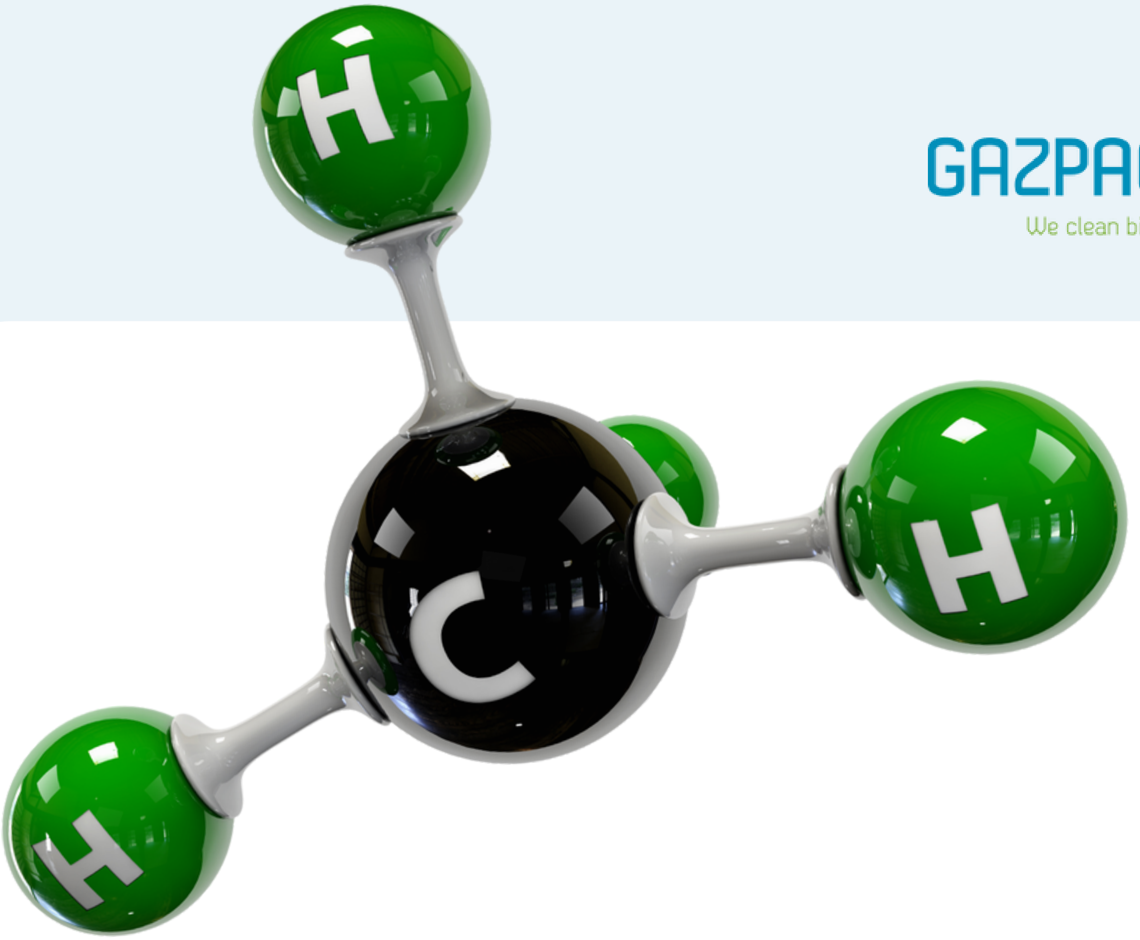

WHITEPAPER

Mitigating Methane Slip: A Pathway towards a Greener Future

METHANE SLIP

CH_4 slip is a significant contributor to greenhouse emissions. Europe's Sustainable Development Goals strike many as distant, particularly on the environmental side. However, the new resolve toward mitigating slip - including close monitoring, equipment enhancement and greater use of biogas - are the most promising avenues toward SDG fulfillment.

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CHAPTER 1: Introduction

Leaders of the European Union, on the whole, are satisfied with the progress toward the social and economic aims among their Sustainable Development Goals (SDGs). Less clear, however, is how well they are advancing toward improvements in climate and land use. Perhaps one of the greatest obstacles in the fight against greenhouse gases is the matter of methane slip. This term refers to the escape of methane (CH_4) that is intended for combustion as energy. Accidentally released into the atmosphere during storage, transport or usage, CH_4 is -- among greenhouse gases -- the second ranking contributor to global warming. In fact, the U.S. National Aeronautics and Space Administration (NASA) estimates that 20-30 percent of warming since the 18th century finds its origins in methane emissions.

Much of the time, this slippage affects CH_4 manifest as liquid natural gas (LNG) that fuels seafaring vessels. Other occasions of slip take place where methane is produced in the process of anaerobic digestion but has yet to combust in energy production. In addition, energy companies may engage in methane flaring that is part of the venting component of oil and gas production.

Whatever the source of CH_4 slip, its mitigation is essential toward achieving the European SDGs. The chapters below will further identify the origins of slip; the detrimental ecological effects; the policies and actions that governments and NGOs adopt to address the problem; the science and technology that diminish CH_4 slip; and a novel approach to the problem.

CHAPTER 2: CH_4 Slip and Its Environmental Impact

Of course, there are various ways methane enters the atmosphere. Current debates around bovine flatulence illustrate this fact. Meanwhile, emissions emerge from bogs and other wetlands as a natural occurrence in such biosystems. Still, human activity is one of the most significant factors and CH_4 slip is one such result. Although methane is far less prevalent than carbon dioxide (CO_2), its molecular contours fit the gas to be more damaging when it comes to binding heat to the lower atmosphere. Leaking out from untapped oil and gas alluvia or rising from melting permafrost, or even termite waste bear responsibility for the presence of atmospheric methane.

Yet CH_4 slip is a problem humans can and should address, especially since LNG use will increase in the coming years. CH_4 that slips from marine engines accounts for a small percentage of the LNG consumed but, given the greater environmental harm of methane, the subsequent emissions are more devastating than other gases like CO_2 or nitrous oxide (N2O). Indeed, CH_4 that escapes from maritime engines can linger in the atmosphere for up to 12 years, exacerbating the problems of climate change.

How, then, does slip happen?

he engine design; speed at which it runs; weight of the vessel and the kind of liquid natural gas all influence the rate of CH_4 slip. At any rate, the cause of slip is twofold:

- Fissures form between the cylinder units.
- Accelerated cooling, or quenching, in the combustion chamber leads to unfinished combustion of methane.

There is some irony here since liquid natural gas enjoys a strong reputation as an agent for lowering greenhouse emissions, especially among shipping vessels. Attesting to this fact is that 30 percent of new orders to shipbuilders in 2021 were for LNG-powered craft. In large part, the demand for LNG vessels stems from the 23 percent differential in greenhouse output compared to other fossil fuels. With all that said, the critics of LNG emphasize that such reductions are only in the cases of two-stroke, high pressure engines, and that other engines demonstrate a more equal generation of emissions.

The findings of a 2022 study published in the journal Environmental Science & Technology concluded that a freight carrier completing a round trip between the United States and Belgium experienced a 3.8 percent slip rate -- higher than the anticipated two percent - across all of the vessel's engines. Interestingly, most of the increased emissions over and above the usual average two percent find their source in the engines responsible for electrical generation.

Another observation was that slip was higher when the load, i.e. everything and everybody on board, was lighter. Such particulars might hold the key to achieving methane slip reduction. Given the potent impact of CH_4 relative to other gaseous emissions, these clues can lead to significant progress in attaining the European SDGs. The remediation strategies, namely replacing LNGs versus technological improvement, can hinge on where these clues lead.

CHAPTER 3: Policy and Regulatory Frameworks

Clearly, governments, the private sector and numerous international organizations the world over recognize the atmospheric and ecological repercussions of excess methane presence. In the United States, the Environmental Protection Agency recently adopted a new rule under the federal Clean Air Act. The rule aims at shrinking CH_4 emissions by 41 million tons by 2035.

There are two primary responsible parties to this rule: gas and oil producers on the one hand; state governments on the other. For the energy companies, mandates include creating and re-fitting new components such as vent pneumatic controllers. For states, requirements center on passing statutes that place limits on existing methane emitters.

The U.S. is not the only North American country to tackle CH_4 with a new resolve. Canada aims at arriving at 35 percent methane reduction in the atmosphere between 2020 and 2030. This policy will focus mainly on energy production facilities; farms and agribusinesses; and waste management including landfills. Gas and oil companies must, according to this strategy. review their procedures with regard to:

- **Venting** -- a necessary practice for efficient operation and safety
- **Fugitives** -- CH_4 emissions from unpanned leakage and/or equipment malfunction
- **Stationary combustion** -- where non-combusted methane can escape through the flaring process

As these units come under scrutiny, the goal is to upgrade their performance to allow less methane to emerge from a given production facility.

Recognizing the importance of all nation-states to make efforts at diminishing CH_4 emissions, Europe must nevertheless conform to its own SDG standards. In 2020, the European Commission adopted a methane strategy to push the continent further in the mission of restricting CH_4 emissions. Straddling multiple economic sectors, the strategy includes a number of tactics, most prominently the production of biomethane. In terms of regulation, the CH_4 strategy employs a newly rigorous set of guidelines for monitoring emissions by energy producers. In addition, the policy bans venting and flaring while simultaneously enforcing timely repairs and enhancements of components where leaks occur.

Another prong in the push to mitigate atmospheric methane is to stimulate the production of biogas. In essence, this is CH_4 that arises from the process of anaerobic digestion whereby organic materials -- deprived of oxygen -- break down chemically and eventually lead to a release of methane.

As a renewable natural gas, biogas CH_4 boasts carbon neutrality since the organic materials like manure, compost, dead vegetation and animal carcasses, for example, give off methane during decomposition. Biogas is increasingly present as an energy source for electrical grids and as a transportation fuel source as well. The European Commission (EC) announced an ambitious objective in 2022 for biogas and methane from biogas to reach 35 billion cubic meters in annual production by 2030.

In this way, the leaders of Europe hope to capture and refine CH_4 that is, in a real sense, pre-existing. In doing so, they add no new methane to the environment.

CHAPTER 4: Mitigation Strategies and Technologies

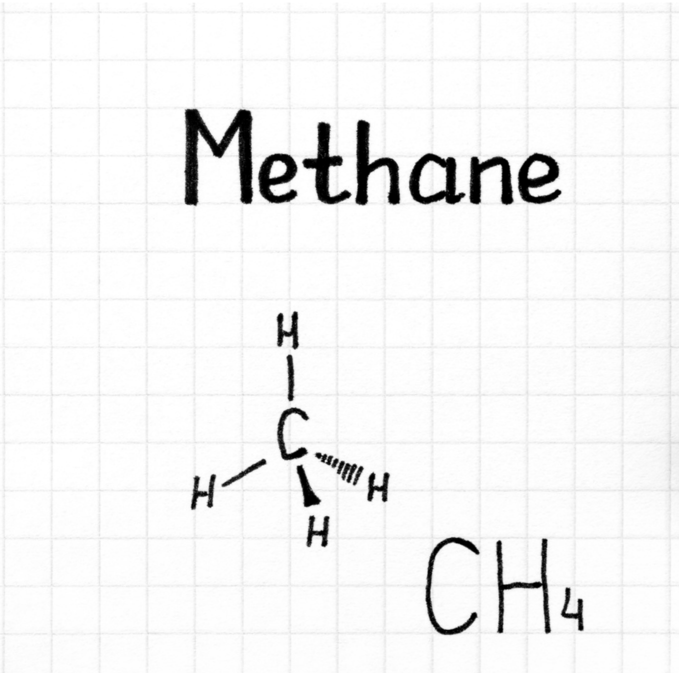
There are a number of ways in which energy producers can blunt CH_4 slip, particularly aboard ships. Among the strategies are:

- **Adoption of electrical compressors** -- Compressors accumulate natural gas and activate its flow. They are also where slip is quite common. However, replacing LNG-fired compressors with electrical compressors precludes the probability of slip at the point of compression, and makes it less likely in other engine components.

- **Modify compressor starters** -- Compressor starters activate both primary and auxiliary engines. These, too, often rely on LNG power where the gas swells and is then vented. That, however, is not the only option. There are also starters that run on electricity and still others that operate pneumatically where air expands as LNG would.

- **Upgrade Compressor Cylinder Unloaders** -- This part provides a way for air confined in the compressor tank to escape, allowing the compressor's motor to reactivate. In other words, accumulated pressure inside the tank prevents the compressor from starting. Yet O-rings, covers and pressure packing each allow for methane leakage in existing unloaders. Replacing these more frequently shrinks the likelihood of CH_4 emissions through these components.

- **Regulate the air-to-fuel relationship** -- The ratio of air to fuel is variable according to need. Speed and loads may demand more horsepower. Under such conditions, a "rich burn," or low air-to-fuel ratio is optimal. When better fuel efficiency is the aim, a high air-to-fuel ratio -- i.e. a "lean burn" -- helps to achieve it.



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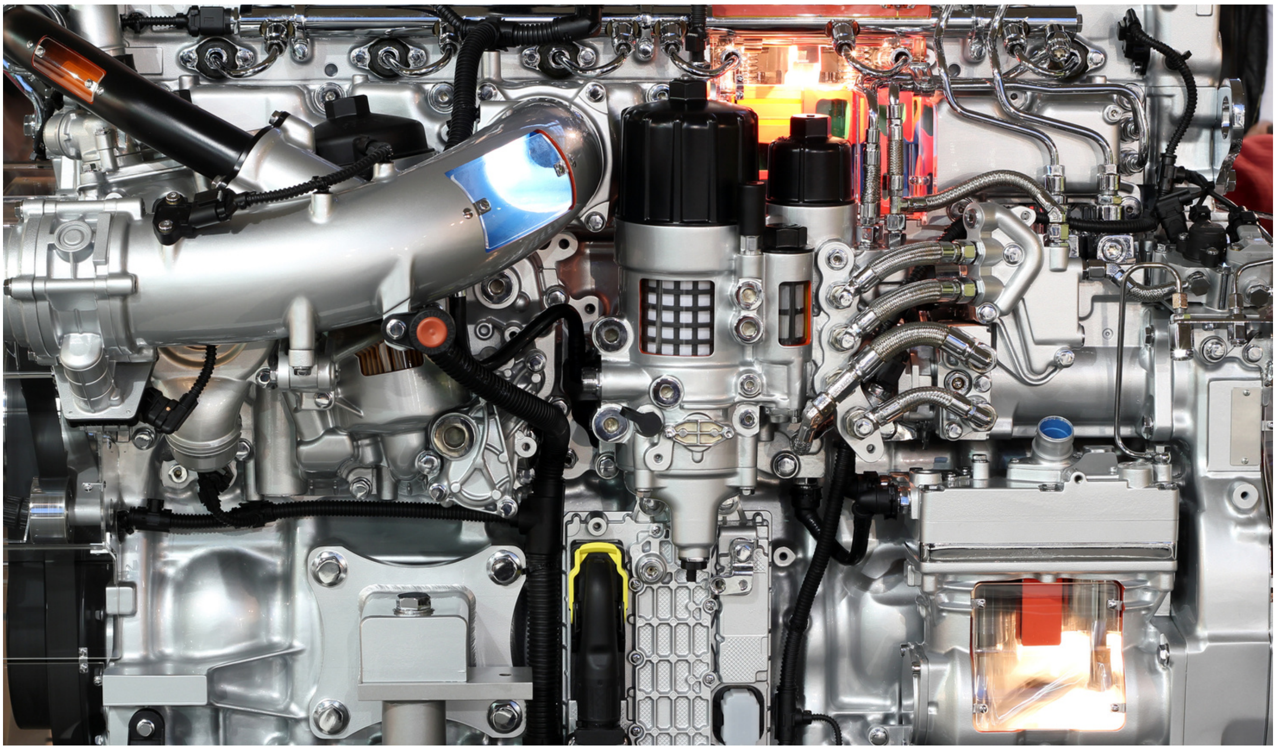
- **Make Gathering Lines More Efficient** -- The volume of liquid natural gas traveling from wells to processing facilities often lacks consistency. This is due to the fact that the gathering lines suffer numerous impacts -- adverse weather, hydrate accumulation and variable LNG composition. In order to minimize the need or flaring, the capacity of these lines should grow. Clearing them of hydrate accretions and liquid accumulation is essential for them to operate at their highest efficiency levels. Chemical injection and heating are two such methods for keeping lines clear.

- **Replace Hoses with Fixed-Arm Conduits during Bunkering** -- Bunkering occurs when LNG is pumped into a marine vessel for use at sea. This procedure can only take place after residual gases are inerted and purged. The source point for new LNG can be a terminal, a tanker truck or another ship. Often, though, hoses are the conduits of choice for LNG bunkering. These are more susceptible to leakage than the more solid fixed-arm channels.

Wind-aided propulsion systems, batteries and fuel cells are also viable alternatives. Each of these remedies commands either a better design or more rigorous maintenance with regard to LNG infrastructure. As noted above, nevertheless, there are voices within the environmental and energy communities that fix the blame for the consequences of CH_4 slip and other accidental emissions in the LNG itself. They consider biogas a safer and more abundant option.



Chapter 5: Gazpack's Biogas Upgrading Solutions

There are reasons biogas has its champions. Among them are:

- Biogas is sustainable in that it is plentiful and serves as a substitute for fossil fuels
- Biogas optimizes waste management by converting large amounts of waste product into useful energy.
- Extracting fossil fuels from the earth releases CO_2 whereas biogas is carbon neutral because the organic matter was absorbing CO_2 during the life cycle.
- Biogas is more immediately available to users than are other green energy forms like solar and wind power.

Innovative companies -- Gazpack among them -- find value in these claims. Accordingly, they set out to overcome the CH_4 slip repercussions by utilizing a cleaner renewable fuel. Using Gazpack as an example, this 17-year old company pursues a mission to cleanse, or sweeten, biogas and geological oil gas.

This treatment involves the removal of Hydrogen Sulfide (H_2S), Carbon Dioxide and other trace compounds that hinder biogas efficiency and damage fuel lines. Based in The Netherlands, Gazpack was founded to address the problem of gaseous emissions from oil flaring. The firm later applied its patented sweetening to biogas as well. Purified biogas is bio-methane.

A side-by-side comparison of biogas and natural gas demonstrates that biogas is more environmentally benign. Its applications are versatile, from vehicular fuel to electrical power and heat generation. According to the International Council on Clean Transportation, the exclusive use of geological natural gas in marine vessels will lead to a 30 percent increase in methane emission by 2030. Within that same decade, the use of exclusively renewable natural gas would see increases of only 20 percent.

Furthermore, biogas is available much more quickly than is natural gas and its production does not damage the local ecosystems either. A combination of greater biogas employment and the mechanical/technological adjustments outlined above could decrease emissions even further.

For over a century, biogas was an energy source for heat and cooking in homes and villages. As it now assumes a greater role in power grids and public transportation fleets, its storage and movement is of greater ecological concern. Gazpack's mission is to provide a pure and clean product that is scaled according to need. Consequently, it offers businesses technology to upgrade their own biogas.

Flexibility is important. Such technology should accommodate larger amounts of gas, if necessary, and remove greater volumes of H_2S and CO_2 in the process. The bio-methane it yields should enjoy a high purity level, making the product easily injectable into the gas grid. Moreover, the capture, liquefaction and storage of CO_2 can offer another revenue stream since there is a demand for this by multiple industries. At the same time, operational facilities and terminal locations come in differing sizes so high-capacity systems may be cost-ineffective. A simpler model can perform the same three functions: H_2S cleansing by means of quenching; CO_2 capture; and grid injection. The difference lies in the scale to which a purification system is designed.

The creation of biogas through anaerobic digestion occurs in three stages:

- Acidogenic bacteria -- sugars and amino acids convert to hydrogen, CO_2, ammonia and organic acids.
- Acetogenic bacteria -- those organic acids further break down into hydrogen, ammonia and CO_2.
- Methanogens -- the predecessor compounds and elements yield NH_4^+ and CO_2.

Yet combustibility, safety and economy are compromised by the H_2S, H_2O and CO_2 that remains in raw biogas after methanogens. On the other hand, purifying technology adopted by Gazpack cleans raw biogas so exhaust is relatively free of toxic particles. Moreover, it diminishes the CO_2 presence, repurposing it for destinations other than the atmosphere. H_2S, also, undergoes a sulfur extraction process; sulfur has multiple uses when released from this compound. Forward-looking companies like Gazpack not only shoot for the cleanest bio-methane; they continuously find new applications for anaerobic digestion substrates and previously discarded upgrading process by-products.

If CH_4 slip is reduced by means of legislation and policy; monitoring and regulation; and technological advancement, then EU SDGs come that much closer to fruition. Yet if CH_4 is more combustible and -- when emitted -- does less ecological damage, the SDG goals will be realizable and, perhaps, achieved. Gazpack technology centers on this future.

Conclusion:

CH_4 slip is a significant contributor to greenhouse emissions. Europe's Sustainable Development Goals strike many as distant, particularly on the environmental side. However, the new resolve toward mitigating slip - including close monitoring, equipment enhancement and greater use of biogas - are the most promising avenues toward SDG fulfillment.

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