Too Small to Collect but Too Large to Ignore

Converting Methane Emission from Distributed Sources to Useful Energy

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Qnergy

Introduction

Methane as a greenhouse gas (GHG) is second only to CO_2 in human-caused impact on climate. Yet despite being number two, solving for methane emissions is step one in any effective strategy to combat global climate change. The rationale is simple; on a per mass basis, over the first 20 years of its emission from any source, methane traps 84X more heat per unit mass than CO_2. Yet solving for emitted methane is both difficult and easy. It is difficult because methane is a product of natural degradation and thus readily generated everywhere there is an organic waste stream to feed it. And we are surrounded by waste. The problem is as distributed as the many sources of methane forming feedstock, and thus not solvable by conventional, centralized thinking. It is easy, because unlike CO_2, methane is a fuel, and with the right technology can be converted into useful energy at the source of its generation.

The potential and challenge of methane today is perhaps best illustrated by the natural gas industry itself. As the most environmentally friendly fossil fuel, it has proliferated, providing >20% of global energy needs today. This most useful molecule requires a sprawling infrastructure to go from discovery to production and delivery, and in the race to scale incurred almost inevitable tradeoffs in efficiencies. Today the leading sources of distributed methane emissions in the natural gas industry occurs through both purposeful venting and fugitive emissions (i.e., leaks). A case in point is the estimated 0.5 million methane venting pneumatic valves controlling well feed pressures, many far from the electrical grid, scattered across the United States. Each emits relatively small amounts of methane, but taken together, emit the equivalent of 45 million tonnes of CO_2e each year: equivalent to the output of 10 million cars on the road per year. Pneumatic valves, until now, have been the go-to solution for gas pressure regulation at well pads remote from any external energy source, i.e., the grid. Utilizing technology that directly harvests energy from the methane itself to produce instrument air, replaces natural gas as a source of pressure in pneumatic valves is now possible, straightforward, and represents a potential 20% reduction of the total methane emissions from the natural gas industry.

But methane release from the natural gas industry is just part of the story. As we'll see, methane is everywhere because of its ability to be generated anywhere from organic waste streams. A world expected to add an additional 2 billion people to its population over the next 25 years has critical need for smart, effective, circular use of both organic resources and energy. Being both a product of a growing world's organic waste streams resulting from food production, consumption, and waste, and subsequent handling in landfills and wastewater, and a useful source of energy that helps bring those goods to market means that thoughtful and purposeful methane management has a crucial role to play now and in our future.

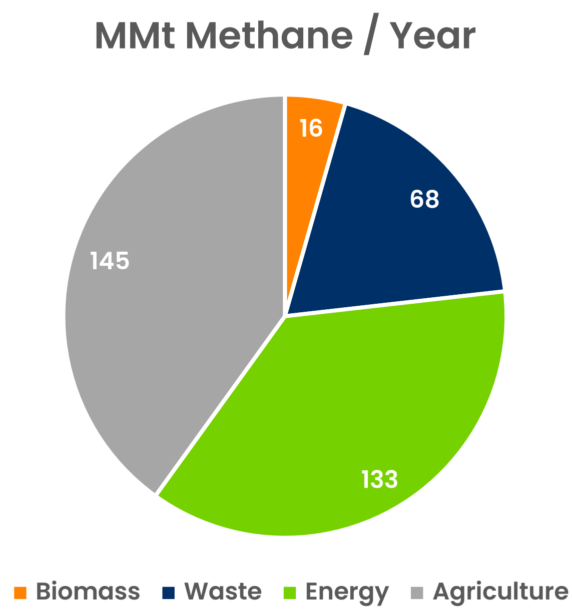
With methane sources growing everywhere, the challenge is truly global, and the timing is now to solve the challenge of distributed methane, both source and use. This is attested to by the more than 111 nations, since the global COP26 summit in November 2021, that have signed the Global Methane Pledge to help combat methane emissions.

Sources of Methane: Varied and Distributed

Because methane is a very useful biological molecule, nature has evolved very efficient mechanisms, namely anaerobic digestion, to create methane from virtually all sources of organic waste, including fossil matter. Hence its generation occurs everywhere there is an organic waste stream, e.g., wastewater and waste food streams from homes, industrial kitchens, food product companies, restaurants grocers, bakeries, municipal landfills, livestock and crop farms, and aquaculture.

Methane is, and will continue to be, a useful fuel, produced in nature through biological systems and tied to human activities. The key to managing methane is to find the right go forward strategy for capturing and utilizing methane effectively, which ultimately is at the source of its generation. The graph below derived from the IEA's 2020 Methane Tracker shows just how large and varied the sources of methane emissions are today.

Each year, 360 MMt are emitted into the atmosphere through a variety of anthropogenic activities, namely energy, agriculture, and organic waste.



Source: IEA

This annual 360 MMT of methane X 84 (the acknowledged warming potential of methane over CO_2) is 30 billion tonnes of CO_2 equivalents (tCO_2e), or equivalent to twice the number of cars on planet Earth today. With this realization, the energy industry is rapidly mobilizing to reduce their portion of methane released into the environment, a significant and good development. It is important to note that while the Energy industry's supply chain is today responsible for more than 133 million metric tons of annual emissions in its pursuit of oil and gas, it is surpassed by methane generated by the daily activities of food production, manufacturing, and consumption, activities necessary for a growing world population, the waste of which ends up as materials in centralized landfills and wastewater.

It is also important to note these numbers represent largely *passive emission* of methane. These sources will continue to emit methane over time until its carbon deposit is exhausted or methanogenic activity inhibited. The growth of organic sources (farms) and the addition of waste from each distributed generation source (residences, restaurants, institutions, food processors) or sink (landfills and wastewater) every day only adds to continued growth of methanogenic potential.

These 360 million tons of anthropogenic methane, methane produced through the combined global daily actions of living, thus represents a tremendously large opportunity to capture and create useful heat and energy while reducing a significant portion of greenhouse gas emissions. In addition to environmental aspects, given today's natural gas prices, passively released methane represents more than $100B in uncaptured fuel potential. How are we to address this challenge and capture this opportunity?

The first part of the solution is to reduce waste. However, while waste reduction is important and necessary, it is not sufficient for a growing world with increasing dispersed and distributed demands.   It is at best one half of the solution. The other half of the solution is the deployment of new and innovative ways to convert waste or byproducts into useful outputs.

Traditional, centralized methods of dealing with waste has been to simply aggregate and deposit waste to decay over time in spaces like landfills. This approach tolerates inefficiencies for expediency and urgency.   Agricultural waste, food waste, and water waste, decay and emit methane over time, sometimes many years and decades. Building ever larger infrastructure to handle waste from growing cities only creates further challenges in transportation, logistics, energy, carbon footprint, and eventually, remediation, and all associated costs thereof.

However, with the purposeful application of the right technologies, the amount and speed by which methane can be abated, i.e., captured and harvested for energy to power our economy is enormous. But to get there we need to transition our thinking from large scale, centralized, controlled containment, to at-the-source, *in situ,* distributed capture and use if we are to truly achieve efficient circular economies.

Indeed, many cities and municipalities are themselves already reaching this conclusion. To tackle part of the 2 billion metric tons of trash (and growing) going into global landfills every year, cities like San Francisco and Boston are actively moving to ban food waste into landfills to decrease both overall waste and methane emissions. According to the Pew Foundation, more than 52 food waste management bills in 18 U.S. states were introduced in 2021. This momentum will only increase with mounting consumer concerns about the environment, food, and energy waste. The inevitable solution is to begin dealing with organic generation of methane emission at its point of generation, whether at the oil well production pad, the farm, the factory, the home, the landfill.

These massive waste streams, stemming from both global growth and rising incomes, presents, as mentioned before, both a problem and an opportunity. Problematic is the long-term potential of these multiple sources to continue emitting methane passively into the atmosphere, which will inexorably increase year over year with continued inputs. The opportunity is the tremendous energy these distributed sources represent if we could technologically harvest them, as close to their source of generation as possible, e.g., as the energy industry is doing at the well pad, through smart municipal waste stream separation, mitigation and mining of existing landfill and wastewater streams for methane, finally, anaerobic digestion, to actively convert remaining carbon waste streams into useful methane for heat and energy.

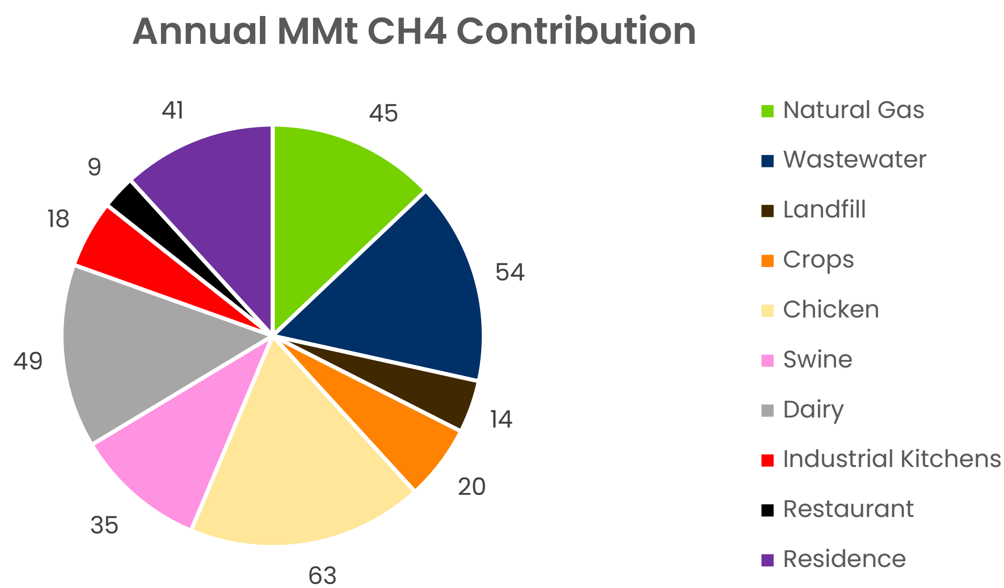
The ability to productively harvest and utilize this energy as close to the point of methane generation as possible accomplishes three significant objectives:

- It significantly mitigates methane emissions
- Creates a tremendous new source of distributed energy
- Moves us closer to achieving a circular economy through smaller, faster loops

Our waste problem constitutes a fundamental challenge to global growth and requires a new way of thinking and solution.

The Paradigm Shift: Distributed vs. Centralized Thinking

As noted above, methane is a natural output of daily and industrial spanning across the activities of living that occurs through organic waste streams and the production of natural gas. It occurs in food production, energy generation and the energy used to produce and deliver that food, and in the preparation, delivery, consumption of that food. Methane generation is as distributed as life itself. We therefore define the methane challenge as one that is fundamentally distributed in its nature.



The graph above depicts our breakdown of the IEA numbers of annual distributed methane from the natural various food supply chain sectors less biomass burning. What we see from an energy and organic production and use perspective is that all of us contribute to methane generation in one form or another. Hence all must be concerned with more effective methane management.

Likewise, we now know that the potential to create and emit methane occurs everywhere there is a point where new or old[1] organic waste is released into the environment. We need to also understand how and why methane is passively released by the activities in each sector. The estimated 133 MMt of methane emitted each year because of oil and gas production is a case in point. Exploration, discovery, and production in pursuit of finding the largest reserves of energy often takes place in areas far flung from the energy grid. Centralized, economies-of-scale thinking has led

[1] Natural gas is 'old' organic waste

to large and cost intensive infrastructure projects to collect, process, and deliver that energy. While this has been tremendously useful in the past, viz., delivering energy to a growing world, it has not been without its consequences.

This pattern is precisely what we have repeated and done in all other areas of our materials and energy ecosystem. The symmetry is striking. Large infrastructure projects pursue the collection of urban and industrial waste into centralized, large scale waste treatment facilities (WWTF) and landfills. Instituted and built many years ago, prior to the realization of fugitive methane's GHG threat potential, many WWTFs and especially landfills, either passively vent methane into the environment, or as a stopgap measure of expediency, simply burn or flare the emitted methane, losing a valuable opportunity to create useful energy.

It is worth noting here that the world needs to radically shift its stance on flaring as an expediency to releasing methane into the atmosphere. In oil production where gas is a minor component, flares are often used to burn methane to avoid the cost of capture and delivery to market from remote fields. Flaring in landfills and WWTFs follow the same expediency-based thinking. But alternative technologies and approaches exist today and hence the world needs rethink its stance to flaring of this valuable resource.

To slow the growth of centralized thinking and the problems it engenders, and to stimulate distributed solution thinking, governmental agencies like the EPA actively regulate the number of new landfills, and many cities and towns are drastically increasing their tipping fees, or what they charge businesses and residences, to dump waste into landfills, with some moving to outright bans. However, these actions, while necessary, are primarily reactive in nature and stopgap in solution potential and therefore require the smart application of technology to complete the intended circular loop. Thus, the trends at this moment in time converge towards a significant opportunity to rethink our centralized approach to everything; to think distributed; agile, at the source or edge of centralized systems, i.e., small, *in situ,* low cost, efficient solutions to capture, convert, and harvest natural methane, viz., the distributed solution paradigm.

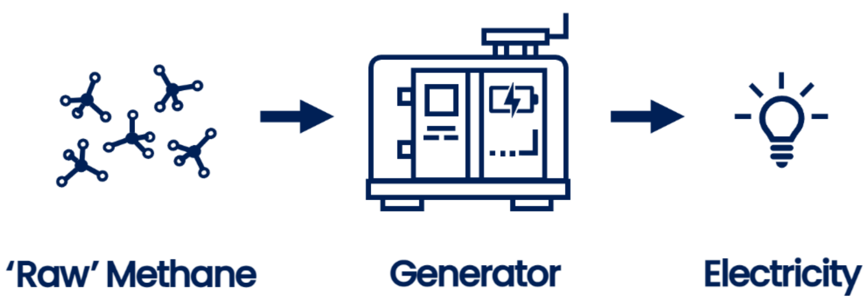
What this means is new technology platforms that enable the capture and use of waste at the very source of its generation; bypassing large, expensive, centralized infrastructure with all its potential points of inefficiencies, and creating a positive feedback loop to the producer/consumer of that methane generating organic stream, i.e., produce, food, manure, wastewater.

Capturing methane as organic byproduct and converting it into useful energy *"in-situ"* can be done at multiple levels. It will not be large scale, one-size-fits-all, but rather form factored to fit the source of generation, be it a farm, a grocery store, a bakery, a home, a food processing facility, or a restaurant. Therefore, the footprint and power requirements for conversion will match the use case appropriately. A large unmet need that we can envision is for generators in the 1-10kW energy range that effectively utilize small amounts of generated methane in the order of 500-5,000 standard cubic feet (scf) of methane per day. For simplicity and cost, it should be maintenance-free and work with any type of unrefined methane, from raw unrefined natural gas, to landfill methane, and bio-digested livestock manure.

This is the Qnergy way, our pursuit, and our solution to the challenge of distributed methane.

A Distributable Solution: The Qnergy Platform

Qnergy is dedicated to solving the distributed methane challenge. Our company produces power generators based on our proprietary free piston Stirling engine technology designed to capture and convert methane into productive heat and electrical power from virtually any methane source, requiring no special enrichment or treatment, making it useful across a wide range of potential applications.



As an *external* combustion engine, it requires no lubricants and due to its design, virtually no maintenance over its designed 80,000 hour (10 year+) life cycle, and therefore has extremely low system maintenance cost. As it converts available methane (or any gaseous fuel, e.g., propane) into electricity, it serves as an *in situ* energy platform to power any range of devices from sensors to lighting to air compressors, to cathodic pipe protection; anywhere methane is found and generated, whether a well pad in an oil field, a dairy farm, a wastewater facility, an industrial kitchen or a home.

As a generator, the Qnergy solution solves a critical bottleneck problem; namely that conventional internal combustion engine (ICE) generators that utilize methane require very clean methane as well as frequent and costly scheduled maintenance to operate while generating exhaust pollutants due to incomplete combustion i.e., NOx, CO, and methane itself. Traditional ICE generators are thus not conducive to solving methane either at the source, e.g., the methane that comes out of the ground in natural gas wells or from organic waste streams like crop and food, or animal manure, or are non-clean [mixed in with other gases] as well as with sites of generation distributed over large distances.

Qnergy solving in the field distributed problems in natural gas

In the case of natural gas, Qnergy's engine serves as a power platform to drive air compressors configured to meet local power needs and completely replace methane venting for power. Because clean, compressed instrument air replaces methane, and because our electronic control system measures inputs and outputs to optimize system performance, a real time read out of how much methane is being replaced or abated is available to our customers and clients for measurement and reporting. Our rugged, reliable, and proven technology platform assures years of maintenance free runtime. To date more than 80 energy customers have placed over 700 of our instruments in the field as a core part of their strategy to achieve methane abatement.

80+
Customers

40,000+
Maintenance-free hours
from earliest installed engine

150,000+
Tons of CO2e abated in 2021

700+
System Installs

10,000,000+
Accumulated engine hours

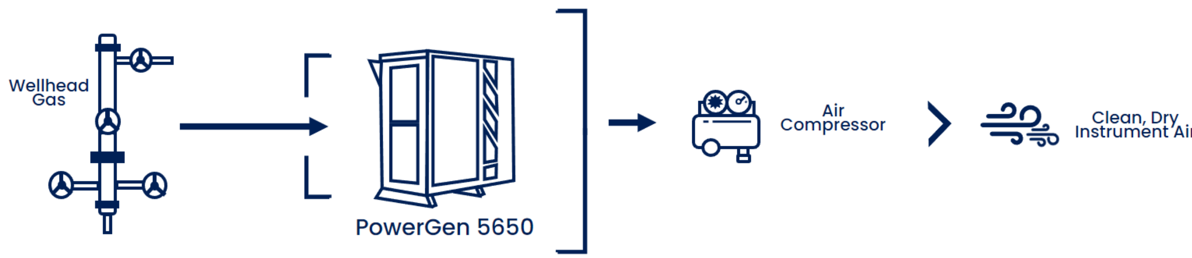
$1 / tCO2e
Abatement Cost

What follows are two case studies which further illustrate our point of view and solution.

Case Study: TotalEnergies

Recognizing the necessity to apply technology solutions to address distributed methane in the energy industry, members of the Oil and Gas Climate Initiative, all major producers of natural gas , have recently pledged to aggressively reduce methane emissions to near zero by 2030.

The lowest abatement cost solution after leak detection and repair, is replacing methane as a source of pressure in pneumatic devices with compressed air. The solution takes advantage of the fact that unprocessed and unrefined methane can power alternatives such as compressed instrument air as a replacement to methane itself as a source of pneumatic pressure.



TotalEnergies is a super major oil and gas multi-national Fortune 50 company with 2020 sales of $140B and operations in 130 countries. In the U.S., Total is a major player in the Barnett Shale with over 1,500 wells in operation. As part of its pledge to achieve carbon net zero across global operations by or before 2050, Total sought a solution that could eliminate venting in its Barnett gas field operations. A 30-day trial worth Qnergy proved a **98% reduction** of onsite methane emissions. Based on the strength

TotalEnergies

of the Qnergy solution and operating performance, Total has placed an order for 100 units with an option to purchase an additional 300 units. Measured data thus far indicate that these 400 units once deployed will deliver over 7,000 tonnes of methane abatement per year.

A follow-on benefit of our system, as shared by other customers with Qnergy, is that once our solution is installed, our proprietary web-based application *SmartView™* which monitors the system performance and air consumption, enables them to see and measure decreases in methane as they repair system leaks upstream of the Qnergy system, as the amount of consumed compressed air changes with each repair, thus creating a record of measurement, maintenance, and repair.

Case Study: Biogas Generation on a Pig Farm

In partnership with Sistema.bio, Qnergy has successfully implemented our solution for a farm in Mexico to capture and convert methane from swine manure. Prior to implementation, the farmer had been threatened with fines of up to $80,000 for polluting the local river and creating environmental and public health hazards. Combining our PowerGen 5650 Stirling engine energy platform with Sistema's anaerobic biodigester, the farmer is now:

- Generating 120 kWh/day of clean power back into his operations, reducing cost
- Removing most of the methane emissions from his farm
- Mitigating the risk of fines and penalties
- Converting the manure mass into useful fertilizer for surrounding farmland.

Figure: Qnergy's PowerGen 5650 system generating power from methane on a pig farm in Mexico. The future of circular material and energy on the farm.

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CREATING VALUE FROM WASTE

Summary and Conclusions:

Methane is a big and distributed challenge and opportunity.

Successfully capturing and converting distributed methane prior to release into the atmosphere is one of the biggest opportunities for reversing impact to the environment, and as such, an extremely large economic opportunity as well. Precisely because methane is such a useful molecule, nature is highly effective in anaerobically generating methane from any organic source or waste stream. Rather than strictly seeing methane merely as a GHG to be mitigated, we need to also see it as a way to harness energy from many processes. We need to evolve a new way of thinking and technologically addressing the distributed nature of methane throughout its many production streams. A truly global solution therefore needs to be fundamentally distributed in nature instead of our traditional reliance on highly centralized, costly, large transport and infrastructure approaches, which to date have been inefficient in capturing and converting methane.

This will require smart, small format solutions, capable of taking various forms of distributed methane and converting it into locally useful electricity and heat. Such a solution will be a platform to power a circular economy of materials and energy at, or close to, the point of methane emitting material generation, whether natural gas, manure, food waste, wastewater, home, business, or industrial waste.

The Qnergy solution provides such an energy platform that productively utilizes methane at its source and can be connected into a wide range of devices requiring power and/or heat, from pneumatic devices in distant gas fields to emitted methane from legacy landfills to digesters on farms, kitchens, and residences.

For more information on distributed methane solutions, contact us at:

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