ISSUE BRIEF

Beyond the Smokestack

Assessing the Impacts of Approaches to Cutting Gas Plant Pollution

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Highlights

As efforts to drive down power sector carbon emissions focus more on gas plants, the fossil fuel industry and utilities with a vested interest have increasingly offered three potential approaches in response: hydrogen cofiring, carbon capture, and use of biomethane. Each has the potential to reduce carbon emissions—yet each is also complicated by climate implications of other steps in the process, threatening to undermine overall climate contributions. Also, each is premised on the full, ongoing use of gas plants—meaning the perpetuation of existing environmental, health, and social inequities, plus the addition of new ones. By contrast, increasing renewable energy generation enables direct reductions in gas generation and its related impacts. As power sector decisionmakers weigh multidecade investments, they must evaluate—and act on—the full picture.

Gas-fired power plants are the largest source of electricity in the United States, supplying more than 40 percent of US electricity in 2023 (EIA 2024e).[1] They are now also the largest source of carbon dioxide (CO_2) pollution from the US power sector, which is itself the second-largest source of US CO_2 emissions economy-wide (EIA 2024c; EPA 2024c). Every path to addressing our nation's climate commitments and public health priorities calls for a cleaned-up power sector—and that makes reducing CO_2 and other harmful emissions from gas plants an urgent priority.

CO_2 emissions from smokestacks are just one way that gas plants exacerbate climate change. Relying on gas at a plant also results in methane pollution from gas extraction and transport. Methane, the primary component of gas, is more potent than CO_2 from a climate perspective, trapping 28 times as much heat over a 100-year time frame (EIA 2024b; Smith et al. 2021).[2] As a result, upstream methane leakage can substantially increase a plant's overall climate impact.[3]

Furthermore, gas plants cause harm to people and communities beyond the plant-level and upstream climate impacts. A key non-carbon pollutant of concern from gas plants is nitrogen oxides (NO_x), which cause and exacerbate respiratory diseases, especially asthma (EPA 2024a). Additional health-harming emissions include hazardous air pollutants, sulfur oxides (SO_x),

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[1] The term *gas* in this document refers to what is traditionally called natural gas.

[2] Over a 20-year time frame, methane traps more than 80 times as much heat as CO_2 (Smith et al. 2021). Except where otherwise specified, this document uses a 100-year time frame for CO_2e. As relevant, decisions should be informed by insights from GWP-100 and GWP-20 calculations.

[3] Leakage rates of 2–3 percent could result in added emissions, in carbon dioxide equivalent (CO_2e), of 22–33 percent of the plant's combustion-related CO_2 emissions (Schlissel and Juhn 2023; UCS 2024). CO_2e is the amount of CO_2 with the same heat-trapping potential as a given quantity of another heat-trapping gas, such as methane.

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and particulate matter (UCS 2023). These harms are inequitably borne; while people of color and people with low incomes constitute 40 percent and 30 percent of the US population, respectively, they make up 54 percent and 34 percent of people living within three miles of a gas plant (Yang 2024; EPA 2023). But even before the point of gas combustion, its extraction, processing, and transport pollute air and water. Air pollution from gas and oil production caused an estimated $77 billion in total health impacts in a single year, chiefly from NO_x, ozone, and particulate matter (Buonocore et al. 2023).

So how do we tackle gas plant pollution?

Using renewable energy sources to produce electricity, aided by energy storage, can directly reduce our use of gas power plants, thereby avoiding the range of harms at the plant and beyond associated with that gas plant use. Solar and wind facilities generate electricity with no CO_2 emissions, do not contribute to methane emissions, and have life cycle carbon, air, and water impacts that are a small fraction of those from gas plants (see, e.g., NREL 2021; Millstein, O'Shaughnessy, and Wiser 2024; Meldrum et al. 2013).

Because increasing renewables usage can directly reduce gas usage, however, the fossil fuel industry and vested utilities have started proposing ways to incrementally cut gas plant carbon emissions that still enable the full, ongoing use of these facilities. These approaches include partially or wholly fueling the plants with hydrogen or biomethane (methane sourced from organic matter) or capturing some of the CO_2 produced when gas is burned and storing it in geologic formations.

Considering these approaches more fully, however, makes clear that they fail to measure up to what can be achieved by renewables when it comes to overall reductions in climate emissions, public health impacts, and costs—sometimes by a little, but often by a lot.[4] Moreover, these approaches perpetuate ongoing gas plant problems and inequities, and introduce new ones.

This issue brief examines a fuller range of climate and health implications of incorporating hydrogen cofiring, carbon capture and storage (CCS), or biomethane use in gas plants, stepping through what each approach might mean in terms of

- plant CO_2 emissions,
- broader emissions of CO_2 and other heat-trapping gases from using the given fuel or technology, and
- non-climate consequences to people and the environment, including of other pollution, costs, and water and land use.

This brief includes results from a new, publicly available analytic tool developed by the Union of Concerned Scientists (UCS 2024), using an illustrative example of targeting power plant CO_2 reductions of 90 percent via each approach to demonstrate how focusing on a narrow, combustion-only target can fail to capture the full emissions impact of each approach. The

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[4] Some of the non-renewable energy approaches may come into play in hard-to-decarbonize sectors of our economy, or even as a final step in decarbonization of the power sector, under certain conditions.

document also explores the implications of using renewable energy instead to drive down the use of gas.[5]

To deliver the best outcomes for people and planet, decisionmaking around proposals to cut a gas plant's carbon pollution must look beyond the smokestack to the full suite of climate impacts and the comprehensive array of broader impacts to the public. Transparent evaluations of these impacts are critical for enabling informed community and decisionmaker engagement and securing the best outcomes.

When we consider the options and do the math, the answer is unequivocally clear: the best way to reduce gas plant carbon emissions—and gas plants' associated harms—is to *use gas plants less by using renewables more.*

Hydrogen Cofiring

Cofiring hydrogen alongside gas offers smokestack CO_2 reductions at the plant, but how the hydrogen is produced greatly affects environmental and public health outcomes—and can even lead to an overall increase in climate pollution compared to burning gas alone. Burning hydrogen in a gas plant can also increase NO_x emissions and, consequently, the public health repercussions of the plant.

CO_2 Reductions at the Plant

Because hydrogen (H_2) itself is carbon free, burning it as fuel in a gas plant to generate electricity results in less combustion-related carbon emissions than burning gas alone to generate the same amount of electricity. Hydrogen carries only a third as much energy as gas by volume, however, so the actual carbon reductions at the smokestack are much less than the share of hydrogen cofired with gas (Goldmeer and Catillaz 2022; see Figure 1). To generate the same amount of electricity, a plant needs to burn more of the blended gas-hydrogen fuel, which means less CO_2 reductions overall.

For example, a mix of half hydrogen and half gas, by volume, requires a plant operator to use 54 percent more fuel to produce the same amount of electricity. With gas making up half of that increased flow, gas use drops only 23 percent. This decrease translates in turn to a 23 percent reduction in CO_2 from combustion. To achieve a 90 percent carbon reduction requires cofiring 97 percent hydrogen.

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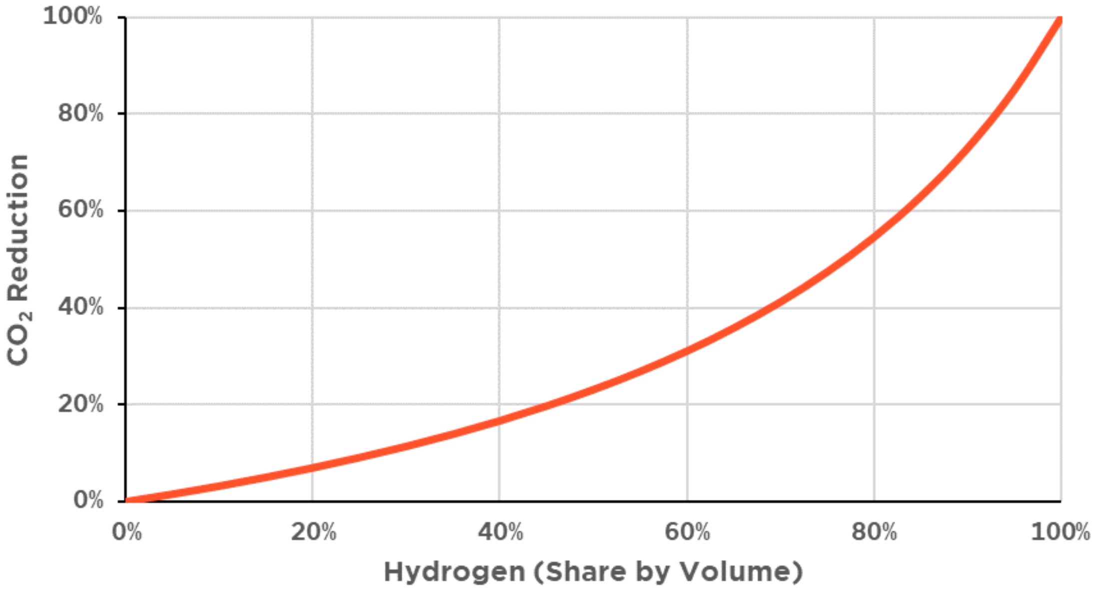
[5] The cheapest and cleanest option for reducing power sector emissions is generally focusing on decreasing electricity demand, including investing in energy efficiency. This brief focuses on how to meet the demand that remains.

Figure 1. Direct Carbon Reductions from Hydrogen Cofiring



Because hydrogen has a lower energy content than methane, the direct carbon reduction benefits of cofiring with hydrogen are less than its blended percentage. Co-firing with 50 percent hydrogen by volume, for example, results in only a 23 percent reduction in gas use and CO_2 emissions from combustion. Blends of 5–30 percent hydrogen, the levels hydrogen project proponents often propose for the near term, would reduce combustion-related CO_2 emissions only 2–11 percent.

Climate Pollution Beyond the Plant

Hydrogen production is energy intensive, making its production method a major factor in determining the overall change in carbon emissions from using hydrogen in gas plants. Virtually all hydrogen used in the United States today—overwhelmingly for petroleum refining and in the chemicals industry—is produced via steam methane reforming (SMR), the main by-product of which is CO_2 (Satyapal et al. 2023; Office of Fossil Energy 2020). This process of creating "gray" hydrogen yields approximately 12 kilograms of carbon dioxide equivalent per kilogram of hydrogen, or 12 kg CO_2e/kg H_2, on a lifecycle basis (McNaul et al. 2023). Producing hydrogen with that carbon intensity emits twice as much CO_2e as cofiring the hydrogen reduces at the smokestack—meaning incorporating fossil-based hydrogen actually *increases* overall CO_2e emissions (Figure 2). Applying carbon capture to the reforming process can ostensibly lower the carbon intensity of produced hydrogen (sometimes referred to as "blue" hydrogen); however, for many of the same reasons detailed in the CCS section, this decrease risks being far less than anticipated, in addition to introducing new harms (see also Schlissel and Juhn 2023; Howarth and Jacobson 2021).

Hydrogen can also be produced using electricity to separate water into hydrogen and oxygen through electrolysis. With this production method, the life cycle carbon emissions associated with the resulting hydrogen depend heavily on the carbon intensity of the electricity used by the electrolyzer. Producing hydrogen using electricity with the average carbon intensity of the US grid could result in emissions of more than 20 kg CO_2e/kg H_2, meaning total CO_2e

emissions from the process would be 3.5 times the combustion-related CO_2 reductions.[6] And powering an electrolyzer with coal-fired generation could result in hydrogen with a carbon intensity of approximately 50 kg CO_2e/kg H_2, meaning 9 times as much CO_2e would be emitted in producing the hydrogen as using the hydrogen would reduce at the smokestack.[7]

Even hydrogen produced with zero-carbon renewable electricity driving the electrolyzers ("green" hydrogen) has potential climate implications. A principal implication stems from the inefficiency of the path from renewable electricity to hydrogen to electricity generation in a gas plant, compared with direct use of the renewable electricity. For instance, producing hydrogen by using solar or wind energy to power an electrolyzer with a typical efficiency of 75 percent and then using that hydrogen in a gas power plant with an efficiency of 45 percent would result in only one-third as much electricity as that originally supplied by the renewable sources (Corbeau and Merz 2023).[8] That is, it would take three times as many wind turbines or solar panels to supply the same amount of electricity via hydrogen blending as from wind or solar directly.

Hydrogen, unlike solar or wind energy, can be directly stored, but as a storage medium a loss of two-thirds of the original electricity means a "round-trip" efficiency—or electricity out divided by electricity in—that is less than half that of the current primary means of storing electricity, pumped hydroelectric storage and battery storage.[9] Such hydrogen-related energy losses might be tolerable where other options to capture and store renewable electricity do not exist or when renewables are sufficiently abundant in the future. At present, however, using renewable electricity *directly* yields the maximum service from a given quantity of wind or solar, and the maximum displacement of carbon-intensive generation.

Diverting existing renewable electricity to generate hydrogen for use in gas plants has further implications, as it requires using other electricity sources to make up for the renewable electricity lost in the inefficient pathway from renewable energy to hydrogen to gas plant generation. Because electricity grid operators typically fully incorporate ("dispatch") solar and wind electricity, as the resources with the lowest operating costs, the diverted electricity would likely be replaced by running a coal or gas plant more—including by increasing the use of the very gas plants prompting that need by undertaking hydrogen cofiring.

Finally, leakage of hydrogen further erodes its effectiveness in mitigating climate change. Hydrogen is an indirect global warming pollutant,[10] and its small molecular size makes it more likely to leak from system infrastructure than methane. Estimates vary widely, but 1–10 percent of hydrogen leaking across the full system (that is, from the point of production to its use in the plant) is equivalent to 1.8–18 percent of smokestack CO_2 reductions (Ocko and Hamburg 2022; UCS 2024).

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[6] UCS calculations based on 390 kg CO_2 per megawatt-hour (kg CO_2/MWh) in 2022 and an electrolyzer electricity demand of 52.5 kilowatt-hours per kilogram of hydrogen, based on an electrolyzer efficiency of 75 percent (EIA 2023a; Corbeau and Merz 2023; Goldmeer 2019)

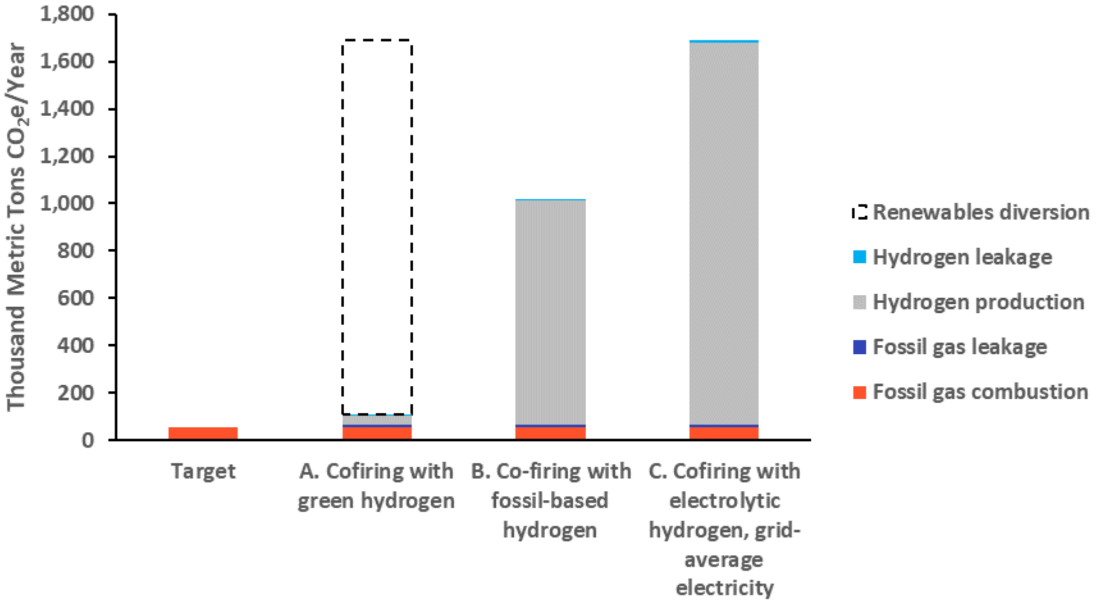
[7] UCS calculations based on coal emissions of 1,043 kg CO_2/MWh (EIA 2023b) and the same electrolyzer assumptions as in the previous note.

[8] The average efficiency of US gas plants in 2022 was 45 percent for combined-cycle plants and 31 percent for single-cycle combustion turbines (EIA, n.d.; Sanchez 2020; EIA 2024d).

[9] Pumped hydroelectric and battery storage have round-trip efficiencies of 70–87 percent and 83–91 percent, respectively (Cole and Karmakar 2023; Mongird et al. 2020).

[10] Hydrogen's global warming potential is more than 11 times that of CO_2 over a 100-year period and more than 30 times that of CO_2 over 20 years (Ocko and Hamburg 2022).

Figure 2. Overall CO_2e Emissions Compared to Target, by Hydrogen Production Scenario



Emissions of CO_2 and other heat-trapping gases during hydrogen production reduce the climate benefits of cofiring with hydrogen and can even lead to overall increases in CO_2e emissions. Cofiring 97 percent hydrogen by volume—the amount required to lower smokestack carbon emissions 90 percent ("Target")—could reduce the net CO_2e emissions at a gas plant by close to that amount if using low carbon-intensity hydrogen, produced through electrolysis powered by renewable energy (A). Yet diverting electricity from existing renewable energy sources to power the electrolysis would require more generation from other power sources to fill the gap, likely leading to overall emissions many times the target amount ("Renewables diversion" box). Using fossil-based hydrogen could similarly result in overall emissions much higher than targeted (B), as could using hydrogen produced via electrolysis powered by electricity with the average carbon intensity of the US grid (C). In addition, each option would increase NO_x emissions if no changes in operation or pollution controls are implemented.

Note: Analysis based on a 250 megawatt power plant with a 60 percent capacity factor, leakage rates of 2.3 percent for methane and 1 percent for hydrogen, and carbon intensities of 0.45 kg CO_2e/kg H_2 (A), 12 kg CO_2e/kg H_2 (B), and 20.5 kg CO_2e/kg H_2 (C). A carbon intensity of 0.45 is the maximum level allowed for the top tier of the federal clean hydrogen production tax credit (EERE, n.d.a)

Beyond Climate Pollution

In addition to having a more complicated climate picture than a simple reporting of fuel mix would suggest, cofiring hydrogen in a gas plant can lead to a range of other effects that often fail to appear in public pronouncements. For example, without changes in pollution control technologies or operations, the increased fuel flow rates required with hydrogen cofiring, along with the fact that hydrogen burns hotter, increase combustion-related NO_x emissions. These potential emissions increase as the use of hydrogen increases. With a 97 percent hydrogen blend (targeting 90 percent smokestack CO_2 reductions), NO_x emissions from the plant could be twice that from the gas plant without hydrogen (Goldmeer and Catillaz 2022).[11]

While cofiring hydrogen can reduce gas use in a gas plant, communities can be affected by gas use elsewhere in the process, principally for producing the hydrogen. Using gas as the feedstock for making hydrogen via SMR or for generating the power for electrolysis, for example, can increase public health impacts on people and communities.

Safety is another consideration. Hydrogen molecules are small, can damage certain steel alloys, and are more flammable than gas (Goldmeer and Catillaz 2022). These attributes make hydrogen more likely to leak, and more dangerous if it does.

Producing hydrogen can involve consuming considerably more water than the power plant consumes as cooling water in the process of generating electricity (UCS 2013). With a 97 percent blend of electrolytically produced hydrogen, for instance, the water consumed by being split apart to make hydrogen could be almost 10 times the water consumed by the power plant in making its electricity.[12]

Hydrogen cofiring also has implications for electricity ratepayers' pocketbooks. Costs for electrolytic hydrogen depend on the electrolyzer cost, the electricity cost, and how often the electrolyzer is used (Longden et al. 2022). The current cost of low-carbon hydrogen is several times the cost of gas per unit of energy; while scale and innovation are likely to rapidly reduce hydrogen production costs, even the Department of Energy's 2031 cost target ($1/kg) would leave hydrogen costing 2–4 times gas's average wholesale prices over the past decade of $2–$6 per million British thermal units, or MMBtu, on an energy-equivalent basis (IEA 2020; UCS 2024; EERE, n.d.b; EIA 2024a).

Required upgrades to power plants themselves, which add to these costs, could include new controls to address NO_x pollution at even low levels of cofiring, and major retrofits to accommodate higher levels of hydrogen, including changes to combustion systems, piping, controls, and monitoring (Simon 2022). Because of the inefficiencies of the green hydrogen approach, generating electricity in a gas plant using hydrogen produced from renewable energy will never be cheaper than if the renewable electricity can be used directly, even without consideration of upgrade costs involved in incorporating hydrogen.

Furthermore, if hydrogen is allowed to count as "clean" under the US tax code even when produced by diverting existing renewable resources, consumers are at risk of seeing double-digit increases in their utility bills due to the potentially massive increases in electricity demand for electrolysis without corresponding new supply (Gimon 2023). Any increased costs passed on to consumers could have the greatest impact on low-income households and Black, Hispanic, and Native American households, who already have median energy burdens (household energy expenses as a portion of income) that are much higher than those of higher-income and White households (Drehobl, Ross, and Ayala 2020).

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[11] Another way to produce electricity from hydrogen, fuel cells, does not result in NO_x emissions.

[12] Analysis based on median values for a combined-cycle gas plant equipped with a cooling tower (Macknick et al. 2012; UCS 2024).

Carbon Capture and Storage

Deploying CCS at a gas plant reduces the CO_2 emissions released by burning gas—but fails to address, and can even exacerbate, upstream methane emissions and the impacts of gas extraction, as well as introduces new issues associated with carbon capture, transport, and storage.

CO_2 Reductions at the Plant

The mechanics of CCS are clear in theory. For gas plants, as with other fossil fuel facilities, CCS involves capturing carbon at a plant (either before or after combustion[13]), compressing it, transporting it via dedicated CO_2 pipelines, and sequestering it either through underground storage or use. In 2024, the US Environmental Protection Agency set stringent carbon emissions standards for new, frequently used gas plants based on the application of CCS, obligating them to achieve CO_2 emissions rates equivalent to 90 percent capture by 2032 (EPA 2024b).

Capturing and compressing carbon for storage requires energy, however, which counteracts some of the capture-enabled carbon reductions. This "energy penalty" can vary depending on fuel type and type of carbon capture system. For gas plants using postcombustion capture, the energy penalty may be 10–20 percent (Vasudevan et al. 2016).

Consider, for example, a plant using CCS to capture 90 percent of the CO_2 emissions from its combustion, powering the CCS with its own output, and incurring an energy penalty of 15 percent.[14] Maintaining the same original net electricity output would require the plant to compensate by increasing its generation 18 percent. That increase in generation would result in the additional consumption of gas and additional carbon emissions, even if 90 percent of the additional emissions were also captured by the CCS.

Climate Pollution Beyond the Plant

The counteracting climate impacts of CCS reach far beyond the plant. One factor is methane leakage. Because adding CCS does not lead to any reduction in the amount of gas a plant uses, it does nothing to abate the associated methane leakage. Also, when the energy penalty results in even more gas usage, the added upstream leakage means even greater CO_2e emissions attributable to the plant. Methane leakage could substantially erode the overall efficacy of CCS (Figure 3).

Other climate impacts result from CO_2 leaks from pipelines or underground storage or in association with use of the captured carbon. Storage of the carbon captured at a plant involves compressing and transporting the CO_2 through pipelines to its final destination. Any CO_2 leaking from the pipelines or the storage would undo the carbon capture effort, at least in part. Over time, CO_2 can slowly leak into the atmosphere if storage reservoirs are not carefully monitored; abandoned oil and gas wells intersecting with CO_2 storage sites also increase the risk of leakage (Environmental Integrity Project, n.d.).

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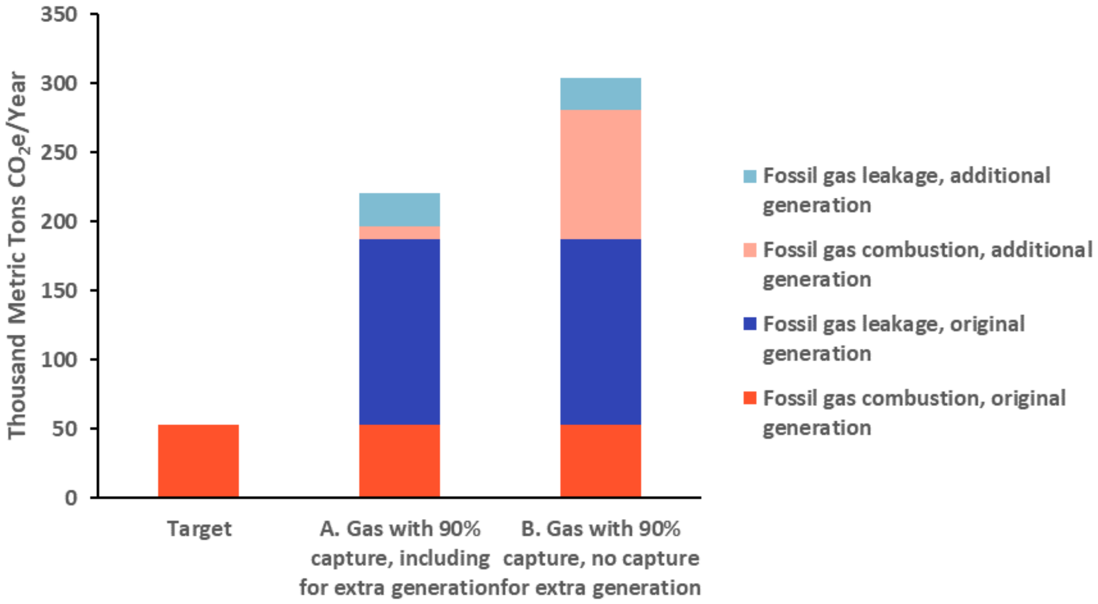
[13] Pre-combustion is more efficient, but post-combustion is more feasible for retrofitting existing plants. This analysis evaluates only post-combustion capture.

[14] CCS systems can also be powered by separate dedicated power units; these units are likely to have higher emissions and not have their emissions captured by the CCS system.

The carbon profile of a CCS project can worsen if the carbon is not simply stored but instead injected into oil wells to increase the extraction of oil—another fossil fuel and source of considerable carbon pollution—through a process known as enhanced oil recovery, or EOR. In fact, EOR is the destination of most carbon currently captured in the United States (EPA 2024d).

Figure 3. Overall CO_2e Emissions Compared to Target, by CCS Scenario



While incorporating CCS can reduce smokestack carbon emissions, the technology does not reduce the emissions associated with methane leakage and leads to added carbon and other pollution from the extra generation required to power the carbon capture, with overall emissions 4–5 times the target.

Note: Analysis based on a 250 megawatt power plant with a 60 percent capacity factor, and a 15 percent energy penalty, with the electricity to power the carbon capture coming either from the plant itself or from a separate generator with similar characteristics. Analysis also assumes 2.3 percent methane leakage and does not include any effects from CO_2 leakage post-capture.

Beyond Climate Pollution

Adding CCS at a gas plant does not address any of the other impacts associated with gas generation, and indeed can worsen some. Without additional controls, the added generation for powering the CCS could result in proportional increases in emissions of NO_x, hazardous air pollutants, SO_x, and particulates, further degrading air quality for surrounding communities and aggravating public health. Employing CCS can also almost double a gas plant's water consumption (Macknick et al. 2012). In addition, CCS systems use amine-based solvents that capture CO_2 from gas. The breakdown of these solvents can release carcinogenic compounds that could pose a hazard to the health of workers or residents of nearby communities—though assessing that risk is challenging because the detailed makeup of these solvents usually remains proprietary (Anderson and Saunders 2022).

CO_2 leaks from carbon pipelines can be hazardous not just for the climate, but for people directly. Although the United States has several thousand miles of CO_2 pipelines, an increase in CCS adoption could lead to many times that amount (Parfomak 2023).[15] Constructing additional miles of pipelines near communities elevates the risk of people being exposed to large amounts of CO_2, which acts as an asphyxiant if it displaces enough oxygen. Exposure causes nausea, shortness of breath, and disorientation, which can lead to hospitalization.[16] Increased exposure to CO_2 could lead to convulsions, coma, or death (Langford 2005).

Cost impacts are an important additional dimension of CCS effects. Implementing CCS requires inclusion (or addition, in the case of plant retrofits) of infrastructure at the plant for capturing and compressing the CO_2. It also can involve investments in additional infrastructure, such as pipeline and storage capacity. Further, it brings the cost of additional fuel and other ongoing operational expenses (Lazard 2023). While few data points exist, projections suggest that including CCS could result in unsubsidized electricity costing on the order of 69–115 percent more than that from gas plants without carbon capture (Lazard 2023).[17] To the extent that consumers bear those costs, CCS will only increase energy burdens.[18]

Biomethane

Gas plants burning a share of biomethane alongside fossil methane maintain the same smokestack CO_2 emissions; the large climate benefits sometimes associated with use of biomethane are premised on offsetting climate pollution elsewhere in the economy. But such assumptions rarely hold up under scrutiny—and all the while, gas plants burning biomethane perpetuate, or even increase, environmental and public health pollution harms.

CO_2 Reductions at the Plant

Biomethane, sometimes referred to as “renewable natural gas,” is functionally equivalent to fossil methane. Instead of being extracted from underground, however, it is produced from the anaerobic breakdown of organic matter, such as animal manure, sewage, or landfill waste.[19] Some gas plant owners and operators have proposed burning biomethane in place of fossil methane as a way to “reduce” the climate pollution associated with gas plants—without changing any onsite processes, infrastructure, or, ultimately, emissions.

When a gas plant burns biomethane, the carbon emissions released at the smokestack remain unchanged. Instead, carbon reductions are premised on emissions offsetting, whereby a gas plant claims credit for emissions reductions occurring elsewhere in the economy to “cancel

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[15] Economy-wide, the DOE estimates that, up from the current 5,000 miles of US CO_2 pipelines, 30,000–96,000 miles could be needed by 2050 to support CCS-reliant pathways for decarbonization (Fahs et al. 2023).

[16] Many local residents experienced such symptoms when a pipe burst and released CO_2 into the nearby town of Satartia, Mississippi, in 2020. The pipeline, owned by CO_2 pipeline developer Denbury Resources (now part of ExxonMobil), was being used for enhanced oil recovery. Forty-five people were hospitalized due to the effects of CO_2 exposure (Mathews 2022).

[17] Figures are based on low-end estimates of the levelized cost of energy from new or existing combined-cycle gas plants incorporating CCS vs. new combined-cycle gas plants without CCS.

[18] The costs of a proposed CCS project in Kemper County, Mississippi, grew from an original $2.4 billion to $7.5 billion before being abandoned in 2017 (Dubin 2017). The utility developing the project was forced to refund $377 million to Mississippi electricity ratepayers (Ablaza 2016).

[19] Although this analysis focuses on biomethane, coal mine methane is also sometimes classified as a carbon-negative fuel via the same flawed “avoided methane” assumptions discussed here.

out" the emissions still occurring at the facility. As explained in the next section, these offsets are overwhelmingly premised on flawed assumptions.

Climate Pollution Beyond the Plant

The claimed climate benefits of a gas plant using biomethane rely on an emissions framework known as life cycle accounting. This framework assesses the climate emissions associated with the production, transport, and use of fuels, both direct and indirect. Life cycle accounting can be valuable for helping to draw out the broader climate impacts associated with the consumption of a given fuel, beyond what occurs at a smokestack. The framework can open the door, however, to polluter greenwashing. For biomethane, this obscuring of facts includes the abuse of a specific assumption around avoided emissions that functionally turns the fuel use into an offset, where actions taken to avoid pollution elsewhere in the economy are credited against the pollution still occurring at—and upstream from—the power plant.

In particular, under certain assumptions, burning biomethane is counted as a net climate benefit because the CO_2 produced from combustion is less harmful to the climate than if the methane had instead been vented (released to the atmosphere unburned). Such calculations can credit biomethane with a deeply negative carbon intensity value despite the fact that no carbon is independently removed from the atmosphere. This means using just a share of biomethane—ranging from around a quarter to far lower amounts—can result in a gas plant being calculated as having reduced plant emissions by 90 percent, even if the remaining fuel is still fossil gas (Figure 4).[20]

This negative carbon intensity score is premised on the deeply flawed assumption that the biomethane would have otherwise been released to the atmosphere. This assumption is not reasonable in a net-zero framework, where every source of pollution counts; with the United States committed to achieving a net-zero economy by 2050, there is no credibility to a baseline assumption of unmitigated methane venting. Instead, if biomethane can be captured for use, at minimum, the appropriate baseline climate comparison is flaring, such as is now required at certain regulated landfills.

Even more appropriate, however, is to compare biomethane to the best climate alternative, including whether production of that biomethane could have been entirely avoided, such as through climate-smart farming or the diversion of organic materials from landfills (EPA 2024e). With this shift in assumption, biomethane receives a carbon intensity value far more comparable to fossil gas—and as a result, would no longer serve as a means of offsetting gas plant carbon emissions (Grubert 2020).

Furthermore, when the environmental attributes associated with biomethane are indirectly consumed via "book-and-claim" accounting as opposed to biomethane being directly consumed for power generation where it is produced, its use has not changed the upstream methane leakage associated with a gas plant's actual methane consumption.

Major climate implications are also directly associated with biomethane production, processing, and use. In particular, because biomethane is still methane, it causes the same climate harms as fossil methane when it leaks. In addition to leakage occurring during fuel

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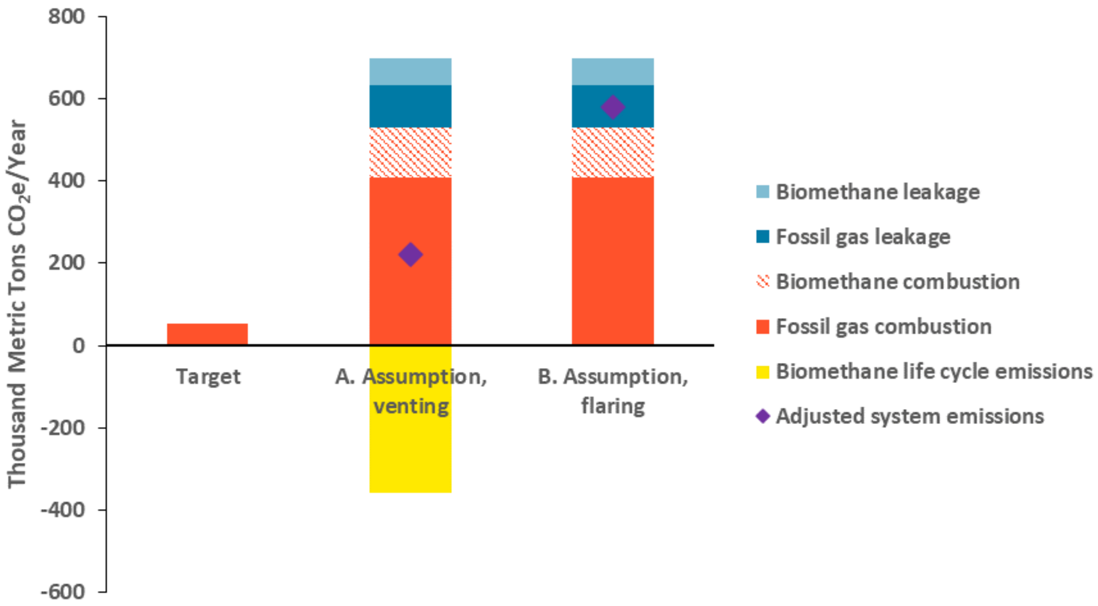
[20] Percentage determined based on the calculated carbon intensity score of the biomethane; the high end of the range corresponds to a carbon intensity representing the default dairy manure feedstock under the California Low-Carbon Fuel Standard while the low end points to more deeply negative awarded specific projects, all relying on a counterfactual assumption of methane venting (see, e.g., Grubert, Ricks, and Cullenward 2024).

transmission and storage, biogas processing and upgrading sites as well as digestate storage have been increasingly identified as large sources of climate pollution. Median supply chain leakage has been estimated at greater than 5 percent—far higher than that of the US oil and gas system as a whole (Bakkaloglu, Cooper, and Hawkes 2022).

When life cycle accounting for biomethane accurately reflects these additional components, the fuel's climate attributes erode further, such that using some sources of biomethane may in fact be worse for the climate than if a gas plant had just continued burning fossil gas.

Figure 4. Overall CO_2e Emissions Compared to Target, by Biomethane Scenario



Burning biomethane at a gas plant does not change actual emissions at the smokestack. The reported life cycle heat-trapping emissions of the electricity generated, however, can change dramatically depending on the source of the biomethane, assumptions around its alternative fate, treatment of biogenic CO_2 *emissions, and whether the full suite of biomethane supply chain fugitive emissions are included. For example, a gas plant targeting 90 percent* CO_2 *reductions could use a 23 percent blend of biomethane credited with avoided methane (here assigned a representative carbon intensity value of -158 kg* CO_2e*/MMBtu) to nominally offset 90 percent of its combustion emissions (A). However, switching the underlying baseline assumption from venting to flaring changes the carbon intensity (here assigned a representative value of 0 kg* CO_2e*/MMBtu), which substantially reduces the purported climate benefits of biomethane use (B). "Adjusted system emissions" includes fossil gas combustion emissions, biomethane and fossil gas upstream emissions, and crediting for methane avoidance (scenario A only).*

Note: Biomethane combustion emissions are calculated as carbon neutral in accordance with standard carbon accounting conventions; however, this assumption is not uniformly valid and declining to treat biogenic CO_2 *as carbon neutral would substantially shift reported emissions outcomes (CLF 2024; EPA 2024f). Analysis based on a 250 megawatt power plant with a 60 percent capacity factor, 2.3 percent fossil methane leakage, and 5 percent biomethane leakage. This scenario demonstrates one possible comparison of counterfactuals, inputs, and assumptions.*

Beyond Climate Pollution

Relying on ultimately meritless avoided-emissions offsets to claim reductions of gas plant climate pollution fails to actually reduce gas plant climate pollution. It also fails to reduce health-harming pollution. For these reasons, even if biomethane were to improve overall climate outcomes, it could never make a gas plant “clean.”

Moreover, the systems and processes leading to biomethane production are typically associated with their own severe pollution harms to water and air, which are disproportionately and inequitably borne by surrounding communities, as with industrial farming operations (Gittelson et al. 2022; Leadership Counsel for Justice & Accountability 2023). These harms include emissions of volatile organic compounds and the pollution of local waterways and groundwater (Lazenby 2022). Policies that prop up the production of biomethane by inappropriately rewarding its downstream use—or, worse, perversely incentivize more biomethane production—are directly culpable in these broader upstream harms.

Finally, biomethane is more expensive than fossil gas. Fuel prices vary but are generally in the range of less than $20 to $50/MMBtu, compared to the past decade’s wholesale gas prices of $2–$6/MMBtu (Staines and Beaman 2023; EIA 2024a).

Renewable Energy: Carbon Reduction with Fewer Impacts

Renewable energy sources can directly displace gas generation, and do so with far fewer impacts than hydrogen blending, CCS, or biomethane. Because electricity grid operators generally choose the lowest-cost source of electricity to meet demand at any given time, and because solar, wind, geothermal, and hydropower have no fuel costs, operators dispatch them before resorting to the more expensive fossil fuel options to meet remaining demand. As coal plants retire, renewable electricity is increasingly displacing gas, and its associated emissions of CO_2 and other harmful pollutants. By reducing the use of gas plants, renewable energy also avoids the methane leakage attributable to gas generation.

Life cycle CO_2e emissions for renewable electricity generation that incorporate the manufacture of solar photovoltaic panels and wind turbines, for example, are much lower than those of gas plants. On average, solar and wind generation are responsible for 91 and 97 percent fewer life cycle carbon emissions per unit of electricity than gas generation, respectively (NREL 2021).

In terms of community impacts and resource use, solar panels and wind turbines generate electricity without water, without air or water pollution, and with life cycle water consumption that is 60–99 percent lower than that of gas plants (Meldrum et al. 2013).[21] In many parts of the country, large-scale solar and onshore wind facilities are the least expensive sources of new electricity generation: unsubsidized costs at the low end are potentially 36 percent and 40 percent lower per unit of electricity, respectively, than that from combined-cycle gas plants without CCS (Lazard 2024). This renewable energy cost advantage will likely grow (EIA 2022).

Renewable energy for displacing gas generation can involve appreciable amounts of land, for the facilities themselves and for associated electricity transmission. Many of the impacts are

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[21] Analysis based on median values for a combined-cycle gas plant equipped with a cooling tower.

short-term or reversible, however, and the land usage is potentially far less than that associated with other approaches for cutting gas plant carbon emissions (Clemmer 2023). Ground-mounted solar (as distinguished from rooftop solar, which requires no land) can encompass 3–4 acres per megawatt of electricity, on average (Bolinger and Bolinger 2022). Wind farms cover much larger areas, but because of the space needed between wind turbines to allow for full power generation, the wind turbines and associated infrastructure occupy only about 2 percent of the area (Denholm et al. 2022). Even a renewables-heavy future would require less land for solar panels, wind turbines, and associated transmission than that included in active oil and gas leases alone (Denholm et al. 2022). As described previously, the greater efficiency of directly using renewable electricity instead of using it to produce green hydrogen to then burn in a gas plant can reduce land impacts by 60–70 percent. Renewable energy also reduces the land impacts of gas extraction, CO_2 pipelines and CO_2 storage, and biomethane production facilities.

Conclusions and Recommendations

With gas-fired electricity generation the largest source of climate pollution in the US power sector, gas plants must be a key focus for efforts to mitigate the climate crisis; a cleaned-up power sector is critical to cutting carbon across the entire economy via electrification of other sectors, such as transportation and heating. And the public health burdens such plants place on people, particularly on people of color and people with low incomes, require that solutions address not only carbon pollution but also other harms that stem from gas plant power generation.

The most effective way to cut the range of harms is to ramp down gas plant use by ramping *up* the use of renewable energy, along with its associated elements of transmission and energy storage. With each of the nonrenewable energy approaches, the overall carbon reductions could be less than targeted—in some scenarios much less—because of the climate impacts of other steps in their processes. Hydrogen, CCS, and biomethane also provide a further rationale for the full, ongoing use of gas plants—and threaten to perpetuate and exacerbate environmental injustices for communities as well.

A range of strategies can help maximize renewable energy adoption to drive down gas plant generation and its associated pollution, including:

- **Accelerate equitable renewable energy siting, permitting, and connection to electricity grids.** Proposed solar, wind, and other renewable energy projects often undergo lengthy approval processes and, even once built, face further delays in connecting to the power grids that will transport their electricity to customers. Accelerated processes must not neglect affected communities, however; project development should involve robust engagement of those communities, particularly environmental justice ones already shouldering disproportionate levels of pollution and other impacts from power and other infrastructure.

- **Facilitate the development of transmission and storage.** Stronger electricity grid connections between different parts of the country can allow for greater levels of renewable energy adoption, as transmission lines serve to carry one region's excess renewable energy to another region in need. Energy storage, by capturing generation not immediately needed or where transmission lines are constrained, can help make better use of both renewable energy facilities and related transmission.

- **Continue investment in scale and innovation.** While the costs of harnessing solar and wind energy and storing it in batteries have dropped significantly in recent years, further improvements in cost effectiveness through scaled-up manufacturing and in efficiency and performance through further technological development will accelerate their adoption. And designing and implementing programs to expand access to solar power to underserved populations and communities will improve equity in adoption (Vote Solar, n.d.)

While ramping up renewable electricity to directly displace the use of gas is generally the best approach to reducing gas plant carbon pollution by far, as in other matters related to fossil fuels, incomplete information, obfuscation, or active disinformation from the fossil fuel industry challenges informed decisionmaking (UCS 2015). To overcome such hurdles, any proposal to tackle gas plant pollution that is premised on the full, ongoing use of a gas plant must be rigorously evaluated with regard to carbon emissions from plant operations, life cycle climate-related emissions, and non-climate impacts on people and communities—and each must be compared to direct use of renewables.

In particular, evaluation of such proposals must include the following:

- **Full-scope analyses of climate impacts:** Power plant decisionmakers, including project proponents, public utility commissioners, and environmental regulators, must account for—and transparently disclose—the full climate implications of each proposal for reducing gas plant carbon emissions. Every approach should be compared against renewable energy options.

    - **Hydrogen cofiring.** Full climate accounting must include information about the carbon implications of producing the hydrogen, including induced grid emissions for electrolytically produced hydrogen,[22] in addition to upstream methane emissions if fossil-based. Proposals must also account for the climate impacts of hydrogen leakage.

    - **Carbon capture.** Full climate accounting must include adjustments for the energy penalty incurred due to CCS operations—including the additional upstream methane emissions attributable to increased gas use at the plant or a separate power source for operating the CCS—as well as the energy required to compress and transport CO_2 for sequestration. CCS proposals must also account for downstream CO_2 leakage from pipelines and sequestration; accurately adjust for emissions resulting from any use of EOR; ensure no double-counting of captured carbon; and account for the need to meet rigorous emissions measurement, monitoring, and verification protocols.

    - **Biomethane.** Full climate accounting must assign a credible, verifiable carbon intensity value for biomethane sources based on a comparison to the best climate alternative, with no crediting for avoided methane. Evaluations must also prohibit pollution shuffling and disallow perverse incentives that would expand waste feedstocks. Methane emissions at biomethane production sites as

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[22] Running electrolyzers on clean energy that is incremental to the system, regionally located, and temporally matched with electrolyzer operations—criteria sometimes referred to as the “three pillars” framework—ensures produced hydrogen is truly low carbon (McNamara 2024).

well as leakage from associated gas infrastructure must be included in climate assessments.

- **Full-scope analyses of broader impacts on the public:** Decisionmakers must also fully consider and address non-climate upstream, downstream, and plant-specific impacts on people and communities. Assessments should include full consideration of the historical burdens of pollution and other impacts that communities have faced, and the often-inequitable distribution of those impacts. And it should include broad examination of what the proposals would add to those burdens by perpetuating full or increased use of the plants, including cumulative burdens that relate to other air and water pollutants, water and land use, safety, and costs (Ellickson 2022).

- **Transparent evaluations and committed community engagement:** Decisionmakers must be fully transparent about the range of climate and non-climate implications of proposals to help enable full community engagement and to guide the selection of solutions that maximize public benefits. Throughout the process, input assumptions and analytical boundaries must be clearly documented.

The above criteria are necessary to ensure informed decisionmaking around the best path forward for addressing gas plant pollution. However, informed decisionmaking is not enough—decisionmakers must also follow through. Climate change and the large role of the US power sector in the country's emissions, combined with the long history of harms from power plants and inequitable burdens borne by communities of color and people with low incomes, demand pursuit of swift, deep reductions in carbon emissions—and to do so in a way that reckons with all the many dimensions of gas plant harms (Clemmer et al. 2023; UCS, n.d.).

The extensive range of complicating effects of using hydrogen, CCS, or biomethane to reduce gas plant carbon pollution points strongly to the value of using truly clean energy to the fullest to displace generation by gas plants. For communities and the climate, the imperative is clear: use renewables more, use gas plants less.

Methodology Note

While this issue brief presents numerical findings based on specific assumptions, identified in the text and, where applicable, in the related UCS tool, the broader implications of those findings are robust across a range of scenarios (UCS 2024). Many of the calculations are linear, such that halving (or doubling) assumptions about an input would halve (or double) the output. Other calculations are not. The type of CCS plant discussed, using postcombustion carbon capture, for example, would require high levels of operation to maintain the high rates of CO_2 reduction targeted in this issue brief; a lower capacity factor would increase the energy penalty (Lazard 2023). Other changes to inputs might lead to step changes, requiring a non-linear upgrade to equipment (for pollution controls, for example), and a non-linear increase in associated costs.

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