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Qnergy Methane Abatement Program and The Inflation Reduction Act

What does it mean for the natural gas industry?

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Abstract

Preventing methane leaks requires power. Where methane is found, Qnergy produces that power. Qnergy's power solutions are based on a unique modification of the Stirling engine called a 'Free Piston Stirling Engine' it is a linear engine design, with no rotating parts, no lubricants, and the ability to run for years with zero engine maintenance, even in extreme environments, and delivers a proven industry leading methane abatement solution. Given prevailing natural gas prices, Inflation Reduction Act (IRA) specified penalties, and voluntary carbon credit generation, the Qnergy solution can be implemented at a negative marginal cost. This remarkable cost to performance dynamic takes Qnergy into the realm of a best system for emissions reduction (BSER), as defined by the EPA, for abating methane emissions from pneumatic devices. The strong cost to performance attribute of the system also breaks down barriers to methane abatement in other sectors. This paper reviews how this US-based innovation helps the industry achieve the ambitious GHG reduction as well as the broad environmental justice targets set by the IRA.

Introduction

Methane is second only to carbon dioxide (CO_2) in contributing to global warming. It has now been almost 10 years since the report by the International Protocol for Climate Change's fifth working group indicated that atmospheric methane has an 84X greater warming potential than CO_2 over its first 20 years.[3] Since that time, concerns over methane contribution to climate change have only grown.[4] We therefore need to aggressively address methane emissions as our primary strategy to achieve the IPCC recommended goal of containing global warming within 1.5°C. This mounting recognition is galvanizing action to contain methane emissions across the globe.

According to the International Energy Association (IEA), anthropogenic emissions of methane across all industries totaled more than 360 million metric tonnes (MMT) in 2020, with 133 from the energy industry.[5] With rising global population and rising incomes this number can only increase without active mitigation. The challenge is, as the IEA points out, that the sources of methane are many and varied. **Figure 1** shows the distribution of attributable methane sources.

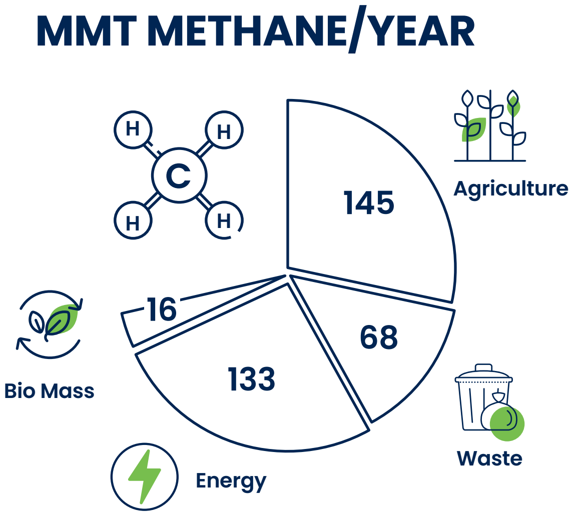


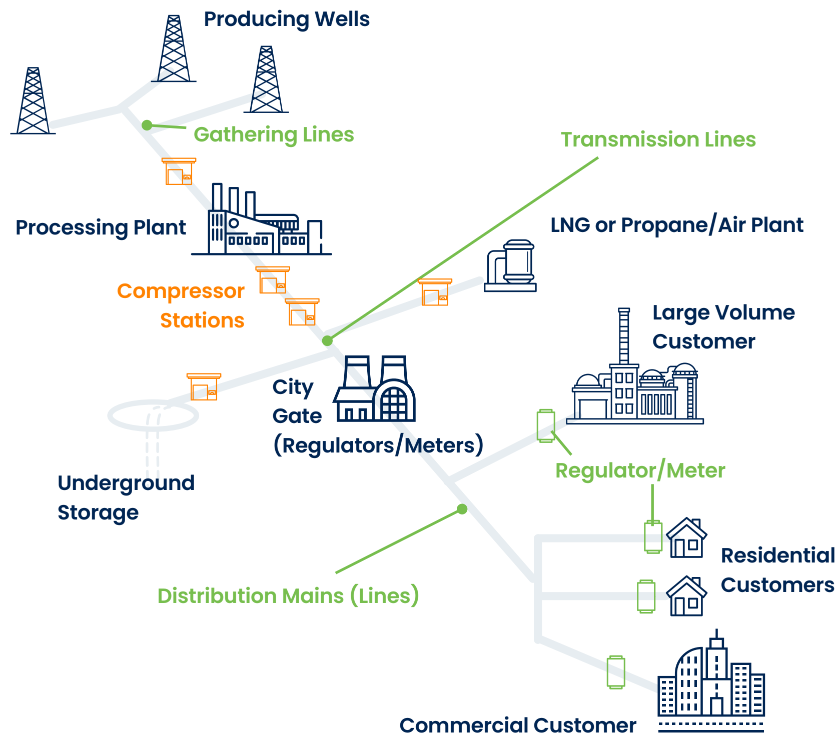
Figure 1. Global MMT of anthropogenic methane emitted per year. Adapted from IEA 2020 Methane Tracker.

3 Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

4 Scientists raise alarm over 'dangerously fast' growth in atmospheric methane. Nature February 8, 2022

5 IEA Fuel report-March 2020: Methane Tracker 2020; https://www.iea.org/reports/methane-tracker-2020

The natural gas industry with its vast sprawling infrastructure covering more than 1.7 million oil and gas well sites and 2.6 million miles of pipe in North America alone, releases methane along any number of points of production, processing, and delivery. **Figure 2** illustrates the natural gas infrastructure, along which at any point methane can and is released.



Production
- Pneumatic Controllers
- Gathering/Boosting Stations
- Tanks
- Chemical Injection Pumps

Gathering and Processing
- Reciprocating Compressors
- Centrifugal Compressors
- Gas Engines
- Blowdowns/Venting

Transmission
- Reciprocating Compressors
- Station Fugitives
- Engines
- Pipelines

Distribution
- Mishaps (Dig-ins)
- Residential
- Mains - Unprotected Steel
- Services - Unprotected Steel

Figure 2. Illustration of natural gas infrastructure (Source: AGA and EPA) Pneumatic valves and controllers are used throughout the natural gas pipeline. Fugitive methane is found throughout the entire process from production to processing to transport and final delivery. The central goal is to remove all methane venting throughout the entire supply chain of natural gas, i.e., zero methane loss.

Methane emissions occur in two major ways. The first, termed, “fugitive emissions,” occurs through random leaks due to equipment failure and human error. The other predominant avenue is through purposeful venting of gas, predominantly through pneumatic controllers (**Figure 3**) often used in remote, off-grid areas. Fugitive emissions require leak detection and repair (LDAR) technologies to detect, visualize, and pinpoint random leaks expected to arise from such massive infrastructure. Purposeful venting, however, is known, and requires new technologies to replace “last generation” methods for controlling well pad and pipeline pressure.

Intent and impact of recent legislation for methane abatement

The Inflation Reduction Act (IRA) sets the framework for an unprecedented reduction of greenhouse gas (GHG) emissions in the U.S, targeting a 40% reduction from 2005 GHG levels by 2030.[6] Estimated at over $370B in spending ($500B including tax credits) between 2023-2031, fully $116B of the $150B in new direct along a wide range of climate focused areas.[7] At least $1.1B targets the energy industry in the form of grants, rebates, contracts, and loans to invest in climate technology specifically for methane abatement. A breakdown of this spending can be found in **Appendix A**.

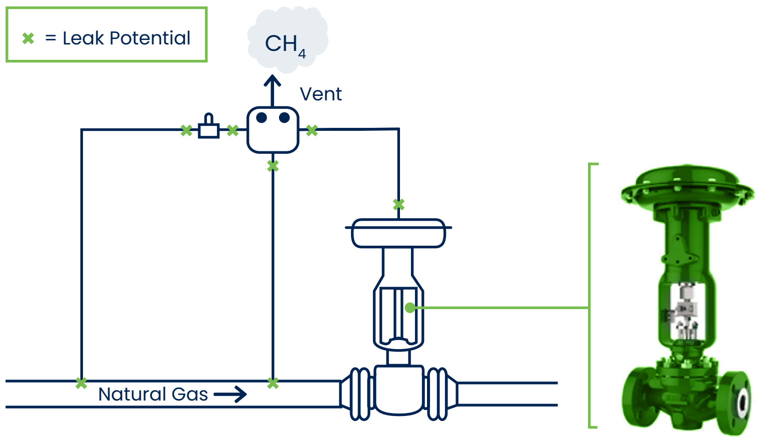


Figure 3. Depiction of the pneumatic controller challenge at oil and gas well pads. Historically, purposeful, passive venting of methane as the source of power for pneumatic valves was the method of choice for wells far from the electrical power grid. Left is system schema; right is example of a pneumatic valve. Substituting natural gas with input dry instrument air via compressed air system eliminates methane venting while maintaining proper pipeline flow, pressure, and liquid levels.

A central target is ensuring methane emissions abatement within Natural Gas (NG) production and transmission, while promoting U.S. climate related innovation. In doing so the bill recognizes the key climate role that methane plays,[8] and the need for urgency and primacy of strategy in methane abatement to attain climate goals. It further recognizes the very distributed nature of methane emissions through the spending bill's targets; existing and abandoned and orphaned well pads, leaky transmission pipes, and other methane emissions from sources of biogas, which come from entities such as farms, landfills, and potentially wastewater treatment facilities.

Focusing on the U.S. energy industry is relatively low hanging fruit; since methane release is due to two dominant forms of activities; deliberately vented methane due to the use of passive pneumatic controllers (see below) and "fugitive methane" released due to equipment failure and human error. Solving for these two sources requires coupling new technologies in detection and monitoring with mitigation and abatement. Doing so will yield significant fruit; energy accounts for greater than 130 million metric tonnes (MMT) annually of emitted methane; equivalent to greater than 3.3 billion tons of CO2 equivalent (tCO_2e) or 70% of all cars on the road in the world today. But methane is also a very useful fuel, and that 130 MMT/year of methane represents multiple tens of billions of dollars of value to be captured and turned into effective energy. The new bill is encompassing; covering almost all aspects of energy production from productive well pads, to transport piping, to storage, processing, flaring, and even end of life wells.

According to preliminary analysis by the Harvard Environmental and Energy Law Program the Act allows for $850M towards methane monitoring and mitigation; $700M in reducing methane from marginal producing and/or abandoned wells; $20M in monitoring methane emissions, and $117.5M for fence line monitoring for methane escaping into adjacent areas. In addition, there are penalties for failing to abate methane, beginning at $900/ton of methane in 2024 and increasing to $1200/ton in 2025 and $1500/ton in 2026. Stimulating the implementation of methane monitoring and mitigation and providing penalties for failure to do so is not just good for the environment,

6 https://www.congress.gov/bill/117th-congress/house-bill/5376/text

7 Details & Analysis of the Inflation Reduction Act Tax Provisions; Inflation Reduction Act Tax Changes: Details & Analysis | Tax Foundation

8 Distributed Methane: Too small to collect, too large to ignore. Qnergy whitepaper https://qdev.adamchiaravalle.com/wp-content/uploads/2022/06/Qnergy-Distributed-Methane-White-Paper-FINAL.pdf

but also a plus for the energy industry and economy.

A further stick to the carrot is found in Section 50263 of the IRA. The federal government typically charges a royalty of 12.5% to all operators that deliver oil and gas from federal lands and the continental shelf. Energy companies typically have paid for gas delivered; but going forward they will need to pay the 12.5% on all gas produced; "including all gas that is consumed or lost by venting, flaring, or negligent releases through any equipment during upstream operations." This point is significant in that it brings us back full loop to **monitoring, measuring, and mitigating methane.** But energy is just part of the distributed methane story.

Taking together the Jobs and Infrastructure Act signed earlier in the year and the even more recently signed CHIPS and Science Act, these three bills represent the largest sweeping attempt to stimulate the active reduction of methane and other greenhouse gases ever attempted in the U.S. Citing work by RMI recent articles including one in The Atlantic estimates that the three bills commit the U.S. to tripling its spending on achieving a green economy, to over $80B/yr for the next ten years.[9] This is because, as mentioned above in the IEA analysis, methane is both valuable and everywhere; the three bills together address the diversity of methane sources, whether from dairy farms, wastewater, and defined biomass sources of methane.

This sweeping series of legislation positions the U.S. as the committed leader in green economy technologies and climate change. What follows is a Qnergy perspective of why such legislation is needed now, what has been missing technologically until now, and how our technology and others, combined, will provide many of the solutions anticipated and supported by the recent legislation.

Why now?

Abating methane is an effective strategy

Even as the world moves towards increasing electrification, fuels like natural gas, landfill gas, and biogas will continue to play a role in the energy transition. Methane, the main component of all the above gases is not just a greenhouse gas (GHG) but also a useful fuel, one that today powers more than 24% of the world's energy. Therefore, a strategic approach to better capture and convert methane that is otherwise vented, released, or flared makes sense as part of a global approach to energy management. **Figure 4** illustrates the benefits of doing so.

GHG Abatement of Instrument Air vs. Electric Vehicle

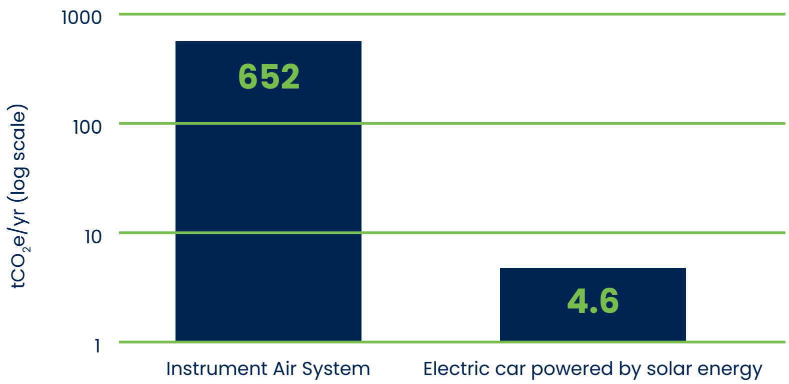


Figure 4. Why abating methane matters. Replacing one internal combustion engine vehicle with an electric vehicle abates an average 4.6 tCO_2e/year in Scope 1 emissions. Abating just one natural gas production well pad that vents methane via pneumatic devices has a potential >100X impact on GHG emissions. See **Appendix B** for further detail.

9 Congress Just Passed a Big Climate Bill. No, Not That One; The Atlantic, August 10, 2022.

Abating methane venting from an average off-grid, pneumatic device controlled well pad that emits up to 22 tons of methane per year (Qnergy data) has 100X the GHG abatement impact on a tCO_2e basis than swapping one internal combustion engine (ICE) car for an electric vehicle on an annual emissions basis. The scale of the impact in successively doing this as part of a net zero strategy for the natural gas industry across hundreds of thousands of well pads (not including processing stations and storage tanks), is shown in **Table 1**.

	Small	Medium	Large	Source/Note
Well Count	1-3	4-6	>7	EIA
Total Sites	242,943	28,896	5,962	Science
Emissions per site per year (tCO_2e)	1,200	4,000	7,000	Qnergy Data assuming X84
Total Emissions per year (tCO_2e)	**291,531,600**	**115,584,000**	**41,734,000**	
Total emissions from Natural Gas venting (tCO_2e)	448,849,600			
Cars off the road	97,576,000			(4.6 tCO_2e/car/year)
Total cars in the US	274,000,000			
Ratio	**36%**			

Table 1. Intentional GHG methane venting from Natural Gas supply chain is equivalent to about a third of the emissions of all the US cars. Well count is number of wells per well pad. Fracking introduced a number of new techniques, e.g., multiple drill holes per well pad as numerous horizontal drills could be done for one site; the result of which is higher volumes and pressures per well pad, more pneumatic devices to control pressure and flow, and more methane venting. Conservative estimate of total U.S. sites is shown. However, internal estimates (not shown) indicate that the total number of sites could be up to 4X bigger. Emissions per site is proportional per number of wells per pad and number of pneumatic controllers and calculated using a global warming factor of 84X methane over CO2. Eliminating pneumatic driven methane venting will have the impact of eliminating more than 1/3 of all cars on the road in the U.S., with significant concomitant GHG impact.

The above data and given knowledge that in its first 20 years after atmospheric emission that methane has 84X the global warming potential over CO2, and 25X over 100 years, to achieve the COP26 goals of limiting climate change to 2°C by 2050, methane release from all sources must be contained, captured, and harvested for productive use.

Current industry dynamics

The Environmental Protection Agency (EPA) is in the process of constructing a final rule regarding the use of pneumatic devices. Under the proposed final ruling, companies that eliminate methane emissions from Pneumatic Devices, i.e., adhere to 86 Fed. Reg. 63110[10] (November 15, 2021) will be exempt. This regulation is known in the field

10 https://www.federalregister.gov/documents/2021/11/15/2021-24202/standards-of-performance-for-new-reconstructed-and-modified-sources-and-emissions-guidelines-for

11 https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-60/subpart-OOOO

as the Quad O ('OOOO') regulation for standards of performance for crude oil and natural gas facilities.[11] Under the proposed regulations:

- OOOOb: Will ban gas pneumatics at all new sites.
- OOOOc: Would outlaw gas pneumatics at all existing sites. States have ability to propose equivalent rules to substitute for federal rules.

For further reading, see Qnergy's letter to the EPA on 'OOOO' regulation.[12]

However, these rules as to how it pertains and importantly, how vented methane is to be measured, today, self-reported, is complex. Recent media reports show that definitional wrangling over [time of] "operation" has allowed some companies to slash by more than half their self-reported methane emissions.[13]

From Bloomberg:

"Most companies report that their controllers are operational virtually all the time — 23 or 24 hours a day, 365 days a year. But a few companies have taken the word "operational" to refer only to the brief moments when a device is actually releasing gas. Range, for instance, estimated its 11,610 controllers were operational an average of just 8 minutes a day in 2020, the latest year for which disclosures have been published. Cabot Oil & Gas Corp., which merged with another company to form Coterra last year, reported its controllers were operational for just 4 minutes a day in 2020. BP said controllers in a field in Louisiana operated for a daily average of 10 minutes, although it used much higher figures in other basins." In the June proposal, the agency said that interpretation is wrong, and that companies are supposed to include all of the times the devices are in service, not just when they're releasing gas. It noted that the factor used to ballpark emissions from the devices — 13.5 cubic feet of gas per hour per device — was based on measurements over sustained periods of time. But Range says its reading is valid, and notes that the recent clarification doesn't have the force of law because it hasn't been formally adopted as a final rule. "We believe our reported data meets the current agency definition. If this, or any definition were to change, we would meet those definitions with our reporting," Mark Windle, a Range spokesman, said in an email."

12 Qnergy-Methane Rule Comment Letter to the EPA. January 2022; available on request.

13 https://www.bloomberg.com/news/articles/2022-08-10/methane-loophole-shows-risk-of-gaming-new-us-climate-bill?sref=7aiMgx1j

The article further notes that since then, other companies such as Terra, Flywheel, in addition to Coterra and BP have adopted this controversial approach.

Qnergy notes that if Range had interpreted the rule the way most other energy companies do, it might have reported releasing up to an additional 22,000 metric tons of methane in 2020 (from Qnergy wellpad data), which under the new IRA regulations would result in a fine of more than $2M. The Congressional Budget Office (CBO) estimates that the fines under IRA can be expected to generate up to $1.9B in fines for the energy industry, with fines for the greatest violators to reach into the tens of millions of dollars per year. This is significant is as current estimates list the number of pneumatic devices, from well pad to processing stations in the U.S. alone is 1.7 million.[14]

Considering the controversy in definition and self-reporting, the $850M in grants, rebates, contracts, loans, and other vehicles to owners and operators of methane sources within the oil and gas industry to both monitor and mitigate methane release, in addition to the anticipated Quad O ruling finalization, is intended to create a unified platform of "always on" monitoring of actual, versus calculated, methane emissions together with active mitigation. Together these are intended to address and solve both pneumatic controlled venting and fugitive emissions along the natural gas supply chain.

The European gas crisis

The IRA also recognizes the immediate business opportunity that the U.S. has in helping alleviate the European gas crisis. While NG prices (per MMBTU) range from ~$4-6 in the U.S. retail spot market and the cost of U.S. NG in Europe is at about $9 including transportation, liquification and gasification, the price in Europe today is now over $30, creating hardship for many homes and businesses.[15]

According to Goldman Sachs the impact of the war in Ukraine is far reaching, extending into changes in natural gas policy that will need to take place over the next two decades. According to Goldman Sachs:

> "Natural gas remains key to Europe's energy supply for the next two decades and we believe it is in Europe's interest to sign up to an additional 40 mtpa of 15-yr LNG contracts[16]"

Qnergy notes that even without domestic regulations yet in place, many U.S. NG companies are already in the process of eliminating their supply side emissions to be able to sell in the EU. As one Qnergy customer noted on installation of Qnergy's Compressed Air Pneumatic system,

14 Kleinberg, Robert, EPA Methane Emission Controls, Obama vs Trump vs Biden: What Needs to Be Fixed and What Should be Left Alone (March 22, 2021). Available at SSRN: https://ssrn.com/abstract=3810337 or http://dx.doi.org/10.2139/ssrn.3810337

15 https://www.youtube.com/watch?v=dXSTID4dInk

16 Goldman Sachs, Carbonomics: Re-Imagining Europe's Energy System. https://www.goldmansachs.com/insights/pages/gs-research/carbonomics-re-imagining-europes-energy-system/report.pdf

> "Th[is] project allowed us to retain our largest [European] LNG purchaser, which announced that field emissions are a key buying criterion"
>
> - Engineer, GeoSouthern Energies

Transmission and community climate resilience

Gas production is not the only area of relevance of the IRA to the NG industry. The other main sector is transmission. According to the Department of Transportation (US-DOT), the U.S. has more than 2.6 million miles of natural gas pipelines.[17] Many stretches of pipeline leak methane and the US-DOT has called for action to repair and protect pipeline.[18] A 2018 Science paper[19] from estimated that the U.S. NG transmission emits 1,116 Gg CH4 (about 1.1 million annual tons of methane). This is equivalent to about 20 million cars.[20]

A primary method to prevent pipeline corrosion and therefore reduce methane leaks is cathodic protection.[21]

There is a recognized need for cathodic protection of natural gas pipelines, including the "last mile" linking to consumers.[22] Recent studies indicate that on the end consumer side of the pipeline, that there exists a large and consistent loss of natural gas in transmission within cities,[23] leading to, at the previously assumed levels.[24] Significant aging of infrastructure, with average age of 40-50 years per mile of pipe is to blame. Regulations (49 CFR Part 192) specify replacement of cast and wrought iron, bare steel, iron, with polyethylene or polyamide piping in repairs, but also cathodic protection of remaining pipeline, utilizing constant low current voltage across the length of pipe to prevent corrosion.

Most pressing however, as per a November 2021 Department of Transportation final ruling, an additional 400,000 miles of gas gathering pipeline now falls under federal oversight for both safety and emissions reasons.[25] Since the last such ruling in 2006, fracking and new drilling technologies have greatly increased the volume of gas that can

17 https://www.phmsa.dot.gov/faqs/general-pipeline-faqs

18 https://www.hsdl.org/?view&did=7546

19 https://www.science.org/doi/10.1126/science.aar7204

20 A U.S. car emits about 4.6 tCO_2/yr. The 1.1 million tons of methane are equivalent to about 92.4 tCO_2-e (using the global warming factor of 84). Dividing the two values: 92.4/4.6~20.

21 Cathodic protection is a technique used to control corrosion by making the metal pipe a cathode of an electrochemical cell. Essentially, the pipeline is connected to a more easily corroded metal that acts as an anode. That "sacrificial anode" metal corrodes instead of the metal that is being protected. For pipelines, passive galvanic cathodic protection is often not adequate, and an external direct current (DC) electrical power source is used to provide sufficient current.

22 U.S. Energy Information Administration; Natural Gas Explained; Natural gas pipelines - U.S. Energy Information Administration (EIA)

23 Majority of US urban natural gas unaccounted for in inventories. Sargent M.R., et al., Proceedings of the National Academy of Science, October 25, 2021, https://doi.org/10.1073/pnas.2105804118

24 A national estimate of methane leakage from pipeline mains in natural gas local distribution systems. Weller, Z.D., et al., American Chemical Society, June 10, 2020, https://doi.org/10.1021/acs.est.0c00437

25 https://www.phmsa.dot.gov/news/phmsa-final-rule-safety-gas-transmission-pipelines-repair-criteria-integrity-management-Improvements-cathodic-protection-management-of-change-and-other-related-amendments

be "gathered" from a single site, resulting in higher volumes and higher pressures that must be controlled for safety and emissions. Since these gathering sites and pipelines are in remote areas (though not always so), and are in or near, or pass through rural, tribal, and disadvantaged community areas, under environmental justice, these need prioritization.

Marginal wells and abandoned wells

Under the umbrella of improving climate resiliency of communities and petroleum and natural gas systems, Part (D) of Section 136 of the IRA is of interest, "permanently shutting in and plugging wells on non-Federal land" as it ties into Title VI Methane Reduction Act, Section 40601 of the Jobs and Infrastructure Bill pertaining to orphan wellsite plugging, remediation, and restoration on both federal and non-federal (tribal) lands. The budget calls plugging, remediation, and restoration of idled and abandoned wells.

Marginal and abandoned wells are those the operator deems as having been depleted or of natural low productivity and therefore of low economic value, though they likely continue to vent methane. The EPA estimates that there are more than 3 million abandoned wells in the U.S.[26] Increasing health reporting show the adverse effects of methane on human health.[27]

In Qnergy's view the $117.5M the Harvard University ELP program estimates the IRA allocates for "fence line monitoring" is intended to help protect communities by enabling active monitoring and mitigation of methane emissions into local communities. A significant portion of the IRA notes the need for such solutions for disadvantaged communities located near to industry and ports.

Qnergy notes that active measuring of vented methane from low production abandoned wells coupled with new methane harvesting technologies designed to work well at low volume and percentage methane gas can restore an otherwise orphaned wellsite into profitability before plugging and remediation, especially on tribal lands and given the call for a national electrical vehicle charging infrastructure in the Infrastructure and Investment Jobs Act. The Highway Infrastructure Program has carved out $5B to be expended between 2022 and 2026 under the National Electric Vehicle Formula Program to provide funding to states to "strategically deploy electric vehicle charging infrastructure and to establish an interconnected network to facilitate data collection, access, and reliability." It may be possible to connect some of these 3M abandoned wells into such an infrastructure, truly transforming waste into wealth and into the fold of a national strategic priority.

A recent publication by the organization Resources for the Future indicates that plugging just a single well costs $76,000.[28] They further note an EPA estimate (likely low, given other studies) that abandoned wells release 280,000 metric tons of methane per year, equivalent to more than 4B kWh of wasted power. Their study cohort of just 62,000 wells (versus the more than 3M estimated extant by the EPA) shows that on average each well emits 0.13 metric tons per year, so a wide range likely exists between low and high emitters. A solution that measures and remediates with lower cost than plugging could effectively provide useful energy.

26 https://www.epa.gov/sites/default/files/2018-04/documents/ghgemissions_abandoned_wells.pdf

27 https://wedocs.unep.org/bitstream/handle/20.500.11822/35917/GMA_ES.pdf

28 Resources for the Future; Plugging Abandoned Wells: Effects of the Draft Energy Infrastructure Act. https://www.rff.org/publications/issue-briefs/plugging-abandoned-wells-effects-of-the-draft-energy-infrastructure-act/#:~:text=RFF%20analysis%20shows%20that%20plugging,using%20a%20100%2Dyear%20GWP.

What has been missing?

Needed Technology

A key aspect of our current, large, centralized problem of 362 MMT of anthropogenic methane emitted each year (Figure 1) is the tolerance of millions of small emitters; each of which in the past has been regarded as too small to collect or deal with, yet in aggregate is too large too ignore; which the three Acts seek now to mitigate. What is needed is a distributed solution mindset; the ability to monitor and measure each methane producing source, whether well heads, processing stations, pipelines, storage tanks, within the energy industry or the millions of abandoned wells, dairy and crop farms, landfills, and wastewater treatment facilities; many of which abut communities impacted by methane and other GHG.

Qnergy's methane abatement program provides such "right-sized," economic, distributed solutions. Qnergy's Methane Abatement Program enables **owners and operators of methane**, i.e., gas producers and gas transmission companies and even landfill operators to:

1. **Reduce emissions at a low cost of compliance with proven technology** - The program, operating today, allows companies to achieve compliance with a positive cash flow through fine-avoidance and carbon credits

2. **Deploy early with a minimal upfront financial commitment** - Flexible business models such as Energy as a Service (EaaS) and Compressed Air as a Service (CAaaS) allow operators to accelerate deployment without using OpEx rather than CapEx. Application of voluntary carbon credits accelerates installation profitability

3. **Promote U.S. technologies and innovations** - Qnergy's U.S. invented and produced technology is unique in enabling operators to deploy power with utility-like (in fact - better than utility–like; see below) reliability even in stranded locations far from the electrical grid. This allows operators to concurrently eliminate methane emissions and improve production efficiency across all their distributed assets. To further foster competitiveness and on-shore innovation, Qnergy is actively on-shoring its supply chain to also meet demand even more robustly.

4. **Apply a surgical approach to 'deploying what is needed'** - Qnergy developed a broad product line to address the variability between wells. Experience gained in hundreds of installations allows the company to precisely configure the solution that operators need.

5. **Measure and monitor methane impact** - Qnergy is an energy platform that converts methane into useful local heat and electrical energy to power from compressed air to replace vented methane (mitigation) to sensors and cameras to monitor and measure for successful methane abatement.

6. **Proactively mitigate** – Qnergy's monitoring capabilities discovers leaks that operators can address. Qnergy's abilities to measure energy deployed, air consumed, and other sensing improves real time detection of problems.

What needs to be done?

The Qnergy Solution

Qnergy has been invited to submit papers to the Society of Petroleum Engineers[29] and the American School of Gas and Measurement Technology[30] which go into detail regarding its proven solution for the 11 MMT annual methane release from pneumatic controllers. **Figure 5** illustrates example solution installations. A brief synopsis follows here.

Figure 5. Qnergy's PowerGen platform in various installations working as both Prime and standby power. (1) A system in Louisiana supplying prime power for Cathodic Protection working after being through Hurricanes Laura and Delta; (2) A remote weather station in Colorado - Rocky Mountains; (3) Remote cell tower in Alaska. PowerGen on the right side of the picture serves as backup power for always-on telecommunication, charging standby batteries when needed using propane. The insert (circle, upper right) shows the system working during winter at -40F. This picture was taken through a helicopter window. Some of our distributed installations require a helicopter trip for maintenance. In those cases, the ROI of our elevated reliability is nearly immediate; (4) A pilot installation in Mexico in collaboration with Sistema bio utilizing biogas from animal manure digested in the sleaves in the left side of the picture. Low-pressure biogas is fed into PowerGen to create clean on-farm power; (5) Off-shore installation providing prime power to an unmanned platform in the Gulf of Mexico.

29 2022 SPE Annual Technical Conference and Exhibition, *Compressed Air Pneumatics For Methane Mitigation*, Manuscript SPE-123456-MS, in press, see Qnergy website for draft.

30 ASGMT 2022 Annual Conference; *Developing Measurements and Methods for Effective Abatement of Methane Atmospheric Emissions, in press, see Qnergy website for draft.*

In the simplest depiction of capabilities, Qnergy provides an energy platform that abates methane while also providing useful local, in situ, power for local needs; whether supplying compressed air, sensing and monitoring equipment, battery charging (some Qnergy units are already deployed as EV chargers), or other power needs (**Figure 6**).

Figure 6. Qnergy converts methane into useful power. A benefit of Qnergy's system as an external combustion engine is its ability to take raw methane, whether unprocessed natural gas, landfill gas, or farm-based biogas and convert it into useful energy without expensive scrubbers and the ability to run for years with no required scheduled maintenance. The key is its unique, proprietary Stirling engine technology.

Of interest and significance is the IRA's mandate and the EPA's desire to both monitor and abate methane. The Qnergy platform does one and enables the other. Otherwise vented or flared methane is captured and converted into electricity, simultaneously mitigating and transforming into useful power for local applications, but also providing power to enable a range of sensors, cameras, and measurement devices everywhere a generator is in place. This enables a potential connected network of always on environmental and climate monitoring to take place, as opposed to intermittent satellite and airplane measurements in use today.

Solving the distributed methane challenge

There are two main reasons why distributed methane has not been solved until now. The first is that abating methane takes energy, and many sources, especially well heads lack access to grid energy. Greater than 50% of all well pads in the U.S. might lack access to such energy and even such, are at risk when grids go down. Thus, alternatives such as solar plus batteries, diesel generators and fuel cells have been attempted in the past to provide such power, either as primary source or as backup. All have drawbacks both physical and economic. The second is that internal combustion (ICE) engines require routine oil change and maintenance and are not designed to run 24/7/365 and so are very costly to maintain if not impossible in the many stranded, remote, and hostile environments that contain the most productive wells.

Solar plus battery work in southern latitudes but are disadvantaged in northern climes with low sun winter conditions. ICE/diesel engine solutions suffer from high operating expense mentioned above as well as very poor GHG footprint with high emissions. Modified ICE engines that run on methane require costly scrubbers to remove the highly corrosive hydrogen sulfide (H2S) present in all (whether raw natural gas, landfill gas, or biogas) which rapidly corrodes engines resulting in high replacement as well as maintenance costs. Fuel cells, which are expensive and still largely in development,[31] suffer the same outcome when run on raw methane.

31 In its 2021 assessment, the U.S. Department of Energy calls for R&D to create fuel cells capable of 40,000 hour durability at a $.20/kWh levelized cost by 2030; https://www.hydrogen.energy.gov/pdfs/review21/2021-amr-05-fuel-cell-technologies.pdf

Given the operating constraints for solution, the only viable technology alternative that remains is a linear, external combustion engine capable of handling raw methane, delivering better than utility grade electricity, due to remote site application, the need for reliability, and desire for low operating cost. Further, desired is an engine with no rotating parts, thus eliminating the need for frequent maintenance and lubrication, is mandated. Engines with rotating components require lubrication replacement every 400-800 hours of operation or 10-17 oil changes per year, a clear impediment to total cost of ownership and solution adoption.

Qnergy believes it is with these considerations in mind that the IRA specifically states that any linear generator assembly in the context of an energy storage device "does not include any assembly which contains rotating parts." Qnergy is currently preparing an open letter to EPA discuss the benefits of linear engines vs. engines with rotating parts.[32]

Qnergy technology: a linear engine with no rotating parts

In 2018 NASA scientists announced that a Stirling engine built by some of Qnergy's engineers had surpassed 12 continuous years of operation with no maintenance, making it "the longest-running heat engine in the history of civilization[33]."

Qnergy's Generator - The PowerGen delivers highly reliable, uninterrupted, 24/7 clean and sustainable prime power. Its linear Free Piston Stirling Engine (FPSE) converts heat into electrical energy. All motion is linear with the piston suspended on flexures, giving rise to the name "Free Piston Stirling Engine." Qnergy's FPSE technology enables us to build systems that are customizable, always-on, and a reliable source of power. The heat source is external to the sealed engine, which contains a fixed

> Qnergy's "PowerGen Free Piston Stirling Engine provides up to 5,650 Watts of AC and DC power. Overall test site power of 4300 watts. This Stirling engine provides 30% thermal-to-electric efficiency while maintaining an impressive zero (0) VOC emissions"
>
> -Principal Engineer, Shell Canada

32 Qnergy work in progress-check our website

amount of compressed helium gas. The FPSE has no rotating parts and hence no need for lubrication or routine maintenance.

The electrical output of the PowerGen is connected to the customer's electrical load. The typical use configuration for our products provides reliable distributed power in modules of 500 to 5,600-watt range. The footprint is roughly equivalent to five kilowatts per square meter, or approximately fifty times more space-efficient than solar power generation.

As mentioned above, Qnergy's generators are 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.

And again, as an external combustion engine, it requires no lubricants and due to its design, virtually no maintenance over its designed 80,000 hours (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 has a 99.7% GHG abatement to emissions ratio, far superior to the GHG footprint of ICE engines, which are prone to incomplete combustion, releasing e.g., NOx, CO, and methane itself (**Table 2**). Therefore, 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.

(Units: gr/kWh)	PowerGen 5650(CAP3)	EPA (1039)[1]	Ratio
NOx	0.066	7.5	**99.1%**
CO	0.012	8	**99.9%**
PM	0*	0.4	

Table 2. Output of PowerGen emissions relative to EPA 2014 regulation for non-road compression engines. Emission profile excels EPA required minimum emissions by >99%. PM = Particulate Matter emission.

33 Spaceflight Insider, July 2018; It keeps going and going: Stirling Engine test sets long-duration record at NASA Glenn; https://www.spaceflightinsider.com/space-centers/glenn-research-center/it-keeps-going-and-going-stirling-engine-test-sets-long-duration-record-at-nasa-glenn/

Deployment examples and case studies

Today Qnergy has over 80 clients and close to 1000 deployments in the oil and gas industry. Our solution for solving the 11 MMT/year pneumatic controller, vented methane challenge is rapidly becoming the leader and proven solution (**Figure 7**).

Solving the wellpad problem: Replacing gas pneumatics with compressed air

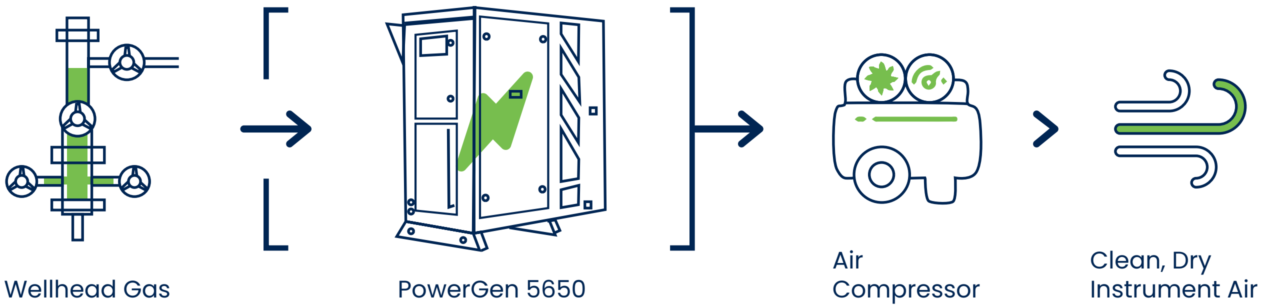


Figure 7. Qnergy's solution for pneumatic controllers. Qnergy's energy platform drives the power need for an air compression system that replaces vented methane at pneumatic control points with clean, dry, instrument air.

Says TotalEnergies, a Qnergy client:

> "We have successfully demonstrated the effectiveness of Qnergy's technology on the Barnett field. By immediately deploying this technology on our US onshore operations, we are actively demonstrating our commitment to reducing our own methane emissions by 20% between 2020 and 2025."
>
> -Carole Le Gall, Senior Vice President Sustainability and Climate

33 Spaceflight Insider, July 2018; It keeps going and going: Stirling Engine test sets long-duration record at NASA Glenn; https://www.spaceflightinsider.com/space-centers/glenn-research-center/it-keeps-going-and-going-stirling-engine-test-sets-long-duration-record-at-nasa-glenn/

When fully deployed, the 400 PowerGen Cap3™ systems (**Figure 8**) ordered by TotalEnergies for its Barnett Shale operations will decrease methane venting by 7,000 tons per year at an industry leading abatement cost of <$2/ tCO_2e (**Table 3**). With the avoided cost of penalties in 2024, the marginal cost of abatement turns negative.

This abatement figure places the Qnergy cost for abatement at the low end of the cost spectrum for a variety of CO2 abatement strategies and technologies including solar, wind, and EVs[34]

Figure 8. Qnergy CAP3™ system. Powergen 5650 engine/generator is depicted on right, the air compression system containing cabinet on left. Compressed air substitutes vented methane in powering and controlling pressure controlling pneumatic valves, eliminating vented methane. Hundreds of these units are deployed across North America to address the estimated millions of pneumatic controllers in use today.

Parameter	Value (x25)	Value (x84)	Units
Air supply (U.S units)	185	185	scfm
Net Annual GHG abatement	547	1,869	tCO_2e/yr
GHG Abatement to Emissions Ratio:	98%	99.3%	
Gasvalue ($/yr)	5,834	5,834	
Life time cost	$13,158	$13,158	
Abatement Cost	**$2.4**	**$0.7**	**$/$tCO_2e$**

Table 3. Abatement cost per tCO_2e for Qnergy's solution. Example scenario using aggregated data from hundreds of deployments indicating an average 22 tons of methane per site abated per year. GHG Abatement to Emissions Ratio is >98% in all scenarios and is the proportion of methane and other GHG gases destroyed (to produce heat and electricity) to CO2 emissions. Value of wholesale gas is estimated at $.006/scf. Using global warming factors from 25 to 84 gives a 10 year abatement value < $3/$tCO_2e$. scfm = standard cubic feet per minute.

34 The Cost of Reducing Greenhouse Gas Emissions, Gillingham, K. and Stock, J.H., https://scholar.harvard.edu/files/stock/files/gillingham_stock_cost_080218_posted.pdf

An example of Qnergy's PowerGen performance and specifications is shown in **Appendix B**.

Solving for cathodic protection: protecting pipelines

Today Qnergy provides hundreds of units to protect pipelines and prevent methane leakage in remote mountainous areas in the Pacific Northwest and Intermountain regions without access to grid power. In the following example the PowerGen unit was flexibly configured to deliver single-phase 240V AC for use with a standard 50V/50A rectifier for Impressed Current Cathodic Protection (IPCC). Schema is shown below in **Figure 9**. Figure 10 shows an example of the more than 200 Qnergy deployments for cathodic protection to date.

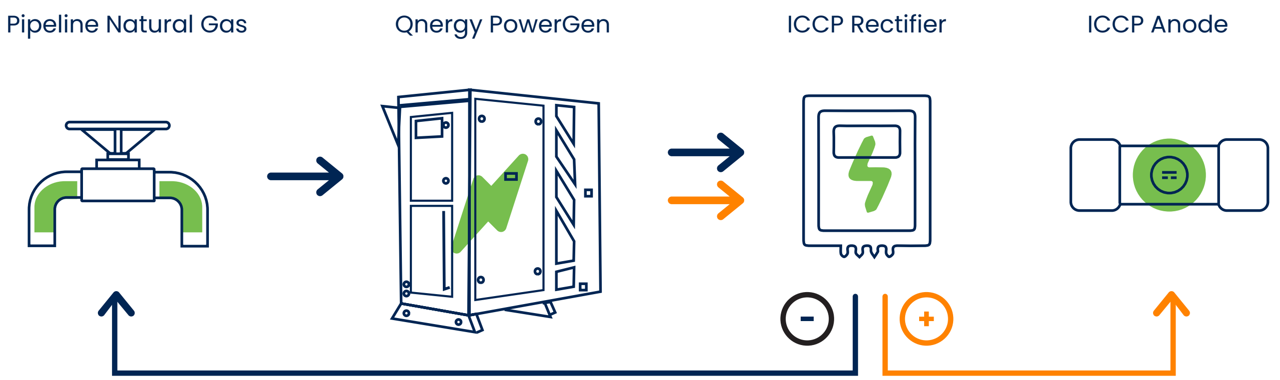


Figure 9. Impressed Current Cathodic Protection schema. Powergen was configured for 2800 watts continuous 24/7 delivery. As noted above in Footnote 19, cathodic protection works by converting the pipeline into a cathode by powering a low voltage electrolysis, effectively transferring corrosion to a sacrificial anode. Direct current for the system is supplied by the PowerGen unit fueled by pipeline gas itself.

Figure 10. Qnergy PowerGen unit providing cathodic protection in the Colorado region. Unit is combined with a rectifier configured to match the power and direct current needs of the pipeline. Qnergy estimates that one such unit per 10 miles of pipeline is sufficient to provide protection against pipeline corrosion.

Solving for farm-based methane: providing on-farm power from biogas

In partnership with Sistema.bio, Qnergy is supplying electricity from biogas to a pig farm in Mexico (**Figure 11**). As a pilot project, Qnergy is taking low pressure, extremely high H2S biogas from Sistema's anaerobic digestion system and creating up to 134kWh/day of power for the farmer. According to the IEA analysis (Figure 1, Footnote 5), agricultural methane release is even larger than that of the energy industry.

Figure 11. Qnergy and Sistema.bio collaboration on pig farm anaerobic digestion. Foreground shows Qnergy PowerGen unit creating up to 5.6kW of electricity from high H2S containing raw methane gas derived from anaerobic digestion of pig manure (background, black bags). On farm generation of useful heat and power creates a circular economy from manure and crop waste when combined with anaerobic digestion technology as well as potential carbon credits.

This ability to deal with biogas is important to consider as the IRA defines a "qualified biogas property" as any property converting biomass into "not less than 52 percent methane by volume or is concentrated by such system into a gas which consists of not less than 52 percent methane, and captures such gas for sale or *productive* use, and not for disposal via combustion."

Two important points emerge here; 1) since both landfill gas and farm biogas typically exceed 55% methane content, both are impacted by the IRA, and further, as is any gas that can be concentrated to exceed 52% or higher, and 2) productive use means converting the captured methane into local power and energy. Preliminary evidence shows that the Qnergy system can successfully deal with low percentage (40-42%) methane containing landfill gas (not shown).

While the main thrust of the IRA is to deal with the low hanging fruit that is the industry in terms of methane abatement, many of the same expectations and perhaps potential future rulings will also roll into landfills, dairy and crop farms, and even wastewater treatment facilities.[35]

35 In 2010 the Global Methane Initiative estimated 512 MMT CO_2e from wastewater, most of which comes from methane, a large amount of which is flared or vented; https://www.globalmethane.org/documents/ww_fs_eng.pdf

Economic Overview

The IRA's potentials to mix various direct incentives with tax credits and penalty avoidance enable suit-to-fit combinations for technology acquisition. An example of such is shown in **Table 4** below using data from hundreds of Qnergy implementations on pneumatic controlled well pads. Stacking penalty avoidance with the direct benefit of rising gas prices and credits leads to payback in under two years.

GAS SAVING			
Parameter	Value	Units	Source
Conversion factor	1,037	BTU/cf	EIA
Typical flow	3	Cfm	Qnergy proprietary data
Minutes per year	525,600	m/year	
Flow per year	1,576,800	cf/year	
Energy saving per year	1,635	MBTU/year	
Gas price	$9.3	$/MBTU	EIA
Gas saving	**$15,207**		

FINE AVOIDANCE			
Parameter	Value	Units	Source
Abatement	22	tCH4/y	Qnergy proprietary data
2025 fine	$1,500	Cfm	IRA
Fine Avoidance	**$33,000**		

CARBON CREDITS (TYPICALLY NOT ADDITIONAL TO FINE AVOIDANCE)			
Parameter	Value	Units	Source
Abatement	22	tCH4/y	Qnergy proprietary data
U.S. value of carbon	$10	$/t$CO_2$e	Qnergy's estimate of the current value of 1tCO_2e in the US voluntary carbon market
Conversion factor	25		
Carbon Credits	**$5,500**		
TOTAL	**$53,707**		

Table 4. Example economic return model under IRA for abating methane from a single well pad equipped with Qnergy's CAP system. Combinations of direct funding support, penalties for waiting, and tax credits (not shown), in conjunction with possible private market carbon and "clean methane" credits provide strong payback incentives to accelerate investment in near net zero methane loss in the energy industry. Qnergy proprietary data is an average over hundreds of units that the company has installed in the U.S. Not included is the value of providing up to 5.6kW of utility grade electricity 24/7/365.

The model above is just one illustration on the techno-economic return on investment possible: considering the value of methane as a fuel, fine avoidance per the IRA, and the growing voluntary carbon credit market. Qnergy offers other models under our methane abatement program, including Energy as a Service (EaaS) and other system acquisition options to help customers deploy as quickly and easily as possible. This includes partnering with other technology providers to use the energy from our platform, up to 56. kW continuous, to power advanced environmental sensing and monitoring and other data gathering instrumentation across North America.

A Qnergy solution on a single wellpad abates up to 22 tons of methane release per year, equivalent to 550 tCO_2e or 120 cars on the road and make that otherwise vented methane available for market as natural gas. In the example above, a unit runs on gas that would otherwise be vented (or flared), converts it into electricity and powers an air compression unit that then replaces methane with stored instrument air to control pneumatic devices.

Qnergy's power solutions are based on a unique modification of the Stirling engine called a 'Free Piston Stirling Engine' it is a linear engine design, with no rotating parts, no lubricants, and the ability to run for years with zero engine maintenance, even in extreme environments, delivers an industry leading methane abatement solution at an abatement cost of less than \$2/tCO_2e (using January 2022 gas prices). With the incentives and penalties contained in the IRA the abatement cost for the same period turns negative. This remarkable cost performance takes Qnergy into the realm of a best system for emissions reduction (BSER) for abating methane emissions from pneumatic devices. The strong cost to performance attribute of the system also breaks down barriers to methane abatement in other sectors, offers GHG improvement, and enhanced environmental safety and air quality solution implementations, significant in enabling the scale of solution distribution needed to achieve the ambitious GHG reduction as well as the broad environmental justice targets set by the IRA.

Figure 12. Continuous improvement, relentless innovation. Depicted is a recent deployment of a beta version of the new Qnergy CAP3nano which produces 3 scfm instrument air at 140 psi. As noted in **Table 1**, there are many small wellpads in existence which are often deemed too small to warrant capital expenditures to solve methane venting. Qnergy continues to work with clients to create products to fit power, compressed air needs as well as environmental operating challenges such as operating in temperature ranges from -40F to 140F in the most remote sites-eliminating the need for onsite maintenance and human intervention for years of continuous operation. Our goal is to eliminate operational challenges to methane abatement through wellpad automation accomplished at the lowest cost to abate value in the industry.

With over 1000 installations, Qnergy has a proven solution that leading energy companies are already using to abate methane loss and improve economic performance per install site. These owner/operators have already discovered that the ability to utilize any methane from anywhere to power local devices, whether compressed air for pneumatic devices, rectifiers for cathodic protection, sensors for air quality monitoring, or battery charging, creates methane abatement solution opportunities all along the gas supply chain. An example of a recent innovation is shown in **Figure 12**.

Final Take Aways

Qnergy's Methane Abatement Program is designed to minimize the cost of compliance with the new regulations. It is based on primary data and experience gained from close to a thousand installations over half a decade. The Qnergy program offers Superior Technology at the lowest abatement cost along with a Flexible Business Model to speed adoption, solution, and benefit. The new regulations with its intricate but interweave-able elements of subsidies and penalties should produce remarkable effects in the natural gas industry. We expect these regulations, along with market mechanisms already in play, to:

- Boost reduction of methane emissions in gas production and transmission and accelerate a new U.S. industry standard
  - Cleaner U.S. natural gas will enhance international sales, especially in the EU, where clean provenance of energy is important, and need is especially high
  - Negative incentives beginning in 2024 are sufficiently high that there is no point in companies waiting to implement; 2023 will see significant movement in technology implementation
    - Promote U.S. innovation by accelerating the implementation and convergence of monitoring and abating technologies to form long term solutions.
  - To date, monitoring is episodic and low granularity, e.g., satellite and airplane flybys. Called for is long term sustainable monitoring and measuring technologies everywhere there is methane; from wellpad to final customer
  - Abatement technologies are specifically called for, from LDAR to systematic addressing of pneumatic controller infrastructures
    - Challenging to accomplish is delivering power to the millions of sites and millions of miles of pipeline- much of which lack access to power
      - Qnergy's ability to take raw methane and turn it into local power makes the IRA goals possible in these areas since both monitoring and abatement technologies can be powered off this platform
    - The IRA in combining monitoring together with abatement/mitigation as a solution and solution category is calling for long term on-the-ground integration of these two components to create a new technology solution
- Importantly, the IRA seeks long term solutions; and interestingly mentions the search for solutions in various contexts that have "no rotating parts." Traditional ICE engines which do, are not designed to run 24/7, require lubricants, and often monthly maintenance, with high replacement frequencies due to failure have plagued much of the industry. The IRA seeks to eliminate this cost barrier to solution implementation and calls for innovative technologies.

- Qnergy's proprietary linear free piston Stirling engine with no rotating parts is the kind of long term, sustainable solution called for by the IRA

- Owner/operators of methane assets will align with states and municipalities through which much of the funding will flow. Issues such as environmental justice; prioritizing of tribal, rural, and disadvantaged communities for solutions will drive alignment with local flow of dollars.

    - This is a remarkable opportunity for owner/operators daunted in the past by the sheer operational and economic scale of trying to deal with all methane sources and all leaks. The support offered by the U.S. government in direct funding and tax credits coupled with penalties to start in 2024, will drive industry change beginning by the second half of 2023.

        - Qnergy's ability to offer flexible pricing models enables owner/operators to construct best return on investment scenarios

    - Recapturing the 45MMT of methane estimated by the IEA lost each year by the industry will itself pay back >$10B annually in now economically available gas.

        - Qnergy's ability to deliver better than utility power and availability performance enables operators to simultaneously reduce GHG and improve production efficiency

- Qnergy's Methane Abatement Program is designed to minimize the cost of compliance with the new regulations. It is based on primary data and experience gained from close to a thousand installations over half a decade. The Qnergy program offers Superior Technology at the lowest abatement cost along with a flexible business model to speed adoption, solution, and benefit.

Appendix A: Further breakdown of IRA funding in methane monitoring and mitigation

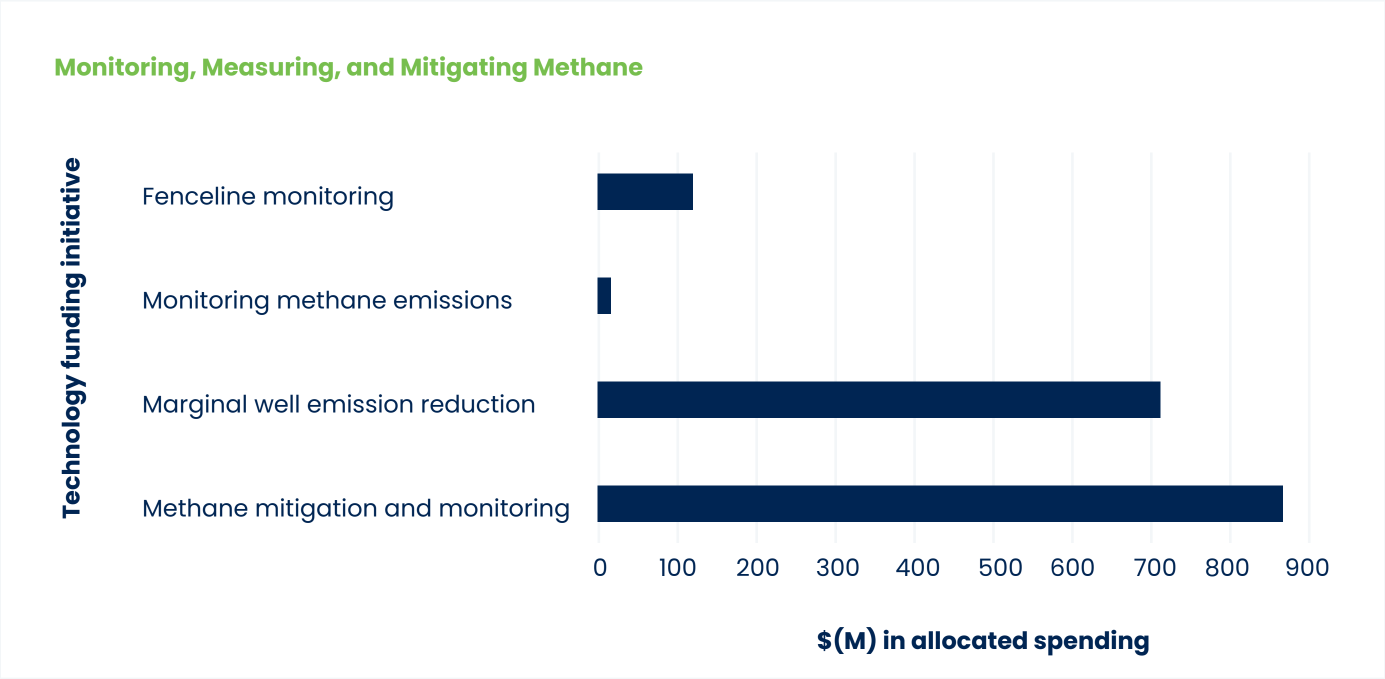


Figure 1. Direct spending allocations in the IRA. Adapted from Harvard Environmental and Energy Law Program[36]

- The bulk of IRA spending is focused on methane mitigation (abatement) and monitoring and expected to stimulate new combinations of technologies such as Qnergy's mitigation capabilities along with active surface monitoring
- Millions of economically marginal but still methane venting wells are in existence and need evaluation and decision on plugging or harvesting via new technologies such as Qnergy's which are capable of creating electricity and power from low volume, low pressure wells
- $20M is allocated for development of new types of methane monitoring technologies that will provide more granular, surface, continuous monitoring for methane
- Fence line monitoring is a broad term to cover vented methane, as a colorless and odorless gas migrates over traditional property and operational boundaries (e.g., well pads and landfills), sometimes into neighboring communities, requiring remediation via capture and either storage or conversion into energy.

36 Harvard EELP; The Inflation Reduction Act's Implications for Biden's Climate and Environmental Justice Priorities; https://eelp.law.harvard.edu/2022/08/ira-implications-for-climate-ej-priorities/

Appendix B. Total GHG Impact of CAP3 vs. Electric Vehicles

Consider three scenarios:

1. A Qnergy CAP3 system powered by a PG5650 Stirling Generator. We will call this scenario CAP3+PG
2. An Electric Vehicle charged by the Average U.S. Power Grid. We will call this scenario EV
3. An Electric Vehicle charged by solar panels. We will call this scenario EV+PV

This Appendix calculate GHG benefits of the three different projects, by examining:

1. Scope 1 – Direct emissions
2. Scope 2 – Emissions related to electricity consumption
3. Scope 3 – Emissions related to the Supply Chain or the 'embodied carbon'
4. Scope 4 – Emissions that are avoided because of the installation of the product.

The Table and Chart below summarizes the results:

GHG Emissions in kgCo2e per year	CAP3+PG	EV Grid	EV+PV	Notes
Scope 1 (direct emissions)	13	0	0	PowerGen has direct emissions
Scope 2 (electricity consumption emissions)	0	2.1	0	
Scope 3 (Supply chain emissions)	0.8	0.0	0.0	Ignoring embodied carbon of EV since the baseline is a regular car
Scope 4 (Avoided Emissions)	(666)	(4.6)	(4.6)	
Net	**(652)**	**(2.5)**	**(4.6)**	

PowerGen **5650**

Remote Power Industrial Application

Qnergy's PowerGen is a thermal-powered generator suitable to meet remote power needs utilizing virtually any combustible gaseous fuel.

All Qnergy PowerGen generators feature our patented QB80 Series Stirling Engines.

The PowerGen generator provides reliable, affordable electricity to areas around the globe with little or no existing power distribution infrastructure.

PowerGen Engine Specifications

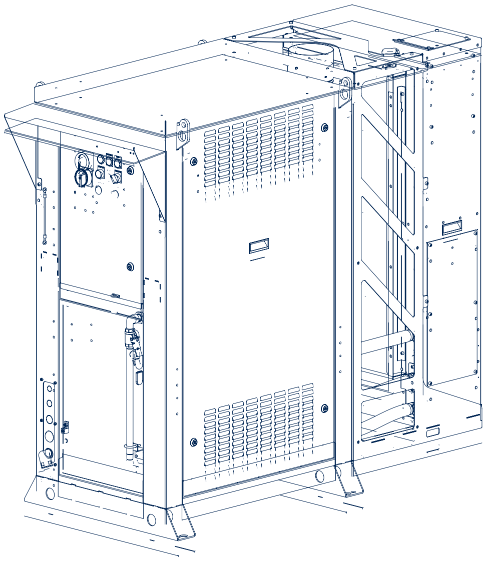
The PowerGen utilizes the Qnergy QB80 series engine. They are the most powerful Stirling machines on the market today. As an external combustion engine, the Qnergy QB80 can run on almost any heat source. The engine is designed for long, uninterrupted and quiet operation.

QB80 Engine Specifications

Engine Model	**QB80**
Engine Type	**Stirling Engine**
Engine Architecture	**Free Piston (frictionless)**
Service	**None**
Weight	**242 lbs**
Length	**33.10 in**
Diameter	**14.45 in**
Charging Gas	**Inert Helium**

CERTIFICATION ETL Listed Intertek UL2200

Product Application and Engineering



General

Make	**Qnergy**
Model	**QRP 2A-HNS**
Engine	**QB80**
Engine Type	**Stirling Engine**
Engine Controller	**QEC 3.5**

Electrical System

System Output Power	**See Configuration**
Power Max Gage Wire Interface	**6-20 AWG**
Cable Gland Input	**3/4" Std**
Ignition/Standby Battery (standard)	**Sealed AGM Deep Cycle, 12V DC 40 Ah**
Battery Capacity (Optional: for increased standby)	**Up to 160 Ah**
Safety	**E-stop (normally closed)**

Cooling System

Cooling System Type	**Closed Loop**
Pump Type	**High Efficiency Grundfos Circulating Pump**
Cooling Fan Type	**EC Fan (qty. 2)**
Coolant Type Required	**Prestone 50/50 Cor-Guard or equivalent - 5 Gal**
Coolant Ratio	**50/50 (EG)**
Max Coolant Volume	**4.2 gal**

Fuel System

Fuel Type	**Dry Natural Gas, Propane (C1-C4), other gaseous fuel***
Burner	**Pre-mix**
Ignition	**Direct**
Gas Regulator	**2-Stage**
Gas Pressure Monitor	**Transducer**
Fuel Port	**1/2" NPT Male**

*contact us regarding using any non-standard gaseous fuels (C1-C4)

Communication

Ethernet	**RJ45**
Protocol	**Modbus RTU**
Internet Infrastructure	**TCP/IP**
Remote Data Viewer	**Qnergy SmartView**
Discrete I/O's	**Configurable**
Inputs (Dry Contact)	**x6 (16-20 AWG)**
Outputs (Relay)	**x8 (16-20 AWG) (Max 250 V / 1 A)**

Product Operational Data

SERIES	CONFIGURATION	OUTPUT	PHASE ANGLE	CONNECTION	MAX POWER (5650) @85ºF | 120ºF
A (Standard)	**120V/240VAC Split Phase**	**Output A: 120VAC 60Hz Output B: 120VAC 60Hz**	**A: 0º B: 180º**	**3 wire: L1, L2 & Common/Neutral**	**5.65kW | 5.1kW**
OPTIONAL CONFIGURATIONS:					
B	**120VAC SYNC**	**Output A: 120VAC 60Hz Output B: 120VAC 60Hz**	**A: 0º B: 0º**	**3 wire: L1, L2 & Common/Neutral**	**5.65kW | 5.1kW**
D	**120V/240VAC 2 Phase**	**Output A: 120VAC 60Hz Output B: 240VAC 50/60Hz**	**A: 0º B: 180º**	**3 wire: L1, L2 & Common/Neutral**	**5.65kW | 5.1kW**
E	**240VAC SYNC**	**Output A: 240VAC 50/60Hz Output B: 240VAC 50/60Hz**	**A: 0º B: 0º**	**3 wire: L1, L2 & Common/Neutral**	**5.65kW | 5.1kW**
F	**+/- HVDC (-365/+365)**	**Output A: +365VDC Output B: -365VDC**	**A: 0º B: 180º**	**3 wire: +ve, L2 & Common**	**5.65kW | 5.1kW**
G	**+HVDC/120VAC**	**Output A: +365VDC Output B: 120 VAC 60Hz**	**A: 0º B: 0º**	**3 wire: +ve, L2 & Common**	**5.65kW | 5.1kW**
H	**+HVDC/240VAC**	**Output A: +365VDC Output B: 240 VAC 50/60Hz**	**A: 0º B: 0º**	**3 wire: +ve, L2 & Common**	**5.65kW | 5.1kW**

Low voltage DC outputs (24 VDC / 48 VDC) requires the use of the Qnergy Power Interface Package (PIP)

Fuel Operational Specifications

Fuel Consumption Natural Gas (min/max)	**1,433 / 3,964 ft3/day**
Fuel Consumption Propane (min/max)	**15.2 / 44.4 gal/day**
Fuel Pressure Range Natural Gas	**3-50 PSI**
Fuel Pressure Range Propane	**2-10 PSI**
Wobbe Index (min/max)	**832 / 2,163 BTU/ft3**
Caloric Value (min/max)	**751 / 3,382 BTU/ft3**

*contact us regarding using non-standard gaseous fuels (C1-C4)

HRU Operational Specification

Thermal Heat Rejection (Max Available)	**x2.5-3.5 of Electric Power Output**

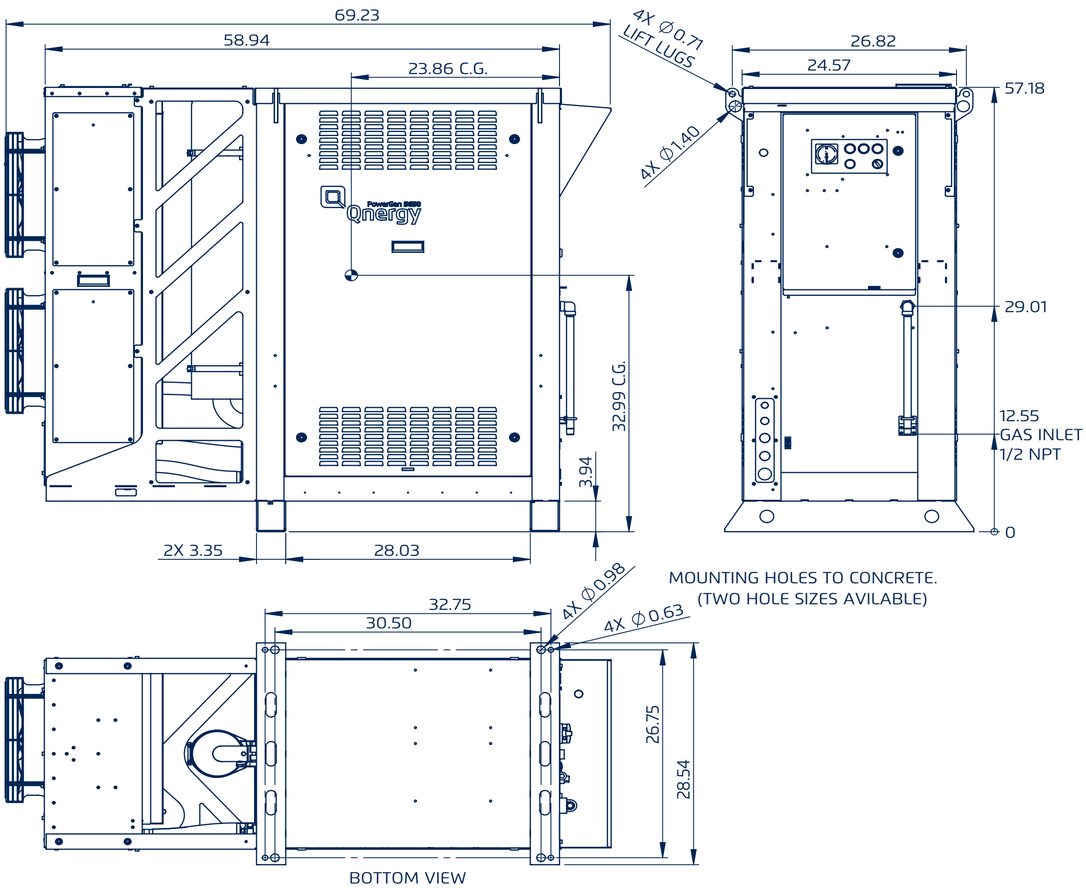
Environmental Condition Specifications

Sound	Max dBA	**< 75 dBA @ 1 m**
Ambient Temp Continuous Operation* (min/max)		**-13 ºF / 122 ºF**
Ambient Temperature Rated (Startup)* (min/max)		**5 ºF / 122 ºF**
Altitude	Derate	**5% derate every 1,000 ft (above 5,000 ft)**

*Ask about our low temperature cold-start package (down to -40 ºF)

Emissions

NOx @ 5% O2	**30.0 ppm**	**66 mg/kWh**
CO @ 5% O2	**9.0 ppm**	**12 mg/kWh**
VOC	**– Combustion**	**Negligible, Lean**



PowerGen Dimension/ Weight

Dry Weight
866 lbs

Base Crate:

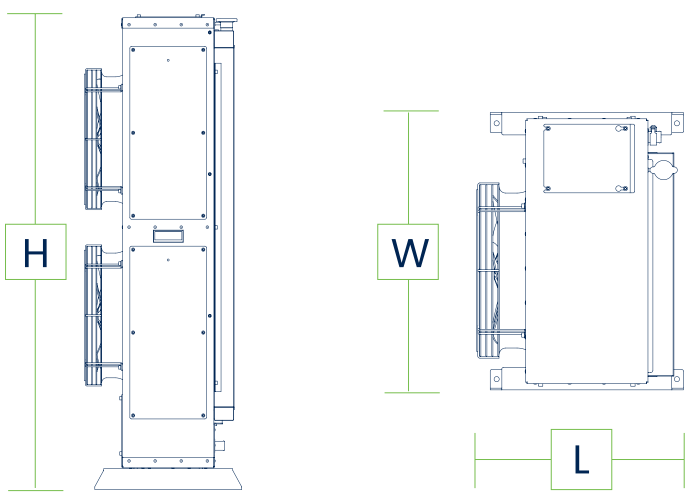
Length (L)
75.25 in

Width (W)
40.25 in

Height (H)
63.8 in

Weight
220 lbs

HRU Standalone Dimensions



HRU Floor Standing:

Length (L)
19 in

Width (W)
25.4 in

Height (H)
54 in

HRU Wall Mounted:

Length (L)
28.8 in

Width (W)
24.9 in

Height (H)
53.3 in

HRU Max Placement Distance **65.5 ft**

CAP+PG/Scope 1 (direct emissions)	Parameter	Units	Notes and sources kW Power rating of PG
Equipment Rating/kW	5.6	kW	
% Load	25%		Percentage loading based on Qnergy's experience
Operating Hours	8,760	hours	Operates the whole year
PowerGen Electricity Emission Factor	1.10	tCO_2e/MWh	Measured and verified
Emissions Air Compression CAP 3 Skid	**13**	**tCO_2e/yr**	

CAP+PG/ Scope 3 (supply chain emissions)			
Embodied carbon of EV	20.0	tCO_2e	Assuming that the whole Generator and Compressors are made of steel (conservative assumption)
Weight	660	kg	Qnergy literature
Electric vehicle weight	1,700	kg	2020 average mass of new EVs sold in Europe was nearly 1,700 kg (3,750 lbs). See link.
Weight factor	0.4		We assume that the embodied carbon per kg is the same as EV. A conservative assumption
Lifetime assumption	10	years	Assuming that both EV and CAP have a 15 years lifetime Conservative on assumption since the EV has also battery replacement issues
Annualized embodied carbon	**0.8**	**tCO_2e/yr**	

CAP+PG/ Scope 4 (avoided emissions)			Units
Air supply	22	scfm	Qnergy proprietary data
Annual air consumption	1,156,320	scf/yr	Effective air supplied to project
Gas Equivalency Ratio/ GEF	1.2977		Conversion from volume of air to volume of natural gas that would have been vented in the baseline
% CH4	94%		Percent methane (by volume) contained in the fuel gas (instrument gas)
Density of Methane (P_{CH4})	0.01889	kg/scf	0.6797 kg/m3 at 15°C and 1 atmosphere
Global Warming potential (GWP_{CH4})	25	$tCO_2e/CH4$	100 year horizon - per US government value
Vented Instrument Gas (x25)	**666**	**tCO_2e/yr**	**Calculation of baseline emissions**
Vented Instrument Gas (x84)	**2,265**	**tCO_2e/yr**	**Calculation of baseline emissions**

EV Grid / Scope II (electricity consumed)	Parameter	Units	Notes and sources
Grid Intensity	0.433	kg CO_2e/kWh	Greenhouse Gas Equivalencies Calculator
Car efficiency	2. 9	miles/kWh	What Are The Different Levels Of Electric Vehicle Charging?
Miles per year	14,230	miles	Average Miles Driven Per Year: Why It Is Important
Emissions Air Compression CAP 3 Skid	**2.1**	**tCO_2e/yr**	

EV Grid / Scope III (supply chain emissions)			
Embodied carbon of EV	20.0	tCO_2e	Assuming that the whole Generator and Compressors are made of steel (conservative assumption)
Lifetime assumption	10	years	Assuming that both EV and CAP have a 15 years lifetime Conservative on assumption since the EV has also battery replacement issues
Annualized embodied carbon	2.0	tCO_2e/y	The supply chain emission could be offset if the comparison is to buying a regular ICE car
Adjusted embodied carbon	0.0		The baseline case is buying a regular car with a similar embodied carbon

EV Grid / Scope 4 (avoided emissions)			
Avoided emissions (avoiding buying an ICE)	4.6	tCO_2e/yr	Greenhouse Gas Emissions from a Typical Passenger Vehicle