Solutions Project Portfolio Carbon Dioxide Impact Analysis

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PSE

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About PSE Healthy Energy

PSE Healthy Energy is a scientific research institute generating energy and climate solutions that protect public health and the environment. PSE provides expertise in public health, environmental science, and engineering and brings science to energy policy through actionable research, communications, and advising. **Visit us at psehealthyenergy.org and follow us on X at @PhySciEng.**

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Executive Summary

Summary: PSE Healthy Energy (PSE) conducted a review to calculate CO_2 mitigation impacts of awards granted by the Solutions Project between 2021-2023. This effort focused on projects that have direct, measurable CO_2 reductions. As these projects are typically pilots and demonstrations, PSE also calculated the potential CO_2 reduction impacts if these demonstrations were scaled to be deployed everywhere where it was applicable.

Project Selection: We focused on three grantee wins in New York State that have clear, measurable, and direct CO_2 reduction impacts: (1) 2023 grants supporting NYC Environmental Justice Alliance and The Point CDC, which won their campaign to replace the Ravenswood (New York) Generating Station with offshore wind power; (2) 2022 grants supporting the NY Renews state-wide frontline coalition and key founding members ALIGN, UPROSE, The Point CDC, and NYC Environmental Justice Alliance, which won their campaign for no new natural gas combustion in new buildings in New York City, which was then adopted at the state-wide level in 2023[1]; and (3) 2022 grants supporting ALIGN and NYC Environmental Justice Alliance, which secured a commitment for all-electric schools in New York City.

Overview of Methods: Direct impact calculations are relatively straightforward, given well documented emissions data from the specific gas generation plant in question, from energy use in buildings, and from schools. Indirect impacts are more nuanced, requiring assumptions on how the demonstrations and pilots might scale state-wide or nation-wide. We do not provide analysis for economic or policy barriers to adoption, but focus solely on the technical feasibility and impact of expanding the methods across New York (all three example projects are in New York) and across the nation. A key consideration for scaling will be deployment adoption rates for the proposed technical solutions, and where possible, PSE includes analysis of deployment timelines to achieve state-wide and nation-wide scaling. An additional consideration for electrification is the depth of simultaneous building efficiency retrofits, which can significantly impact energy use. So in the case of school electrification, we include low, medium, and high efficiency scenarios, representing the broad range of possible emissions reductions. Given the necessary assumptions for state- and nation-wide scaling, all estimates included in this report are consistent with this type of range, with potential values possibly more than double or less than half of the estimates presented. PSE does not offer

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[1] Ramirez, R., & Nilsen, E. (2023, May 3). *New York becomes the first state to ban natural gas stoves and furnaces in most new buildings* | *CNN*. https://www.cnn.com/2023/05/03/us/new-york-natural-gas-ban-climate/index.html

this to be a definitive final report or peer reviewed science, but as a best defensible analysis in the limited time available, based on available data and reasonable assumptions.

Potential CO_2 Reduction Summary: We summarize the potential CO_2 reduction impacts in Table 1. The table shows that replacing gas generation with renewable sources has potential for the greatest impact, followed by school electrification and banning gas combustion in new construction.

Table 1: Summary of Potential CO_2 Impacts at Scale

Scale	**Replace Gas with Wind**		**No New Gas**		**All Electric Schools**	
	Change in CO_2 Emitted (thousand metric tons/yr)	**Change in CO_2 Cars Equivalent (thousand cars)**	**Change in CO_2 Emitted (thousand metric tons/yr)[2]**	**Change in CO_2 Cars Equivalent (thousand cars)**	**Change in CO_2 Emitted (thousand metric tons/yr)**	**Change in CO_2 Cars Equivalent (thousand cars)**
Project	-900	200	-150	32	-91	20
New York Statewide	-26,000	5,600	-160	35	-300	67
Nationwide	-740,000	160,000	-1,500	340	-11,000	2,400

Health Impacts: In addition to the CO_2 mitigation benefits, these projects will also reduce the health impacts of fossil fuel use due to outdoor and indoor air pollution. Quantifying these impacts is the subject of ongoing research, and beyond the scope of this report.

Research shows that living near fossil fuel power plants is associated with adverse health outcomes ranging from respiratory disease hospitalizations[3] to preterm births.[4] Numerous studies have found that power plants are disproportionately located in communities of color and low-income communities,[5] and this is also true in the case of Ravenswood. Siting of all

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[2] Estimates for NYC include **all new construction**, while estimates for NY State and the US at large only account for **new housing**. Therefore, emissions (and avoided emissions) for the state and country should be much higher.

[3] Liu, Xiaopeng, et al. "Association between residential proximity to fuel-fired power plants and hospitalization rate for respiratory diseases." *Environmental Health Perspectives* 120.6 (2012): 807-810.

[4] Casey, Joan A., et al. "Retirements of coal and oil power plants in California: association with reduced preterm birth among populations nearby." *American Journal of Epidemiology* 187.8 (2018): 1586-1594.

[5] Declet-Barreto, Juan, and Andrew A. Rosenberg. "Environmental justice and power plant emissions in the Regional Greenhouse Gas Initiative states." *Plos one* 17.7 (2022): e0271026.

power plant types is associated with historically redlined communities and contributes to persistent air pollution inequities today.[6]

Research also links gas appliances to indoor air pollution, from the stoves, hot water heaters, and furnaces. Studies have focused on nitrogen dioxide produced when gas is burned, which is linked to asthma and other respiratory conditions. Recently, researchers from PSE Healthy Energy have identified additional hazardous air pollutants in unburned gas that leaks into homes and offices, including the carcinogen benzene.[7]

Portfolio: PSE does not consider these three projects to be a complete representation of the Solutions Project's climate action portfolio. These three projects do demonstrate that significant reductions in CO_2 can be achieved, and that the Solutions Project is supporting work that has the potential to significantly reduce carbon emissions and other pollutants at state and national levels.

The remainder of the Solutions Project portfolio is not necessarily less impactful, only their CO_2 emissions are more challenging to estimate . It is beyond the scope of this report to identify and quantify the immediate and long term impacts of stopping a pipeline from going through certain neighborhoods, or preventing oil and gas extraction in other neighborhoods. While these efforts may help protect these neighborhoods, and also may increase the cost of extraction and exploitation to the point where pipelines and drilling become economically untenable everywhere, quantifying that impact requires additional research beyond this effort.

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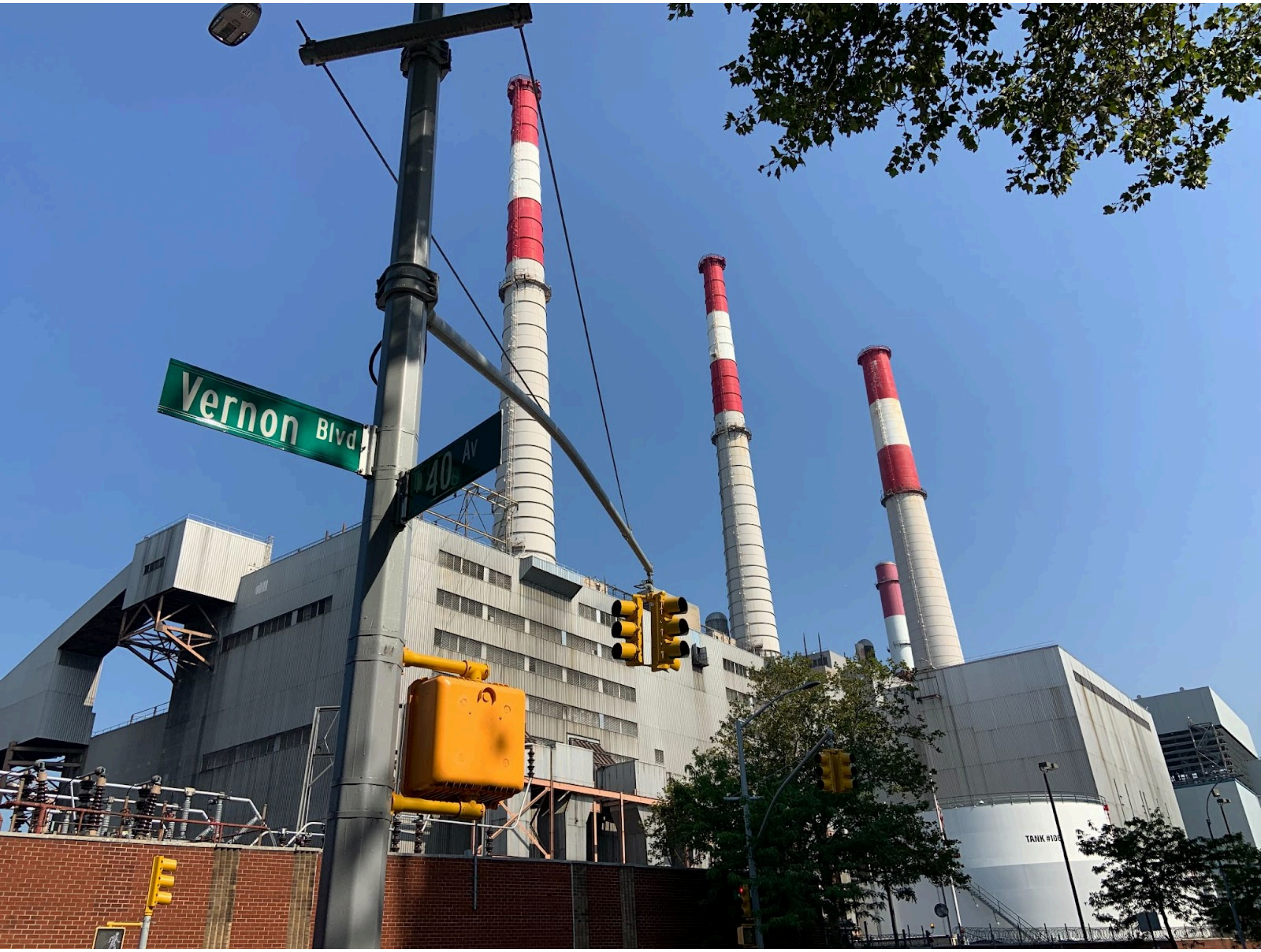
[6] Cushing, Lara J., et al. "Historical red-lining is associated with fossil fuel power plant siting and present-day inequalities in air pollutant emissions." *Nature Energy* 8.1 (2023): 52-61.

[7] Kashtan, Y. S., Nicholson, M., Finnegan, C., Ouyang, Z., Lebel, E. D., Michanowicz, D. R., Shonkoff, S. B. C., & Jackson, R. B. (2023). Gas and Propane Combustion from Stoves Emits Benzene and Increases Indoor Air Pollution. *Environmental Science & Technology*, *57*(26), 9653–9663. https://doi.org/10.1021/acs.est.2c09289

Photo Caption: Ravenswood Generating Station



Ravenswood Generating Station Replacement with Wind

Queens-based developer Rise Light & Power, LLC (Rise) will repower its Ravenswood Generating Station in Long Island City using offshore wind energy. This replaces the largest fossil fuel plant in New York City with renewable energy. In addition, more than 1.2 million people live within a three mile radius of the plant.

1.1 Summary

The direct impacts of replacing this gas generation plant with wind power are significant - cutting 900,000 metric tons of CO_2 emissions per year, the equivalent of taking nearly 200,000 cars off the road. More importantly, this project will demonstrate the potential for replacing gas generation nationwide toward which we calculate the CO_2 impacts for three levels of indirect impacts: (1) achieving New York's goal of deploying 9 GW of offshore wind by 2035; (2) Replacing all of New York's gas generation with offshore wind; and (3) Replacing gas generation with offshore wind across the U.S. A summary of these results is presented in **Table 2**, with supporting data and references detailed in **Table 3**.

1.2 Results and Impacts

1.2.1 Direct Impacts of Replacing Ravenswood with Wind.

EPA data shows that completely shutting down this plant would cut nearly 1 million metric tons of CO_2 equivalent[8] annually. Replacing this with wind plus battery storage, given per kWh emissions at 9.1% of gas emissions, would produce 91,000 metric tons of CO_2 equivalent annually, with a net reduction of 900,000 metric tons of CO_2 per year. The proposed wind power (1.4 GW) is more than enough to replace Ravenswood, as it will annually generate two and a half times as much energy as the gas plant. Even though the capacity (1.4 GW) is less than the plant's total power (2.5 GW), the plant's relatively low capacity factor of 9%, and Long Island offshore wind's relatively high capacity factor of 40% makes this reasonable.

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[8] CO_2 equivalent emissions are the amount CO_2 emissions with the same global warming potential as a fixed amount of another greenhouse gas. This allows for comparison of warming impacts for different emissions, including methane (natural gas), nitrous oxide, and fluorinated gasses (refrigerants like HCFC-22 and gaseous insulators like sulfur hexafluoride). https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Table 2: Summary of Carbon Dioxide Impacts

Goal	Power		Energy		CO_2 Emissions				Timeline
	Gas Power Replaced (GW)	Wind Power Deployed (GW)	Annual Gas Energy Replaced (TWh)	Annual Wind Energy Potential Deployed (TWh)	Gas CO_2 Emitted (million metric tons/yr)	Wind CO_2 Emitted (million metric tons/yr)	Change in CO_2 Emitted (million metric tons/yr)	Change in CO_2 Cars Equivalent (million cars)	Estimated Time to Complete (years)
Replace Ravenswood with Offshore Wind	2.5	1.4	2	5	1	0.1	-0.9	-0.2	1
9 GW Offshore Wind by 2035	9.3	9.0	26	32	13	1.4	-11.6	-2.5	5.3
Replace all NY Gas Plants with Offshore Wind	21.1	21.4	60	75	29	3.3	-25.7	-5.6	12.6
Replace all US Gas Plants with Offshore Wind	570	670	1,700	2,100	830	92	-738	-160	155

1.2.2 Indirect Impacts – Enabling New York Goal of 9 GW Offshore Wind by 2035

New York has pledged to build 9 GW of offshore wind capacity by 2035. With Long Island's offshore wind capacity factor of 40%, this would be capable of generating 32 TWh per year. As some energy will be lost when it is stored in batteries for later use, this could deliver 80% of the 32 TWh for consumption, replacing about 26 TWh per year of gas generation (just under half of New York's total gas generation of 60 TWh/year). This would replace 13 million metric tons of gas-powered CO_2 emissions with 1.4 million metric tons of lifecycle CO_2 equivalent emissions from the wind and battery systems, for a net reduction of almost 12 million metric tons per year, or the equivalent of 2.5 million cars off the road each year. Achieving this falls well within the net technical potential of offshore wind in New York, which is more than 73 GW. At current deployment rates, this swap should be achievable by 2030, and easily achievable by the goal year of 2035.

1.2.3 Indirect Impacts – Enabling Shutdown of all New York State Gas Generation

Replacing all gas generation in New York State with offshore wind would require 75 TWh of offshore wind generation, slightly more than double that required for the 2035 goal. This would require a total of 21.4 GW of offshore wind power and would cut gas powered emissions from 29 million metric tons per year to 3.3 million metric tons per year, with a net reduction of almost 26 million metric tons per year, or 5.6 million cars worth of CO_2 each year. At current deployment rates, this should be achievable by 2035.

1.2.4 Indirect Impacts – Enabling Shutdown of all United States Gas Generation

The U.S. uses 1,700 TWh of gas-generated electricity per year. Replacing this with wind and battery storage would require 2,100 TWh of wind generation from 670 GW of offshore wind turbines. This would remove 830 million metric tons of gas-powered CO_2 emissions, replacing it with 92 million metric tons of lifecycle CO_2 emissions from the wind and battery systems, for a net reduction of 738 million metric tons per year. This is equivalent to taking 160 million cars (55% of all cars in the US) off the road each year. Achieving this falls well within the net technical potential of offshore wind in the US, which is more than 2,058 GW. But at current deployment rates this would take 155 years, would require a massive build-out of infrastructure for transmission and storage.

1.3 Methods

Calculating direct CO_2 impacts is reasonably straightforward, given that multiple years of emissions data exists for this plant and emissions rates for gas generation, wind, and batteries are well accepted. To scale for potential indirect impacts we assume power, energy, and CO_2 emissions scale linearly with energy production. We base the estimates on the fixed points of the 9 GW wind generation goal capable of 32 TWh of annual production, the total gas generation in New York (60 TWh/year), and total gas generation in the United States (1,700 TWh/year) in 2022.

1.3.1 Direct Impacts of Replacing Ravenswood with Wind.

1.3.1.1 Gas Emissions. EPA data from Table 3 shows Ravenswood emits nearly 1 million metric tons of CO_2 equivalent[9] annually.

1.3.1.2 Wind Emissions. Table 3 also shows lifetime CO_2 emissions from manufacture and deployment of wind and battery totals 44 grams per kWh, compared to 486 grams per kWh for gas generation. Emissions from 2 TWh of gas generation would total:

$$\frac{2\ TWh * 486\ g/kWh * 1{,}000{,}000\ metric\ tons/g}{1{,}000{,}000{,}000\ TWh/kWh} = 1\ million\ metric\ tons\ CO_2$$

This is consistent with the EPA estimate. Wind generation to replace this would be 2.5 TWh/year, or about half of the 5 TWh/year the system could generate. Emissions from 2.5 TWh of wind generation would total:

$$\frac{2.5\ TWh * 44\ g/kWh * 1{,}000{,}000\ metric\ tons/g}{1{,}000{,}000{,}000\ TWh/kWh} = 0.1\ million\ metric\ tons\ CO_2$$

1.3.1.3 Sufficiency. The proposed 1.4 GW of wind power with a capacity factor of 40% would generate:

$$1.4\ GW \ * \ 0.4 \ * \ 365\ days/year \ * \ 24\ hours/day \ = \ 5\ TWh/year$$

This is more than enough to replace Ravenswood's 2 TWh/year.

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[9] CO_2 equivalent emissions are the amount CO_2 emissions with the same global warming potential as a fixed amount of another greenhouse gas. This allows for comparison of warming impacts for different emissions, including methane (natural gas), nitrous oxide, and fluorinated gasses (refrigerants like HCFC-22 and gaseous insulators like sulfur hexafluoride). https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

1.3.2 Indirect Impacts – Enabling New York Goal of 9 GW Offshore Wind by 2035

1.3.2.1 Wind Production. A 9 GW of wind farm deployed off Long Island would generate:

$$9\,GW\ *\ 0.4\ *\ 365\ days/year\ *\ 24\ hours/day\ =\ 32\ TWh/year$$

Because some of this will have to be stored for later use, we must take into account the losses incurred from storing and retrieving electricity from batteries–the round trip efficiency. This is also shown in **Table 3** to be approximately 80%. Conservatively assuming this penalty applies to all energy generated, this means that energy available for end use would be:

$$0.8\ *\ 32\ TWh/year\ =\ 26\ TWh/year$$

1.3.2.2 Gas Reductions. With 26 TWh/year of wind energy available, and the average gas plant capacity factor of 32% (**Table 3**), the amount of gas power that can be shut down is:

$$\frac{26\ TWh/year}{0.32} * \frac{1\ year}{365\ days} * \frac{1\ day}{24\ hours} = 9.3\ GW$$

1.3.2.3 Emissions Reductions. Emissions from 26 TWh of gas generation would total each year:

$$\frac{26\ TWh * 486\ g/kWh * 1{,}000{,}000\ metric\ tons/g}{1{,}000{,}000{,}000\ TWh/kWh} = 13\ million\ metric\ tons\ CO_2$$

Emissions from 32 TWh of wind generation would total each year:

$$\frac{32\ TWh * 44\ g/kWh * 1{,}000{,}000\ metric\ tons/g}{1{,}000{,}000{,}000\ TWh/kWh} = 1.4\ million\ metric\ tons\ CO_2$$

1.3.3 Indirect Impacts – Enabling Shutdown of all New York State Gas Generation

Replacing all gas generation in New York State with offshore wind would require 75 TWh of offshore wind generation, slightly more than double that required for the 2035 goal. This would require a total of 21.4 GW of offshore wind power and would cut gas powered emissions from 29 million metric tons per year to 3.3 million metric tons per year, with a net reduction of almost 26 million metric tons per year, or 5.6 million cars worth of CO_2 each year. At current deployment rates, this should be achievable by 2035.

1.3.2.1 Wind Production. Gas generation capacity in New York state totals 21.1 GW producing 60 TWh of energy with a capacity factor of 32%. Given round trip battery losses, this would require 75 TWh of wind generation. Again, with a capacity factor of 40% for offshore wind, this would require 21.4 GW of wind power.

1.3.2.2 Emissions Reductions. Analysis of reductions statewide follow the same methods above.

1.3.4 Indirect Impacts – Enabling Shutdown of all United States Gas Generation

Analysis of reductions nationwide follow the same methods above.

1.4 Data and Assumptions

Supporting data and assumptions are presented in **Table 3**.

1.5 Caveats

Battery storage necessary may be larger than currently planned at Ravenswood. Nguyen and Lee showed that to maintain constant power dispatch for grid stability, at least two hours of storage at 0.67 times the power rating of the wind turbines could be necessary for a site in South Korea. Local wind variability would impact the size requirements, but if that model applies for Long Island, Ravenswood would require 930 MW and 1,860 MWh battery storage–three times the power and one and a half times the energy in the currently approved storage capacity.

Table 3: Data and Assumptions

Data Category	Data Detail	Data and Assumptions
Gas Generation	Ravenswood generating capacity	Ravenswood Generating Station has a total capacity of 2.48 gigawatts (GW), generating approximately 2 terawatt hours (TWh) in 2021.[10] [11]

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[10] Rosane, O. (2023, January 30). *Largest fossil fuel plant in New York City could become nation's first to convert to renewable energy | NationofChange*. https://www.nationofchange.org/2023/01/30/largest-fossil-fuel-plant-in-new-york-city-could-become-nations-first-to-convert-to-renewable-energy/

[11] *Electricity data browser—Ravenswood*. (n.d.). Retrieved September 18, 2023, from https://www.eia.gov/electricity/data/browser/#/plant/2500?freq=A&start=2016&end=2018&ctype=linechart&ltype=pin&pin=&maptype=0&linechart=ELEC.PLANT.GEN.2500-ALL-ALL.A&columnchart=ELEC.PLANT.GEN.2500-ALL-ALL.A

	Ravenswood capacity factor	This indicates a plant-wide average capacity factor of approximately 9%, but that varies across the 4 steam turbines and multiple gas peakers at the plant.[12]
	New York State gas generating capacity	Forty four percent (59.5 TWh) of New York state's electricity comes from 21.1 GW of natural gas power plants (sate-wide capacity factor of 32 percent).[13]
	US gas generating capacity	2022 US gas powered electricity totals 1,689 TWh from 570 GW of utility scale power plants (nationwide capacity factor of 34 percent).[14]
	Fuel mix and load growth	One might consider load patterns and fuel mixes changing over time with resulting differences in emissions from more or less generation and dirtier or cleaner fuel sources, but for this simple analysis we will assume 2021 is a representative snapshot, and extend plant energy production and emissions from the 2021 data.
Gas Emissions	Ravenswood emissions	EPA data shows total plant emissions in 2021 were just under 1 million metric tons of CO_2 equivalent, including 18 metric tons of methane. In addition, the plant emitted 1.8 metric tons of nitrous oxides.[15]
	Average gas emissions, US nationwide	Lifecycle CO_2 emissions from natural gas are estimated to be 486 grams per kWh generated.[16]
Wind Generation	Ravenswood replacement proposed	Proposed offshore wind capacity proposed for replacing Ravenswood is 1.4 GW, with a wind capacity factor off Long Island of 40%. This indicates a capability for up to 4.9 TWh of annual production possible.[17]

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[12] Capacity factor: The ratio of the electrical energy produced by a generating unit for the period of time considered to the electrical energy that could have been produced at continuous full power operation during the same period. (https://www.eia.gov/tools/glossary/index.php?id=Capacity_factor)

[13] https://www.energy.gov/sites/prod/files/2016/09/f33/NY_Energy%20Sector%20Risk%20Profile_0.pdf

[14] https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

[15] *GHG Summary Report*. (n.d.). Retrieved September 18, 2023, from https://ghgdata.epa.gov/ghgp/service/html/latest?et=undefined&id=1000764

[16] ibid

[17] GE Energy "The Effects of Integrating Wind Power on Transmission System Planning, Reliability, and Operations: Report on Phase 2," Prepared for The New York State Energy Research and Development Authority, March 2005. https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/Research/Biomass-Solar-Wind/wind-integration-report.pdf

	Ravenswood battery storage	The Ravenswood site has already been approved to build 316 MW, 1200 MWh of battery storage (four hours of storage at peak power).[18] [19] [20]
	New York offshore wind goals	New York's 2019 climate law calls for the installation of 9 GW (6.4 times this proposal) of offshore wind by 2035, enough to satisfy roughly one-third of the state's energy needs.[21]
	New York offshore wind generation capacity	New York offshore net technical wind capacity (where land use, environmental and technical exclusions don't limit development) is 73 GW and 300 TWh/yr.[22] [23]
	New York wind generation growth rate	A DOE report shows that New York will have almost 12 GW of offshore wind by 2030, or about 1.7 GW/year.[24]
	National offshore wind capacity	Nationwide offshore net technical wind capacity (where land use, environmental and technical exclusions don't limit development) is 2,058 GW and 7,203 TWh/yr, nearly twice the energy consumed in the United States.[25] [26]

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[18] Blum, A. (2021, February 2). At New York City's biggest power plant, a switch to clean energy will help a neighborhood breathe easier. *Popular Science*. https://www.popsci.com/story/environment/nyc-plant-changes-to-clean-energy/

[19] *New York Approves 316MW Battery Plant for Peak Power, First of Its Kind in Region*. (n.d.). Retrieved September 20, 2023, from https://www.greentechmedia.com/articles/read/new-york-approves-316-mw-battery-plant-for-peak-power

[20] Additional analysis will be necessary to determine that sufficient battery storage on-site exists to achieve that capacity factor. Hourly wind generation and grid demand matching analysis to lay out how much storage needs to be built on-site to make this replacement feasible remains to be done.

[21] Blum, A. (2021, February 2). At New York City's biggest power plant, a switch to clean energy will help a neighborhood breathe easier. *Popular Science*. https://www.popsci.com/story/environment/nyc-plant-changes-to-clean-energy/

[22] Musial, W., Heimiller, D., Beiter, P., Scott, G., & Draxl, C. (2016). *2016 Offshore Wind Energy Resource Assessment for the United States* (NREL/TP--5000-66599, 1324533; p. NREL/TP--5000-66599, 1324533). https://doi.org/10.2172/1324533

[23] Gilman, P., Maurer, B., Feinberg, L., Duerr, A., Peterson, L., Musial, W., Beiter, P., Golladay, J., Stromberg, J., & Johnson, I. (2016). National offshore wind strategy: Facilitating the development of the offshore wind industry in the United States. National Renewable Energy Lab.(NREL), Golden, CO (United States). https://www.energy.gov/eere/wind/articles/national-offshore-wind-strategy-facilitating-development-offshore-wind-industry

[24] Musial, W., Spitsen, P., Beiter, P., Duffy, P., Marquis, M., Hammond, R., & Shields, M. (2022). *Offshore Wind Market Report: 2022 Edition* (p. 111). Department of Energy. https://www.energy.gov/eere/wind/articles/offshore-wind-market-report-2022-edition

[25] Musial, W., Heimiller, D., Beiter, P., Scott, G., & Draxl, C. (2016). *2016 Offshore Wind Energy Resource Assessment for the United States* (NREL/TP--5000-66599, 1324533; p. NREL/TP--5000-66599, 1324533). https://doi.org/10.2172/1324533

[26] Gilman, P., Maurer, B., Feinberg, L., Duerr, A., Peterson, L., Musial, W., Beiter, P., Golladay, J., Stromberg, J., & Johnson, I. (2016). National offshore wind strategy: Facilitating the development of the offshore wind industry in the United States. National Renewable Energy Lab.(NREL), Golden, CO (United States). https://www.energy.gov/eere/wind/articles/national-offshore-wind-strategy-facilitating-development-offshore-wind-industry

	National offshore wind capacity factor	Offshore wind capacity factor in the United States ranges from 24 percent to 56 percent, with an average of 36 percent.[27]
	National offshore wind generation growth rate.	A DOE report shows a goal and prediction that offshore wind will grow to 30 GW by 2030, nationwide, with a growth rate of 4.3 GW/year.[28] We assume offshore wind capacity growth rates remain constant in New York and nationwide for the duration of this analysis.
Wind Emissions	Wind and battery lifecycle emissions	Lifecycle CO_2 emissions from wind turbines are estimated to be 13 grams per kWh generated. Lifecycle CO_2 emissions from grid scale lithium-ion batteries tied to wind generation is estimated to be 33 grams per kWh of wind generation, for a total of 44 grams per kWh of battery supported wind generation.[29]
Vehicle Emissions	Typical automobile emissions	For comparison, a typical gasoline automobile emits 4.6 metric tons of CO_2 per year.[30]
Battery Efficiency	Round trip battery efficiency	Round trip efficiency for battery storage is on the order of eighty percent, meaning that if all wind energy is stored for later rather than direct use, wind energy generation must exceed the replaced gas generation by twenty five percent.[31]
Demographics	Ravenswood population	1.2 million people live within 3 miles of the plant, 45% of whom are non-white, and 25% of whom are low income (less than double the federal poverty level).[32]
	Coastal population	While coastal areas (counties with coastal access) account for less than 10% of US land mass in the contiguous United States, forty percent of Americans live in these areas.[33] In addition, eighty percent of Americans live within 200 miles of the coast.[34]

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[27] https://css.umich.edu/publications/factsheets/energy/wind-energy-factsheet#:~:text=Capacity%20factor%20of%20land%20based,%25%20and%20averages%20of%2036%25.&text=Offshore%20winds%20are%20generally%20stronger,expensive%20to%20build%20and%20maintain.

[28] Musial, W., Spitsen, P., Beiter, P., Duffy, P., Marquis, M., Hammond, R., & Shields, M. (2022). *Offshore Wind Market Report: 2022 Edition* (p. 111). Department of Energy. https://www.energy.gov/eere/wind/articles/offshore-wind-market-report-2022-edition

[29] Nicholson, S., & Heath, G. (n.d.). *Life Cycle Greenhouse Gas Emissions from Electricity Generation: Update*. https://www.nrel.gov/docs/fy21osti/80580.pdf

[30] https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle

[31] https://www.eia.gov/todayinenergy/detail.php?id=46756

[32] https://www.psehealthyenergy.org/wp-content/uploads/2020/06/New-York.pdf

[33] US Department of Commerce, N. O. and A. A. (n.d.). *What percentage of the American population lives near the coast?* Retrieved September 22, 2023, from https://oceanservice.noaa.gov/facts/population.html

[34] ACP. (n.d.). *Offshore Wind Power Facts*. ACP. Retrieved September 22, 2023, from https://cleanpower.org/facts/offshore-wind/

No Natural Gas in New Construction in New York City

In 2022, New York City passed legislation to electrify all new buildings. Implementation would start in 2024, beginning with small, one to two family homes before ramping up to buildings under seven stories by 2026 and all buildings by 2029. The city will do this by banning natural gas hookups for heating and cooking in new buildings and replacing them with high-efficiency heat pumps for space heating and electric stoves for cooking. On-site building fuel use (natural gas and a small amount of fuel oil) is the largest source of greenhouse gas emissions in New York City (41 percent of emissions), followed by transportation and waste (32 percent) and building electricity and steam use (27 percent).[35] Using high-efficiency electric technologies instead of gas combustion in new buildings would reduce greenhouse gas emissions significantly, and would help serve New York City's overall climate targets.

2.1 Summary

In 2024, gas-powered space heating and cooking in new buildings in NYC would directly emit around 238,400 metric tons of CO_2e, or around 4.4 pounds CO_2e per square foot of building space. If building construction continues increasing linearly as it did from 2022 - 2024, this number would increase by 13,100 tons of CO_2 annually. Electrifying these new buildings with heat pumps and induction stoves would **avoid 75,600 metric tons of direct CO_2e emissions in 2024**, with greater savings in subsequent years due primarily to the decarbonization of the electric grid. Additionally, electrifying new buildings would avoid around **69,100 metric tons CO_2e in indirect emissions** due to methane leaks from gas infrastructure in 2024, or about 1.3 pounds CO_2e per square foot of building space.

Governor Kathy Hochul announced a similar policy would be executed at the state level. This same policy would avoid **105,300 metric tons of direct CO_2 emissions annually** from the residential sector alone (or **1.71 pounds CO_2 per square foot of home construction**), with greater annual emissions savings as NY decarbonizes its electric grid. The policy would also avoid **52,300 metric tons of CO_2e annually that would result from methane leaks**, or about 0.85 pounds per square foot.

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[35] Urban Green Building Council. (2023). NYC All Electric New Buildings Law. https://www.urbangreencouncil.org/wp-content/uploads/2023/01/LL154-Factsheet_1.5.2023.pdf

If this same policy were applied to the U.S at large, it would avoid **762,000** metric tons of direct CO_2 emissions, or **0.67 lbs CO_2e per square foot** from the residential sector alone. These CO_2 savings would likely increase over the years as more zero-carbon energy is added to the electric grid. It would also avoid an additional **772,100 metric tons of CO_2e in indirect emissions** due to methane leaks annually, or about 0.68 lbs CO_2e per square foot of home space.

2.2 Results and Impacts

See Methods section below for a detailed breakdown on numbers and calculations used.

2.2.1 Direct Impacts of Banning Gas in New Construction

We estimate NYC residents use about 0.038 MMBTU gas per square foot, and therefore will require about 4.49 million MMBTUs of gas for the 118.2 million square feet of new construction expected in 2024, which is associated with a direct CO_2 impact of 238,400 metric tons in 2024. This equals roughly 4.4 pounds CO_2 avoided per square foot of new building space.

For New York State at large, we calculate an average gas use of 0.025 MMBTU per square foot, which will require roughly 3.4 million MMBTU of gas for the approximately 136 million square feet of new housing constructed annually. This amount of gas burned for heating and cooking would have a direct CO_2 impact of 180,500 metric tons CO_2 annually, or about 2.93 pounds CO_2 per square foot.

For the U.S, we estimate an average use of 0.020 MMBTU gas per square foot. New homes would therefore require about 50.2 million MMBTU for the approximately 2.51 billion square feet of new housing space constructed annually. This would have an associated direct CO_2 impact of 2.67 million metric tons per year, or 2.34 pounds per square foot of new housing space.

2.2.2 Indirect Impacts of Banning Gas in New Construction

Methane leakage from gas infrastructure is a significant concern, and has an outsized impact on climate change. It is estimated that around 2.9% of gas delivered to end users is leaked from wells, pipelines, and other infrastructure.[36] For the 118.2 million square feet of building space projected to be built in NYC in 2024, this would result in around 69,100 metric tons of CO_2e emissions, or around 1.3 pounds CO_2e per square foot of building space constructed. For NY State, we calculate that methane leaks from supplying gas to new homes would result in roughly 52,300 metric tons of CO_2e emitted (or about 0.85 pounds per square foot). For the U.S at large, we estimate 772,100 metric tons of CO_2e would be emitted annually (or about 0.68 pounds per square foot) due to methane leaks, just from gas used in new housing.

2.2.3 Impacts of Electrifying New Buildings

NYC's electric grid (subregion NYCW) has a CO_2e emissions factor of 817.9 pounds per MWh generated. Assuming electric appliances require one third the energy as their gas-powered counterparts, this would result in 162,700 metric tons of CO_2e emissions from new buildings in 2024, or about 75,600 fewer metric tons of direct CO_2e emissions compared to the gas alternative. This would also likely entirely avoid the 69,100 metric tons of CO_2e emissions from leaked upstream methane. These CO_2 savings would likely increase after 2024 due to NYC's electricity grid decarbonizing.

NY State's electric grid emits about 499 pounds of CO_2 per MWh produced. Using similar assumptions made for NYC, using electric appliances instead of gas in new homes would emit 75,200 metric tons of CO_2 emissions, or about 105,300 fewer metric tons of direct CO_2 emissions compared to the gas alternative. These savings would also likely increase as NY transitions to zero-carbon electricity.

The U.S on average emits 857 pounds of CO_2e per MWh generated. A hypothetical national gas ban similar to NYC's would reduce direct CO_2 emissions by about 762,000 metric tons annually from the residential sector alone, which equates to 0.67 lbs CO_2 per square foot of housing constructed.

2.3 Methods

2.3.1 NYC - Direct Impacts of Banning Gas in New Construction

2.3.1.1 Amount of New Construction: In 2022, about 105.1 million gross square feet of building space was constructed in NYC. NYBC predicted this to increase to 110.8 million

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[36] Alvarez, R. A., Zavala-Araiza, D., Lyon, D. R., Allen, D. T., Barkley, Z. R., Brandt, A. R., ... & Hamburg, S. P. (2018). Assessment of Methane Emissions from the US Oil and Gas Supply Chain. Supplementary Material. *Science*, *361*(6398), 186-188.

square feet in 2023, and further increase to 118.2 million square feet in 2024. For the purposes of this estimation, we assumed a linear increase of 6.5 million square feet of building constructed annually after 2024 (e.g: ~124.7 million sqft in 2025, etc.)

2.3.1.2 Estimating Gas Usage per Square Foot: In 2019, NYC residents used about 206 million MMBTUs of natural gas in buildings for space heating and cooking. In 2017, there was about 5.4 billion square feet of building space total in NYC. Therefore, we estimate a gas usage factor by dividing the gas used by the total building space:

$$\frac{2.06 * 10^{8}\ MMBTU}{5.4 * 10^{9}\ sqft} = 0.038\ MMBTU\ gas\ used\ per\ sqft$$

The gas usage factor above allows us to estimate how much gas will be used by future building space based on the square footage constructed in 2019:

$$0.038\ \frac{MMBTU\ gas}{sqft} * 118.2\ million\ sqft = 4.49\ million\ MMBTUs\ required$$

Assuming the amount of building space constructed increases by 6.5 million square feet each year, gas use may increase by 247,000 MMBTU each year.

2.3.1.3 Estimating CO_2 Emissions Based on Gas Usage: According to the U.S Energy Information Administration (EIA), each MMBTU of gas burned emits around 117 lbs of CO_2. We can use this emissions factor to approximate CO_2 emissions from burning gas:

$$4.49\ million\ MMBTUs\ gas * \frac{117\ lbs\ CO_2}{MMBTU\ gas} * \frac{1\ metric\ ton}{2204\ lbs} = 238,400\ metric\ tons\ CO_2\ in\ 2024$$

Every year, this may increase by:

$$247,000\ MMBTU * \frac{117\ lbs\ CO_2}{MMBTU\ gas} * \frac{1\ metric\ ton}{2204\ lbs} = 13,100\ metric\ tons\ CO_2$$

Based on these numbers, we estimate CO_2 emissions from burning gas in buildings to be around 238,400 tons in 2024, increasing by 13,100 tons annually (assuming linear construction of new building space).

2.3.1.4 Estimating CO_2 Emissions from Electric Appliance Replacements: Under the new policy, all gas appliances (heaters, stoves, etc.) in buildings will be replaced by high-efficiency electric space heaters and stoves. The grid electricity used to power these appliances also has emissions associated with it – primarily because natural gas comprises a large portion of NYCW's electricity mix. As electric appliances like heat pumps and induction stoves are around three times more energy-efficient than their gas counterparts[37,38], we assume they use one third the energy for the same uses. Therefore:

$$4.49\ million\ MMBTU\ *\ \frac{293\ kWh}{1\ MMBTU}\ *\ \frac{1\ MWh}{1000\ kWh}\ *\ \frac{1}{3}\ =\ 438,600\ MWh$$

According to the EPA's eGRID, NYCW emits about 817.9 pounds CO_2e per MWh generated (in 2021). Using this emissions factor, we calculate CO_2e emissions from the now-electrified building spaces:

$$438,600\ MWh\ *\ \frac{817.9\ lbs\ CO_2e}{MWh}\ *\ \frac{1\ metric\ ton}{2204\ lbs}\ =\ 162,800\ metric\ tons\ CO_2e$$

Therefore, in 2024, electrifying new buildings would save:

$$238,400\ metric\ tons\ CO_2e\ -\ 162,800\ metric\ tons\ CO_2e\ =\ 75,600\ metric\ tons\ CO_2e\ in\ 2024$$

Each year after 2024, CO_2 savings should increase by nearly 4,200 metric tons CO_2e (again assuming linearity in the rate of construction increase). In reality, these savings would increase much more drastically, as NYC is aiming to decarbonize its electric grid almost entirely by 2050.

2.3.2 NYC - Indirect Impacts of Banning Gas in New Construction

2.3.2.1 Estimating CO_2 Emissions from Gas Leaks:

Methane, the primary compound in natural gas, is a powerful greenhouse gas, with a global warming potential around 28 times that of carbon dioxide over a hundred year period. Roughly 2.9% of methane delivered to end users leaks from gas infrastructure[39], like transmission pipelines, which has a significant warming effect in addition to CO_2 produced by burning gas for heat, cooking, and power. Below, we estimate the CO_2-equivalence of these gas leaks:

$$\frac{1\ mol\ CH_4}{845\ BTU} * \frac{16.04\ grams\ CH_4}{1\ mol\ CH_4}\ *\ \frac{1\ BTU}{10^{-6} MMBTU}\ *\ \frac{0.0022\ lbs}{1\ gram}\ =\ 41.76\ \frac{lbs\ CH_4}{MMBTU}$$

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[37] IEA (2022). The Future of Heat Pumps. https://www.iea.org/reports/the-future-of-heat-pumps, License: CC BY 4.0.

[38] Bui, V. (2023). Making the Switch to Induction Stoves or Cooktops. U.S Department of Energy. https://www.energy.gov/articles/making-switch-induction-stoves-or-cooktops

[39] Alvarez, R. A., Zavala-Araiza, D., Lyon, D. R., Allen, D. T., Barkley, Z. R., Brandt, A. R., ... & Hamburg, S. P. (2018). Assessment of Methane Emissions from the US Oil and Gas Supply Chain. Supplementary Material. *Science*, *361*(6398), 186-188.

$$41.76\ \frac{lbs\ CH_4}{MMBTU} * 28\ \frac{lbs\ CO_2e}{1\ lb\ CH_4} * 0.029 * 4.49\ million\ \frac{MMBTU}{year} * \frac{1\ metric\ ton}{2204\ lbs} = 69,100\ \frac{metric\ tons\ CO_2e}{year}$$

Based on our estimates for energy requirements for new buildings in 2024, about 69,100 metric tons of CO_2e will be emitted as a result of methane leakage from gas infrastructure. If the amount of building space constructed increases in the years after 2024, this value will likely increase as well. These emissions can be avoided entirely by electrifying new buildings.

2.3.3 NY State - Direct Impacts of Banning Gas in New Construction

2.3.3.1 Amount of New Homes Being Built in NY State: In 2023, New York Governor Kathy Hochul outlined a suite of policy changes known as the New York Housing Compact, which aims to construct 800,000 new homes over the next decade.[40] For simplification, we assume the total new homes built will be equal each year, or roughly 80,000 homes per year. The average home in NY State is roughly 1,700 square feet.[41] This gives an annual home area construction estimate of:

$$80,000\ homes\ per\ year * 1,700\ \frac{sqft}{home} = 136\ million\ sqft\ per\ year$$

2.3.3.2 Estimating Gas Usage per Square Foot: In 2020, there were about 7.52 million housing units in New York state using roughly 319.8 million MMBTU of natural gas.[42] Again assuming the average home size in NY is 1,700 square feet, this gives a total home area of 12.78 billion square feet for NY. Using this information, we estimate a gas use factor of:

$$\frac{319.8\ million\ MMBTU\ gas}{12.78\ billion\ sqft} = 0.025\ \frac{MMBTU}{sqft}$$

The gas usage factor above allows us to estimate how much gas will be used by future home space based on our projects for home square footage construction moving forward:

$$0.025\ \frac{MMBTU\ gas}{sqft} * 136\ million\ sqft = 3.4\ million\ MMBTUs\ required$$

2.3.3.3 Estimating CO_2 Emissions Based on Gas Usage: We use the same methodology as in section **2.3.1.3** to estimate CO_2 emissions from the estimated required natural gas.

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[40] Mitchell, B. (January, 2023). News10. https://www.news10.com/news/new-york-aims-to-build-800000-new-homes-over-next-decade/

[41] HomeAdvisor. (2023). 2023 Cost of Building a House in NY. https://www.homeadvisor.com/cost/architects-and-engineers/build-house-new-york/

[42] EIA 2020 Residential Energy Consumption Survey (RECS). https://www.eia.gov/consumption/residential/data/2020/index.php?view=state

$$3.4 \frac{million\ MMBTU\ gas}{year} * \frac{117\ lbs\ CO_2}{MMBTU\ gas} * \frac{1\ metric\ ton}{2204\ lbs} = 180,500\ metric\ tons\ CO_2\ per\ year$$

Constructing 800,000 new homes over the next 10 years in NY State that use gas for cooking and heating would cause an estimated 180,500 metric tons of direct CO_2 emissions annually. This does not account for gas usage in new non-home construction, like businesses, schools, etc.

2.3.3.4 Estimating CO_2 Emissions from Electric Appliance Replacements:

We follow the same methodology outlined in section **2.3.1.4** to determine emissions from high-efficiency electric heating and cooking appliances to compare against the gas alternative:

$$3.4\ million\ MMBTU * \frac{293\ kWh}{1\ MMBTU} * \frac{1\ MWh}{1000\ kWh} * \frac{1}{3} = 332,100\ MWh$$

According to the Energy Information Administration, NY emits about 499 pounds CO_2 per MWh generated (in 2021).[43] Using this emissions factor, we calculate CO_2e emissions from the now-electrified building spaces:

$$332,100\ MWh * \frac{499\ lbs\ CO_2}{MWh} * \frac{1\ metric\ ton}{2204\ lbs} = 75,200\ metric\ tons\ CO_2$$

Therefore, every year, electrifying new buildings would save:

$$180,500\ metric\ tons\ CO_2 - 75,200\ metric\ tons\ CO_2 = 105,300\ metric\ tons\ CO_2\ annually$$

Electrifying new homes would save 105,300 metric tons of CO_2e annually. As above, these savings would increase annually as NY decarbonizes its electric grid.

2.3.4 NY State - Indirect Impacts of Banning Gas in New Construction

2.3.4.1 Estimating CO_2 Emissions from Gas Leaks:

We follow the same methodology as outlined in section **2.3.2.1** to calculate CO_2e emissions resulting due to methane leaks from gas infrastructure:

$$41.76 \frac{lbs\ CH_4}{MMBTU} * 28 \frac{lbs\ CO_2e}{1\ lb\ CH_4} * 0.029 * 3.4\ million \frac{MMBTU}{year} * \frac{1\ metric\ ton}{2204\ lbs} = 52,300 \frac{metric\ tons\ CO_2e}{year}$$

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[43] Electricity Data Browser. (2022). New York Electricity Profile. U.S Energy Information Administration. https://www.eia.gov/electricity/state/newyork/

Methane leaks resulting from supplying 80,000 new homes every year would result in an additional 52,300 metric tons of CO_2e emissions annually. Electrification of new homes would avoid these emissions entirely.

2.3.5 National - Direct Impacts of Banning Gas in New Construction

2.3.5.1 Determining Gas Usage Per Square Foot of Housing: In 2022, there was a total of 256.1 billion square feet of housing in the US.[44] According to the EIA, 4.96 million MMcf of natural gas was delivered to residential customers nationwide in 2022. We first convert this to MMBTUs:

$$4.96\ million\ MMcf\ * \frac{1000\ Mcf}{1\ MMcf} * 1.036\frac{MMBTU}{Mcf} \ = \ 5.14\ billion\ MMBTUs$$

We then derive a gas usage factor based on national 2022 housing area and residential gas usage:

$$\frac{5.14\ billion\ MMBTU}{256.1\ billion\ sqft} \ = \ 0.020\ \frac{MMBTU}{sqft}$$

2.3.5.2 Determining Annual New Home Construction

From 2018-2022, the rate of new housing construction has remained fairly steady, with an average of 929,000 new single-family homes, 335,000 multifamily rentals, and 27,000 multifamily units for sale built each year.[45] Median single-family home size was around 2,300 square feet; median size of a multifamily for rent was about 1,000 square feet, while the median size of a multifamily unit for sale was 1,300 square feet.[46] Using these numbers, we can approximate the average square footage of homes built from 2018-2022 to be:

$$(929,000\ sf\ homes\ *\ 2300\ \frac{sqft}{sf\ home})\ +\ (335000\ mfr\ homes\ *\ 1000\frac{sqft}{mfr\ home})\ +$$
$$(27,000\ mfs\ homes\ *\ 1300\frac{sqft}{mfs\ home})\ =\ 2.51\ billion\ sqft.$$

This equates to an average of **2.51 billion square feet of housing** built annually. As the rate of new home construction has remained steady from 2018-2022, we assume the rate of new housing construction will remain constant in the coming years.

2.3.5.3 Amount of Gas Required in New Homes Nationwide:

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[44] Statista. (2023). Total Space of Homes in the United States from 2015 to 2023. https://www.statista.com/statistics/1072321/total-home-square-footage-usa-timeline/

[45] U.S Census Bureau CHARS Dataset

[46] U.S Census Bureau (2022). Highlights of 2022 Characteristics of New Housing. https://www.census.gov/construction/chars/highlights.html

With the above assumption that roughly 2.51 billion square feet of housing will be constructed nationwide every year, we estimate gas consumption from these new homes to be:

$$2.5\ billion \frac{sqft}{year} * 0.020 \frac{MMBTU}{sqft} = 50.2\ million \frac{MMBTU}{year}.$$

2.3.5.4 CO_2e Emissions from Gas in New Homes:

We repeat the calculation above from the NYC section to calculate CO_2 emissions from natural gas use in new homes:

$$50.2\ million\ \frac{MMBTU}{year} * 117 \frac{lbs\ CO2}{MMBTU} * \frac{1\ metric\ ton}{2204\ lbs} = 2.67\ million\ metric\ tons\ CO_2\ per\ year$$

.

Direct emissions from natural gas use in new residential buildings would result in around **2.67 million metric tons of CO_2 emissions annually**.

2.3.5.5 CO_2e Emissions from Electrifying New Homes & Emissions Avoided:

Again, we repeat the methods from the NYC section to calculate emissions from electricity use for space heating and cooking using an average electricity emissions factor for the entire U.S.

$$50.2\ million \frac{MMBTU}{year} * \frac{293\ kWh}{1\ MMBTU} * \frac{1\ MWh}{1000\ kWh} * \frac{1}{3}\ (efficiency\ factor) = 4.9 \text{ million MWh}$$

$$4.9\ million\ MWh * 857 \frac{lbs\ CO_2e}{MWh} * \frac{1\ metric\ ton}{2204\ lbs} = 1.91\ million\ metric\ tons\ CO_2\ per\ year$$

$$2.94\ million\ MT\ CO_2 - 1.91\ million\ MT\ CO_2 = 0.76\ million\ metric\ tons\ CO_2\ per\ year$$

.

Therefore, electrifying new homes across the US would save around **760,000 metric tons of direct CO_2 emissions annually**. However, as many states, as well as the federal government, have pledges to decarbonize their electricity grids, the annual CO_2 savings will likely increase over time.

2.3.6 National - Indirect Impacts of Banning Gas in New Construction

We follow a similar methodology as shown in section 2.3.2 above to calculate indirect CO_2e emissions from methane leakage:

$$41.76\ \frac{lbs\ CH_4}{MMBTU} * 28\ \frac{lbs\ CO_2e}{1\ lb\ CH_4} * 0.029 * 50.2\ million\ \frac{MMBTU}{year} * \frac{1\ metric\ ton}{2204\ lbs} = 851,100\ \frac{metric\ tons\ CO_2e}{year}$$

Electrifying new homes would likely avoid around **772,100 metric tons of CO_2e emissions** from leaked methane annually.

2.4 Data and Assumptions

Data and related assumptions used in the above calculations are presented in Table 4 below.

Due to data availability, we examined total building construction for NYC, but focused on housing construction for the broader U.S. A primary assumption made in the above NYC calculations is that the rate of building construction will linearly increase after 2024. We based this on new building construction for 2022-2024, which followed a roughly linear rate of increase of 6.5 million square feet per year. However, this is by no means guaranteed – this increase in building construction may be a result of a post-pandemic boom, and may be impacted by economic winds (such as high interest rates).[47] For the U.S more broadly, we assumed that new housing construction would stay fairly level as it has from 2018-2022, however, this could similarly be affected by macroeconomic headwinds. We report CO_2 emissions both as overall estimates (in tons) and in pounds per square foot constructed. The latter may be useful to estimate CO_2 emissions if future building construction, either in NYC or nationally, does not align with our earlier assumptions.

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[47] Vollmar, A. (2023). What the Rise of Global Interest Rates Means for the Real Estate and Construction Industry. https://hegias.com/en/knowledge/rise-global-interest-rates-means-real-estate-construction-industry/

Table 4: Supporting data and assumptions used to calculate emissions savings from electrifying new buildings.

Data Category	Data Detail	Data and Assumptions
Building construction	Forecasted building construction 2022-2024 (NYC)	NY Building Congress (NYBC) estimates 105.1 million gross sqft of building space constructed in 2022, increasing to 110.8 million sqft in 2023 and 118.2 million sqft in 2024. We assumed a linear increase in new building space constructed moving beyond 2024.
	Forecasted home construction for NY State	Governor Kathy Hochul announced plans to construct 800,000 new homes over the next decade throughout NY.
	Historical Housing Construction (U.S)	An average of 2.51 billion square feet of housing has been added in the US from 2018-2022. Calculated from U.S Census Bureau CHARS data.
	Total housing area in the US	Obtained from Statista data.
NYC building gas usage	Amount of gas NYC residents used for cooking and space heating	NYC residents used 206 million MMBTU natural gas for heating and cooking in 2019.
	Estimate for total building space in NYC	In 2017, there was about 5.4 billion sqft of building space in NYC.
NY State building gas usage	Amount of gas NY residents consumed in 2020	Obtained from the Energy Information Administration's RECS survey data.
USA residential gas usage	Amount of gas delivered to residential customers	EIA indicates that around 4.96 million MMcf gas was delivered to residential customers in 2022.
CO_2e emissions from natural	CO_2 emissions from direct burning of gas for	Burning 1 MMBTU of natural gas results in about 117 pounds of CO_2 emissions.

gas	heating and cooking	
	CO$_2$e emissions resulting methane leaks	Roughly 2.9% of methane delivered to end-users is leaked from gas infrastructure. 1 mole of methane contains about 845 BTUs of thermal energy. Methane has a global warming potential of 28 times CO$_2$ over a 100 year time frame.
CO$_2$e emissions from NYC's electricity grid (NYCW)	Estimating CO$_2$e emissions from the NYCW electricity mix to adequately compare savings compared to gas.	According to EPA eGRID, NYCW's electricity mix emits about 817.9 pounds of CO$_2$e per MWh generated as of 2021. This is largely due to the reliance of natural gas for electricity, which increased in recent years due to the shutdown of the Indian Point nuclear power plant, which supplied 25% of NYCW's electricity mix. However, as NYC transitions to more renewable and zero-emission electricity, the CO$_2$ emissions per MWh should decrease over the coming years.
Average CO$_2$ emissions from NY's electricity grid	Estimating CO$_2$ emissions from the NY's electricity mix to adequately compare savings compared to gas.	According to the EIA, electricity in NY emits about 499 pounds per MWh generated as of 2021. This value should decrease as NY decarbonizes its sources of electricity.
Average CO$_2$e emissions from USA's grid	Estimating CO$_2$e emissions from the national average electricity mix to adequately compare savings compared to gas.	According to EPA eGRID, the nation's electricity mix on average emits about 857 pounds of CO$_2$e per MWh generated as of 2021. As with NYC, the transition to more renewable and zero-emission electricity should reduce CO$_2$ emissions per MWh over the coming years.
Electric appliance efficiency vs. natural gas	Modern electric appliances are more energy-efficient than their natural gas counterparts.	Heat pumps on the market are currently three to five times as efficient than natural gas boilers. Induction stovetops are up to three times more efficient than gas-powered stoves.

2.5 Caveats

There are several caveats to many of these calculations, some of which have already been discussed.

- We assume a linear growth in construction for NYC and a flat growth in home construction for NY and the U.S over the coming years – this is not a guarantee, and economic headwinds can just as easily cause slumps in construction after 2024.
- NYC's policy has multiple phases – initially prioritizing new buildings under 7 stories for electrification first, before moving to schools in 2024, and finally buildings taller than 7 stories by 2029. However, most new buildings built are one- and two- family homes[48], so for the purposes of these estimations, we did not take building size into consideration, as most new buildings would be impacted by 2024.
- NYC (and the state at large) have ambitious plans to decarbonize their electric grid by 2050. Therefore, avoided CO_2e emissions from building electrification will increase annually as the grid implements more zero-carbon energy sources.
- For New York State, we assumed the 800,000 new homes built over the next decade would be constructed evenly each year, at about 80,000 new homes built per year.
- For NY State and the U.S at large, we focused solely on new residential buildings rather than building construction more broadly due to data availability. If other building types (like commercial buildings) are included, then CO_2 savings from electrification would be even higher.

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[48] Urban Green Building Council. (2023). NYC All Electric New Buildings Law. https://www.urbangreencouncil.org/wp-content/uploads/2023/01/LL154-Factsheet_1.5.2023.pdf

All Electric Schools in New York City

Under Mayor Eric Adams' "Leading the Charge" plan, New York City (NYC) plans to convert 100 existing schools to all-electric heating by 2030 and make all new city schools all-electric. The plan also aims to phase out city schools' use of No.4 heating oil and install efficient LED lights in 800 schools by 2026.

This plan dovetails with New York City's existing greenhouse gas reduction targets. Based on existing law, NYC plans to reach 40% below 2005 levels by 2030 and carbon neutrality and 100% clean electricity by 2050. Under city law, No. 4 heating oil should also be phased out of most buildings by 2030, with limits on building greenhouse gas emissions beginning in 2024.[49]

3.1 Summary

Achieving the above goals could reduce NYC school emissions by an estimated 91,000 metric tons of CO_2e annually.[50] Depending on concurrent efficiency retrofits, electrifying all K-12 school buildings in NYC could lead to between 29,000 and 251,000 metric tons of avoided emissions annually. This is equivalent to getting roughly 6,500 to 56,000 cars off the road each year. Critically, this plan demonstrates the potential for electrifying schools across the state and nationwide. We estimate that undertaking efficiency upgrades while switching all K-12 school buildings in New York to all-electric operations could avoid up to 596,000 metric tons of CO_2e annually–equivalent to taking more than 132,000 cars off the road each year. Additionally, we estimate that electrifying K-12 school buildings across the full U.S. could avoid between 5.4 and 17 million metric tons of CO_2e annually, depending on the depth of simultaneous retrofits–the same as getting 1.2 to more than 3.8 million cars off the road.

These estimates are likely an underestimation, as they assume no increase in local solar generation that would offset on-site energy consumption and no reduction in the emissions intensity of the grid. Supporting data and references for these results are detailed in **Table 6**.

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[49] Elsen-Rooney, Michael. (2022) *NYC will convert 100 fuel-burning public schools to all-electric energy by 2030.* https://ny.chalkbeat.org/2022/10/28/23429053/nyc-schools-clean-energy-greenhouse-gas-emissions-retrofit

[50] The City reports that this program will reduce greenhouse gas emissions by 120,000 tons per year, which equates to roughly 109,000 metric tons. Our initial estimate is a little lower, likely because it does not use data from any specific schools being targeted for upgrades or retrofits.

3.2 Results and Impacts

3.2.1 Direct Impacts of Electrifying Schools in New York City

Between 2018 and 2019, NYC's Department of Education reported an average of 749,00 metric tons of CO_2e from building operations. Installing more efficient lighting in 800 schools, retrofitting schools using heating oil to use electric heat pumps, electrifying an initial 100 schools, and ensuring all new schools are fully electrified could reduce emissions from NYC schools by roughly 91,000 metric tons a year. Simply electrifying all school operations, with minor efficiency upgrades, could result in an annual emissions reduction of almost 29,000 metric tons of CO_2e. Undertaking additional building efficiency upgrades–including improving insulation, installing more efficient lighting, and updating outdated appliances–could result in an annual savings of up to 251,000 metric tons of CO_2e.[51]

3.2.2 Indirect Impacts - Scaling School Electrification Across New York State

There are more than 4,500 public K-12 schools across New York state, which are estimated to produce almost 1.8 million metric tons of emissions each year.[52] Scaling our estimates to New York state, we calculate that electrifying all K-12 schools could reduce emissions between 71,000 and 596,000 metric tons annually.

3.2.3 Indirect Impacts - Scaling School Electrification Across the United States

We estimate that across the U.S., K-12 schools produce 56.8 million metric tons of emissions annually. A significant portion of this is from the use of fossil fuels for heating and cooling. Switching to heat pumps for more efficient space heating and cooling, electrifying cooking, water heating, and other school operations could reduce annual CO_2e emissions between 5.3 and 17 million metric tons.

3.2.4 Indirect Health Impacts of Electrifying Schools

While this analysis does not quantify them, it's worth noting that school electrification can have significant positive health impacts. Burning fossil fuels releases air pollution that

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[51] Under the new policy, the city plans to install more efficient lighting in 800 schools by 2026. Given the aging nature of many school buildings, the achievable energy reductions for space heating and cooling that result from building envelope efficiency upgrades, and the significant costs of energy for school operations, administrators may pursue additional efficiency upgrades if funding is available.

[52] See Table 6.

contributes to chronic health conditions, including asthma. In 2008, children across the U.S. missed roughly 14.4 million school days due to asthma, making it one of the leading causes of missed school.[53] Missing school is associated with worse academic performance and a lower likelihood of graduating, and students with asthma are more often absent than their counterparts without the condition.

In both NYC and across the U.S., asthma disproportionately affects Black and Latino children and those living in poverty-stricken neighborhoods.[54, 55] This makes the electrification of school buildings an environmental justice concern as well. NYC's program prioritizes schools in disadvantaged neighborhoods and is estimated to remove more than 20,000 pounds of fine particulates from the air annually.[56]

Improving indoor air quality through good ventilation and air filtration have been linked with improved health and educational outcomes.[57, 58] Studies suggest that improving ventilation rates in schools can decrease illness-related absences and that removing common air pollutants can raise student test scores.[59, 60] Electrifying school operations means improved air quality in and around buildings that use fossil fuels for heating, potentially leading to fewer school absences due to asthma and better academic performance. Simultaneous efficiency upgrades can help ensure that electrification does not unduly increase energy demand.

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[53] Meng, Y., Babey, S., & Wolstein, J. (2012). *Asthma-Related School Absenteeism and School Concentration of Low-Income Students in California. Centers for Disease Control and Prevention.* https://www.cdc.gov/pcd/issues/2012/11_0312.htm

[54] Zanobetti A, Ryan PH, Coull B, et al. (2022). *Childhood Asthma Incidence, Early and Persistent Wheeze, and Neighborhood Socioeconomic Factors in the ECHO/CREW Consortium.* JAMA Pediatr. 2022;176(8):759–767. doi:10.1001/jamapediatrics.2022.1446

[55] NYC Health. (2021). *Epi Data Brief: Disparities among Children with Asthma in New York City.* https://www.nyc.gov/assets/doh/downloads/pdf/epi/databrief126.pdf

[56] NYC.Gov. (2022). *Mayor Adams Announces $4 Billion Plan To Make new Schools All-Electric, Electrify 100 Existing Schools.* https://www.nyc.gov/office-of-the-mayor/news/787-22/mayor-adams-4-billion-plan-make-new-schools-all-electric-electrify-100-existing

[57] Brink, Henk W. et al. (2020). *Classrooms' indoor environmental conditions affecting the academic achievement of students and teachers in higher education: A systematic literature review*. Indoor Air, 31(2), 405-425. https://doi.org/10.1111/ina.12745

[58] Martenies, S.E., & Batterman, S.A. (2018). *Effectiveness of Using Enhanced Filters in Schools and Homes to Reduce Indoor Exposures to PM2.5 from Outdoor Sources and Subsequent Health Benefits for Children with Asthma.* Environmental Science & Technology, 52(18), 10767–10776. https://doi.org/10.1021/acs.est.8b02053

[59] Mendell, M.J., et al. (2013). *Association of classroom ventilation with reduced illness absence: a prospective study in California elementary schools.* Indoor Air. 23: 515–528. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7165692/

[60] Gilraine M. (2020). *Air filters, pollution and student achievement.* Ed Working Papers: Annenberg Brown University. https://www. edworkingpapers.com/ai20-188

3.3 Methods

NYC's new policy outlines numerous steps, including efficiency upgrades for lighting and an interim goal of converting some schools to low-sulfur biofuels before full electrification. In this analysis, we leapfrog the biofuel step, in part because NYC's ultimate goal is to replace fossil fuel boilers and furnaces with highly efficient heat pumps and for schools to be energy efficient and all-electric.[61] Thus, this analysis mainly looks at the targeted end result of full electrification.

Making a building more energy efficient before switching to an electric heat pump–thereby reducing the size of heat pump required–is best practice. Given that more than half of public school districts need to update or replace multiple building systems (such as HVAC) in at least some of their schools[62] and that there is federal support for building energy efficiency upgrades,[63] it is likely that schools undergoing electrification efforts will also pursue energy efficiency improvements. However, funding is often limited. To that end we looked at three different scenarios: where schools electrify and undertake some minor electric efficiency improvements ("Low Scenario"), where schools electrify and undertake moderate efficiency improvements ("Moderate Scenario"), and where schools simultaneously electrify and undertake deep efficiency retrofits ("High Scenario"). This results in wide ranges for annual emissions reductions.

3.3.1 Direct Impacts of Electrifying Schools In New York City

3.3.1.1 Emissions for NYC schools. Data from NYC's Department of Education in **Table 6** shows that K-12 schools in NYC emitted an average of 749,000 metric tons of CO_2e annually between 2018 and 2019. Given steep energy consumption reductions in 2020 due to COVID-19, we used this as our baseline for emissions. Divided by the total number of schools in NYC, this gives us a CO_2e intensity of roughly 401 metric tons CO_2e per school.

$$\frac{749{,}000\ metric\ tons\ CO_2e}{1{,}867\ total\ schools} = 401\ metric\ tons\ CO_2e\ /\ school$$

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[61] NYC.Gov. (2022). *Mayor Adams Announces $4 Billion Plan To Make new Schools All-Electric, Electrify 100 Existing Schools.* https://www.nyc.gov/office-of-the-mayor/news/787-22/mayor-adams-4-billion-plan-make-new-schools-all-electric-electrify-100-existing

[62] U.S. Government Accountability Office. (2020). *K-12 Education: School Districts Frequently Identified Multiple Building Systems Needing Updates or Replacement*. https://www.gao.gov/products/gao-20-494

[63] Office of Energy Efficiency & Renewable Energy. (n.d) *Efficient and Healthy Schools*. https://www.energy.gov/eere/buildings/efficient-and-healthy-schools

3.3.1.2 Efficiency of modern electric appliances and retrofits. Data on the energy efficiency of heat pumps compared to natural gas and fuel oil is listed in **Table 6**, as is data on the reduction in energy from more efficient lighting. Additionally, the IEA reports that homes can cut the energy required for heating in half by improving their efficiency rating two grades. As the 2021 American Society of Civil Engineers' Infrastructure Report Card gave U.S. schools a D grade for efficiency, there exists significant potential for energy savings alongside electrification. So for our calculations, we used a range of compounding efficiencies, depending on the scenario.

3.3.1.3 Emissions Reductions from this program and full electrification. The breakdown of energy consumption (in MBTU) for 2018 and 2019 for schools in NYC is given in **Table 6**. To approximate the change in energy needs for different fuels, we averaged total energy consumption by fossil fuel source between our baseline years and multiplied the result by an efficiency factor (e.g., the likely percentage of energy needed to provide the same heating, cooling, or other service from an electric appliance such as a heat pump). We applied a different efficiency factor to fossil fuels and electricity, as only 26% of electricity consumption in schools is used for space heating and cooling. The moderate and high efficiency scenarios, which included differing levels of energy efficiency retrofits prior to electrification, also added a building efficiency retrofits factor. This indicates the potential reduction in energy needed for school operations based on common building energy retrofits.

$$sum\ average\ fossil\ fuel\ consumption\ *\ electrification\ efficiency\ factor\ *\ building\ efficiency\ retrofits\ factor$$

$$sum\ average\ electricity\ consumption\ *\ electrification\ efficiency\ factor\ *\ building\ efficiency\ retrofits\ factor$$

Once we had the updated energy consumption totals, we multiplied them by 817.9 pounds CO_2e / MWh (the 2021 CO_2e emissions factor for New York's electricity grid) converted to metric tons of CO_2e / MBTU.

Table 5 shows the electrification and building energy retrofit efficiency multipliers used for each of our three scenarios as well as final differences from baseline emissions.

To calculate emissions reductions from the outlined program goals, we first calculated the emissions intensity of schools given our high efficiency scenario[64] and multiplied it by 100 schools. This is the total emissions from these 100 schools after they've been updated.

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[64] The program intends to prioritize schools in disadvantaged neighborhoods, which likely have high potential for emissions reductions from electrification and any co-occurring efficiency updates.

$$\frac{498{,}000\ metric\ tons\ CO_2e}{1{,}867\ total\ schools} * 100\ schools = 26,700\ metric\ tons\ CO_2e$$

Table 5. Summary of Efficiency Multipliers and Carbon Dioxide Equivalents Impacts

	Low Scenario	Moderate Scenario	High Scenario
Electrification Efficiency Factor (fossil fuel sources)	0.5	0.5	0.4
Electrification Efficiency Factor (electricity)	0.85	0.8	0.8
Building Efficiency Retrofits Factor		0.8	0.6
CO_2e emissions (lbs CO_2e/ MWh)	817.9		
Total annual emissions (metric tons CO_2e)	720,000	623,000	498,000
Emissions Reductions (metric tons CO_2e)	29,000	126,000	251,000

We then subtracted this from the emissions these schools would have produced, given the current CO_2e intensity of NYC schools, if they hadn't been updated. This is the emissions reductions from making 100 existing schools all electric.

$$(\frac{401\ metric\ tons\ CO_2e}{school} * 100\ schools) - 26,700\ metric\ tons\ CO_2e = 13,400\ metric\ tons\ CO_2e$$

As new buildings must be all-electric and the NYC School Construction Authority plans to have at least 20 new schools next year,[65] we used the same calculation to find the emissions reductions from making these new schools all-electric.

$$(\frac{400\ metric\ tons\ CO_2e}{school} * 20\ schools) - (\frac{267\ metric\ tons\ CO_2e}{school} * 20\ schools) = 2,700\ metric\ tons\ CO_2e$$

To address the fuel oil and efficient lighting goals we used the same baseline fuel consumption as above, but instead of applying efficiency factors to all fuels, we only addressed fuel oil and some electricity consumption. First, we simulated swapping fuel oil for

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[65] Belle Lin, Sarah. (2023). *Ten new New York City school buildings opened with over 4,400 new seats for the 2023-24 school year*. https://www.amny.com/education/ten-new-school-buildings-opened-with-new-seats-school-year/

electric heat pumps by multiplying the total fuel oil consumed by an efficiency factor of 0.3, as heat pumps are reported to be three times more efficient than fuel oil systems.

$$3,254,000\ MBTU\ *\ 0.3\ *\ \frac{817.9\ lbs\ CO_2e}{MWh}\ *\ \frac{1\ MWh}{3.142\ MBTU}\ *\ \frac{1\ metric\ ton}{2{,}204.6\ lbs}\ =\ 106,000\ metric\ tons\ CO_2e$$

We then split off the electricity that would be used for lighting in 800 schools and multiplied it by how much more efficient LEDs are than traditional bulbs. (Approximately 17% of electricity in schools is used for lighting and LEDs are roughly 90% more efficient. See **Table 6** for more on these assumptions.)

$$3,580,000\ MBTU\ *\ \frac{800\ efficient\ schools}{1{,}867\ total\ schools}\ *\ 0.17\ *\ 0.1\ *\ \frac{817.9\ lbs\ CO_2e}{MWh}\ *\ \frac{1\ MWh}{3.142\ MBTU}\ *\ \frac{1\ metric\ ton}{2{,}204.6\ lbs}\ =\ 2,850\ metric\ tons\ CO_2e$$

For the electricity that was not used for lighting in those 800 schools, we calculated how much energy those schools would have otherwise used for lighting and subtracted it from the total MBTU consumed for electricity.

$$3,580,000\ MBTU\ -\ (3,580,000\ MBTU\ *\ \frac{800\ efficient\ schools}{1{,}867\ total\ schools}\ *\ 0.17)\ =\ 3,320,000\ MBTU$$

We then converted the result to metric tons CO_2e by the same process but without the LED efficiency factor.

$$3,320,000\ MBTU\ *\ \frac{817.9\ lbs\ CO_2e}{MWh}\ *\ \frac{1\ MWh}{3.142\ MBTU}\ *\ \frac{1\ metric\ ton}{2{,}204.6\ lbs}\ =\ 392,000\ metric\ tons\ CO_2e$$

We then added these results to the emissions reported for natural gas and steam to get the total updated emissions from schools annually before subtracting them from our baseline. The result was the difference in annual emissions.

$$106,000\ tCO_2e\ +\ 2,850\ tCO_2e\ +\ 361,000\ tCO_2e\ +\ 203,950\ tCO_2e\ =\ 674,000\ metric\ tons\ \ CO_2e$$

$$749,000\ tCO_2e\ -\ 674,000\ tCO_2e\ =\ 75,000\ metric\ tons\ \ CO_2e$$

Finally, we added this to the difference in annual emissions that would result from electrifying 100 schools.

$$13,400\ tCO_2e\ +\ 75,000\ tCO_2e\ +\ 2,7000\ tCO_2e\ =\ 91,000\ metric\ tons\ CO_2e$$

3.3.2 Indirect Impacts - Scaling School Electrification Across New York State

3.3.2.1 Emissions from New York K-12 schools. The New Buildings Institute estimates that building operations in public K-12 schools in New York produce 1,778,815 metric tons of CO_2e per year.

3.3.1.2 Emissions Reductions from electrification. To estimate emissions reductions, we assumed schools across New York had similar fuel mix percentages as schools in NYC, so electrification and building energy retrofits would decrease school emissions by the same percentage for each scenario (low / medium / high). Thus, we calculated the percentage reduction in total emissions for each scenario in NYC, multiplied it by the total emissions from schools in New York State, and subtracted that number–which would be the emissions after electrification and/or efficiency retrofits under each scenario–from the current estimated emissions level. This gives a rough estimate for emissions reductions under each scenario.

$$1,778,815\ tCO_2e - (1,778,815\ tCO_2e * \frac{720,000\ tCO_2e}{749,000\ tCO_2e}) = 71,000\ metric\ tons\ \ CO_2e$$

$$1,778,815\ tCO_2e - (1,778,815\ tCO_2e * \frac{623,000\ tCO_2e}{749,000\ tCO_2e}) = 299,000\ metric\ tons\ \ CO_2e$$

$$1,778,815\ tCO_2e - (1,778,815\ tCO_2e * \frac{720,000\ tCO_2e}{749,000\ tCO_2e}) = 596,000\ metric\ tons\ \ CO_2e$$

3.3.3 Indirect Impacts – Scaling School Electrification Across the United States

3.3.3.1 Emissions from U.S. K-12 schools. We used data from the Energy Information Administration on commercial building energy consumption and emissions factors for various fuels (see **Table 6**) to estimate the total greenhouse gas emissions from K-12 schools across the U.S. First, we estimated what percentage of fuels would be used by K-12 schools by dividing the total square footage estimated for K-12 buildings by the total square footage of all education buildings.

$$10,619\ million\ square\ feet\ /\ 13,623\ million\ square\ feet\ = 0.779$$

We used this percentage to scale the total consumption of major fuels before multiplying the total estimated fuel consumption from different sources by their respective emissions factors as given by the EIA. The resulting total is the total emissions from K-12 schools, and served as our baseline for emissions reductions.[66]

$$
\begin{aligned}
&(328\ trillion\ BTU\ natural\ gas\ *\ 0.779\ *\ 117\ lbs\ CO_2e/\ MMBTU)\\
&+\ (29.3\ trillion\ BTU\ fuel\ oil\ *\ 0.779\ *\ 163\ lbs\ CO_2e/\ MMBTU)\\
&+\ (60\ trillion\ BTU\ district\ heat\ *\ 0.779\ *\ 134\ lbs\ CO_2e/\ MMBTU)\\
&+\ (437\ trillion\ BTU\ electricity\ *\ 0.779\ *\ \frac{857\ lbs\ CO_2e}{MWh}\ *\ \frac{1\ MWh}{3.142\ MBTU}\ *\ \frac{1\ metric\ ton}{2204.6\ lbs})\\
&=\ 56.8\ million\ metric\ tons\ \ CO_2e
\end{aligned}
$$

3.3.3.2 Emissions Reductions from electrification. Analysis of reductions nationwide followed the same methods as for NYC, with the exception of using a different CO_2e emissions rate. In this case, we used 857 pounds CO_2e / MWh (the 2021 national eGrid emissions factor).

3.3.4 Indirect Health Impacts of Electrifying New York City Schools

These were not calculated directly, as they are beyond the scope of this project. Instead, they were inferred from studies demonstrating the impact that reducing fossil fuel usage can have on public health.

3.4 Data and Assumptions

Supporting data and related assumptions are presented in **Table 6**.

This analysis also assumes that enough new electricity generation capacity, transmission, and distribution infrastructure is built to support electrification efforts. Data are also reported as a full switchover to all-electric operations. However, the electrification of K-12 schools across NYC and the U.S. will require numerous years to reach its full potential.

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[66] This result differs from an annual emissions estimate for all K-12 schools in the U.S. provided in a New Buildings Institute report on the climate impacts of decarbonizing U.S. schools. (See Table 6.) This is due to the fact that they used different underlying data to estimate total K-12 square footage. When our final result is scaled by their total square footage, the annual emissions results are roughly the same.

Table 6: Data and Assumptions

Data Category	Data Detail	Data and Assumptions
NYC schools: emissions and fuel usage	Number of schools in NYC	The New York City Department of Education indicates that there are 1,867 schools (including charter schools) within their jurisdiction.[67]
	CO_2e emissions for FY2018 & FY2020	Based on data from NYC's Department of Education's Sustainability Office, City schools averaged 748,891 metric tons of CO_2e between Fiscal Year (FY) 2018 and FY 2019.[68] While 2020 data is available, we did not include it in our baseline given the dramatic drop in energy usage due to COVID-19 that was not indicative of a normal operating year.
	Total energy consumption by source (MBtu)	NYC schools used an average of 1,165,806 MBTUs from #2 fuel oil, 2,088,305 MBTUs from #4 fuel oil, 3,638,662 MBTUs from natural gas, 3,581,029 MBTUs from electricity, 265,730 MBTUs from steam, and 23,811 MBTUs from solar between FY 2018 and FY 2019.[69]
	Fuels used for heating	Based on the EIA's 2018 Commercial Buildings Energy Consumption Survey (CBECS), roughly 33% of buildings in mixed-mild climate zones–where it places NYC–use electricity for heating. This means that while some school buildings may already use electric heating, we can assume some efficiency improvements if switching from electric resistance heating to high-efficiency heat pumps.
New York state and U.S. schools: Emissions and fuel usage	Number of schools in New York state	The NY State Education Department indicates that there are 4,767 total public schools (including charter schools) in New York.[70] We limited the statewide calculation to public schools for consistency with the NYC evaluation.
	Total buildings square footage and total energy and fuel consumption by source	CBECS estimates that K-12 education buildings have a total floorspace of 10,619 million square feet and all education buildings combined account for 13,623 million square feet.[71] We assume that this ratio (that 77.9% of education-related floorspace is designated for K-12 schools) also holds true for fuel consumption.

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[67] New York City Public Schools. (n.d.) *DOE Data at a Glance*. https://www.schools.nyc.gov/about-us/reports/doe-data-at-a-glance

[68] NYC Office of Sustainability. (n.d.) *DOE Office of Sustainability Annual Report 2019-2020.* https://infohub.nyced.org/docs/default-source/default-document-library/sustainability-annual-report-2019-2020.pdf

[69] *ibid.*

[70] New York State Education Department. (n.d.) *New York State Education at a Glance.* https://data.nysed.gov/

[71] U.S. Energy Information Administration. (n.d.) *2018 CBECS Survey Data.* Table B15, B22, E3, E4, E7, E9, E11. https://www.eia.gov/consumption/commercial/data/2018/

	Electricity consumption by end use	CBECS indicates that education buildings used 437 trillion BTUs total, with 25 trillion for space heating, 90 trillion for cooling, 65 trillion for water heating, 22 trillion for refrigeration, 11 trillion for lighting, and the rest for other uses. This suggests that roughly 26% of electricity in schools is used for space heating or cooling, which could be replaced by high-efficiency heat pumps, and up to 66% could be impacted by efficiency improvements from modern, high-efficiency appliances.
	Estimated annual emissions from K-12 schools	The New Buildings Institute estimates that public K-12 schools in the U.S. generate 41,951,864 metric tons of emissions annually from 7,837 million square feet of building space.[72] This is fewer square feet than the CBECS data, as their square footage estimates indicate less square footage overall. For just New York state, they estimate 1,778,815 metric tons of emissions per year.
	Use of fossil fuels in schools	In NYC and across the U.S., K-12 schools are frequently older buildings and still rely largely on fossil fuels for heating–which can be a significant source of greenhouse gas emissions and local air pollution.[73] So we assume that fossil fuels for school operations are largely used for heating and that we can scale the energy required for space heating by the appropriate electric appliance efficiencies.
Electric appliance efficiencies	Heat pumps compared to gas systems	Currently available heat pumps are two-to-three times more efficient than fuel oil systems, depending on their type (air or ground source).[74] We use these efficiencies to inform our NYC scenarios.
	Heat pumps compared to fuel oil systems	Currently available heat pumps are listed as three-to-five times more energy efficient than natural gas boilers.[75] We use these efficiencies to inform our NYC scenarios.
	Heat pumps for cooling	We assume the efficiencies for heat pumps compared to gas and oil systems hold true for cooling. The Department of Energy's EnergySaver program notes that high-efficiency heat pumps are better at dehumidifying than standard air conditioners. This potential energy saving was not included in our analysis.[76]

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[72] New Buildings Institute. (2021). *Why K-12 Should Feature in America's National Climate Strategy.* https://newbuildings.org/wp-content/uploads/2021/04/Schools_WhitePaper_202104.pdf

[73] National Center for Education Statistics. (2014). Condition of America's Public School Facilities: 2012-13. https://nces.ed.gov/pubs2014/2014022.pdf

[74] NYSERDA. (n.d.) *U.S. Heat Pump Sales Surpass Gas Furnaces.* https://www.nyserda.ny.gov/Featured-Stories/US-Heat-Pump-Sales

[75] IEA. (n.d.) *The Future of Heat Pumps.* https://www.iea.org/reports/the-future-of-heat-pumps/executive-summary

[76] Energy Saver (n.d.) *Heat Pump Systems.* https://www.energy.gov/energysaver/heat-pump-systems

	Heat pumps (general)	Many heat pump systems have supplemental resistance heatings to provide additional heating in case the heat pump itself can't meet total need. As numerous heat pump models can now operate efficiently at 5°F, and some as low as -12°F, this backup electric resistance heating was not considered in our analysis.[77]
	Lighting efficiency factors	According to EnergyStar, LEDs use 90% less energy than traditional bulbs.[78]
Efficiency retrofits	Improving a building's energy efficiency	We assume that home efficiency multipliers–that improving a home's energy efficiency by two grades can halve heating energy demands–generally holds true for education buildings.[79]
	Common building efficiency upgrades	Given that it's best practice to undertake efficiency audits and upgrades before updating a building's heating or cooling system, we assume schools will do so in our moderate and high scenarios. The efficiency modifiers included in these scenarios are estimated based on the above building energy efficiency data from the IEA as well as common efficiency upgrades cited by the EPA.[80]
Emissions factors	Grid electricity rates	eGrid's 2021 national average emissions rate for electricity is 857 pounds CO2e / MWh and their average emissions rate for the subregion that includes NYC is 817.9 pounds CO2e / MWh.[81] Our analysis assumes this remains constant while determining emissions differences from electrification and efficiency upgrades. However, greater CO_2e reductions are likely to result as time moves on, as both New York and the U.S. continue to decarbonize the electric grid. This will lower emissions from electricity production.
	Fuel mix	While a more exact analysis would consider different, and changing, fuel mixes and emissions intensity for electricity, this analysis assumes FY18 and FY19 as representative years for fuel mixes in NYC and fuel mixes outlined in the CBECS data as representative nationwide. Additionally, it uses the eGrid 2021 average emission rates as representative snapshots for electricity.

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[77] Corvidae, J., Gartman, M., Petersen, A. (2019). *The Economics of Zero-Energy Homes.* Rocky Mountain Institute. https://rmi.org/insight/economics-of-zero-energy-homes/

[78] EnergyStar. (n.d.) *Upgrade Your Lighting.* https://www.energystar.gov/buildings/save_energy_commercial_buildings/ways_save/upgrade_lighting

[79] IEA. (n.d.) *The Future of Heat Pumps.* https://www.iea.org/reports/the-future-of-heat-pumps/executive-summary

[80] U.S. Environmental Protection Agency. (n.d.) *Rules of Thumb: Energy Efficiency in Buildings.* State and Local Climate and Energy Program. https://www.epa.gov/sites/default/files/2016-03/documents/table_rules_of_thumb.pdf

[81] U.S. Environmental Protection Agency. (2023). *Emissions & Generation Resource Integrated Database (eGRID), 2021.* Office of Atmospheric Protection, Clean Air Markets Division. https://www.epa.gov/egrid/summary-data

		In doing so, we do not account for a potential increase in local renewable generation (such as installing solar panels on schools or school parking lots) that would decrease a school's reliance on grid electricity.
	Fossil fuel emissions rates	We used the emissions coefficients provided by the EIA to determine final emissions values.[82] For the national estimates, this assumes that all fuel oils e.g., fuel oil #2 and fuel oil #4) have the same emissions coefficient. We also use the representative fuel types and percentages provided by the EIA to calculate the emissions coefficient for district heating (energy) and assume that the biomass listed is municipal solid waste.[83]

3.5 Caveats

The results presented here are rough estimates. Fuel usage and emissions intensities are averaged across all schools in NYC–including newer, more efficient buildings that would not be targeted for upgrades. On the national scale, we used data aggregated from schools in different climate zones with different specific grid electricity emissions factors. We also do not account for different primary heating fuel mixes in different geographic areas. A more specific analysis that accounted for heating and cooling energy needs in different parts of the country, different emissions factors for different portions of the nation's electric grid, and different fuel mixes for schools in different areas would produce more accurate results.

Schools across the country are also facing changing energy and community needs. Changes in heat projections may shift cooling energy needs in the coming years. An increase in extreme weather events has also led some to pursue the idea of climate-resilient schools that can serve as a resource for local communities, and for the Environmental Protection Agency to promote schools as possible clean air and cooling centers.[84, 85] Both of these will shift HVAC and energy requirements. Plans for creating climate prepared schools and school-based resilience hubs may also include on-site solar generation and battery storage systems. These installations can increase local resilience during power outages and help offset both utility

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[82] U.S. Energy Information Administration. (2023). *Carbon Dioxide Emissions Coefficients.* https://www.eia.gov/environment/emissions/co2_vol_mass.php

[83] U.S. Energy Information Administration. (2018). *U.S. District Energy Services Market CHaracterization.* https://www.eia.gov/analysis/studies/buildings/districtservices/

[84] Patel L, Vincent JM, Veidis E, Klein J, Doane K, Hansen J, Lew Z, Yeghoian A. (2023). *A Call to Action: Climate Resilient California Schools. Safeguarding Children's Health and Opportunity to Learn in TK-12.* Palo Alto, CA: Stanford University. https://www.climatereadyschoolscoalition.org/ourwork/climate-resilient-schools-report

[85] U.S. Environmental Protection Agency. (n.d.) *Schools as Community Cleaner Air and Cooling Centers.* https://www.epa.gov/arp/schools-community-cleaner-air-and-cooling-centers

bills and greenhouse gas emissions from school operations.[86] However, this analysis does not address the emission reductions from solar installations on school buildings and parking, either as part of or separate from a resilience hub strategy. It also does not characterize the resilience benefits and challenges presented by efficiency upgrades and full electrification.[87]

Additionally, while much of the K-12 school infrastructure across the U.S. is older, an overhaul of any individual school will depend not only on the current equipment in operation, but the date it was last replaced and district budgets for retrofits, replacements, and other energy efficiency efforts. This will ultimately decide the timeline for electrification.

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[86] Murphy, Patrick. (2023). *Method for Estimating Solar Plus Storage Microgrid Installations Needed for California Public Schools.* PSE Healthy Energy. https://www.psehealthyenergy.org/wp-content/uploads/2023/03/SS-for-Schools-Google-Docs.pdf

[87] Energy efficiency, particularly when paired with a solar and storage system, can improve resilience by enabling operations to run for longer on less power. However, full electrification can make resilience more challenging, as all operations shift to the same energy source and become vulnerable to electrical outages.