

Burning gas -- we hope completely.

Where are the methane leaks? And why that's critical for electrification policy.



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I spend most of my time helping clean energy program administrators plan, develop, and run successful programs. I get especially excited about residential HVAC and building electrification. Unfortunately for me, there's an important methane component to the greenhouse gas impacts of electrification and this has led back into chemistry and my chemistry is old and hasn't really been used since a couple of classes in stationary and mobile power plants during undergrad. My atmospheric chemistry is especially weak. But we need to consider the interactions of these two areas to set effective policy. So I'm giving it a shot.

In recent years, I've been advocating for the idea of partial electrification with dual fuel heat pump systems being the killer app for our next phase of building energy decarbonization. There are a host of reasons why this makes sense, but people have also asked me a really hard question, which is "What about the methane?" To which I've responded that the distribution system leaks are a very small part of the GHG emissions and that they don't really change the story. But what if that conclusion is incorrect? I've been challenging this assumption in recent weeks and this is my conclusion:

Methane emissions in our natural gas system and their exact nature are a big deal.

Methane from natural gas systems has several pathways to enter the atmosphere. I split these pathways into four different groups that have specific implications for electrification methane reduction impacts:

1. **Upstream leakage** in natural gas fields (a really big deal) and transmission pipelines (less of a big deal). The general consensus is that this is the biggest source of methane emissions in the natural gas system.
2. **Distribution system leakage** in pipelines within towns, cities, and rural areas, more or less between citygate and point of customer delivery at the meter.
3. **Customer site passive leakage** occurs regardless of usage, but on the customer side of the meter. These are generally very small, because larger leaks can be detected by odor, but they exist.
4. **Combustion-related methane emissions** occur in conjunction with burning natural gas in devices and is present in the exhaust gas from various systems.

Unfortunately, as is common in science (and climate science), the data on methane emissions from natural gas are incomplete and at least somewhat conflicting. What is understood is that they are large and important and represent both an important source of GHG emissions and potential GHG savings.

When you simplify the math, you can create a rough rule of thumb that says that every 1% of natural gas consumed that is emitted to the atmosphere increases GHG emissions from combusting natural gas by 10%. The slightly more complicated math is: GHG emissions_methane = Fraction of methane emitted X GWP X molecular weight of methane / molecular weight of CO2 X GHG emissions_CO2. Choices for GWP vary a little bit based on what time period you're talking about, but it's ~25 for a 100 year period and it goes up as the lenght of the time period drops down. The molecular weight of methane, CH4 is 16, while the molecular weight of CO2 is 44. When you take something that's ~25 / ~2.75, I get the rule of thumb multiplier of 10 for the ratio of % methane emissions to % increase in GHG emissions.

So with my new rule of thumb in hand, going from 1% methane leakage to 3% or 4% increases GHG emissions by 20 or 30%. That's a big deal.

For electrification decisions, the size of each component matters quite a bit to the math calculations of GHG impacts. Reducing consumption by large amounts is assumed to reduce upstream leakage and combustion-related emissions, whether its full or partial electrification of individual buildings. Fully electrifying individual buildings and shutting off gas service further reduces emissions by getting rid of the customer-site passive methane leakage at that building. Fully eliminating gas distribution infrastructure (as some have advocated doing) would further eliminate the distribution system leakage. If passive home leakage is tiny, then GHG benefits of eliminating gas at individual homes will be tiny. If it's large, then the impacts will be large.

Now we get to the hard question: Where exactly are the leaks occurring and how big are they? Actual atmospheric scientists have done recent work trying to answer this question. So far, they've been able to quantify emissions within cities vs upstream of cities. That's super helpful, but it doesn't give me quite enough information to feel great about making electrification policy decisions. I particularly like this paper: **Majority of US urban natural gas emissions unaccounted for in inventories | PNAS**

They found 2.5% emission rates in Boston for the city-side emissions sources, using a highly rigorous approach that tried to separate out the methane emissions from natural gas vs other major sources (natural sources like wetlands and unnatural sources like landfills), by also measuring ethane levels. I have a few questions around the methods, but I'm not knowledgeable enough to even be sure I'm asking the question correctly. That's a big, important number, but I would love to better understand how those emissions break down across different parts of the system. What fraction are passive leaks in distribution system vs in buildings vs active emissions associated with using the gas?

There were also a couple of other interesting findings in the data from this study:

1. They observed 60% higher natural gas-related methane emissions in the winter than the summer. I'm sure there's plenty of uncertainty around this, but this serves as a smoking gun indicating that there are some methane emissions associated with actually using natural gas, likely through incomplete combustion or fugitive emissions during lighting, which makes it likely that the fourth category I identified, combustion-related methane emissions, are likely a substantive part of the total. The only complication I can think of is that there could be other methane/ethane combustion or emission sources that are seasonal as well. It's not just a Boston phenomenon -- other studies have shown similar (but smaller) impacts in other places. But I'm still guessing that this piece could be in the range of 0.1% to 0.5% of natural gas consumption.

2. In April, 2020, during the Covid lockdown, they observed a big dropoff in natural gas-related methane levels at one of their sites (the lower altitude BU site), relative to previous Aprils. This is a real head-scratcher for me. It could be a coincidence or it could be that a significant anthropogenic source of methane (and/or ethane) was significantly reduced or eliminated during the COVID lockdown. The overall natural gas usage didn't really change compared to previous Aprils, so that's not it. But some components (like restaurant meals and nearby dining halls at BU) did get significantly reduced to near zero. It's unlikely that this was a simple point source of methane going away, but maybe it could have been a point source of ethane? Or some other source of anthropogenic ethane (like automobiles, trucks, or buses) maybe got significantly reduced. This one is definitely a puzzle to which I don't see a likely answer, but it helps support my ultimate conclusion:

We need more research on where methane emissions are coming from and how we might reduce them. How big are distribution system leaks? How low can we make them? How big are leaks within homes and buildings? It's of vital importance to the decisions we need to make now about what our decarbonized infrastructure build should look like.

In fact, I think that each jurisdiction trying to make a decision about what to do with their gas system infrastructure should study leakage from that infrastructure. The research that is available shows that certain kinds of aging gas infrastructure have much higher leak rates than newer infrastructure. So cities and suburbs that have grown recently are likely to have very low distribution system emissions, while cities with old infrastructure are likely to have higher distribution system emissions.

In addition, we really need a good study of methane leak rates from gas equipment of different types including methane in the exhaust (at startup, steady state, and turn off) and passive leaks within the home. I think this would require high frequency monitoring of exhausts and within the home, while simultaneously monitoring gas usage at the appliance level. And maybe pick a different tracer gas than SF6 for determining the infiltration/exfiltration mass flow rate, if we're trying to do a study to look at GHG emissions.

My hypotheses, which I'd love to see tested:

- Passive leaks within distribution systems are highly variable, ranging from low enough to not worry about them to high enough to worry a lot about them.
- Passive leaks within homes are very small. If they were bigger, we'd smell them.
- Emissions associated with using the gas are higher than we think, but should be at least somewhat controllable through equipment improvements.

I think there's proof that leaks in the portion of the natural gas system are large and that there are plenty of opportunities for reducing those emissions, but there's an open question as to how low we can make them.

Depending on what leak rates you're getting from each of the different pathways, efforts to eliminate gas in favor of full electrification at the building or neighborhood or city level may have higher or lower impacts. And then the decision turns into an economic one -- What's the cheapest way to achieve full decarbonization in your city? If you have an old leaky gas distribution system, can it be repaired or replaced economically? Or should it be abandoned? Or will it be cheaper to do atmospheric carbon capture and sequestration? There aren't any easy solutions to that problem.

If, on the other hand, your city has a newer gas distribution infrastructure with minimal leaks, and your decarbonized electricity grid still features burning gas during cold days (which it mostly likely will), then it probably doesn't save any GHG emissions to abandon the gas grid and we might as well continue to use some kind of gas for backup until there's an economically viable alternative for meeting loads during extreme cold. Unless of course you can build out electrical grid for these same extreme events for less money than keeping the gas grid. It doesn't look that promising here and now, but maybe someday?