Natural Gas End Use Decarbonization: What we Know so Far

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ABSTRACT

Natural gas has been a relatively inexpensive and clean source of heating for buildings and industry for decades, but looking forward to economy-wide decarbonization it is imperative to find alternatives. Electrification has emerged as a promising strategy, but complete electrification of all end uses currently served by gas is likely cost prohibitive, in some cases, technologically infeasible, and may increase energy burden for low-or-moderate income households. The federal government, states, utilities, and communities are in the early stages of grappling with building and industrial decarbonization, but some initial programs to promote or require electrification or alternative decarbonization strategies are beginning to be implemented. This research digs into some examples of policy and regulatory structures that are being tested across the country to promote electrification, alternative decarbonization strategies (e.g. renewable natural gas, hydrogen, carbon capture, etc.), and combination approaches. Specific cases that are explored are the federal High-Efficiency Electric Home Rebate, the Minnesota Natural Gas Innovation Act, Colorado Clean Heat Plans, networked geothermal pilots in Massachusetts and New York, zonal electrification in California, the expansion of demand side management programs to include building electrification in various states, bans on natural gas in new construction in various communities, and the Oregon voluntary renewable natural gas targets. While all of these programs are relatively new, this discussion will highlight what we know so far about the success or failures of these efforts to drive greenhouse gas emissions reductions at a reasonable cost.

Introduction

Direct greenhouse gas ("GHG") emissions from the residential, commercial, and industrial sectors make up approximately 36% of total U.S. GHG emissions and a substantial part of those emissions come from burning fossil fuels for heat and energy (EPA 2024b). Over the last several years there has been an increased focus on addressing these emissions through government and utility programs beyond traditional natural gas efficiency offerings. Policies and proposals in various jurisdictions seek to deploy a variety of technologies, most prominently electrification, but also low-carbon fuels, carbon capture, and networked geothermal systems. This paper will discuss some of these policies with a focus on what can be said about the costs of each program relative to GHG emissions reductions.[1] It is difficult to compare different programs on numerical terms because of the myriad ways that costs and GHG emissions can be calculated, however, we have endeavored to provide numbers where possible to aid in understanding the effectiveness of various offerings. In addition, because the programs and

[1] For brevity, throughout this paper we often refer to this simple comparison of costs to GHG emissions reduction as "cost effectiveness". We recognize however that there may be other important goals and costs other than GHG reductions and monetary costs associated with these programs that would ideally also be included in a full evaluation of cost effectiveness.

policies discussed have either only recently launched or are still only proposals, in many cases we are left with only estimates and expectations for performance.

Specifically, this paper will discuss two holistic GHG reduction planning structures for gas utilities: the Minnesota Natural Gas Innovation Act ("NGIA") and Colorado Clean Heat Plans ("CHPs"). Next, we will discuss various policies designed to promote electrification, including the federal High-Efficiency Electric Home Rebate program, building electrification as part of utility demand-side management ("DSM") offerings, Pacific Gas and Electric's ("PG&E") proposed zonal electrification program, and policies in various jurisdictions that prohibit the sale or installation of gas appliances (so-called "gas bans"). Finally, we address two other technology-specific approaches: networked geothermal pilots in New York and Massachusetts and the Oregon Voluntary Renewable Fuels Standard.

Minnesota Natural Gas Innovation Act

The NGIA gives Minnesota gas utilities the option to file five-year "innovation plans" consisting of "pilots" deploying "innovative resources". Innovative resources include biogas, carbon capture, district energy,[2] energy efficiency, power-to-ammonia, power-to-hydrogen, renewable natural gas ("RNG"), and strategic electrification. Plans are cost capped in relation to the size of the utility filing the plan.[3]

As of March 2024, only CenterPoint and Xcel have filed innovation plans. The tables below summarize some of each utility's proposed pilots. For brevity the tables include only the three most expensive and three least expensive pilots, on a cost/GHG reduction basis for each of the utilities.[4]

Table 1. Selection of pilots and innovative resources proposed in CenterPoint's innovation plan

Pilot Name	Innovative Resources	Estimated Costs[5]	Estimated GHG Reductions (tons CO_2e)	Cost/GHG Reduction ($/ton CO_2e)
Decarbonizing Existing District Energy Systems	Various	($3,422,215)	124,030	($27.59)
New District Energy System	District Energy, Strategic Electrification	($784,412)	40,882	($19.19)

[2] District energy is defined to exclude systems fueled by fossil energy (NGIA 2021, § 216B.2427, Subd. 1 (e)) and so the "district energy" contemplated by the Act may be more similar to the common understanding of the term "networked geothermal".
[3] CenterPoint Energy ("CenterPoint"), calculated their cost cap as approximately $100 million for their first NGIA plan (CenterPoint 2023, 19). Xcel Energy ("Xcel"), calculated their cost cap as approximately $60 million in their first NGIA plan (Xcel 2023, 29).
[4] Omitted CenterPoint pilots include carbon capture, strategic electrification, power-to-hydrogen, energy efficiency and RNG programs ranging from $0.42 up to $294.84/ton CO2e. Omitted Xcel offerings include carbon capture, RNG, and district energy programs ranging from $46.19 to $310.40/ton CO2e.
[5] Estimated costs in this column and the same column in Table 2 are net of certain savings including fossil gas commodity costs. Negative numbers indicate expected savings in excess of costs.

Industrial and Large Commercial GHG Audit Pilot	Various	($242,844)	35,560	($6.83)
New Networked Geothermal Systems	District Energy	$42,223,212	107,355	$393.30
Green Hydrogen Blending into Natural Gas Distribution System	Power-to-Hydrogen	$22,961,186	27,993	$820.25
Residential Gas Heat Pumps	Energy Efficiency	$343,818	235	$1,463.06
Plan Total		$186,028,684	1,185,620	$156.90

Estimated costs and estimated GHG reductions are from CenterPoint's plan while cost/GHG reduction was calculated by the authors. *Source:* CenterPoint 2023, Table 1.

Table 2. Selection of pilots and innovative resources proposed in Xcel's innovation plan

Pilot Name	Innovative Resources	Estimated Costs	GHG Reductions (ton CO_2e)	Cost/GHG Reduction ($/ton CO_2e)
Custom Projects for Large Customers	Strategic Electrification	($1,350,000)	30,148	($44.78)
Dem-Con HZI Biochar	Carbon Capture	$1,990,000	70,000	$28.43
Indian Land Tenure Foundation IFM	Carbon Capture	$3,030,000	102,977	$29.42
Sherco 5MW	Power-to-Hydrogen	$26,310,000	70,073	$375.47
Pine Bend	RNG	$7,290,000	17,828	$408.91
Prairie Island Indian Community Weatherization/Electrification	Strategic Electrification	$1,560,000	3,503	$445.33
Plan Total		$138,910,000	789,523	$175.94

Estimated costs and estimated GHG reductions are from Xcel's plan while cost/GHG reduction was calculated by the authors. *Source:* Xcel 2023, Table 3, and Exhibit B.

Neither CenterPoint's nor Xcel's plans have been approved yet, so it is impossible to say how accurate their cost and GHG reduction estimates are. However, there is likely some value to considering which pilots they expect to be least and most expensive.

Topping both CenterPoint and Xcel's pilot lists with the lowest cost per ton of GHG reduction are programs that target large customers and offer custom solutions to reduce GHGs. CenterPoint's least expensive project targets existing natural gas-powered district energy systems, offering them a variety of pathways to reduce or eliminate their GHG footprints including "strategic electrification, energy efficiency, or other innovative resources…" (CenterPoint 2023, Exhibit D, 33). Similarly, Xcel's least expensive project is targeted at large customers and will assist them with certain custom strategic electrification projects (Xcel 2023, Exhibit B, 60). Both Xcel and CenterPoint's least expensive projects anticipate paying an incentive based on unit of savings and may not cover full participant costs.

On the other end of the spectrum, CenterPoint's and Xcel's highest cost per ton of reduced GHG emissions are both residentially focused and will cover 100% of participant costs. CenterPoint Energy's pilot with the highest cost per avoided ton of GHG emissions would install a handful of residential gas heat pumps in residential homes as a demonstration of the technology. The utility would pay the full cost for the equipment and monitor the performance of the units after installation (CenterPoint 2023, Exhibit D, 50-52). Xcel's most expensive pilot would conduct home energy audits, weatherize, and electrify 72 homes in a Native American community. Xcel plans to pay 100% of the costs for the "holistic weatherization/electrification retrofit effort" (Xcel 2023, Exhibit B, 64).

Interestingly, both the most and least expensive pilots proposed by each utility would deploy energy efficiency and/or strategic electrification, while low-carbon fuels, networked geothermal, and carbon capture focused pilots fall in-between these extremes. On the low-cost end of the spectrum, this is likely because even after decades of efficiency efforts in Minnesota, there remain cost-effective opportunities for energy efficiency and strategic electrification, especially for large energy users, and especially when the cost comparison is with other options to reduce GHG emissions rather than with the price of geologic natural gas. On the high-cost end, CenterPoint and Xcel are, for different reasons, pursuing high-touch residential projects. Resources such as low-carbon fuels or carbon capture generally either serve the entire system (such as when RNG is blended into the gas distribution system) or only especially large users (such as when a large industrial customer installs a carbon capture system at their facility), so it makes sense that these residential projects deploy energy efficiency and/or strategic electrification.

Colorado Clean Heat Plans

Colorado SB 21-264 established GHG reduction targets for Colorado natural gas utilities and required them to file plans describing how they will meet the targets using "clean heat resources". Clean heat resources include gas DSM, recovered methane,[6] green hydrogen, beneficial electrification, pyrolysis of tires, or other technologies approved by the Colorado Public Utilities Commission ("Colorado PUC"). GHG reduction targets are 4% by 2025 and 22% by 2030, both relative to a 2015 baseline (SB 21-264 2021).

As of March 2024, all three of the state's investor-owned natural gas utilities have filed CHPs but none of the plans have yet been approved. The tables below summarize costs and GHG savings for the two larger gas utilities – Xcel and Black Hills. In each case, the tables show data related to the utility's preferred plan.

Table 3. Resources proposed in Xcel's CHP

Resource	Cumulative Program Costs 2024-2028	Cumulative Emissions Reductions 2024-2028 (ton CO_2e)	Cost/GHG Reduction ($/ton CO_2e)
Gas DSM	$81,000,000	152,292	$531.87

[6] Includes methane from the decomposition of organic matter, manure management systems or anaerobic digesters, municipal solid waste, the pyrolysis of municipal solid waste, biomass pyrolysis or enzymatic biomass, and wastewater treatment, coal mine methane, and avoided methane leakage from repairs to the gas distribution system.

Electrification	$303,000,000	453,436	$668.23
Hydrogen	$26,000,000	53,723	$483.96
RNG/Recovered Methane	$362,000,000	256,438	$1,411.65
Certified Natural Gas[7]	$13,000,000	329,147	$39.50
Offsets	$31,000,000	365,000	$84.93
Total	$816,000,000	1,610,036	$506.82

Cumulative program costs and emissions reductions from Xcel's filed testimony. Cost/GHG reduction calculated by the authors. *Source:* Ihle 2023, Table JWI-D-3.

Table 3. Resources proposed in Black Hills's CHP

Resource	Cumulative Program Costs 2025-2028	Cumulative Emissions Reductions 2025-2028 (ton CO_2e)	Cost/GHG Reduction ($/ton CO_2e)
Energy Efficiency	$13,105,713	31,004	$422.71
Advanced Monitoring and Leak Detection	$4,773,262	42,027	$113.58
Beneficial Electrification	$80,000	126	$634.92
Renewable Natural Gas	$4,980,125	4,130	$1,205.84
Total	$22,939,100	77,287	$296.80

Cumulative costs and emissions from Black Hills's CHP Plan. Cost/GHG reduction calculated by the authors. *Source:* Black Hills 2023, Tables 15 and 17.

As with the Minnesota innovation plans, we cannot know how accurate each utility's estimates are, but we might still learn something from their modeling and expectations. The most cost-effective resources included in the Colorado utilities' plans are notably unrelated to changing the fuel used by customers or reducing customer fuel consumption. Instead, the three most cost-effective resources are: (1) Xcel's certified natural gas; (2) Xcel's offsets; and (3) Black Hills's advanced monitoring and leak detection. Of these, two relate to improvements in how geologic natural gas is produced and transported and one is unrelated to the natural gas system.[8]

The most expensive resource in each CHP is RNG/recovered methane, which the Colorado utilities estimate will be substantially more expensive in the context of Colorado plans than the Minnesota utilities estimate for their plans. Most strikingly, in Xcel's Colorado plan, recovered methane/RNG is expected to cost over $1000 per ton of GHG emissions reduction whereas in Xcel's Minnesota plan it will range from $135-$408 per ton. It appears that this dramatic difference is the result of (1) a requirement in Colorado that recovered methane be sourced within state and, probably more significantly, and (2) different GHG-accounting methodologies for RNG. In Minnesota, the GHG emissions reduction of RNG are evaluated on a lifecycle basis (MPUC 2022, Order Point 4) whereas in Colorado only avoided methane emissions are

[7] Certified natural gas is fossil gas produced using methods that result in less methane leakage than results from standard production techniques.
[8] The offsets included in Xcel's CHP "include a variety of project types, including avoided grassland conversion, improved forest management… and hydrofluorocarbon reclamation…" (E3 2023, 23).

considered (Weinberg 2023, 14). One consequence of this difference is that RNG in Colorado is not credited with end-use benefits of RNG in avoiding use of geologic natural gas.

High-Efficiency Electric Home Rebate

The High-Efficiency Electric Home Rebate Program ("Home Electrification Program") was included in the 2022 Inflation Reduction Act ("IRA") § 50122. The Home Electrification Program provides funding for states and tribal governments to develop and run programs to rebate the installation of electric home appliances to replace fossil fuel appliances or as the first such appliance in the home, such as when the home is newly constructed.[9] The program has a total in $4.5 billion in funding to be spent before September 2031, with amounts allocated to states based on the 2022 State Energy Program Formula. Participation in the program is subject to an income cap of 150% of area median income. For households making between 80 and 150% area median income, the rebate amount may not exceed 50% of qualified project costs. For households making less than 80% area median income rebates may be up to 100% of qualified project costs. (IRA 2022, § 50122)

As of March 2024, no state is yet operating a Home Electrification Program and therefore no information is yet available quantifying actual costs or GHG reduction benefits that can be attributed to the program. The U.S. Department of Energy ("DOE") plans to conduct process, impact, and market transformation evaluation activities as part of an independent evaluation process. States must participate in the DOE evaluation process or conduct their own processes consistent with DOE guidelines (SCEP 2023, 60). These evaluations should give valuable insights into the effectiveness of the program in achieving GHG reductions and other program goals.

Despite the unprecedented scale of investment this program makes into home electrification in the United States, it is important to keep in perspective the size of the potential need. Imagine that the program was used entirely to fund replacement of natural gas heating systems with air source heat pumps and the average home received a $5,000 rebate. If we assume no administrative or other expenses in this scenario, the program would serve 900,000 homes with the available $4.5 billion in funding.[10] In contrast, the number of homes in the United States that are heated with natural gas is approximately 64 million, (AGA 2023), meaning that even in a world where the program only tackled natural gas home heating it could directly facilitate the replacement of substantially less than 14% of systems.

Given that the Home Electrification Program can only tackle a small portion of the total need directly, in order to create a major shift in fossil fuel use within homes, the Home Electrification Program must (1) inspire market transformation so that even without rebates many more households select electric appliances; (2) work in tandem with other state, federal, utility or other programs that are also promoting electrification to increase the total number of homes reached by at least one program; or (3) both. The federal government is wisely targeting both options to increase the program's ultimate impact. Other IRA programs and tax provisions, with different primary focuses, have also been designed to give a boost to home electrification,[11]

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[9] Funding may also be used to replace inefficient electric resistance heating with air source heat pump heating (SCEP 2023, 69-70).

[10] Of course, there will be administrative expenses. In addition $5,000 may be a low estimate for the average rebate for a home heating system especially since low-income households may be eligible for 100% of measure cost.

[11] For example, the Energy Efficient Home Improvement Credit, which was modified by IRA § 13304, is generally limited to $1,200 per year for most eligible upgrades. However, heat pumps, heat pump water heaters, biomass

and states participating in the Home Electrification Program are required to develop market transformation plans describing how they will leverage federal funds along with other sources of funding to achieve greater change in residential energy upgrades and continued investments after rebate funds are expended (SCEP 2023, 82).

Of course, hopes for significant market transformation effects from the Home Electrification Program also presume that on a basic level the program works effectively – that states and tribes find eligible households wanting to fully or partially electrify, that program participation is simple enough that these interested households can access rebates, and that the households that participate were actually influenced by the rebate and not simply free riders. It is likely that the Home Electrification Program will operate more effectively in some states than in others and the planned evaluations will hopefully provide valuable insights into what makes a large-scale residential building electrification program successful.

Building Electrification as Part of DSM

Over the last several years, more and more states have begun to incorporate building electrification into their general DSM programs. A July 2022 policy brief by ACEEE describes state policies and lists 11 states as having policies to encourage fuel switching (ACEEE 2022), but since the time of that brief at least one more state has taken significant action to incorporate electrification into their utility DSM offerings.[12] A full review of these policies could easily be its own paper, and our discussion of them here is cursory. We merely note them as a significant source of electrification funding and point out that some of the programs have been limited in ways that other offerings we discuss in this paper have not been.

One theme that emerges when reviewing filings in these jurisdictions is a perceived tension between costs of electrification and policy or stakeholder pressure to achieve high levels of electrification. For example, the Massachusetts program administrators state in their 2022-2024 Efficiency Plan, "The [program administrators] remain committed to promoting electrification within the bounds of the energy efficiency programs; however, for the electrification of heat to proceed at the scale and pace envisioned by the Commonwealth, additional policy support that tilts the relative economics in favor of electrification will be necessary…" The program administrators went on to explain that they focused their electrification efforts on market transformation and on propane and fuel oil customers due to the poor economics of switching from natural gas to electric heat (MassSave 2021, 15). Similarly, in PG&E's 2024-2031 energy efficiency business plan testimony they cite the challenge of pursuing electrification without exacerbating issues of affordability and equity for gas customers. They explain that this is one reason they seek to leverage zonal electrification (discussed below) rather than single appliance incentives (PG&E 2022, 1-24).

These perspectives indicate that some energy efficiency program administrators are unwilling or unable to provide customer incentives high enough to overcome the operating cost difference between natural gas and electric heating through their DSM portfolios.[13] This

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stoves, and biomass boilers have a separate annual credit limit of $2,000. While this higher credit amount is available to certain fossil fuel equipment (e.g. gas heat pumps), electric heat pumps for space or water heating are the most commercially available of the measure types eligible for the $2,000 limit (2022).

[12] In 2023 Michigan enacted a law that allows electric providers to offer an "efficient electrification measure plan," and provides a framework for the Michigan Public Service Commission to evaluate these plans (Enrolled 2023).

[13] As an alternative to paying high up front incentives, electrification could potentially also be advanced by rate design changes.

hesitation limits our ability to understand the full potential of electrification in DSM portfolios as a GHG mitigation strategy. It is possible, and we would argue likely, that high customer incentive levels to encourage replacement of natural gas measures may be a more cost-effective GHG reduction strategy than some of the other options described in this paper at least in some circumstances, while still being significantly less cost-effective than traditional DSM.

California Zonal Electrification

PG&E's proposed zonal electrification pilot is a particularly interesting effort to target electrification to the most beneficial locations, taking into account the gas and electric systems. PG&E has proposed to replace the current gas distribution service to California State University Monterey Bay ("CSU Monterey Bay") with behind-the-meter electrical investments (Kuykendall 2022, 1-2). PG&E has several reasons to target CSU Monterey Bay with this project including the fact that without the project, the local gas system will soon need substantial upgrading to maintain safe and reliable service. PG&E estimates that the project will cost $17.2 million, but estimates the net present value impact to ratepayers to be approximately $1 million less than completing gas system upgrades (Cruz 2022, 3-5 – 3-6). PG&E estimates that the proposed project would result in an annual CO_2 emissions reduction of 1,139 metric tons (Kuykendall 2022, 1-8).

One potential limitation of the zonal electrification approach is that all participating buildings in the project area need to agree to replace their gas appliances with electric. In PG&E's proposal this is made easier because a large majority of the buildings are owned by CSU Monterey Bay, which has its own aggressive GHG emissions reduction goals (Kuykendall 2022, 1-AtchA-1). It is not difficult to imagine that a project with a more diverse set of property owners might run into difficulty with "hold outs." However, there are other areas of concentrated ownership, such as college and corporate campuses, throughout the United States for which this approach may be promising. Indeed, if zonal electrification proves to be one of the most cost-effective approaches to decarbonization, it's not impossible to imagine some states and municipalities exploring the use of eminent domain or similar to overcome the resistance of "hold outs" to achieve their decarbonization goals with less overall cost. Another challenge for the zonal electrification approach is that it requires substantial coordination of the gas and electric systems. This limitation may make it much easier to pursue zonal electrification in areas of the country where both gas and electric service are provided by the same utility.

Natural Gas Bans

Several communities and states across the United States have enacted or are considering policies prohibiting the extension of natural gas into new homes or buildings and/or the sale of natural gas appliances, sometimes referred to as "gas bans". However, very few of these bans have gone into effect as of March 2024. Some of the gas bans include:[14] [15]

[14] The Building Decarbonization Coalition maintains a tracker of zero emissions building ordinances listing state and local governments with policies that "address building specific operational fuel types and related emissions in the United States." We have not independently verified all jurisdictions they have identified but note that what they are tracking is broader than we would consider to be "gas bans". For example, they reference the Colorado Clean Heat legislation, which we would not consider to be a gas ban policy (Building 2024).

[15] In 2019, Berkeley, California was the first city in the United States to pass a ban on installing natural-gas piping in new buildings and they were followed by many other local governments. However, Berkeley's ban was struck down

- In May 2023, New York became the first state to adopt a ban on new natural gas hookups in new homes and other construction. The ban is phased in starting in 2026 but includes several exemptions including for emergency backup/standby power, in manufactured homes, in manufacturing facilities, commercial food establishments, car washes, laundromats, medical facilities, critical infrastructure, and where the New York Public Service Commission ("NYPSC") determines that electric service cannot reasonably be provided by the grid (NYSAR 2024).
- The Massachusetts Department of Energy Resources is operating a pilot program wherein up to 10 cities or towns may adopt zoning ordinances or by-laws that require new building construction or major renovation projects to be fossil fuel-free (25 Mass. 2023). Seven cities were accepted into the program in December 2023 (DOER 2024).
- Denver, Colorado adopted new building code regulations in January 2023 that ban natural gas furnaces and water heaters in new commercial and multifamily construction starting in 2024 and ban the installation of new gas heating equipment in existing commercial and multifamily buildings starting in 2027 (Weiser 2023).
- In 2021, New York City adopted a local law phasing out the combustion of fossil fuels in new buildings. Buildings of all sizes must be constructed without fossil fuels by 2027 although there are some exemptions such as for commercial kitchens and emergency or standby power (NYC 2021).
- In 2022, the Montgomery County Council passed a law requiring the county executive to incorporate an all-electric construction standard into building codes by 2027. Montgomery County is the most populous county in Maryland and abuts Washington, DC (DiChristopher 2023b).
- In 2022, the Washington DC Construction Codes Coordinating Board approved an all-electric building mandate for the residential code but voted against a similar proposal for the commercial code (DiChristopher 2022).

It is striking how quickly so many jurisdictions have acted to ban or limit the use of natural gas over the last five years.[16] Unlike the other programs we describe, gas bans place the cost of the GHG reduction entirely or nearly entirely onto the economy generally rather than on a utility's customers or taxpayers. We are unaware of any plans by any of the jurisdictions to evaluate whether their ban is a cost-effective GHG reduction strategy, taking into account compliance costs for builders, property owners, etc. On the one hand, because these bans affect so many actors they may be particularly effective at causing market transformation and reducing the overall cost of electrification. On the other hand, certain buildings may be particularly expensive to electrify for various reasons. While the laws generally apply to new construction and make various exemptions, it may be that they are still too blunt an instrument – forcing electrification in situations when other decarbonization strategies would be preferrable. We sincerely hope that research will be completed as these bans go into effect to determine their effectiveness as a GHG reduction strategy.

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by the 9th Circuit Court of Appeals, casting uncertainty about the legality of similar local government policies throughout the 9th Circuit's region including in California, Oregon, and Washington (Hu 2024).

[16] There has been similar quick action in some states to prevent municipalities from adopting bans (DiChristopher 2023a).

Networked Geothermal Pilots in Massachusetts and New York

Networked geothermal systems use the relatively stable temperature of the ground to provide heating and cooling to multiple buildings. The systems being pursued by utilities in the United States generally use closed loops of underground heat-exchanging pipes that circulate water underground. The water is brought to surface in each building and run through a heat pump which then provides heating and cooling. As described above, CenterPoint and Xcel in Minnesota have each proposed network geothermal systems in their NGIA innovation plans, however utilities in Massachusetts and New York are somewhat further along in pursuing networked geothermal opportunities. Some details on activities by utilities in each state are as follows.

Eversource has begun construction of a networked geothermal system in Framingham, Massachusetts. Their route includes 44 buildings – 10 residential apartment buildings owned by the Framingham Housing Authority, 5 commercial buildings, and 29 other residential buildings. Estimated costs for the project are approximately $14.7 million (Eversource 2023). Prior to receiving approval for their networked geothermal pilot, the utility estimated that the pilot would result in a 60% reduction in emissions for buildings served. It appears that their estimate may have assumed that they would convert buildings currently served by fuel oil (Eversource 2020).

National Grid has selected an area in Lowell, Massachusetts as the site of a networked geothermal system pilot and expects to begin construction in 2024. The selected route could serve 63 gas customers representing 22 distinct buildings. The project could serve a mix of market rate residential customers (60%), income-eligible residential customers (29%), and commercial customers (11%). The Company has estimated that the project will cost $15.6 million (National Grid 2023a). This demonstration project will convert customers who currently use natural gas for heating. The authors could not identify a GHG reduction estimate for the project.[17]

In September 2022, the NYPSC required the seven largest electric, gas, or combination utilities in the state to submit pilot proposals for network geothermal systems (NYPSC 2022). The table below provide information on the pilots filed by ConEd and National Grid. Note that National Grid provided annual estimated emissions reductions over the course of a five-year period whereas ConEd provided estimated lifetime reductions.

Table 4. Information on Networked Geothermal Pilots by ConEd and National Grid in New York

Utility/Location	Estimated Costs (millions)	Estimated GHG Emissions Reductions na(tons CO2e)	Emissions Reduction Timescale	Site Description
National Grid - Long Island	$122	517	Annual	Three buildings on Suffolk Community College Grant Campus

[17] National Grid previously completed two small geothermal network systems in conjunction with the Long Island Power Authority. The larger of the two involved 30 manufactured homes using propane and kerosene heating (KeySpan 2023).

National Grid - Brooklyn	$108	448	Annual	Three 10-story buildings owned by the New York City Housing Authority and a low-rise community center
National Grid - Syracuse	$133	2,798	Annual	One mixed use building, a hotel, and expected 14 new construction buildings
National Grid - Troy	$53	1,782	Annual	Nine mixed-use buildings including offices, retail, and multifamily housing
ConEd - Chelsea	$92	29,000	Lifetime	Four buildings including New York City Housing Authority Dwelling units
ConEd - Mount Vernon	$77	133,000	Lifetime	76 buildings including 1-4 unit residential homes, multifamily, and commercial space
ConEd - Manhattan	$86	273,000	Lifetime	Three large commercial buildings

Sources: ConEd 2023a, ConEd 2023b, ConEd 2023c, National Grid 2023b, National Grid 2023c, National Grid 2023d, National Grid 2023e.

The New York projects summarized in the table above would replace natural gas service in the converted buildings, thus the estimates above may provide a more appropriate source of comparison with the NGIA and CHP resources than the available GHG reduction estimates from Massachusetts. However, caution must be taken when comparing filings by different utilities, and especially different utilities operating in different states as there are a myriad ways to calculate project costs and GHG emissions reductions. One type of comparison that seems fair to make though is the costs of emissions reductions estimated by each New York utility for their different projects, and the variation between projects is striking. National Grid's most expensive proposed pilot on a ton of GHG emissions basis is the Brooklyn project at over $240,000 per ton of annual CO_2e emissions reduced while their least expensive is Troy at approximately $30,000. Similarly, ConEd's most expensive project appears to be Chelsea at over $3,000 per ton of lifetime CO_2e emissions and their least expensive is Manhattan at only $16. With this extreme range of possibilities, it must be the case either that the prospects of networked geothermal as a GHG reduction solution are highly location specific or there is a high degree of uncertainty in the estimates, or both.

Oregon Voluntary Renewable Fuels Standard

Oregon's 2019 SB 98 gives Oregon gas utilities the option to participate in a renewable natural gas portfolio standard. The statutory term "renewable natural gas" includes RNG, green hydrogen, synthetic methane produced from green hydrogen, and a few other low-carbon fuel resources. To avoid confusion between the terms we refer to the statutory requirement as for procurement of RNG/hydrogen and references to RNG or hydrogen alone refer only to that resource type. Large natural gas utilities[18] that choose to participate are permitted to make certain investments in RNG/hydrogen and procure RNG/hydrogen from third parties to meet an escalating schedule of RNG/hydrogen volumes expressed as a percentage of their overall portfolios. The percentage begins at 5% in 2020-2024 and grows to 30% by 2045 (SB 98 2019).

The state's largest gas utility, NW Natural, delivered their first RNG to customers in 2021 (NW Natural 2021, 4). The company reported in their 2022 integrated resource plan that they had secured five sources of RNG and anticipated receiving 332,310 MMBtu from those sources in 2022, growing to 1,241,469 MMBtu by 2025 (NW Natural 2022, 216). For purposes of their IRP modeling, NWt Natural expected to acquire most RNG for between $10.50/MMBtu and $24/MMBtu. They estimated that green hydrogen would be available for $23/MMBtu in 2022 and for $5/MMBtu by 2050 and they estimated that synthetic methane would be available for between $30/MMBtu and $9/MMBtu over the same timeframe. Oregon's laws relating to RNG procurement do not specify a GHG accounting standard for RNG and Northwest Natural considers RNG to be carbon neutral (NW Natural 2022, 190, 225).

If we assume that each therm of natural gas results in 0.0053 metric tons of CO2e (EPA 2024a) and adopt Northwest Natural's carbon neutral perspective on RNG, their estimated cost ranges translate to the following costs per ton of GHG emissions:

- RNG: \$198/ton CO_2e - \$453/ton CO_2e
- Green Hydrogen: \$434/ton CO_2e now; \$94/ton CO_2e in 2050
- Synthetic Methane: \$566/ton CO_2e now; \$170/ton CO_2e in 2050

The Oregon approach to RNG procurement without regard to specific GHG emissions reductions attributable to certain RNG sources is unique of the programs we have considered. The approach has the benefit of simplicity, and simplifying assumptions may be appropriate to avoid overburdening novel decarbonization solutions before they find their footing. However, if we accept that a lifecycle accounting approach is more accurate, the carbon intensity of various RNG feedstocks can vary widely, as can be seen in NW Natural's presentation of carbon intensities for registered products in the Oregon Clean Fuels Program (2022, 191). Treating all RNG sources as equivalent from a GHG reduction perspective could lead to suboptimal investment choices between different RNG sources or between RNG and other resources. Again, as with the Minnesota NGIA and the Colorado CHP, we see the critical importance of choice of GHG accounting methodology for RNG policy.

Conclusion

We have reviewed some of the key approaches being taken in the United States to tackle emissions from residential, commercial, and industrial use of fossil fuels. As these programs are generally very new and calculate costs and GHG reductions in different ways, there is as yet no definitive answer regarding what approaches demonstrate the most cost-effectiveness. Moving forward, it will be important to find ways to make different technologies and programmatic approaches more comparable, so that we can invest resources into the most promising options, while recognizing that it is unlikely that any approach is a "silver bullet" that will allow us to easily decarbonize all natural gas end uses in every circumstance. Some actions that would make programs more comparable include:

[18] Defined as utilities with more than 200,000 customers. This includes the three largest gas utilities in the state: Northwest Natural, Cascade, and Avista. Small gas utilities may also engage in RNG purchases but are not subject to the same schedule of increasing RNG volumes.

- Reaching a consensus on the GHG accounting approach for low-carbon fuels or making sufficient information public to allow the application of multiple different approaches;
- Providing estimates of total costs for utility programs including any participant contributions or increased ongoing operating costs;
- Providing estimates of lifetime costs and GHG emissions reduction as opposed to annual or other time periods; and
- Evaluating the societal costs of policies such as "gas bans" where costs are disbursed among many different actors.

We recognize that the actions described above are easier said than done, however for taxpayers or customers to get the full value from these various efforts it is essential that we find a fair way to compare them. Understanding what programs work well and in what circumstances can reduce the total societal cost of decarbonization will make it easier to transition to a decarbonized economy in an equitable and affordable manner.

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