Research Report

Fuel Gas Selection Based Upon Minimizing Greenhouse Gas Generation

by Westleigh Cutts & Dr. Albert Chung (2021)

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Overview of Research

American Tank & Vessel's (AT&V) research will be utilized to create a model for gas type selection based on minimizing greenhouse gas emissions. This model, combined with cost data, will give customers the ability to choose a best fit gas type consistent with their corporate environmental goals. Until recently the effort to utilize gas for power generation, replacing diesel, HFO, and residuals, was such an environmental benefit little consideration was made to the selected gas type's impact on the environment.

The model being pursued will consider each gas type based on the following criteria:

1. **Fugitive Emissions from Source to Burner Tip**
2. **Life of Greenhouse Gas (GHG) emissions in the atmosphere**
3. **Global Warming Potential (GWP)**
4. **GHG emissions from degradation**

AT&V research efforts will generate information for customers to better understand their gas choices and the ultimate near and long-term impacts on Global Warming, as well as the ozone. Information provided is not the opinion of AT&V, but the work of others referenced within this document and organized for further use.

Summary of Methane, Ethane, Propane, and Carbon Dioxide

The following analysis for these gas types is based on the release of the primary gas into the atmosphere through fugitive emissions. CO_2 is considered, as it relates to fugitive emissions degradation, but CO_2 is not considered from the combustion of the gas. CO_2 generation from gas combustion is relatively equal across these fuel gases in relationship to BTUs from the combustion of the gas and will be addressed further in the next report.

Methane (CH_4) is a colorless, odorless gas, and the simplest of all hydrocarbon molecules. It is also the largest component of natural gas. In the Earth's atmosphere, CH_4 is ubiquitously present at approximately 2 parts per million by volume (ppmv) and is of considerable environmental concern because it is a significant GHG and is increasing in concentration at a rate of about 1% per year. Even though methane is non-toxic, its presence in soil gas creates environmental concern because it can act as an asphyxiant and is an explosion hazard when present at concentrations between 5 and 15 percent by volume in air.[1] Methane is the second most abundant anthropogenic GHG after CO_2, accounting for almost 20% of global emissions. Methane is also a much more potent GHG compared to CO_2 in retaining heat in the atmosphere.

Ethane (C_2H_6) is a two-carbon alkane that, at standard temperature and pressure, is a colorless, odorless gas. Ethane is isolated on an industrial scale from natural gas and as a by-product of petroleum refining. Its chief use is as petrochemical feedstock for ethylene production, usually by pyrolysis: $CH_3\,CH_3 \rightarrow CH_2CH_2 + H_2$. Ethane is also used for power generation and has a history of being safe, clean, and reliable.

After methane, ethane is the second-largest component of natural gas. Natural gas from different gas fields varies in ethane content from less than 1% to as high as 14% being produced from West Texas "shale oil" wells. Ethane can also be separated from petroleum gas, a mixture of gaseous hydrocarbons that arises as a by-product of petroleum refining.[2]

[1] Bastviken, D. (2009). Methane. In 1048644612 801240175 G. E. Likens (Ed.), *Encyclopedia of Inland Waters* (pp. 783-805). Academic Press.

[2] Speight, J. G. (2011). Production of Hydrocarbons from Natural Gas. In 1048666880 801254105 J. G. Speight (Ed.), *Handbook of Industrial Hydrocarbons Processes* (pp. 127-162). Gulf Professional Publishing.

An argument can be made as to the impact of ethane on climate change, but its impact is certainly complex. On one hand, ethane can be argued to be negligible in respects to GHG. It is not emitted in great quantities, has a lifetime of only a few months, and is not very effective at absorbing radiation. There are no GHG protocols that even specify a global warming potential for ethane. On the other hand, ethane can contribute to climate change through the conversion of ethane to methane in the atmosphere. It can also be converted to ozone; however, ozone can be good or bad depending on where it is in the atmosphere. In the stratosphere (higher elevations) it can be beneficial by providing a layer that blocks UV light from reaching the surface; however, lower atmosphere ozone can be harmful to human health.

Ethane does have some value in that it can be studied as a tracer for fossil fuel activity since ethane is only emitted through the fossil fuel industry, as opposed to methane, which is emitted through a variety of sources. For example, if ethane concentrations drastically increase, that likely means global concentrations of GHG are increasing because increases in ethane is a marker for increased fossil fuel activity which emits CH_4 and CO_2. It is the CH_4 and CO_2 emissions from fossil fuel activity that drives climate change, not ethane.

Propane, also referred to as liquefied petroleum gas, is often shortened to "LP gas" or "LPG". It is an alternative fuel that is a byproduct of natural gas processing and petroleum refining. It is safe, clean, powerful, and reliable—and it is powering homes and businesses all over the world.

Propane is a fossil fuel that is found naturally alongside natural gas and oil. It is separated from natural gas during processing, often using refrigeration—so contrary to popular belief, propane is not made from natural gas, but is extracted from it. Propane is also extracted from heated crude oil using a distillation tower. Once the propane is isolated, it is pressurized so it can be stored as a liquid in cylinders and tanks that can be seen in cages at retail locations nationwide.[3]

The impact of propane on climate change is minor, other than the CO_2 emissions through combustion.

Propane is not considered a GHG, and it is a non-toxic/non-caustic gas and does not create environmental hazards if released as a liquid or vapor into the water or soil.[4]

[3] What is Propane? (n.d.). Retrieved November 12, 2020, from https://www.amerigas.com/about-propane
[4] Propane and the Environment. (n.d.). Retrieved October 23, 2020, from https://www.propane101.com/propanegreenenergyfuel.htm

However, if spilled in large quantity, it can cause environmental damage to those organisms or plant life in the immediate areas.[5] Damage and potential dangers only exist if the vapor is ignited following the spill, and even then, there are no long-term effects to the environment.[6]

Carbon Dioxide (CO_2) is a naturally occurring, colorless, and odorless gas produced from the combustion of any of the gases being studies. It has a boiling point of −70 °C (sublimes), vapor density of 1.53, and is slightly soluble in water. It is essential for the survival of most living organisms and cycles in the ecosystem, through respiration (aerobic and anaerobic), photosynthesis, and combustion. CO_2 plays an important role in the regulation of Earth's temperature, and is considered a GHG.[7] The concentration of CO_2 has been over 400 ppm and has increased over 10% in the past two decades and is the primary GHG present in the atmosphere. The scientific community agrees that the increase of CO_2 in the atmosphere is attributable to anthropogenic activities and the combustion of fossil fuels. Although the focus of this research is on methane, propane, and ethane, CO_2 has an impact as a byproduct of combustion for these three gases. Report Number 2 will further address this issue.

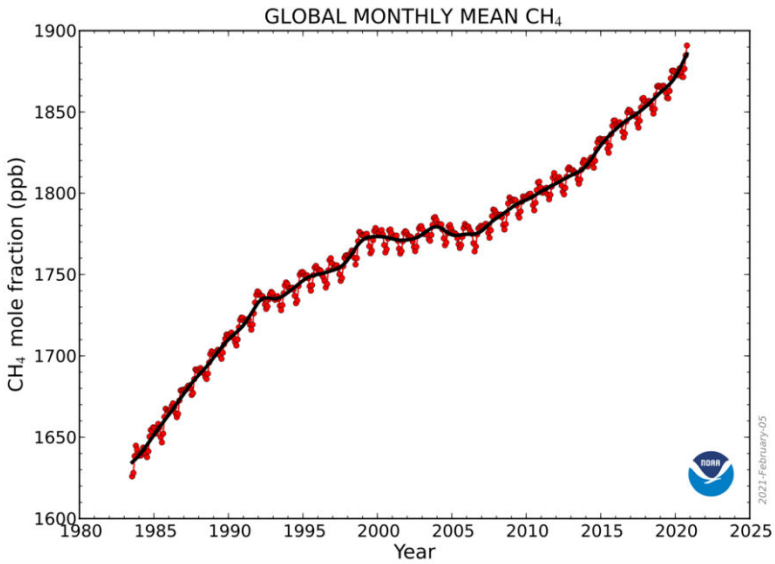
1. Life of Greenhouse Gas Emissions (Minimum Life Utilized for All Gases)

1.1 Methane has an atmospheric lifetime of 12 to 15 years and a half-life of about 9 years in the atmosphere.[8] Methane is the second most abundant GHG in the atmosphere only behind CO_2. As of the 2018 EPA GHG inventory, methane makes up about 10% of the GHG emissions. Although the emissions of CH4 are much less than CO_2, it has over 20 times the global warming potential than CO_2 over the span of 100 years.

U.S. methane emissions have gradually decreased over time as reported by EPA, but due to the lifetime of atmospheric methane, the global presence in the atmosphere has gradually increased over the years.

[5] Propane and the Environment. (n.d.). Retrieved October 23, 2020, from https://www.propane101.com/propanegreenenergyfuel.htm
[6] Propane and the Environment. (n.d.). Retrieved October 23, 2020, from https://www.propane101.com/propanegreenenergyfuel.htm
[7] Goel, S., & Agarwal, D. (2014). Carbon Dioxide. In 1048696919 801273169 P. Wexler (Ed.), *Encyclopedia of Toxicology* (Third ed., pp. 675-677). Academic Press.
[8] US Department of Commerce, N. (2005, October 01). Global monitoring Laboratory - carbon cycle greenhouse gases. Retrieved February 22, 2021, from https://www.esrl.noaa.gov/gmd/ccgg/trends/

The figure below shows historical methane concentrations monitored at Mauna Loa, Hawaii.



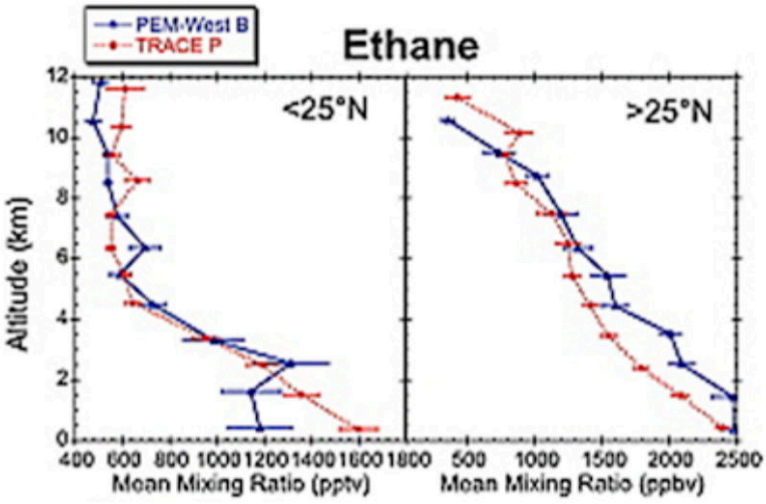
(**Figure 1:** Historical methane concentrations monitored at Mauna Loa, Hawaii.[9])

1.2 According to an article titled, "Ethane: Sources and Sinks", after methane, ethane is the second most common hydrocarbon in the atmosphere. Ethane is also significantly shorter-lived than methane[10], with an average lifetime of 2 months.[11] 16 grams of methane (one mole) when completely burned produces 44 grams of CO_2 (one "gram molecular weight" or mole).

[9] US Department of Commerce, N. (2005, October 01). Global monitoring Laboratory - carbon cycle greenhouse gases. Retrieved February 22, 2021, from https://www.esrl.noaa.gov/gmd/ccgg/trends/

[10] Ethane: Sources and Sinks - Atmospheric Kinetics - Global Ethane Decline and Implications for Methane. (n.d.). Retrieved October 23, 2020, from https://sites.google.com/site/group7atmosphericethane/background/ethane-sources-and-sinks

[11] Ethane: Sources and Sinks - Atmospheric Kinetics - Global Ethane Decline and Implications for Methane. (n.d.). Retrieved October 23, 2020, from https://sites.google.com/site/group7atmosphericethane/background/ethane-sources-and-sinks



(**Figure 2**: Examining the vertical mixing ratio of ethane in the atmosphere in the following figure, we can note that the mixing ratio is largest at the surface and decreases with elevation.[12])

1.3 Two propane references, by Stig Bjørløw Dalsøren, discovered that propane life is measured in weeks, rather than years like methane.[13] Propane is also shorter lived than ethane (2 months) and particularly methane (12 years).[14]

Propane will not harm people or the environment and while its harmless attributes are eco-friendly, its temperature characteristics can and will cause harm when handled with carelessness.[15] According to Propane and the Environment, propane is listed as an approved clean fuel by the U.S. Government energy policy makers and energy administrative bodies.[16] Stig Bjørløw Dalsøren indicated that propane has a slightly higher CO_2 emission factor compared to ethane, but still very low compared to conventional liquid fuels.

[12] Ethane: Sources and Sinks - Atmospheric Kinetics - Global Ethane Decline and Implications for Methane. (n.d.). Retrieved October 23, 2020, from https://sites.google.com/site/group7atmosphericethane/background/ethane-sources-and-sinks
[13] AV: Stig Bjørløw Dalsøren, G. (n.d.). Ethane and propane emissions have been underestimated. Retrieved October 23, 2020, from https://cicero.oslo.no/no/posts/nyheter/ethane-and-propane-emissions-have-been-underestimated
[14] AV: Stig Bjørløw Dalsøren, G. (n.d.). Ethane and propane emissions have been underestimated. Retrieved October 23, 2020, from https://cicero.oslo.no/no/posts/nyheter/ethane-and-propane-emissions-have-been-underestimated
[15] Propane and the Environment. (n.d.). Retrieved October 23, 2020, from https://www.propane101.com/propanegreenenergyfuel.htm
[16] Propane and the Environment. (n.d.). Retrieved October 23, 2020, from https://www.propane101.com/propanegreenenergyfuel.htm

1.4 Lastly is CO_2; once CO_2 is in the atmosphere, it can last for as long as 300 to 1,000 years.[17] Combined with its long lifetime, CO_2 emissions make up over 80% of the GHG emissions to the atmosphere. CO_2 is a direct emission of the combustion of fossil fuels, such as methane, ethane, and propane, and is believed to be the primary driver behind climate change. Other process emissions can also result in the production of CO_2 such as cement manufacturing. The main CO_2 sinks are plants, soil, and the ocean. These sinks can absorb nearly half of the CO_2 emissions, but unfortunately the rate of CO_2 emissions outpace the rate of CO_2 removal by sinks. Although uptake of CO_2 by natural resources may have its benefits, it can also cause problematic events. For example, the acidification of the ocean due to CO_2 uptake has caused adverse impacts to marine animals and have deteriorated coral reefs.

2. Global Warming Potential (GWP)

GHG have the ability to warm the surrounding atmosphere by absorbing incoming energy and preventing energy leaving the Earth that would naturally be released. The global warming potential, or GWP, is a measure of how a specific GHG warms the atmosphere. In technical terms, it measures how much energy the emissions of one unit of gas will absorb over a period of time, relative to the emissions of one unit of CO_2. The larger GWP value, the more potential that gas has to warm the atmosphere.

A specific gas may have a range of GWP's depending on the time horizon being evaluated. For example CH_4 has a higher GWP for shorter time periods of evaluation. This can be explained by the lifetime of CH_4. Since the lifetime of this gas is on the order of 10-20 years, its impact to global warming diminishes the longer time period which is why CH_4 has a lower GWP for longer time horizons.

Methane is over 20 times more effective at trapping heat compared to CO_2 on a 100 year time period. When evaluating the GWP on a shorter time scale of 20 years it is 84 times more effective compared to CO_2. Propane released to the atmosphere has very negligible effects on climate change. This gas, if released, typically will descend and not mix with the atmosphere due to its density. Ethane is considered negligible at absorbing radiation and in itself does not significantly impact the climate. Ethane's GWP largely results from its conversion in the atmosphere to methane.[18]

[17] The Atmosphere: Getting a Handle on Carbon Dioxide – Climate Change: Vital Signs of the Planet. (2020, March 03). Retrieved October 26, 2020, from https://climate.nasa.gov/news/2915/the-atmosphere-getting-a-handle-on-carbon-dioxide/

[18] Ethane. (2020, October 17). Retrieved October 26, 2020, from https://en.wikipedia.org/wiki/Ethane

Although the presence of propane and ethane in the atmosphere poses little climate change impact relative to methane, they still contribute to climate change burden through their combustion in stationary or mobile sources. The combustion of any fossil fuel results in CO_2 being emitted. Figure 4 shows emission factors (kg CO_2/scf or kg CO2/MMBTU) for the three gases.

While methane does not linger as long in the atmosphere as CO_2, it is initially far more devastating to the climate because of how effectively it absorbs heat.[19] Because methane is so potent from a climate impact perspective, and because there are solutions to control emissions, addressing methane can potentially be a very effective way to slow the rate of warming now.[20]

The GWP of various GHG's are constantly updated by the Intergovernmental Panel on Climate Change (IPCC) due to an increased understanding of climate change however, it becomes problematic when adopting mitigation measures or regulatory commitments based on specific GWP values, only to have those commitments modified by changing GWPs. For these reasons we will utilize the latest values published by the IPCC for the GWP of any gas and/or decomposition gases being calculated.

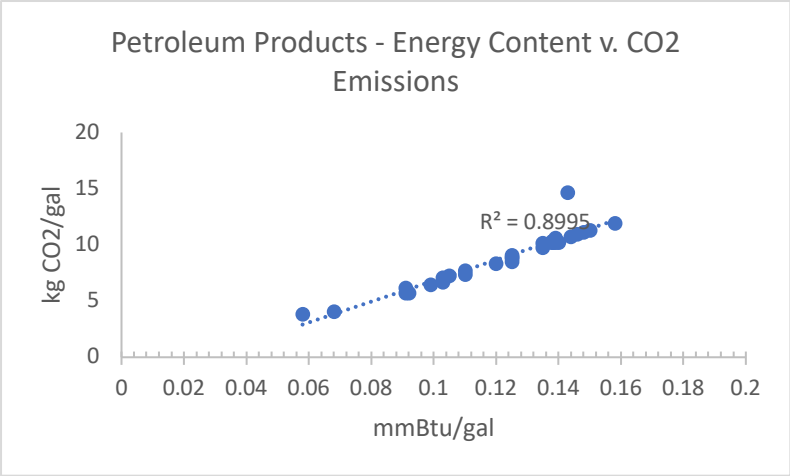
3. Combustion Generation of CO_2

Although not typically referred to when discussing climate change, the BTU content of a fuel is an indirect measure of climate change impacts. The BTU content of a fuel is a measure of its energy content. A fuel high in BTU content is desirable because it can deliver more energy per unit mass or volume than a lower BTU fuel. In reviewing the BTU content and CO_2 emission factors for the combustion of various liquid fuels, the BTU content is related to the CO_2 that is emitted when that fuel is combusted.

Below is a chart plotting BTU content versus CO_2 emission factor based on various fuels from EPA guidance. Other than the one anomalous data point (for petroleum coke), the results are very linear.

[19] Methane: The other important greenhouse gas. (n.d.). Retrieved October 23, 2020, from https://www.edf.org/climate/methane-other-important-greenhouse-gas

[20] Methane: The other important greenhouse gas. (n.d.). Retrieved October 23, 2020, from https://www.edf.org/climate/methane-other-important-greenhouse-gas



(**Figure 3**: Energy contact versus CO_2 emissions.[21])

Figure 4 summarizes the GWP, BTU content and CO_2 emission factors (kg CO_2/scf and kg CO_2/MMBTU) of methane, propane, and ethane from its combustion.

Gas	CO_2 Emission Factor (kg CO_2/MMBTU)
Methane	54
Propane	62
Ethane	57

(**Figure 4**: Greenhouse Gas Inventory Guidance, Direct Emissions from Stationary Combustion Sources, EPA, January 2016[22])

The next edition will address BTUs based on volume, supporting a result for future emissions that favor ethane and propane.

4. Greenhouse Gas Emissions from the Degradation of Each Gas

Although, each gas has a significantly different pattern for degradation and future impacts to the environment this category is considered minimal to the overall calculation. Therefore, as more information is made available we will continue to

[21] GHG Research Report. [Email Interview]. Chung, Albert. (2021, January).
[22] Greenhouse Gas Inventory Guidance, Direct Emissions from Stationary Combustion Sources, EPA, January 2016

research and improve the accuracy of our formula by including the degradation of each gas from a global warming perspective. We anticipate that this could be in the latter edits of this document. At this time, each gas will be allocated a 1 for the calculation associated with the degradation of the gas.

5. Additional Information on Climate and Environmental Impacts

5.1 Detrimental effect of methane released to the atmosphere: The impact of CH_4 on climate change has been well documented in this report. Methane is about 28 times more powerful than CO_2 at warming the Earth, on a 100 year timescale, and more than 80 times more powerful over 20 years.[23] The shape of a methane molecule is remarkably effective at trapping heat, which means adding just a small portion more of methane to the atmosphere can have big impacts.[24] Any given methane molecule, once it is spewed into the atmosphere, lasts about a decade before it is cycled out.[25]

5.2 Detrimental effect of ethane released to the atmosphere: Ethane is a GHG, but it is not present in the atmosphere in large amounts and has a very short lifetime, so its impact on climate change is minimal. Most of ethane's GHG potential is through its conversion to methane in the atmosphere.

5.3 Detrimental effect of propane released to the atmosphere: Liquid propane dissipates into the air if it leaks from its container.[26] Propane's lower carbon content helps make it a clean fuel source. As it burns, it also produces fewer tailpipe emissions than typical petroleum fuels. Propane cannot hurt water or soil because it is not toxic. When utilized it will reduce carbon monoxide, hydrocarbon and GHG emissions relative to conventional fossil fuels.[27]

6. Conclusion

[23] Thiessen, P. (2019, January 23). Methane, explained. Retrieved October 23, 2020, from https://www.nationalgeographic.com/environment/global-warming/methane/
[24] Thiessen, P. (2019, January 23). Methane, explained. Retrieved October 23, 2020, from https://www.nationalgeographic.com/environment/global-warming/methane/
[25] Thiessen, P. (2019, January 23). Methane, explained. Retrieved October 23, 2020, from https://www.nationalgeographic.com/environment/global-warming/methane/
[26] Lee, K. (2019, March 02). What Effects Does Propane Have on the Environment? Retrieved October 23, 2020, from https://sciencing.com/effects-propane-environment-16139.html
[27] Lee, K. (2019, March 02). What Effects Does Propane Have on the Environment? Retrieved October 26, 2020, from https://sciencing.com/effects-propane-environment-16139.html

In the Methane, Ethane, and Propane comparison as GHG research report, AT&V targets three main factors: life of GHG in the atmosphere, global warming potential (GWP), and GHG impacts generated from degradation.

Results include the following:

1. Ethane appears to have the lowest CO_2 emissions from combustion and will be studied in our next edition.
2. Life in the atmosphere is the main factor with propane at 3 weeks, ethane at 8 weeks, and methane at 624 weeks.
3. The three gases are similar in relationship of safety, reliability, and use for power generation.
4. If fugitive emissions are consistent from gas to gas ethane appears to the be the best choice when you consider the factors reviewed plus the CO_2 emissions from combustion.

AT&V has constructed a formula based on fugitive emissions. Emissions from combustion have not been considered within the formula due to the fact that methane, ethane, and propane are considered to have similar CO2 emissions when considering the BTUs consumed for combustion. The following formulas should help in determining your project's gas selection impact on global warming associated with GHGs.

Methane

[(fugitive emission for 1 yr.) x (volume factor) x half-life] + (decomposition gas value for 1 yr. x half-life of decomposition gas]) x GWP = project gas equivalent factor

Ethane

[(fugitive emission for 1 yr.) x (volume factor) x half-life] + (decomposition gas value for 1 yr. x half-life of decomposition gas]) x GWP = project gas equivalent factor

Propane

[(fugitive emission for 1 yr.) x (volume factor) x half-life] + (decomposition gas value for 1 yr. x half-life of decomposition gas]) x GWP = project gas equivalent factor

*Refer to The Definition of Terms, on page 13, for information needed in regard to the above formulas.

Although the formula presented does not address all variables required to calculate the project gas equipment factor it is important to note that those of significant impact, such as the volume adjustment, Life of GHG, and Global Warming Potentials have been incorporated. This should result in a clear environmental guide between the gases.

Each project, based on the specific project fugitive emissions, can have a different result because of the logistics of one gas from source to burner tip versus another. All things equal associated with the generation of fugitive emissions the conclusions show that propane may be the most environmentally friendly gas followed by ethane, and then methane trailing significantly behind the first two.

7. Contact AT&V

Future editions of this research report will address the following:

1. CO_2 generated from combustion.
2. Global Warming Potential (GWP) of each gas in more detail.
3. Carbon footprint associated with the infrastructure to support each gas.
4. Utilizing gas infrastructure in the renewable future.

If you have information or comments regarding this report please share them with our team at tanks@at-v.com.

Definition of Terms

Acidification – ocean acidification refers to a reduction of the pH of the ocean over an extended period of time, caused primarily by uptake of carbon dioxide from the atmosphere.

Alkane – organic compounds that consist entirely of single-bonded carbon and hydrogen atoms and lack any other functional groups.

Anaerobic - relating to, involving, or requiring an absence of free oxygen.

Anthropogenic – chiefly of environmental pollution or pollutants originating in human activity.

BTU – abbreviation for “British Thermal Unit”.

Degradation – the changing of a chemical compound to a less complex compound .

Distillation Tower (also known as a Distillation Column) - the distillation column is made up of a series of stacked plates. A liquid feed containing the mixture of two or more liquids enters the column at one or more points. The liquid flows over the plates, and vapor bubbles up through the liquid via holes in the plates.

Distillation towers/columns are used to separate products from one another.

Ethane Half Life – approximately 3 months.[28]

Fugitive Emissions – fugitive emissions are unintentional leaks emitted from sealed surfaces, packages, and gaskets, or leaks from underground pipelines resulting from corrosion or faulty connections.

Graphene – is an allotrope of carbon consisting of a single layer of atoms arranged in a two-dimensional honeycomb lattice.

[28] Ethane. (2021, February 16). Retrieved February 24, 2021, from https://en.wikipedia.org/wiki/Ethane#:~:text=CH4%20%E2%86%92%20CH3,3%20%E2%86%92%20C2H&text=On%20Earth's%20atmosphere%2C%20hydroxyl%20radicals,life%20of%20around%20three%20months.

Global Warming Potential (GWP) - refers to the total contribution to global warming resulting from the emission of one unit of that gas relative to one unit of the reference gas, carbon dioxide, which is assigned a value of 1.

Half Life - the time required for half of something to undergo a process: such as, the time required for half of the atoms of a radioactive substance to become disintegrated.

Methane Half Life – approximately 9 years.[29]

Non-caustic - an adjective and means that whatever is being described as non-caustic will not burn or corrode something else.

Photocatalyst - is a material which absorbs light to bring it to higher energy level and provides such energy to a reacting substance to make a chemical reaction occur.

Ppm – abbreviation for “parts per million”.

Propane Half Life – approximately a few weeks.[30]

Project Gas Equivalent Factor – is a factor used to convert a liquid volume to its theoretical gas equivalent volume.

The term Project Gas Equivalent Factor is used throughout this research report to compare environmental impacts of potential fuel gases.

Pyrolysis - decomposition brought about by high temperatures.

Sinks – are natural systems that suck up and store carbon dioxide from the atmosphere.

The biggest sink appears to be oxidation in the atmosphere, but some oxidation occurs in soils as well. The main sources are rice fields, wetlands, biomass burning, ruminants, landfills, natural gas production, and coal mining.

Ubiquitously - being present everywhere at once.

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[29] US Department of Commerce, N. (2005, October 01). Global monitoring Laboratory - carbon cycle greenhouse gases. Retrieved February 22, 2021, from https://www.esrl.noaa.gov/gmd/ccgg/trends/

[30] AV: Stig Bjørløw Dalsøren, G. (n.d.). Ethane and propane emissions have been underestimated. Retrieved October 23, 2020, from https://cicero.oslo.no/no/posts/nyheter/ethane-and-propane-emissions-have-been-underestimated

Volume Factor – an adjustment based on the heating value to equate each gas to another using the formula of 1,618 divided by the selected gases heating value at 60° F BTU/STF net value". This calculates the volume of gas utilized for the net power required realizing the fugitive emissions are a function of total cubic feet of gas processing.