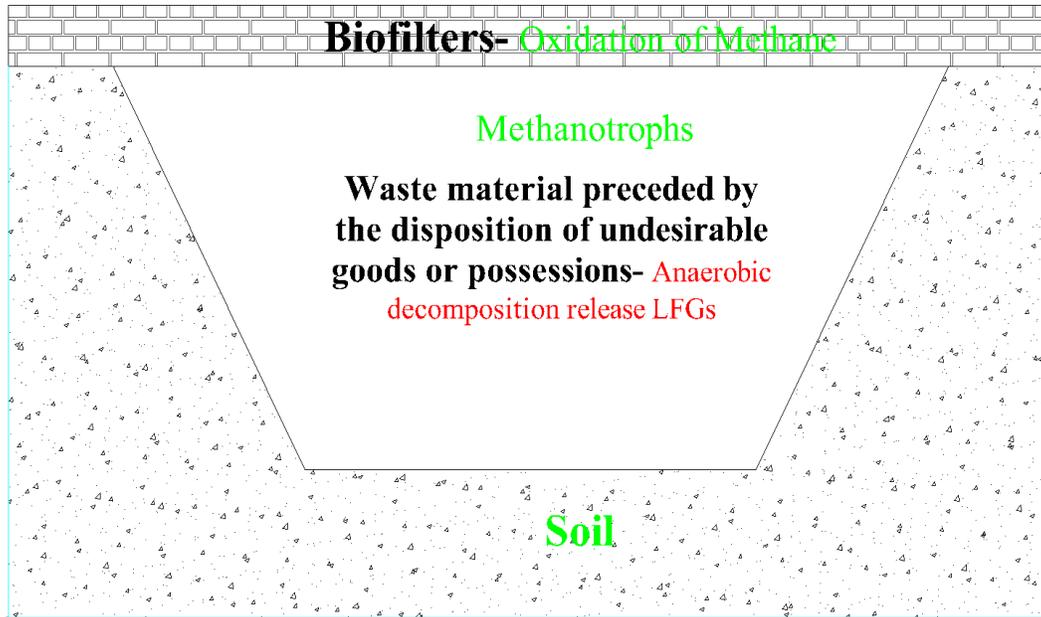
In this work, we are discussing the five different methods of Methane mitigation. These methods are shown in Fig. 1 and are discussed under the following heads.



**2.1 Landfill Treatment**

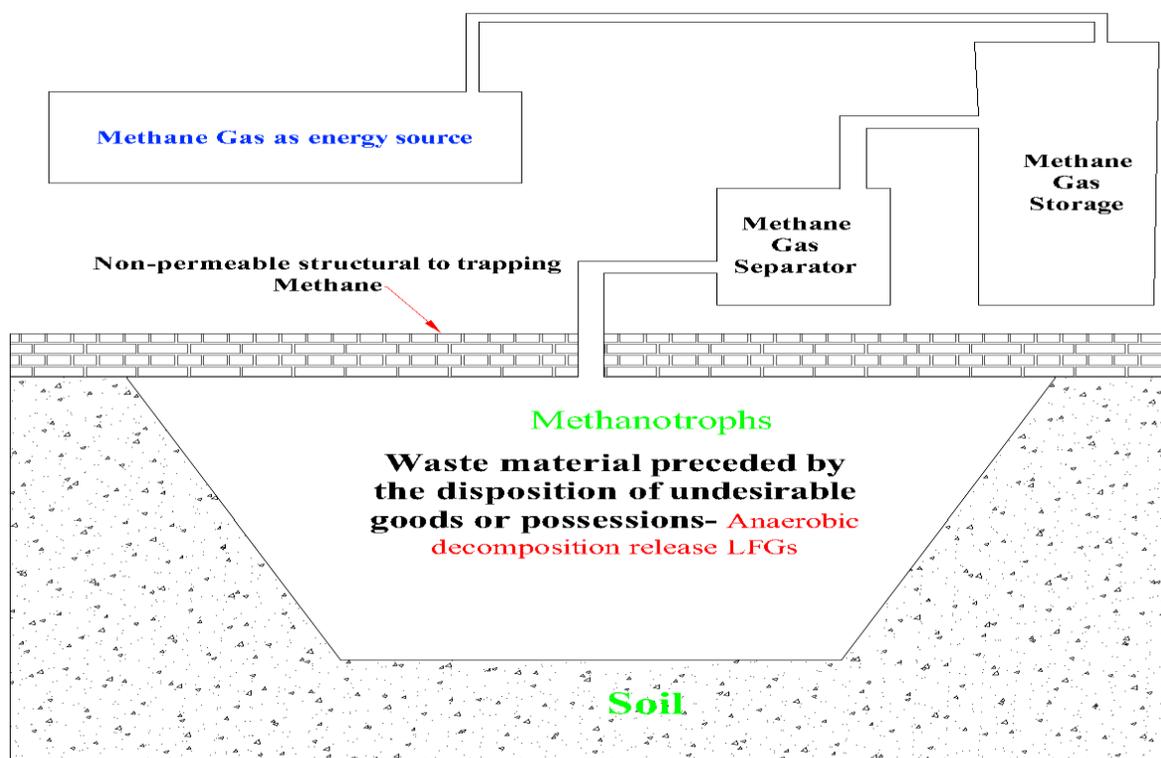
Landfills or dump yards in a broader manner can be defined as an assemblage of waste material preceded by the disposition of undesirable goods or possessions (Charlotte, 2004). These assemblages undergo anaerobic decomposition, contributing to the release of methane in the atmosphere. This methane is one of the many gases produced, and most obviously as the name suggests is known as landfill gases or LFGs (Soyoung, 2009). Methane constitutes 55-60% of this vindication adding up to plenty of problems, not only related to the greenhouse effect but also the rarest yet uncontrollable fires (Joseph, 2009). Coming back to the greenhouse effect, methane being a potent greenhouse gas ingurgitates more impactful amounts of infrared radiation than any other greenhouse gases (Alex, 1999). Its concentration is hitting the high spots of increase i.e. 0.6% per year, further linking directly to global climate change (Marion H-H ,2008) and in the most obvious of its manner, human activities lead to almost 70% percent of CH<sub>4</sub> emissions (Charlotte, 2004), also as much as startling it sounds, 19% of those emissions are attributes of our landfills (Barlaz, 2004).

To decline these emissions by a noticeable figure, there are several ways we can administrate, working on the basic coherence of biofilters (Bala, 2013). Biofilters, in general, are defined as biological barriers set up to segregate desirable and undesirable components in certain associations (Alex, 1999). Here, in its most specific sense, it means a layer of soil separating the disposition from the depositor in an effective way such as the layer of soil acts as a filter for any LFG vindications. Several of these filters focus on the oxidation of methane, sequentially ending its existence (Fig. 2),



**Fig. 2 Oxidation of Methane Using Biofilters**

While others focus on storing it to be further used as a potent and impactful energy source (Charlotte, 2009). Certain of these arrangements focus on forming a layer of sand and silt while providing them with methanotrophs, ultimately oxidizing the given methane (Alireza, 2017). Other filtering arrangements include the formation of a layer of clay or another non-permeable structural compound, trapping methane which can be further used as an energy source (Fig. 3) for the landfills' operations (Duangporn, 2016). However in the case of smaller landfills that are incapable of doing such arrangements, release methane directly into the atmosphere, decreasing the chances of fire and other accidents while increasing the major problems, such as the greenhouse effect (Jeyapandiyan, 2017). As previously mentioned about methanotrophs,



**Fig. 3 Methane entrapping and using as an energy source**

their actions vary to the attributes provided, thereby effecting their consumption of atmospheric methane. However, the process of oxidation might not always coincide with the behavior of the methanotrophs. It might vary to other factors of oxidation present such as the attributes of the layers used in the given biotic filter (Khalil, 2006).

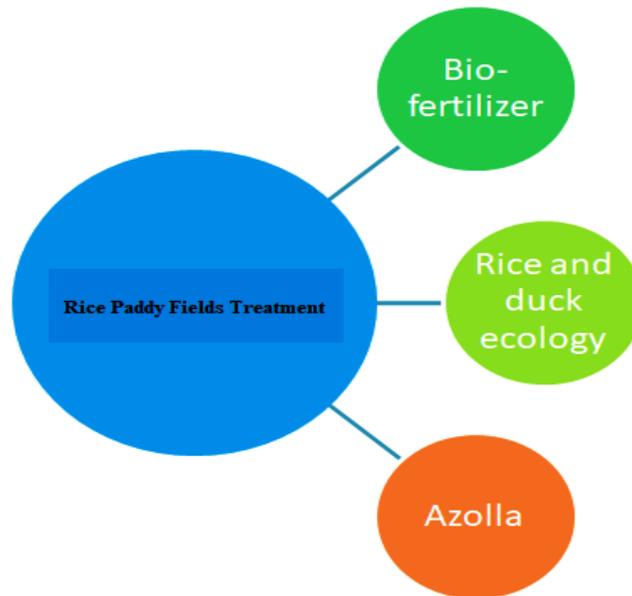
## 2.2 Rice Paddy Fields Treatment

Rice Paddy Fields i.e. a continuation of plantation regarding the desirability of one specific species while endeavoring the end of the remnant (Kazuyuki, 2003). As in its most obvious sense, the methane emissions occur expectedly owing to the existence of CO<sub>2</sub> breathing microscopic organisms ensuring the process of anaerobic decomposition sequentially being enhanced by the behavior of rice as in its prevailing nature of embellishment in CO<sub>2</sub> rich environment stereotyped due to its plant nature directly connecting the relation between the embellishment of rice and the emission of methane in a discrete and startling process (Ying, 2000).

Apart from its general procedure, further enhancements might be obtained, basing on the attributes of the provided circumambient (Aung, 2018). Further in its specific sense one of the attributes includes the basic addition of another CO<sub>2</sub> absorber basing it on the previously mentioned phenomenon, Azola, i.e. an aquatic fern, working based on respiration, and aggrandizing the vindications, ultimately detaining the aspiration of control (Mujiyo, 2016). With all of this knowledge taken into account, the analysis reflects developing

countries as a major producer of greenhouse gases, expecting it up to be the representation of further growing emissions in the future to come (Prasanna, 2002). However, these specific countries still make up to 70% of climate shift control potential for each piece of land that is to be used in agriculture. 52% of these countries lie in the brackets of targeting their agricultural sectors as alluring to reduce their carbon footprints (Kofi, 2017). While most countries have followed this bracket successfully, some of them are lacking in the furthermore set of data and resources to target such a big divergence in their intricacies (Xiang, 2006).

As an obvious consideration, Africa as a collection of developing countries is not been able to meet the demands of mitigating its GHG emissions. Specifically, Ghana has not been able to reduce its rice cultivation, through its abnormally huge impact, noticeable to the major scales due to government policies focusing on major boost in rice cultivation for the reasonable expenses primarily as the production level currently, existing meets up to merely 30% of local demand while the huge gap of 70% deficit is to be filled through foreign rice import, steering up a mind-numbing bill of U.S. \$450 (Mcallister, 1996).



**Fig. 4 Rice Paddy Fields Treatment**

Shifting our focus from Ghana, the rest of Africa is inadequate when one is speaking of the potential of the continent both as a source and mitigates the methane (Fig. 4) vindications (Waghorn, 2011). Focusing on the complications, the generalist of the conclusion focuses on the reduction technologies such as biofertilizers of specific strings as mentioned in (Eckard , 2010) while maintaining the attributes effecting as written in (Broucekm, 2014) to the execute rice/duck ecological system, an old Chinese system of ecology maintaining an aesthetically pleasing ode to time while scientifically reducing the methane additions, showing us the obviousness of the unobvious facts that might pass by our facing in the researches to come (Mathison,1998).

### 2.3 Ruminant Treatments

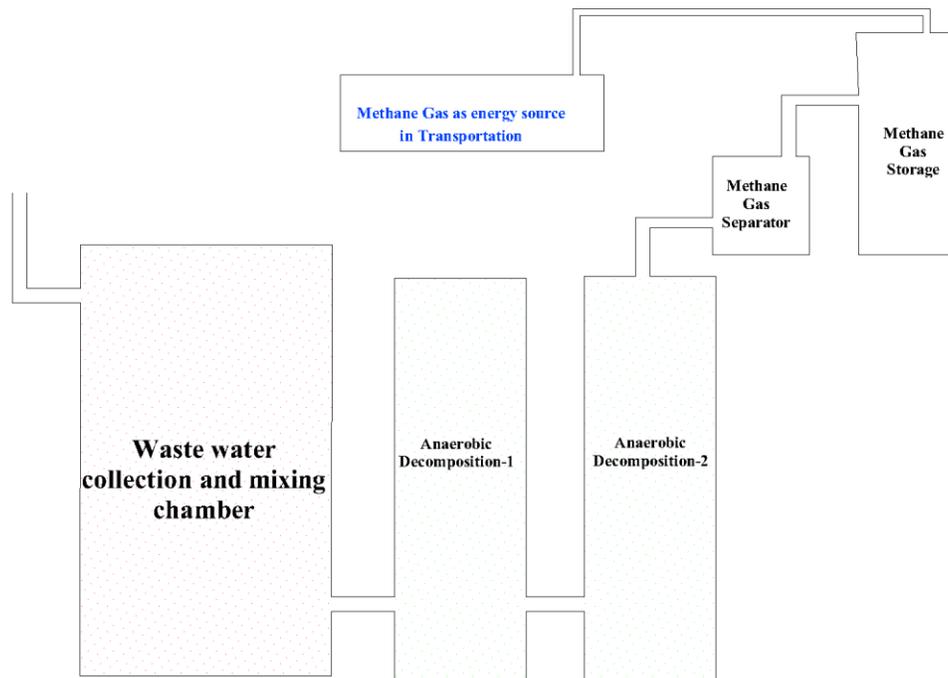
Ruminants in its most basic sense mean organisms with rumens as a major portion of their biological systems. The rumen occupies more than 70% of total stomach capacity. Its volume varies from 15 liters for sheep to a startling amount of 100-150 liters in case of cattle, as well as fellow livestock, contributing up to 90% of agricultural methane emissions for the major of events. It is indeed a focusable point to be concentrated especially to the point of atmospheric concerns and climatic shift patterns (Broucek, 2014). As the process goes, rumen takes part in partial digestion constituting long fermentation periods resulting in the release of methane and other fellow gases in the form of oral and rectal release (Mathison, 1998). Estimation of the production and the production itself varies from the process of enteric emissions from a focus point of several depending attributes, to be taken in the context of Dependence such as nutrition inefficiency, dietary concentrations, temperature rates, and many more (Wright, 2004). In several of the experiments conducted the direct relations to be found have been reasonably identifiable using the basic rationality of principles. As per the size of dietary concerns, cattle produce as much as 7-9 times methane compared to sheep and goats, while 87-97% is produced by rumen, 13-10% to a smaller extent is produced by the large intestine (Hegarty, 1999). The exhalation mainly through mouths and nostrils are to be considered a point to be reduced regarding the points of mitigation (David, 2011). As much as an influence acts as in the type of release, the temperature-pressure rate acts as an important factor in the eructation potential. More specifically, to our referred studies, the methane production in an adult sheep has been recorded to be decreased by 20% when the temperature was reduced from 33°C to 8°C. Hence the results are collected as of a 30% decrease in methane production regarding cold-adapted sheep (Su, 2003). Other factors that constitute the changes in methane production in methane production are dietary dependency, change in consistency of feed relating to animal production, animal manipulation, and dietary manipulation, constituting forage quality, plant secondary compounds, dietary supplements, and rumen manipulation. Other methods including Alternative Electron Acceptor, taking part in sequential oxidation, inhibition of methane emission with halogenated methane analogs and other compounds, use of Ionoforce, Defaunation, and Dietary Lipids (Diksha, 2012).

Enteric methane mitigation options provide us with a broad range of processes to take care of such as Rumen Manipulation and Ecology, Breeding, and Management. R.M.E. takes care of inhibiting methanogens while also enhancing non-methanogens ultimately following the process of Defaunation, Antibiotics, and Feed Activities; Diet Manipulation and Inoculance, respectively (Campos, 2016). Further being responsible for the Lipids, Synthetic Chemicals, and Natural Compounds taking parts in such processes for Forage Quality and Rumen Conditioning. Some other ways include vaccination (Wagner, 2009). Breeding follows on Quantitative Genetics, Genomics, and Planned Breeding. While the last but not the least, Management is the major of the important deals with Stock Numbers, Reproductive Rates, Turn Off and Enterprise Mix, Grazing Management, Finishing in Feedlots (Inamori, 2007).

Several sources taken into consideration, methane vindication has been a considerable problem created by anaerobic decomposition i.e. continuous fermentation of certain solids or liquids in the presence of considerably low traces of oxygen. The fermentation is further driven by factors such as temperature

especially in an uncontrolled system and in warm climates (Daelman, 2012). The total methane emission goes through a correction factor of in-situ absorption, summing up to an emission factor taken to be in consideration and further calculation. Certain other things that balance up the percentages related to methane emissions links directly to the attributes of area in terms of meat production factor, as a conclusive idea (El-Fadel, 2001). What we feel to realize is the obviousness of the type of decomposing or decomposed was taken into consideration i.e. solid and liquid sludge prone to fermentation of the quantity of organic degradable material and all of this is measured relative to wastewater (Pinchas, 2011). Hence to lower down the percentages and increase the reduction potential, wastewater treatment seems to be an indulging and a significant process to be overtaken (Yoshihito, 2003). Several of these releases impacting secondarily to human health and life quality by being destructive in the middle term, such as affecting the health of swine farms hence increasing the number of stillbirths by significant figures with shorter life spans, less feed, and lesser and unhealthier excretion, even the ones waning pigs die (Andrea, 2008).

To cut off the previously mentioned results, IPCC has established certain standards to avoid such ill-events from occurring. However, the countries facing these emergencies differ from those standards from specific terms, i.e. Taiwan gives a lot of significance to its swine health getting up to its business and consumption that it provides (Jarosław, 2018). Other fellow gases that are produced and cause similar effects as CO<sub>2</sub> and N<sub>2</sub>O (Jarosław, 2018).



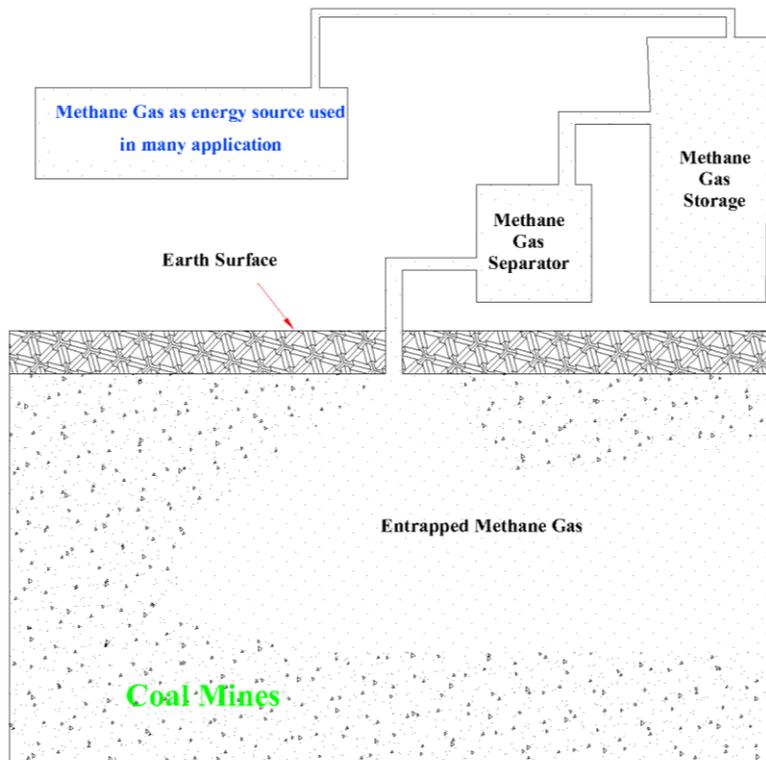
**Fig. 5 Wastewater Treatment Systems**

As the treatment goes, the raw sewage water goes through bar screening only to be gritted in great chambers, so raw sewage samples can be taken to be further be mixed into the mixing chambers, finally going through anaerobic tanks (Fig. 5), passing the stage of anaerobic decomposition, then to be reacted biologically for

least production of methane going through a second bar screen only to be clarified and effluent (Hendy, 2013). However, humanity, this time, not following it is usually the course has had the potential to think for turning it out into an opportunity of energy source, driving several factors and interestingly enough driving in actuality too, bio-gas road transport fuel, which has been used (Özgen, 2011). Other such processes, receiving search giving potential are factory generation, power plant continuation, and other self-sufficient systems (Wang, 2012).

## 2.5 Coal Mines

Coal mines, a part of its general hazardous nature provides us the knowledge of several hidden troubles related to natural methane dispersions in the form of sudden blasts as a result of removal of semblance in certain acts of quarrying through as much as of a drilling operation to be undertaken for the sense of excavating through the mining process (Cheng, 2011). The sudden blare is a release of trapped methane under the rocks of the mining location offering this interesting yet destructive and life-threatening phenomenon to be observed (Zhengfu, 2010). By far, 70% of all coal mines that have been related to emission are from underground ventilation provided to avoid the sinister consequences (Krzysztof, 2008).



**Fig. 6 Mitigation of Methane Gas in Coal Mines**

Certain factors depend on providing us with a certain conclusion with the specifications of the subject, depending on the technology, oxidation mechanism, principle, and application status (Olajossy, 2003).

Several ideas (Fig. 6) such as combustion air for conventional power stations with thermal oxidation mechanism based on the principle of PF power station boiler furnace (Carol, 1998). The application can be direct mitigation or the utilization to be demonstrated in a pilot-scale unit (Somers, 2008). Further technologies include Combustion Air for Gas Turbine, Combustion Air for Gas Engine, some principle uses such as Thermal Flow Reverse Reactor, Catalytic Flow Reverse Reactor, Catalytic Monolith Combustor, Catalytic Lean Burn Gas Turbine, and Recuperative Gas Turbine. For further more specification regarding the calculations of methane emissions, the formula that has been satisfied through real observation graphically mentioned and opened to a view describes a lot of its potential. (William, 1991).

**Table 1 Summary of the review work**

S.No.	Emission System	Emission Control	Pros.	Cons.
1	Land Fills	Bio Filters	This is quite a convenient system being Used Worldwide. Resources and the planning for this are easily available.	The filters or the segregations based on trapping and not oxidation are in some cases end up directly releasing the methane into the atmosphere, working against the goal itself.
2	Rice Paddy Fields	Rice Duck Ecology	The process of having its heritage, culture, and history has won itself, several practitioners, making the process better by each day.	The process doesn't satisfy modern needs and is not as practical in the sense of profit to be considered an option.
		Reduced Flooding Method	This process is practical as well as cheap while providing a good range of profit ultimately increasing the yield as it decreases the methane emission	Very few people practice it. Other than some countries like Japan, it is not practiced on such a large scale.
3	Ruminants	Dietary Changes	It can bring change in the rumen emissions without actually harming the ruminant, being an ethical way to control rumen emissions.	Not specific enough to be considered a process in a broader sense. Doesn't have a flow of processes
		Temperature Changes	It can bring change in the rumen emissions without actually harming the ruminant, being an ethical way to control rumen emissions.	Not specific enough to be considered a process in a broader sense. Doesn't have a flow of processes
		Rumen Reduction Tablets	Quite Effective and Cheap for the user. No extra preparation needed.	Harmful at certain points for the ruminants themselves.
		Rumen Reduction Vaccine	Quite Effective and Cheap for the user. No extra preparation needed.	Harmful at certain points for the ruminants themselves.
4	Waste Water	IPCC Standard Treatment	Similar standards for worldwide treatments.	Rigid Standards. Narrows the chances of further development.

			Creates less confusion	
5	Coal Mine	Combustion Air for Convention Power Stations	Prevents hazardous accidents while creating a source of energy itself.	The source of energy created is not steady enough.

### 3. Conclusions

Several of the solutions being discussed in this work. Starting with the biofilters mechanism as being discussed in the landfill treatments has been a great real-life representation of the solution working at the extent of noticeable figures. The separation of biomass from the biotic through biological barriers based on a distinguished yet akin focusing the mechanism based on oxidation, separation through sand, silt, and clay respectively. Coming to the rice paddy emission problem, several processes can be obtained encapsulating both old and the new i.e. Rice Duck Ecology from China and reduced flooding treatment from Japan. Rice Duck Ecology based on the old system of agriculture backing up from China has many pros., but far more cons., especially taking for the fact of the resources needing to fulfill the attributes of the process. However; reduced flooding was an instantaneous thing done by Japanese Farmers through trial and observation the method along with the scientific community having variously studied showing methane emissions in reduced ways, which seem like a commonly logical step to be taken regarding the negation of Azola and any other CO<sub>2</sub> breathing organisms contributing to methane emissions. Rumens being one of the largest, in the standard of figures, producers of methane through various ongoing biological processes have to have a solution regarding the negation or even lessening of the vindications. And as the methods state, it encapsulates all the dietary changes and temperature changes depending on various studies on livestock around the world. Other chemically induced methods regard drugs as supplements. Things as rumen-reduction tablets and vaccines seem to be a popular and cheaper alternative while sometimes not entertaining the health of the mammal itself. On the discussion of water-based treatments, IPCC standard treatments are accepted worldwide, except some countries lacking financial stability to perform so. Coal mine as a problem of methane emission and hazardous encounters, needing to be solved for certain life-threatening problems that may occur if not. Quiet popularly used, combustion air control has been a conventional; energy source provider for various power stations around the world. The contribution of Methane emission in the USA is about 10% (59) in overall emission of Greenhouse gases, by adopting the above methods we will be able to mitigate the methane emission in all the countries.

#### Authors contribution statement:

SS. (Ph.D. scholar) collected the data and Writing - original draft.

PKS (Professor) Supervised and finalized the review work.

AR (Associate Professor) Supervised and finalized the review work.

## References

1. Shibata, M., Terada, F (2010). Factors Affecting Methane Production and Mitigation in Ruminants. *Animal Science Journal* 81: 2-10. ([www.onlinelibrary.wiley.com](http://www.onlinelibrary.wiley.com))
2. Margaret, F.H., Robert, A., Bahare, S.M (2016). Fugitive Methane Emissions from Leak-Prone Natural Gas Distribution Infrastructure in Urban Environments. *Environmental Pollution* 213: 710-716. ([www.journals.elsevier.com/environmental-pollution](http://www.journals.elsevier.com/environmental-pollution))
3. Susan, C.A., Joel, S., Drew, S (2012). Global Air Quality and Health Co-Benefits of Mitigating Near-Term Climate Change Through Methane and Black Carbon Emission Controls. *Environmental Health Perspectives* 120 (6): 831-839. ([www.ehp.niehs.nih.gov](http://www.ehp.niehs.nih.gov))
4. Achim, J.K (2003). Global methane emission through mud volcanoes and its past and present impact on the Earth's climate. *International Journal of Earth Sciences* 92: 806-816. ([www.springer.com/journal/531](http://www.springer.com/journal/531))
5. Joshua, K.S., Subarna, B., Clara, A.S (2012). Review of Methane Mitigation Technologies with Application to Rapid Release of Methane from the Arctic. *Environmental Science and Technology* 46 (12): 6455-6469. ([www.pubs.acs.org/journal/esthag](http://www.pubs.acs.org/journal/esthag))
6. Izzet, K., Gokhan, A., Kerim, A (2012). Sources and Mitigation of Methane Emissions by Sectors: A Critical Review. *Renewable Energy* 39 (1): 40-48. ([www.journals.elsevier.com/renewable-energy](http://www.journals.elsevier.com/renewable-energy))
7. Gerhar, K. H (1994). The Greenhouse Gas Methane (CH<sub>4</sub>):Sources and Sinks, the Impact of Population Growth, Possible Interventions. *Population and Environment* 16 (2): 109-137. ([www.springer.com/journal/11111](http://www.springer.com/journal/11111))
8. Charlotte, S., Hans, M., Peter, K (2004). Attenuation of Methane and Volatile Organic Compounds In Landfill Soil Covers. *Journal of Environmental Quality* 33(1): 61-71. ([www.acsess.onlinelibrary.wiley.com/journal/15372537](http://www.acsess.onlinelibrary.wiley.com/journal/15372537))
9. Soyoung. P., Cheol-Hyo, L., Cheong-Ro R (2009). Biofiltration For Reducing Methane Emissions from Modern Sanitary Landfills at the Low Methane Generation Stage. *Water, Air & Soil Pollution* 196: 19-22. ([www.springer.com/journal/11270](http://www.springer.com/journal/11270))
10. Joseph, C.P., John, L.B (2009). *Composting: Processing, Materials and Approaches*. Nova Science Publishers 199-224.
11. Alex, D.V., Dirk, T., Pascal, B (1999). Methane Oxidation in Simulated Landfill Cover Soil Environment. *Environmental Science and Technology* 33 (11): 1854-1859. ([pubs.acs.org/journal/esthag](http://pubs.acs.org/journal/esthag))
12. Marion, H-H., Julia, G., Helene, H (2008). Biotic Systems to Mitigate Landfill Methane Emissions. *Waste Management and Research* 26 (1): 33-46. ([journals.sagepub.com/home/wmr](http://journals.sagepub.com/home/wmr))
13. Charlotte, S., Peter, K (2004). Environmental Factors Influencing Attenuation of Methane and Hydrochlorofluorocarbons In Landfill Cover Soils. *Journal of Environmental Quality* 33(1):72-79. ([www.acsess.onlinelibrary.wiley.com/journal/15372537](http://www.acsess.onlinelibrary.wiley.com/journal/15372537))
14. Barlaz, M.A., Green, R.B., Goldsmith, C.D (2004). Evaluation of a Biologically Active Cover for Mitigation of Landfill Gas Emissions. *Environmental Science & Technology* 38(18): 4891-4899. ([pubs.acs.org/journal/esthag](http://pubs.acs.org/journal/esthag))
15. Bala, Y.S., Krishna. R.R (2013). Landfill Methane Oxidation in Soil and Bio-Based Cover Systems: A Review. *Reviews in Environmental Science & Bio/Technology* 13: 79-107. ([www.springer.com/journal/11157](http://www.springer.com/journal/11157))
16. Alex, D.V., Dirk, T., Pascal, B (1999). Methane Oxidation in Simulated Landfill Cover Soil Environments. *Environmental Science and Technology* 33(11): 1854-1859. ([www.pubs.acs.org/journal/esthag](http://www.pubs.acs.org/journal/esthag))
17. Charlotte, S., Peter, M.K., Jean, E.B (2009). Microbial Methane Oxidation Processes and Technologies for Mitigation of Landfill Gas Emissions. *Waste Management & Research* 27(7): 409-455. ([journals.sagepub.com/home/wmr](http://journals.sagepub.com/home/wmr))

18. Alireza, M., Qiuyan, Y (2017). Performance of the Biotic Systems for Reducing Methane Emissions from Landfill Sites: A Review. *Ecological Engineering* 104:116-130. ([www.journals.elsevier.com/ecological-engineering](http://www.journals.elsevier.com/ecological-engineering))
19. Duangporn, K., Nunkaew, T., Kantha, T., (2016). Biofertilizers from *Rhodospseudomonas Palustris* Strains to Enhance Rice Yields and Reduce Methane Emissions. *Applied Soil. Ecology* 100: 154-161. ([www.journals.elsevier.com/applied-soil-ecology](http://www.journals.elsevier.com/applied-soil-ecology))
20. Jeyapandiyar, N., Lakshmanan, A., Geethalakshmi, V (2017). Combined Influence of Blue-Green Algae and *Azolla* on Dissolved Oxygen, Redox Status and Methane Emission Potential of Systems of Rice Cultivation. *International Journal of Chemical Studies* 5 (6): 572-575. ([www.chemjournal.com](http://www.chemjournal.com))
21. Khalil, M.A.K., Shearer, M.J (2006). Decreasing Emissions of Methane from Rice Agriculture. *International Congress Series* 1293: 33-41. ([www.journals.elsevier.com/international-congress-series](http://www.journals.elsevier.com/international-congress-series))
22. Kazuyuki, I., Cheng, W., Aonuma, A (2003). Effects of Free Air CO<sub>2</sub> Enrichment (Face) on CH<sub>4</sub> Emission from a Rice Paddy Field. *Global Change Biology* 9: 1458-1464. ([www.onlinelibrary.wiley.com/journal/13652486](http://www.onlinelibrary.wiley.com/journal/13652486))
23. Ying, Z., Boeckx, P., Chen, G.X (2000). Influence of *Azolla* on CH<sub>4</sub> Emission from Rice Fields. *Nutrient Cycling in Agroecosystems* 58: 321-326. ([www.springer.com/journal/10705](http://www.springer.com/journal/10705))
24. Aung Z.O., Sudo, S., Inubushi, K (2018). Methane and Nitrous Oxide Emissions from Conventional and Modified Rice Cultivation Systems in South India. *Agriculture Ecosystem and Environment* 252: 148-158. ([www.journals.elsevier.com/agriculture-ecosystems-and-environment](http://www.journals.elsevier.com/agriculture-ecosystems-and-environment))
25. Mujiyo, Bambang, H.S., Eko H (2016) Methane Emission on Organic Rice Experiment Using *Azolla*. *International Journal of Applied Environmental Science* 11: 295-308. ([www.ripublication.com/ijaes.htm](http://www.ripublication.com/ijaes.htm))
26. Prasanna, R., Vinod, K., Sushil, K (2002). Methane Production in Rice Soil is inhibited by Cyanobacteria. *Microbiological Research* 157: 1-6. ([www.journals.elsevier.com/microbiological-research](http://www.journals.elsevier.com/microbiological-research))
27. Kofi, KB., George, O.Y., Ebenezer, M (2017). Rice Cultivation and Greenhouse Gas Emissions: A Review and Conceptual Framework with Reference to Ghana. *Agriculture-MDPI* 7:1-14. ([www.mdpi.com/journal/agriculture](http://www.mdpi.com/journal/agriculture))
28. Xiang, P-A., Huang, H., Mei, H (2006). Studies on Technique of Reducing Methane Emission in A Rice-Duck Ecological System and The Evaluation of Its Economic Significance. *Agricultural Sciences in China* 5: 758-766. ([www.journal/Agricultural-Sciences-in-China](http://www.journal/Agricultural-Sciences-in-China))
29. McAllister, T.A., Cheng, K-J., Okine, E.K (1996). Environmental and Microbiological Aspects of Methane Production in Ruminants. *Canadian Journal of Animal Science* 76: 231-243. ([www.cdnsiencepub.com/journal/cjas](http://www.cdnsiencepub.com/journal/cjas))
30. Waghorn, G.C., Hegarty, R.S (2011). Lowering Ruminant Methane Emissions through Improved Feed Conversion Efficiency. *Animal Feed Science and Technology* 166-167: 291-301. ([www.journals.elsevier.com/animal-feed-science-and-technology](http://www.journals.elsevier.com/animal-feed-science-and-technology))
31. Eckard, R.J., Grainger, C., De-Klein, C.A.M (2010). Options for the Abatement of Methane and Nitrous Oxide from Ruminant Production: A Review. *Livestock Science* 130: 47-56. ([www.journals.elsevier.com/livestock-science](http://www.journals.elsevier.com/livestock-science))
32. Broucek, J (2014). Production of Methane Emissions from Ruminant Husbandry: A Review. *Journal of Environmental Protection* 1482-1493. ([www.publons.com/journal/21431/journal-of-environmental-protection](http://www.publons.com/journal/21431/journal-of-environmental-protection))
33. Mathison, G.W., Okine, E.K., McAllister, T.A (1998). Reducing Methane Emissions from Ruminant Animals. *Journal of Applied Animal Research* 14:1-28. ([www.tandfonline.com/toc/taar20/current](http://www.tandfonline.com/toc/taar20/current))
34. Wright, A.D.G., Kennedy, P., O'Neill, C.J. (2004). Reducing Methane Emissions in Sheep by Immunization against Ruminant Methanogens. *Vaccine*, 22: 3976-3985. ([www.journals.elsevier.com/vaccine](http://www.journals.elsevier.com/vaccine))

35. Hegarty, R.S (1999). Reducing Rumen Methane Emissions through Elimination of Rumen Protozoa. *Australian Journal of Agricultural Research* 50: 1321-1328. ([www.Australian-Journal-of-Agricultural-Research](http://www.Australian-Journal-of-Agricultural-Research))
36. David, C., John, N., Wiedemann, S.G. (2011). Ruminant Enteric Methane Mitigation: A Review. *Animal Production Science* 51: 491-514. ([www.publish.csiro.au/an](http://www.publish.csiro.au/an))
37. Su, J-J., Liu, B-Y., Chang, Y-C (2003). Emission of Greenhouse Gas from Livestock Waste and Wastewater Treatment in Taiwan. *Agriculture, Ecosystems & Environment* 95: 253-263. ([www.journals.elsevier.com/agriculture-ecosystems-and-environment](http://www.journals.elsevier.com/agriculture-ecosystems-and-environment))
38. Diksha, G., Santosh, K.S (2012). Greenhouse Gas Emissions from Wastewater Treatment Plants: A Case Study of Noida. *Journal of Water Sustainability* 2: 131-139. ([www.jwsponline.com](http://www.jwsponline.com))
39. Campos, J.L., Valenzuela, H.D., Pedrouso, A (2016). Greenhouse Gases Emissions from Wastewater Treatment Plants: Minimization, Treatment and Prevention. *Journal of Chemistry* 1-12. ([www.hindawi.com/journals/jchem](http://www.hindawi.com/journals/jchem))
40. Wagner, R.C., Regan, J.M., Oh, S-E (2009). Hydrogen and Methane Production from Swine Wastewater Using Microbial Electrolysis Cells. *Water Research* 43: 1480-1488. ([www.sciencedirect.com/journal/water-research](http://www.sciencedirect.com/journal/water-research))
41. Inamori, R., Gui, P., Dass, P (2007). Investigating CH<sub>4</sub> And N<sub>2</sub>O Emissions from Eco-Engineering Wastewater Treatment Processes Using Constructed Wetland Microcosms. *Process Biochemistry* 42: 363-373. ([www.journals.elsevier.com/process-biochemistry](http://www.journals.elsevier.com/process-biochemistry))
42. Daelman, M.R.J., Van, Voorthuizen, E.M., Van Dongen, U-G.J.M (2012). Methane Emission during Municipal Wastewater Treatment. *Water Research* 46: 3657-3670. ([www.sciencedirect.com/journal/water-research](http://www.sciencedirect.com/journal/water-research))
43. El-Fadel, M., Massoud, M (2001). Methane Emissions from Wastewater Management. *Environmental Pollution* 114: 177-185. ([www.journals.elsevier.com/environmental-pollution](http://www.journals.elsevier.com/environmental-pollution))
44. Pinchas, F., Efrat, H (2011). Options to Reduce Greenhouse Gas Emissions During Wastewater Treatment for Agricultural Use. *Science of Total Environment* 416: 289-299. ([www.journals.elsevier.com/science-of-the-total-environment](http://www.journals.elsevier.com/science-of-the-total-environment))
45. Yoshihito, S., Wakisaka, M., Sharakbah, Y (2003). Reduction of Methane Released from Palm Oil Mill Lagoon in Malaysia and its Countermeasures. *Mitigation and Adaptation Strategies for Global Change* 8: 237-252. ([www.springer.com/journal/11027](http://www.springer.com/journal/11027))
46. Andrea, T., Michele, G (2008). The Potential of Bio-Methane as Biofuel/Bio-Energy for Reducing Greenhouse Gas Emissions: A Qualitative Assessment for Europe in a Life-Cycle Perspective. *Water Science and Technology* 57: 1683-1692. ([www.iwaponline.com/wst](http://www.iwaponline.com/wst))
47. Jarosław, B., Magdalena, T (2018). Analysis of Methane Hazard Conditions in Mine Headings. *Technicki Vjesnik-Technical gazette* 25: 271-276. ([www.tehnicki-vjesnik.com](http://www.tehnicki-vjesnik.com))
48. Shi, S., Jenny, A (2006). Catalytic Combustion of Coal Mine Ventilation Air Methane. *Fuel* 85: 1201-1210. ([www.journals.elsevier.com/fuel](http://www.journals.elsevier.com/fuel))
49. Hendy, L., Gunawan, C., Rosche, B (2013). Challenges to Developing Methane Biofiltration for Coal Mine Ventilation Air: A Review. *Water, Air, & Soil Pollution* 1566:1-15. ([www.springer.com/journal/11270](http://www.springer.com/journal/11270))
50. Özgen, K.C., Ruiz, F.A., Cote, M (2011). Coal Mine Methane: A Review of Capture and Utilization Practices with Benefits to Mining Safety and to Greenhouse Gas Reduction. *International Journal of Coal Geology* 86: 121-156. ([www.journals.elsevier.com/international-journal-of-coal-geology](http://www.journals.elsevier.com/international-journal-of-coal-geology))
51. Wang, L., Cheng, Y-P (2012). Drainage and Utilization of Chinese Coal Mine Methane with A Coal-Methane Co-Exploitation Model: Analysis and Projections. *Resources Policy*: 37, 315-321. ([www.deas.repec.org/s/eee/jrpoli.html](http://www.deas.repec.org/s/eee/jrpoli.html))

52. Cheng, Y-P., Wang, L., Zhang, X-L (2011). Environmental Impact of Coal Mine Methane Emissions and Responding Strategies in China. *International Journal of Greenhouse. Gas Control* 5: 157-166. ([www.journals.elsevier.com/international-journal-of-greenhouse-gas-control](http://www.journals.elsevier.com/international-journal-of-greenhouse-gas-control))
53. Zhengfu, B., Hilary, I-I., John, L.D (2010). Environmental Issues from Coal Mining and Their Solutions. *Mining Science and Technology* 20: 215-223. ([www.sciencedirect.com/journal/mining-science-and-technology](http://www.sciencedirect.com/journal/mining-science-and-technology))
54. Olajossy, A., Gawdzik, Z., Budner, J.D (2003). Methane Separation from Coal Mine Methane Gas by Vacuum Pressure Swing Adsorption. *Chemical Engineering Research and Design* 81:474-482. ([www.sciencedirect.com/journal/chemical-engineering-research-and-design](http://www.sciencedirect.com/journal/chemical-engineering-research-and-design))
55. Carol, J.B., James, S.M., Raymond, C.P (1998). Status of Worldwide Coal Mine Methane Emissions and Use. *International Journal of Coal Geology* 35: 283-310. ([www.journals.elsevier.com/international-journal-of-coal-geology](http://www.journals.elsevier.com/international-journal-of-coal-geology))
56. Somers, J.M., Schultz, H.L (2008). Thermal Oxidation of Coal Mine Ventilation Air Methane. 12<sup>th</sup> U.S./North American Mine Ventilation Symposium-Wallace, 1<sup>st</sup> January 301-306. ([www.researchgate.net/publication/242231324](http://www.researchgate.net/publication/242231324))
57. William, A.A., Patrick, R.D., Michelle, R.W (1991). Use of Methanotrophic Bacteria in Gas Phase Bioreactors to Abate Methane in Coal Mine Atmospheres. *Fuel*, 70, 1001-1003. ([www.journals.elsevier.com/fuel](http://www.journals.elsevier.com/fuel))
58. USEPA (2020). Greenhouse Gas Emissions: Overview of Greenhouse Gases ([www.epa.gov/ghgemissions/overview-greenhouse-gases](http://www.epa.gov/ghgemissions/overview-greenhouse-gases))