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Arizona State University

2022 Community-Scale Greenhouse Gas Emissions Inventory

A comprehensive report prepared for

City of Phoenix

June 2024

sustainabilitysolutions.asu.edu

Acknowledgements

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We wish to acknowledge the numerous city departments' staff for supplying the data needed to produce the *City of Phoenix 2022 Community Greenhouse Gas Emissions Inventory*.

Finally, we would like to thank City of Phoenix employees, residents, and business owners, who are on the ground supporting the city's efforts and who are working toward reducing their own greenhouse gas emissions.

Note: The data and calculations presented in this report may not be exact due to rounding errors within the GHG emissions template.

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Acronym List

AFFA	Agriculture, Forestry, and Fishing Activities
AFOLU	Agriculture, Forestry, and Land Use
APS	Arizona Public Service
AR	IPCC Assessment Report (Numbered 2 through 5)
ASU	Arizona State University
AZNM	Arizona and New Mexico eGRID Subregion
B20 Biodiesel	Contains up to 20% biodiesel
BEV	Battery Electric Vehicle
CH_4	Methane
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent Emissions
E54	Fuel containing 54% ethanol
E85	Fuel containing 85% ethanol
eGRID	EPA's Emissions and General Resource Integrated Database
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
FERC	Federal Energy Regulatory Commission
FTE	Full-time equivalent
GGE	Gasoline Gallon Equivalent
GHG	Greenhouse Gas
GPC	Global Protocol for Community-Scale GHG Emission Inventories
GWP	Global Warming Potential
ICLEI	International Council for Local Environmental Initiatives,
IE	Included Elsewhere
IPPU	Industrial Processes and Product Use
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MPST	Mining, Processing, Storage, and Transport of Coal
MT	Metric Tons
MWh	megawatt-hour
NAU	Northern Arizona University
NE	Not Estimated
NERC	North American Electric Reliability Corporation
NO	Not Occurring
N_2O	Nitrous Oxide
ONGS	Oil and Natural Gas Systems
PHEV	Plugin Hybrid Electric Vehicle
PNM	Public Service Company of New Mexico
SRP	Salt River Project
T&D	Transmission & Distribution
TRP	Trip Reduction Program
WECC	Western Electricity Coordinating Council
WWT	Wastewater Treatment
WWTP	Wastewater Treatment Plant

Executive Summary

The city of Phoenix (City) has completed a community-scale GHG emissions inventory for the calendar year 2022 using the Global Protocol for Community-Scale GHG Emission Inventories (GPC). The GPC is a worldwide standard for inventorying city-induced GHG emissions developed by the World Resources Institute, C40 Cities Climate Leadership Group, and ICLEI.[1] Additionally, the GPC is the standard supported by the Global Covenant of Mayors for Climate and Energy. The City of Phoenix is a member of the C40 Cities Climate Leadership Group and Global Covenant of Mayors for Climate and Energy.

The GPC categorizes direct and indirect GHG emissions into three sectors: Stationary Energy, Transportation, and Waste. Direct GHG emissions occur within the City boundaries, while indirect GHG emissions occur outside the city boundary but are induced by activity within the City boundary.

- The Stationary Energy Sector includes GHG emissions that occur from energy utilized in residential buildings, commercial buildings and facilities, manufacturing industries, agriculture, forestry and fishing energy use, and electricity transmission and distribution energy losses.
- The Transportation Sector includes GHG emissions from commercial and civil aviation, on-road transportation, non-road vehicle use, freight, and light rail.
- The Waste Sector includes GHG emissions from solid waste disposal, the biological treatment of waste (composting), and wastewater treatment.

The 2022 community-scale GHG inventory is the fifth completed by the City, following calendar years 2012, 2016, 2018, and 2020. During each inventory process, data sources and methods are reviewed for the previous years. Recalculations of GHG emissions totals from previous years occur to reflect updates to source data, data collection and processing methods, GHG global warming potentials, and GHG emissions estimation methods. Changes to GHG emissions totals for previous GHG emissions inventories are reported along with the 2022 GHG emissions totals.

Key Findings

- In 2022, community-scale GHG emissions were 15,804,670 metric tons of carbon dioxide equivalents (MT CO_2e).
- 2022 community-scale GHG emissions were 10.3% lower than the 2012 levels of 17,614,455 MT CO_2e (Figure ES-1).
- Stationary Energy Sector GHG emissions totaled 7,036,729 MT CO_2e.
- Transportation Sector GHG emissions totaled 8,470,357 MT CO_2e.
- Waste Sector GHG emissions totaled 297,585 MT CO_2e.

[1] Greenhouse Gas Protocol. (n.d.). GHG Protocol for Cities | Greenhouse Gas Protocol. Retrieved from http://www.ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities

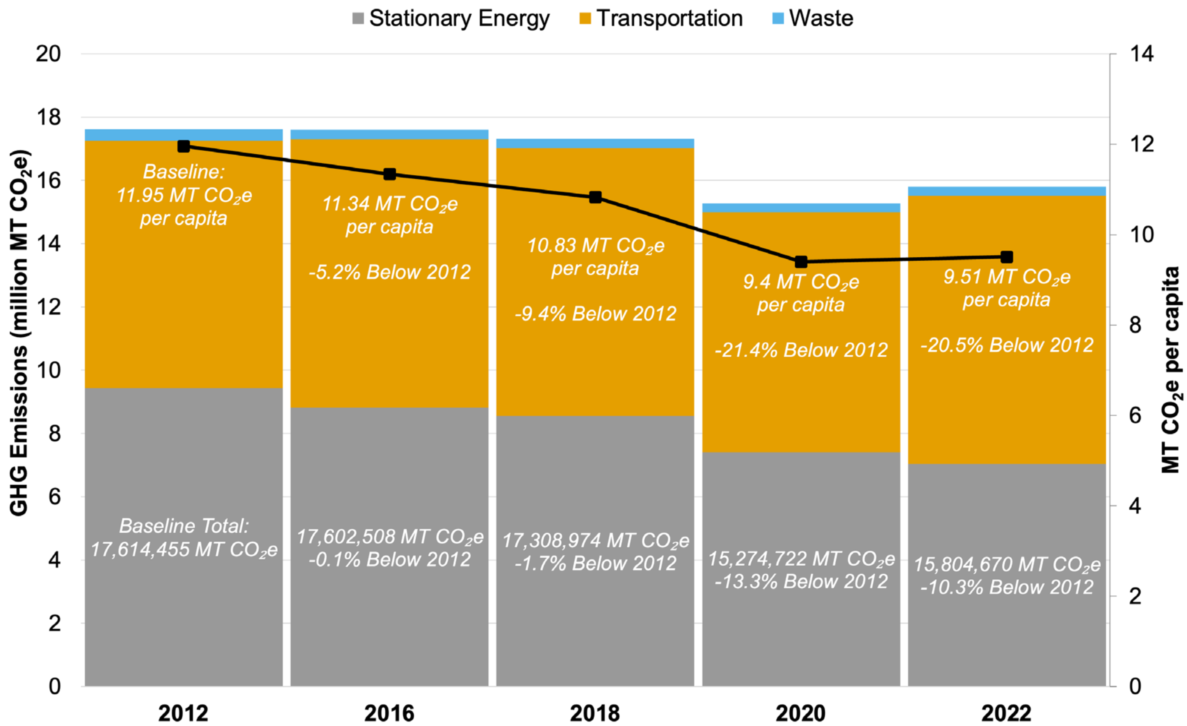

Figure ES-1. City of Phoenix Community GHG Emissions by Inventory Year.

GHG emissions decreased 10.3% during a period where the City's population grew 12.8% and the metro area economy grew 54%. Per capita emissions fell 20.5% from the 2012 baseline of 11.95 MT CO_2e to 9.51 MT CO_2e in 2022. The observed decrease in community-scale GHG emissions were driven by the regional electricity grid becoming less GHG-intensive. GHG emissions from electricity production fell by 2,438,091 MT CO_2e (28%) between 2012 and 2022, leading to a 25.4% decrease in Stationary Energy GHG emissions. Transportation GHG emissions increased 651,675 MT CO_2e (8%). Waste GHG emissions, which are 1.8% of community-scale GHG emissions, decreased by 66,550 MT CO_2e (18%) between 2012 and 2022.

GHG emissions summarized by Stationary Energy, Transportation, and Waste sectors for four community GHG inventories is detailed in Table ES-1.

Table ES-1. Phoenix GHG emissions by Sector (thousand MT CO_2e)

Sector	2012	2016	2018	2020	2022	% Change 2012 - 2022
Stationary Energy	9,432	8,811	8,553	7,407	7,037	**-25.4%**
Transportation	7,819	8,481	8,458	7,585	8,470	**8.3%**
Waste	364	310	298	283	298	**-18.3%**
Total	**17,614**	**17,603**	**17,309**	**15,275**	**15,805**	**-10.3%**

Stationary Energy

Stationary Energy is the second largest source of GHG emissions in Phoenix. These GHG emissions occur from energy utilized in residential buildings; commercial and institutional buildings and facilities; manufacturing facilities; agriculture, forestry and fishing energy use; and electricity transmission and distribution energy losses.

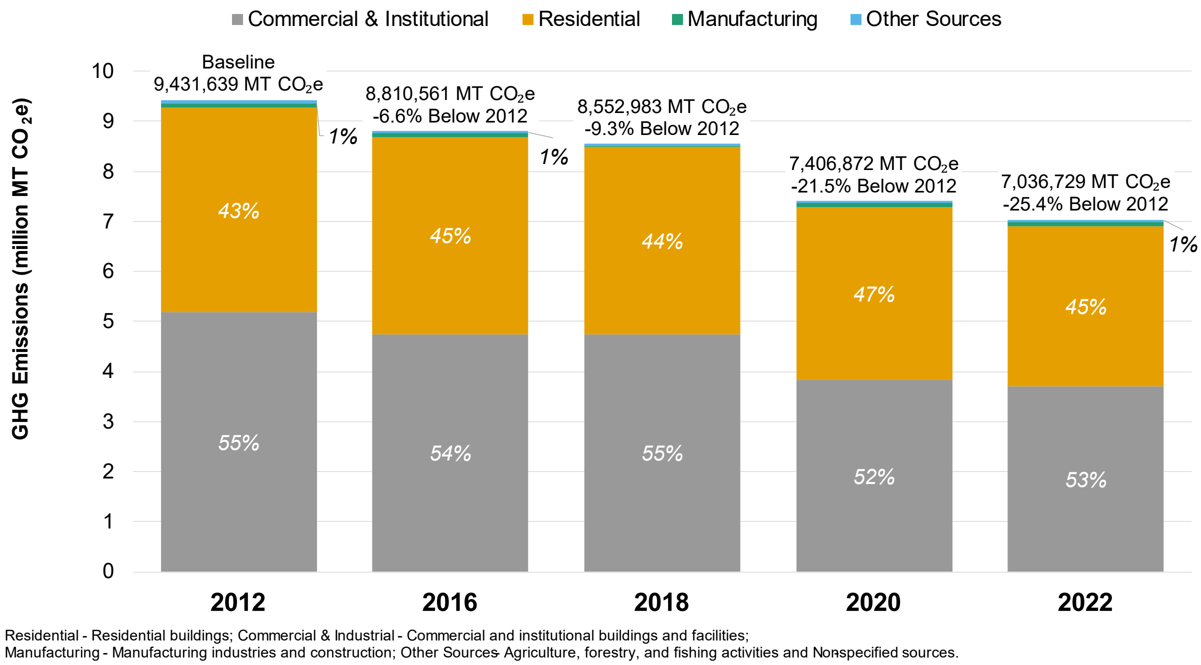

Figure ES-2. Stationary Energy GHG emissions by Inventory Year.

In 2022, Stationary Energy GHG emissions totaled 7,036,729 MT CO_2e; a 25% decrease below 2012 levels. This decline was primarily attributed to a shift towards less GHG-intensive electricity generation within the regional grid. Electricity consumption data were sourced from Arizona Public Service and Salt River Project. Data on electricity T&D loss were sourced from the Energy Information Administration. Natural gas consumption data were not available from Southwest Gas for 2022, so consumption levels were estimated from previous year GHG inventory data and data from the Arizona Corporation Commission. Figure ES-2 illustrates the breakdown of GHG emissions by Stationary Energy sub-sector, while Table ES-2 provides detailed subsector information.

Table ES-2. Stationary Energy GHG Emissions (thousand MT CO_2e)

Stationary Energy	2012	2016	2018	2020	2022
Residential Buildings	4,093	3,939	3,752	3,457	3,190
Commercial & Institutional Buildings	5,183	4,746	4,746	3,832	3,716
Manufacturing Industries & Construction	87	74	8.30	72.5	80.3
Agriculture, Forestry & Fishing Activities	69.0	51.8	46.5	45.5	50.5
Non-Specified Sources	0.06	0.08	0.07	0.12	0.14
Total	**9,432**	**8,811**	**8,553**	**7,407**	**7,037**

Transportation

In 2022, the Transportation Sector was the largest source of GHG emissions in Phoenix. Sources of transportation GHG emissions include commercial air travel, civil aviation, on-road transportation, non-road vehicle use, light rail, and freight rail. These emissions arise from the combustion of fossil fuels (e.g., gasoline, diesel, CNG, LNG, LPG, aviation gasoline, and jet fuel A), blended alternative fuels (e.g., B20 biodiesel, E85 Ethanol), or indirectly through the consumption of electricity to charge electric vehicles. Transportation GHG emissions for 2022 were 8,470,357 MT CO_2e, an 8% increase in GHG emissions from the 2012 level of 7,818,682 MTCO_2e (Figure ES-3).

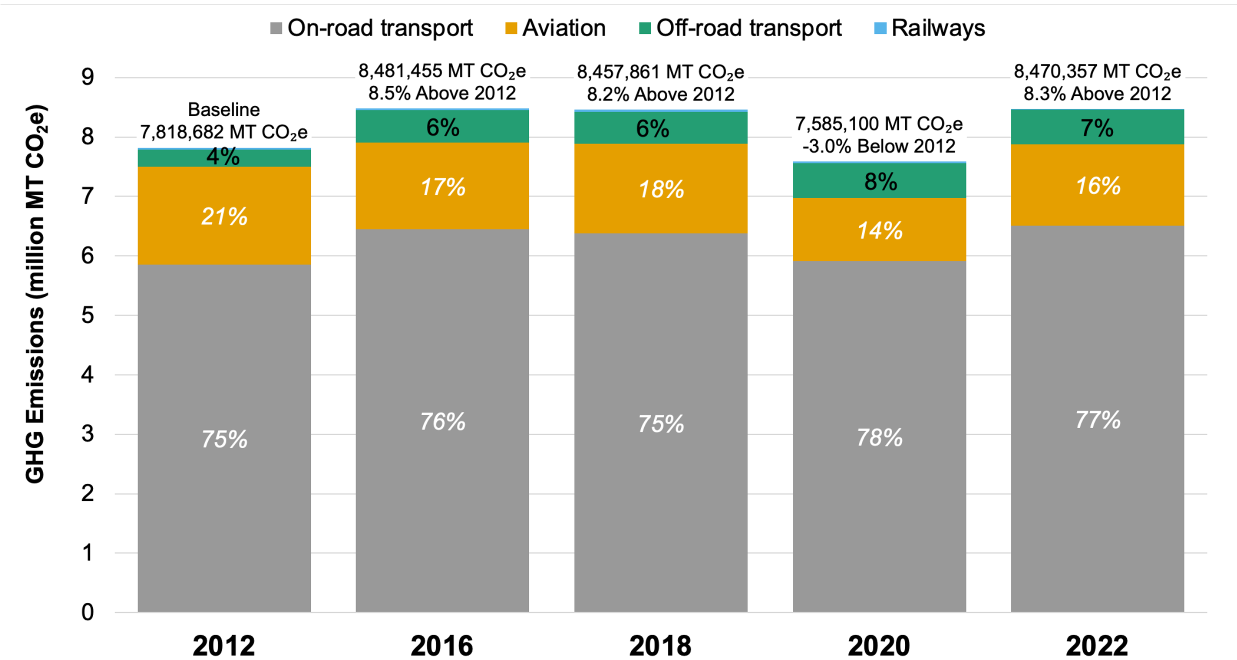

Figure ES-3.Transportation GHG emissions for the Inventory Years.

Community-wide transportation activity saw a rebound from the pandemic-induced lows of 2020 (Table ES-3). This effect was most evident in county-wide fuel sales and airport activity. Nonetheless, Transportation GHG emissions have increased across Phoenix since 2012 as these emissions increase with population growth. Data were obtained from the City of Phoenix, Arizona Department of Transportation, the Weights and Measures Division of the Arizona Department of Agriculture, the Federal Aviation Administration, and the Energy Information Administration.

Table ES-3. Transportation GHG Emissions (thousand MT CO_2e)

Transportation	**2012**	**2016**	**2018**	**2020**	**2022**
On-road transport	5,856	6,446	6,375	5,915	6,504
Railways	29.1	29.3	31.5	29.0	11.8
Commercial Aviation	1,626	1,448	1,495	1,042	1,360
Civil Aviation (Aviation Gasoline)	13.4	11.7	16.2	13.9	9.4
Off-road transport	294	546	540	585	585
Total	**7,819**	**8,481**	**8,458**	**7,585**	**8,470**

Waste

Waste Sector GHG emissions occur at solid waste facilities (landfills), wastewater treatment plants, and composting facilities. Solid waste generated by Phoenix residents is disposed of at landfills outside of the city boundary. Landfills within the city boundary are closed and do not accept waste. Wastewater treated within city boundaries is generated by Phoenix-residents in addition to residents of Glendale, Mesa, Scottsdale and Tempe. Composting GHG emissions were estimated for the city-owned facility within city boundaries. Waste Sector GHG emissions totaled 297,585 MT CO_2e in 2022 an 18% drop below 2012 levels of to 364,135 MT CO_2e (Table ES-4). Several factors contributed to the reduction in Waste Sector GHG emissions. Although emissions from operating solid waste facilities have increased, the emissions from closed landfills within Phoenix have decreased. Additionally, capturing and converting flared methane biogas into renewable natural gas at the 91st Avenue Wastewater Treatment Plant has resulted in flattened GHG emissions from wastewater treatment, despite significant population growth in Phoenix between 2012 and 2022.

Table ES-4. Waste Sector GHG Emissions (thousand MT CO_2e)

Waste	2012	2016	2018	2020	2022
Solid Waste Disposal	351.8	299.1	282.5	269.7	284.4
Wastewater Treatment & Discharge	6.5	7.5	7.5	6.7	6.3
Biological Waste Treatment (Composting)	5.8	4.0	8.1	6.4	6.9
Waste Sector Total	**364.1**	**310.5**	**298.1**	**282.8**	**297.6**

Conclusion

Citywide GHG emissions in Phoenix totaled 15,804,670 MT CO_2e – 10.3% below the 2012 levels of 17,614,455 MT CO_2e. Stationary Energy GHG emissions decreased 2,394,910 MT CO_2e below 2012 levels due to a less GHG-intensive regional electricity grid. Transportation GHG emissions increased to 651,675 MT CO_2e above 2012 levels largely to citywide and regional population growth. Waste GHG emissions decreased by 8% below 2012 levels, although Waste emissions are relatively smaller than the Stationary Energy and Transportation sectors.

Transportation activities comprised 54% of emissions across Phoenix in 2022, overtaking Stationary Energy activities as the largest source of emissions. Gasoline consumption was the largest single source of GHG emissions across Phoenix (5,686,199 MT CO_2e or 36%). While activity in the Stationary Energy and Transportation increased since 2012, stationary energy GHG have decreased due to the less GHG-intensive regional electricity. Fuel efficiency improvements have not offset the increased fuel consumption. Increasing the fuel efficiency of internal combustion engine (ICE) vehicles and the number of battery electric vehicles (BEVs), fuel cell electric vehicles (FCEVs) or plugin electric hybrid vehicles (PEHVs) on the road can decrease transportation-related GHG emissions. Another pathway is to increase the availability of mass transit and active transportation routes.

Introduction

City of Phoenix community-scale GHG emissions were inventoried according to the Greenhouse Gas Protocol for Cities (GPC). The GPC has five GHG emissions sectors – Stationary Energy, Transportation, Waste, Industrial Processes and Product Use (IPPU), and Agriculture, Forestry, and Land Use (AFOLU). The city of Phoenix Community-scale GHG emissions inventory is a BASIC-level inventory. Emission sources and scopes included in BASIC-level inventory include: all Scope 1 emissions from Stationary Energy sources (excluding energy production supplied to the grid, which shall be reported in the Scope 1 total); all Scope 1 emissions from Transportation sources; all Scope 1 emissions from Waste sources (excluding emissions from imported waste, which shall be reported in the Scope 1 total); all Scope 2 emissions from Stationary Energy sources and transportation; scope 3 emissions from treatment of exported waste. IPPU and AFOLU are not required to be inventoried for BASIC-level reporting under the GPC.

In 2022, community-scale emissions totaled 15,804,670 MT CO_2e, 10.3% decrease below the baseline 2012 level of 17,614,455 MT CO_2e (Table 1). Appendix A contains a detailed breakdown of GPC sector and subsector GHG emissions for the inventory years. Stationary Energy and Transportation account for approximately 98% of community-scale GHG emissions. On-road motor gasoline combustion is the single largest source of GHG emissions and comprises 67% transportation GHG emissions and 36% of total GHG emissions. The next largest source of GHG emissions is commercial and industrial electricity consumption, which makes up approximately 21% of total emissions. The top three emitting sources – on-road motor gasoline consumption, commercial and industrial electricity consumption, and residential electricity consumption – are 75% of total emissions. Electricity-related GHG emissions are projected to decrease in the future due to the lower GHG intensity of the regional electricity grid. GHG emissions from on-road motor gasoline consumption will likely remain the single largest source of GHG emissions for the City. Policies to reduce GHG emissions related to gasoline consumption across Phoenix is critical to meeting future GHG emissions targets and goals.

Table 1. Community- Level GHG Emissions by Sector for Inventory Years

Sector	GHG Emissions (MT CO_2e)					% Change 2012-2022
	2012	2016	2018	2020	2022	
Stationary Energy	9,432	8,811	8,553	7,407	7,037	**-25.4%**
Transportation	7,819	8,481	8,458	7,585	8,470	**8.3%**
Waste	364.1	310.5	298.2	282.8	297.6	**-18.3%**
Total	**17,614**	**17,603**	**17,309**	**15,275**	**15,805**	**-10.3%**

The decrease in citywide GHG emissions were driven by the regional electricity grid becoming less GHG-intensive. GHG emissions from electricity production fell by 2,438,091 MT CO_2e (28%) between 2012 and 2022. Waste GHG emissions, which are approximately 2% of community-scale GHG emissions, also decreased by 66,550 MT CO_2e (18%) between 2012 and 2022. Unlike the Stationary Energy and Waste sectors, Transportation GHG emissions increased 651,675 MT CO_2e (8%). Overall, per capita GHG emissions fell by 20% from 11.95 to 9.51 MT CO_2e per resident between 2012 and 2022 (Figure 1).

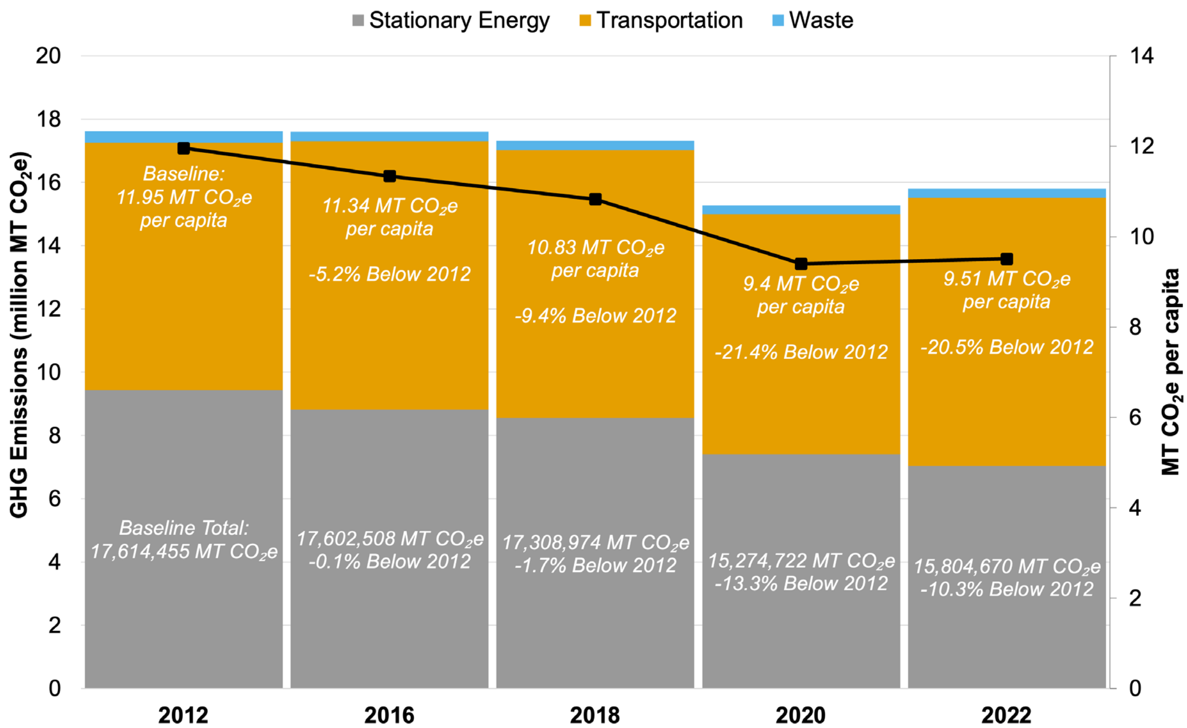

Figure 1. Total GHG Emissions and Per Capita GHG Emissions Since 2012

GHG emissions are assigned to scopes based on where the emitting activity occurs. Scope 1 GHG emissions occur directly within city boundaries from transportation activities, natural gas combustion, and waste disposal. Scope 2 GHG emissions are indirect GHG emissions through the purchase of grid-supplied energy, such as electricity and do not necessarily occur within city boundaries. Scope 3 GHG emissions are other indirect emissions from waste disposed of outside the city boundary. In 2022, 60% of GHG emissions occurred directly within the city boundary as Scope 1 emissions; 39% occurred indirectly as Scope 2 emissions through the purchase of electricity; and approximately 1% occurred indirectly as Scope 3 emissions from waste disposed of outside the city boundary (Table 2)

Table 2. 2022 Community-Level GHG Emissions by Sector and Scope

Sector	GHG Emissions (MT CO_2e)			
	Scope 1	Scope 2	Scope 3	Total
Stationary Energy	849,903	6,186,826	269,697	7,036,729
Transportation	8,453,966	16,391	715	8,470,357
Waste	147,448	NO	150,137	297,585
Total	**9,451,317**	**6,203,216**	**150,137**	**15,804,670**

**Scope 3 Stationary Energy and Transportation GHG emissions do not count toward the BASIC-level GHG emissions total. NO – Not Occurring.*

In 2022, Stationary Energy activities – GHG emissions resulting from natural gas combustion and electricity consumption – accounted for approximately 45% of citywide GHG emissions. Transportation activities comprise approximately 54% of GHG emissions and have increased relative to stationary energy GHG emissions since 2012. Gasoline combustion produced 67% of transportation GHG emissions within city boundaries. The two largest sources of GHG emissions produced 75% of total community-scale GHG emissions – electricity consumption (39%) and gasoline combustion (36%). Citywide GHG mitigation efforts should prioritize these two sources of GHG emissions to achieve GHG emissions reductions.

Plant retirements and the deployment of new renewable energy sources by Arizona Public Service[2] (APS), Salt River Project[3] (SRP) and the Public Service of New Mexico[4] (PNM) include promises to retire and replace coal-fired power plants with generation sources that are less GHG intensive that will result in significant reductions to community-scale GHG emissions. The single largest GHG emissions source in the regional electricity grid – the Navajo Generating Station operated by SRP – closed in 2019 and renewable energy has been further integrated into the electricity grid. The measured GHG intensity of the Arizona-New Mexico subregion of electricity grid – fell by 24% between 2018 and 2022.

On-road transportation is the single largest GHG emitting activity in Phoenix. These emissions grew between 2012 and 2018 but fell back to 2012 levels in 2020 largely due to the pandemic. Since 2020, GHG emissions have rebounded and surpassed pre-pandemic levels. The viability and cost effectiveness of strategies to reduce GHG emissions from transportation activities, specifically on-road motor gasoline consumption, will drive future community-scale GHG emissions and enable the City to meet GHG emissions reductions goals.

Finally, due to the extenuating circumstances of the global pandemic that began in 2020, the 2022 GHG inventory report provides comparisons to calendar year 2018 emissions to avoid comparisons to an outlier year in terms of GHG emitting activities.

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[2] Arizona Public Service (2020). Stakeholder Perspectives. URL: https://www.aps.com/en/About/Our-Company/Clean-Energy/Stakeholder-Perspectives

[3] Salt River Project (2019). Navajo Generating Station Permanently Shuts Down. URL: https://media.srpnet.com/navajo-generating-station-permanently-shuts-down/

[4] PNM (2020). Our Commitment. URL: https://www.pnm.com/our-commitment

1. Stationary Energy Sector

Stationary Energy GHG emissions occur directly within city boundaries from sources like natural gas combustion (Scope 1) and indirectly through purchased electricity consumption (Scope 2). Scope 2 emissions are the largest component of stationary energy GHG emissions in Phoenix (Figure 2), and they significantly contribute to the city's overall emissions total. However, due to the decreasing GHG intensity of the regional electricity grid, the proportion of Scope 2 stationary energy emissions in Phoenix's total community GHG emissions has steadily decreased over the years: 49% of the total in 2012, 45% in 2016 and 2018, 43% in 2020, and 39% in 2022.

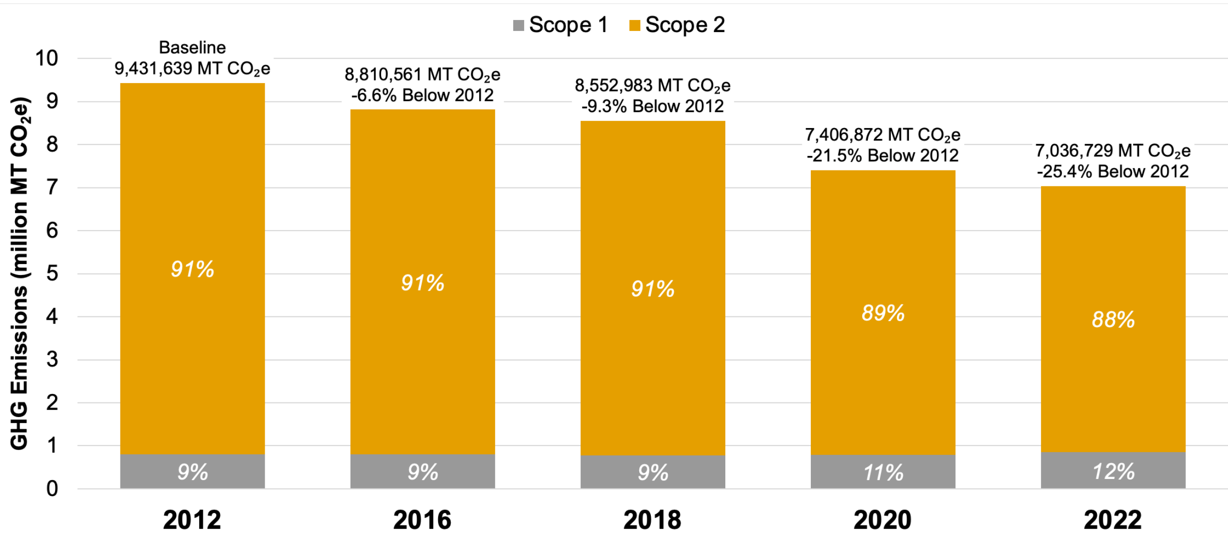

Figure 2. Stationary Energy GHG Emissions by Scope Since 2012

Electricity GHG emissions are calculated using electricity consumption data, also referred to as activity data, and GHG emissions factors provided by the EPA in the Emissions & Generation Resource Integrated Database (eGRID).[5] The eGRID emissions factor (EF) specific to the Arizona-New Mexico (AZNM) subregion is utilized for the community GHG inventory. This EF represents the average annual GHG profile of electricity generation in the AZNM subregion, expressed as CO2e emissions per MWh of net generation. The AZNM subregion includes power plants in Arizona, Western and Central New Mexico, Southern Nevada, and parts of southwestern California.

Since 2012, the GHG EF for the AZNM subregion has decreased by 33%. This reduction is mainly due to increased natural gas and renewable electricity generation, along with a significant decrease in coal-fired electricity generation. Notably, the closure of SRP’s coal-fired Navajo Generating Station in 2019, the largest source of GHG emissions in the AZNM subregion, has further reduced the emissions factor by 17.3%, significantly contributing to the decrease in Phoenix’s GHG emissions.

Looking to long-term goals, SRP has set a long-term goal to reduce the GHG intensity of electricity production by 65% below 2005 levels by 2035 and by 90% by 2050.[6] APS has announced plans to cease coal usage for electricity generation by 2031 and aims for carbon neutrality by 2050. [7] Additionally, PNM plans to achieve 100% carbon-free electricity generation by 2040. [8] These utility initiatives aimed at reducing the GHG intensity of electricity generation will lead to a significant further decrease in Phoenix’s GHG emissions in the future.

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[5] The eGRID database inventories plant-level environmental attributes of electric power generation and its effect on air emissions for every power plant in the United States. Phoenix is in the Arizona and New Mexico (AZNM) subregion. The Emissions & Generation Resource Integrated Database (eGRID), developed by the EPA in collaboration with the Energy Information Administration (EIA), the North American Electric Reliability Corporation (NERC), and the Federal Energy Regulatory Commission (FERC), is a comprehensive source of data on the environmental characteristics of almost all electric power generated in the United States. Detailed information can be found at http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html.
[6] Salt River Project (2024). Sustainability at SRP. URL: https://www.srpnet.com/grid-water-management/sustainability-environment/sustainability
[7] Arizona Public Service (2020). Clean Energy. URL: https://www.aps.com/en/About/Our-Company/Clean-Energy
[8] PNM (2020). Our Commitment. URL: https://www.pnm.com/our-commitment

1.1 Scope 1 Stationary Energy GHG Emissions

Scope 1 Stationary Energy GHG emissions occur, in part, from natural gas combustion (measured in therms) within the city boundary. Unlike previous GHG inventory years, natural gas consumption data were not available from Southwest Gas. Therefore, city-wide 2022 consumption levels were estimated from previously obtain consumption data and data from the Arizona Corporation Commission. In 2022, citywide natural gas estimated consumption was 5% greater than 2012 levels and 9% greater than 2018 levels (Table 3). These emissions will be revised if utility data are made available.

Table 3. Scope 1 Stationary Energy GHG Emissions

Scope 1 Activity Data (kilotherms)	2012	2016	2018	2020	2022
Residential Buildings	58,796	58,946	53,241	60,479	62,461
Commercial & Institutional Buildings	63,802	69,036	83,367	65,688	72,803
Manufacturing Industries & Construction	16,289	13,850	1,562	13,632	15,108
Agriculture, Fishing, and Forestry Activities	12,982	9,737	8,744	8,564	9,492
Non-specified	11.29	14.65	13.85	23.16	25.67
Total	**151,881**	**151,584**	**146,927**	**148,386**	**159,890**

Scope 1 GHG Emissions (MT CO_2e)	2012	2016	2018	2020	2022
Residential Buildings	312,298	313,330	283,007	321,480	332,017
Commercial & Industrial Buildings	338,887	366,966	443,139	349,167	386,989
Manufacturing Industries & Construction	86,522	73,622	8,303	72,459	80,308
Agriculture, Fishing, and Forestry Activities	68,954	51,758	46,477	45,523	50,454
Non-specified	60	78	74	123	136
Total	**806,722**	**805,753**	**781,000**	**788,752**	**849,903**

Scope 1 Stationary Energy GHG emissions increased by 43,181 MT CO_2e above 2012 levels (Figure 3). Natural gas consumption at commercial and institutional buildings are the largest source of Scope 1 Stationary Energy GHG emissions. In 2018, the commercial and institutional buildings and facilities subsector comprised 57% of Scope 1 Stationary Energy GHG emissions, and this percentage has subsequently fallen to 46% in 2022. A likely reason for the increase in GHG emissions associated with natural gas combustion is population growth and new construction increasing in the number residences and buildings with utility natural gas service.

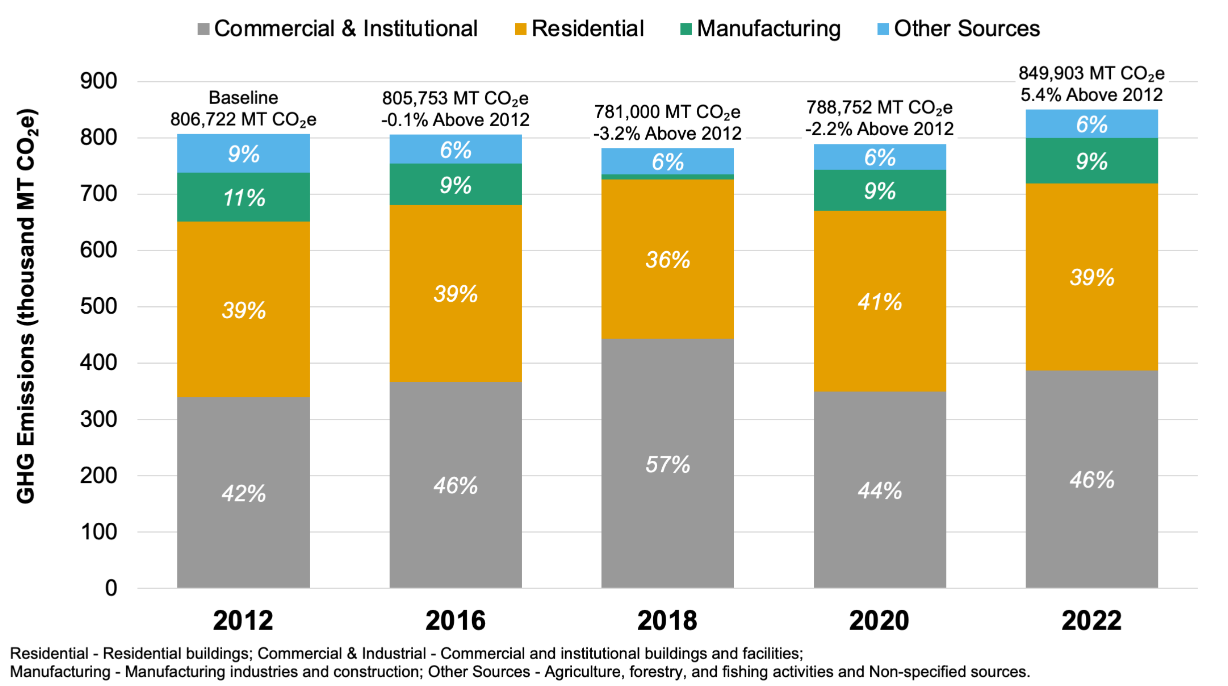

Figure 3. Scope 1 Stationary GHG Emissions Since 2012

1.2 Scope 2 Stationary Energy GHG Emissions

Scope 2 Stationary Energy GHG emissions occur from the consumption of electricity purchased from APS and SRP within the city boundary. As shown in Table 4, Between 2012 and 2022, electricity consumption increased approximately 7% (1,073,351 MWh) and between 2018 and 2022, electricity increased 5% (825,051 MWh). Community behind-the-meter solar generation, which does not factor into the calculation of Scope 2 GHG emissions from stationary energy sources, totaled 718,745 MWh. Behind-the-meter solar, which is solar energy generated on the customer's side of the utility meter, generation comprised approximately 6.6% of total citywide electricity consumption. Residential accounts generated 70% of citywide behind-the-meter solar with commercial and industrial accounts generating the remainder of behind-the-meter solar in Phoenix.

Table 4. Scope 2 Stationary Energy GHG Emissions

Scope 2 Activity Data (GWh)	2012	2016	2018	2020	2022
Residential Buildings	7,202	7,620	7,445	8,133	8,086
Commercial & Institutional Buildings	9,226	9,202	9,232	9,032	9,416
Manufacturing Industries & Construction	IE*	IE*	IE*	IE*	IE*
Total	**16,428**	**16,822**	**16,677**	**17,165**	**17,502**

Scope 2 GHG Emissions (thousand MT CO_2e)	2012	2016	2018	2020	2022
Residential Buildings	3,781	3,626	3,469	3,136	2,858
Commercial & Institutional Buildings	4,844	4,379	4,303	3,482	3,329
Manufacturing Industries & Construction	IE*	IE*	IE*	IE*	IE*
Total	**8,625**	**8,005**	**7,772**	**6,618**	**6,187**

** Manufacturing industries and construction have been included as IE in Commercial and institutional buildings because these data are available for some years and not others. Scope 2 Stationary Energy GHG emissions from Energy Industries; AFFA; and Non-Specified Sources were assumed to be included elsewhere (IE) and, therefore, not included in this table. Scope 2 Stationary Energy GHG emissions Fugitive Emissions from MPST; and Fugitive Emissions from ONGS were NE and, therefore, not included in this table*

In 2022, Scope 2 Stationary Energy GHG emissions were 6,186,826 MT CO_2e, which was 28% below 2012 levels (Figure 4). Scope 2 stationary energy GHG emissions decreased despite increased electricity consumption due to the regional electricity grid becoming 33% less GHG-intensive between 2012 and 2022. The reduction in the GHG intensity of electricity generation resulted from the retirement and replacement of coal-fired power plants with natural gas and renewable (wind and solar) electricity generation.[9]

While natural gas is a source of Scope 1 stationary energy within the city boundaries, the GHG intensity of electricity generated from natural gas is significantly less than electricity generated from coal, so a transition from coal to natural gas reduces the GHG intensity of electricity consumed within city boundaries. Further integration of renewable energy sources into the regional electricity grid also significantly reduces the GHG intensity of electricity consumed within city boundaries. Additionally, the reduction in GHG intensity of Phoenix's regional electricity grid occurred during a period in which GDP grew approximately 54%. The decreased growth in electricity consumption relative to economic growth could have occurred for numerous reasons, including energy efficiency retrofits, energy efficient new construction, and commercial renewable energy generation. Further work is recommended to explore the extent each of these factors contributed to the decreased growth in electricity consumption.

[9] The Emissions & Generation Resource Integrated Database (eGRID), developed by the EPA in collaboration with the Energy Information Administration (EIA), the North American Electric Reliability Corporation (NERC), and the Federal Energy Regulatory Commission (FERC), is a comprehensive source of data on the environmental characteristics of almost all electric power generated in the United States. Detailed information can be found at http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html.

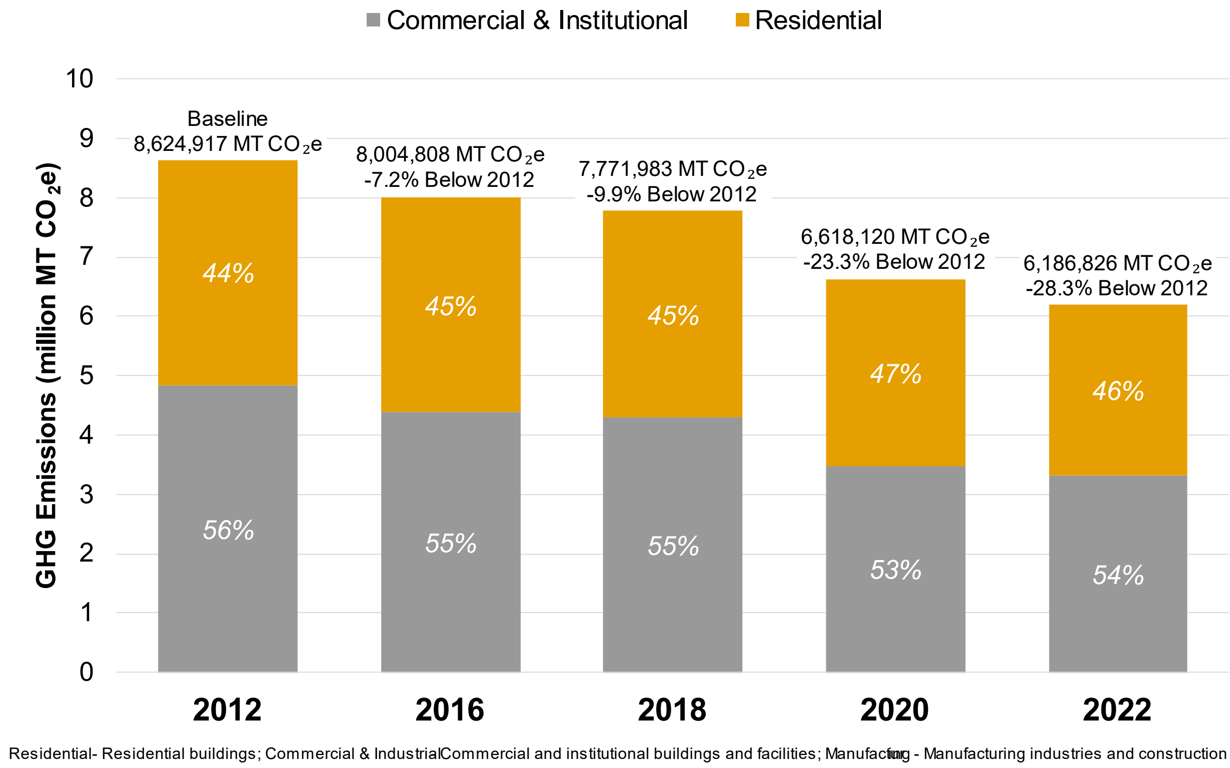

Figure 4. Scope 2 Stationary GHG Emissions for the Inventory Years

1.3 Scope 3 Stationary Energy GHG Emissions

Scope 3 Stationary Energy GHG emissions occur from transmission and distribution loss in the state's electricity grid and fluctuates from year-to-year (Table 5). Between 1990 and 2022, transmission and distribution (T&D) loss in the State of Arizona has averaged 4.5% $\pm$ 0.7% of electricity consumption.[10]

Table 5. Arizona Transmission & Distribution Loss Rate

Transmission & Distribution Loss Rate	2012	2016	2018	2020	2022
Arizona Transmission & Distribution Loss Rate	3.7%	3.8%	3.6%	4.2%	4.4%

Scope 3 Stationary Energy GHG emissions are not within the scope of GPC BASIC-level reporting. However, they are presented in Table 6 to show the full extent of GHG emissions from electricity consumption. T&D loss underscores the fact that on-site renewable energy generation and energy efficiency avoids GHG emissions from the electricity lost during T&D in the electricity grid.

Table 6. Scope 3 Stationary Energy GHG Emissions

Scope 3 Activity Data	**2012**	**2016**	**2018**	**2020**	**2022**
Transmission & Distribution Loss (MWh)	613,578	632,103	602,787	718,298	762,940
Natural Gas Leakage (therms)	NE	NE	NE	NE	NE
Total	**613,578**	**632,103**	**602,787**	**718,298**	**762,940**

Scope 3 GHG Emissions (MT CO_2e)	**2012**	**2016**	**2018**	**2020**	**2022**
Transmission & Distribution Loss (MWh)	322,128	300,780	280,921	276,940	269,697
Natural Gas Leakage (therms)	NE	NE	NE	NE	NE
Total	**322,128**	**300,780**	**280,921**	**276,940**	**269,697**

**NE – Not Estimated*

[10] U.S. Energy Information Administration, Form EIA-923, Power Plant Operations Report and predecessor forms. U.S. Energy Information Administration, Form EIA-860, Annual Electric Generator Report. U.S. Energy Information Administration, Form EIA-861, Annual Electric Power Industry Report. Form EIA-111, Quarterly Imports and Exports Report.

2. Transportation Sector

Transportation GHG emissions have Scope 1, 2, and 3 components. Scope 1 emissions come from the combustion of fossil transportation fuels like gasoline, diesel, CNG, LNG, LPG, and biofuel blends such as B20 biodiesel and E85 ethanol. Scope 2 emissions result from electricity consumption for charging plug-in and battery electric vehicles and powering the light rail, while Scope 3 emissions stem from the T&D loss associated with the electricity consumed for transportation. In 2022, transportation GHG emissions totaled 8,470,357 MT CO2e, marking an 8% increase over the 2012 levels of 7,818,682 MT CO_2e .

The combustion of motor gasoline is the largest source of transportation GHG emissions, comprising 67% of transportation-related emissions and 36% of citywide GHG emissions (Figure 5). Community-level gasoline consumption encompasses all gasoline end uses, although emissions from some end uses, like gasoline lawnmowers, were assumed to be insignificant compared to gasoline consumption for motor vehicles.[11] GHG emissions from Jet Fuel A (16%) and on-road diesel fuel (9%) follow as the next largest sources of transportation GHG emissions.

While transportation sector GHG emissions decreased between 2018 and 2020, transportation activity in Phoenix has rebounded since 2020. Historically, GHG emissions from gasoline combustion have grown with population growth. As growth continues, implementing viable solutions to reduce GHG emissions related to gasoline consumption—developing mass transit options, and fostering active transportation routes—becomes critical for achieving GHG emissions reduction goals. External drivers such as increasing vehicle fuel efficiency, increasing the number of EVs and PHEVs will also decrease transportation-related GHG emissions.

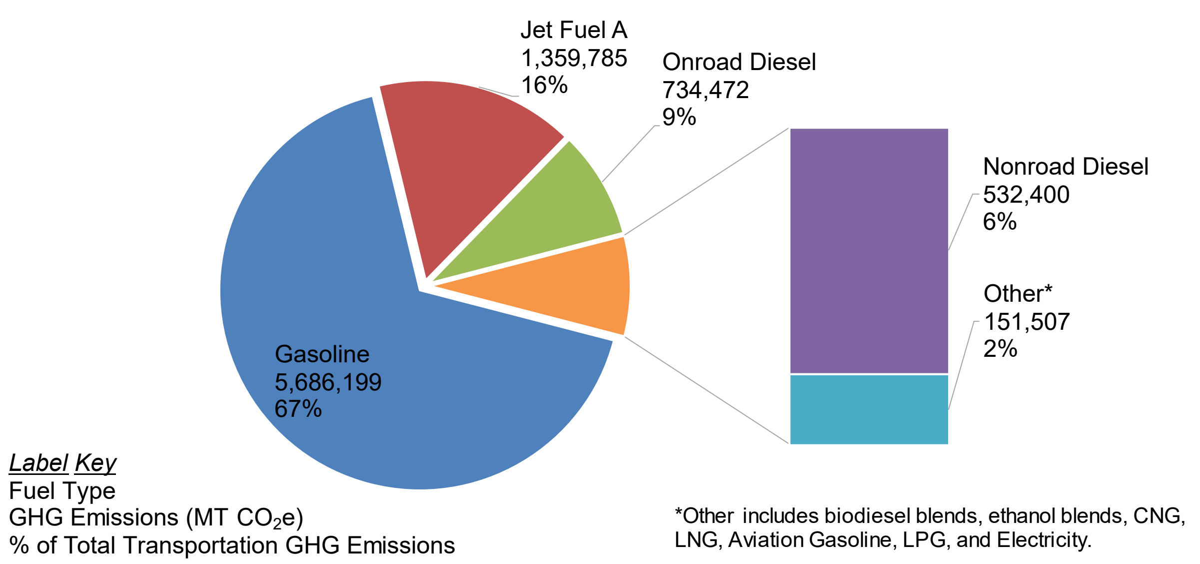

Figure 5. Transportation Sector GHG Emissions by Fuel Type

2.1 Scope 1 Transportation GHG Emissions

Scope 1 Transportation GHG emissions occur from the combustion of fossil fuels and biofuel blends in on-road motor vehicles, commercial and civil aircrafts, freight rail, and nonroad vehicles such as tractors and construction equipment (Table 7). Scope 1 Transportation emissions are driven by the combustion of motor gasoline, which has increased since 2018. The second largest source of community-scale Transportation sector GHG emissions comes from Commercial Aviation, which is almost primarily from the Phoenix Sky Harbor International Airport. In 2022, Commercial Aviation GHG emissions were revised upwards for all inventory years due to revised source data from the EIA. Community-level GHG emissions from off-road transport, which is the third

[11] The U.S. Energy Information Administration estimates light-duty vehicles account for 92% of gasoline consumption in the United States. Source: U.S. Energy Information Administration, 2019. Use of Gasoline. URL: https://www.eia.gov/energyexplained/gasoline/use-of-gasoline.php

largest source community-scale Transportation sector GHG emissions, result from construction equipment, agricultural equipment and mining equipment.

Table 7. Scope 1 Transportation GHG Emissions (MT CO_2e)

Scope 1 Sources	2012	2016	2018	2020	2022
On-road transport	5,855	6,441	6,366	5,908	6,492
Railways*	23.5	23.5	23.5	23.5	7.4
Commercial Aviation	1,626	1,448	1,495	1,042	1,360
Civil Aviation	13.4	11.7	16.2	13.9	9.4
Nonroad transport	293.8	545.8	540.4	585.1	585.1
Total	**7,812**	**8,471**	**8,441**	**7,572**	**8,454**

*Freight rail GHG emissions have not been re-estimated since the 2012 community inventory due to constraints with source data.

Gasoline consumption is the majority of Scope 1 Transportation GHG Emissions (Table 8). Between 2012 and 2022, fuel consumption increased across every fuel type except LNG and B20 biodiesel. The city of Phoenix vehicle fleet – e.g., buses and garbage and recycling trucks – is the primary consumer of LNG and B20 biodiesel. Phoenix has replaced LNG with CNG in City vehicle fleet.

Table 8. Scope 1 Transportation GHG Emissions by Fuel

Scope 1 GHG Emissions (thousand MT CO_2e)	2012	2016	2018	2020	2022
Gasoline [1]	5,251	5,798	5,709	5,180	5,686
On-Road Diesel[1]	529.2	591.1	595.8	645.2	734.5
B20 Biodiesel[1]	24.8	22.1	24.7	35.2	36.7
E85 Ethanol[1]	0.38	0.21	0.41	0.44	0.34
E54 Ethanol [1]	0.00	0.44	0.00	0.00	0.00
CNG[1] – *therms*	22.6	18.3	33.4	27.5	34.5
LNG[1] – *GGE*	27.8	11.3	2.4	19.6	0.0
Jet Fuel A (Commercial Aviation)[2]	1,626	1,448	1,495	1,042	1,360
Aviation Gasoline (Civil Aviation)[2]	13.4	11.7	16.2	13.9	9.4
Railways**	23.5	23.5	23.5	23.5	7.4
Nonroad Diesel[3]	148.5	493.9	493.9	525.0	525.0
Nonroad LPG[3]	145.3	46.4	46.4	54.2	54.2
Nonroad CNG[3]	0.0	5.5	0.0	6.0	6.0
Total	**7,812**	**8,471**	**8,441**	**7,572**	**8,454**

NE – Not Estimated. Emissions estimated from EPA National Emissions Inventory;
Italicized entries denote Activity Data estimated from EPA National Emissions Inventory;
***Emissions estimated from the EPA National Emissions Inventory and not activity data;*
Transportation Sector: [1]On-Road Sector; [2]Aviation; [2]Off-Road.

2.2 Scope 2 Transportation GHG Emissions

Scope 2 transportation GHG emissions result from the consumption of electricity for travel – namely, battery electric vehicles and the Valley Metro light rail. Estimated electricity consumption for transportation activities increased 289% between 2012 and 2022, and 28% between 2018 and 2022. This growth is driven primarily by increased electricity consumption for charging battery electric vehicles, which increased more than 2,500% between 2012 and 2022. Due to the reduced GHG intensity of the regional electricity the growth in GHG emissions associated with battery electric vehicles only increased approximately 1,700% over the same period. While there has been a growth in electricity consumption for the Valley Metro light rail, this growth is modest compared to the growth in electricity consumption for battery electric vehicles. The GHG emissions associated with Valley Metro light rail decreased between 2012 and 2022 despite increased service, as indicated by electricity consumption (Table 9).

Table 9. Scope 2 Transportation GHG Emissions

Scope 2 Activity Data (MWh)	2012	2016	2018	2020	2022
On-road transport	1,269	10,608	18,914	19,907	34,058
Railways (Light Rail)	10,605	12,095	17,157	14,022	12,309
Total	**11,874**	**22,703**	**36,071**	**33,929**	**46,367**

Scope 2 GHG Emissions (MT CO_2e)	2012	2016	2018	2020	2022
On-road transport	666	5,048	8,815	7,674	12,039
Railways (Light Rail)	5,568	5,755	7,996	5,406	4,351
Total	**6,234**	**10,803**	**16,811**	**13,080**	**16,391**

2.3 Scope 3 Transportation GHG Emissions

Scope 3 Transportation GHG emissions occur from transmission and distribution loss in the state's electricity grid (Table 10). Scope 3 Transportation GHG emissions are not within the scope of GPC BASIC-level reporting and presented for informational purposes. Refer to the ***Scope 3 Stationary Energy*** section for a more detailed discussion on T&D loss in the State of Arizona.

Table 10. Scope 3 Transportation GHG Emissions

Scope 3 Activity Data (MWh)	2012	2016	2018	2020	2022
On-road transport	47	399	684	833	1,485
Railways (Light Rail)	396	454	620	587	537
Total	**443**	**853**	**1,304**	**1,420**	**2,021**

Scope 3 GHG Emissions (MT CO_2e)	2012	2016	2018	2020	2022
On-road transport	47	399	684	833	1,485
Railways (Light Rail)	396	454	620	587	537
Total	**443**	**853**	**1,304**	**1,420**	**2,021**

3. Waste Sector

Waste Sector GHG emissions occurring from landfilling solid waste, composting green-organic solid waste, and wastewater treatment. Waste Sector GHG emissions have both Scope 1 and Scope 3 components (Table 12). Unlike Scope 3 emissions in the Stationary Energy and Transportation sectors, Scope 3 Waste emissions are included within the GPC BASIC-level reporting. Overall, Waste Sector GHG emissions decreased 18% (66,550 MT CO2e) between 2012 and 2022.

Solid waste GHG emissions occur within (Scope 1) and outside of the city boundary (Scope 3). While there are several landfills located within the city boundary, these landfills are closed and no longer accepting waste. The last city-owned landfill to accept waste within the City boundary closed in 2006 and the last privately-owned landfill to accept waste within the city boundary – the Waste Management Lone Cactus Landfill – closed in 2019. Over time, these emissions will decrease as the biological processes that generate methane slows. The landfills that accept waste collected within the city boundary are all located outside of the city boundary. These landfills include both the city-owned SR-85 Landfill and privately owned and operated landfills.

In 2017, the City opened the 27th Avenue Compost Facility. The facility processed 39,606 tons of compost in CY 2022, resulting in the emission of 158 MT CH_4 and 12 MT N_2O. Total GHG emissions from the compost facility were 7,585 MT CO_2e. While there are private composting operations within the city of Phoenix, their processing tonnages, and associated greenhouse gas emissions, are proprietary and unavailable at this time.

Wastewater generated by city of Phoenix residents is treated at two facilities: the 23rd Avenue WWTP and 91st Avenue WWTP inside city boundaries (Scope 1). While the 91st Avenue WWTP is located within Phoenix boundaries, it is a regional WWTP also treating wastewater generating in Glendale, Mesa, Scottsdale, and Tempe. Due to this, a fraction of GHG emissions produced at the 91st Avenue WWTP are classified as 'wastewater generated outside the city, but treated within the city', which is classified as a territorial GHG emission, not a Scope 1 GHG emission. Additionally, beginning in 2020, methane biogas generated at the 91st Avenue WWTP that would have been flared has been captured and transformed into renewable natural gas for distribution by a private company.

Table 11. Waste Sector GHG Emissions

Waste Sector GHG Emissions (thousand MT CO_2e)	2012	2016	2018	2020	2022
Scope 1 Waste Emissions	248.2	154.2	147.5	138.2	147.4
Scope 3 Waste Emissions	115.9	156.3	150.7	144.5	150.1
Total	**364.1**	**310.5**	**298.1**	**282.8**	**297.6**

3.1 Scope 1 Waste GHG Emissions

Scope 1 Waste Sector GHG emissions include emissions from municipal solid waste and wastewater generated and treated within the city boundary in addition to waste imported into the city and treated (Table 12). Territorial GHG emissions at the 91st Avenue WWTP are presented in Table 12 for informational purposes.

Table 12. Scope 1 Waste GHG Emissions

Scope 1 Activity Data (MT CH_4)	2012	2016	2018	2020	2022
Disposal of Solid Waste Generated in the City	8,425	5,099	4,707	4,471	4,794
Biological Treatment of Waste Generated in the City	121.2	82.9	169.7	132.9	143.7
Wastewater Generated Inside the City	68.97	80.06	79.88	76.76	69.10
Wastewater Generated Outside the City+	*33.28*	*34.37*	*36.00*	*5.00*	*2.17*
Total	**8,546**	**5,182**	**4,877**	**4,604**	**4,938**

Table 13. Scope 1 Waste GHG Emissions

Scope 1 Activity Data (MT N_2O)	2012	2016	2018	2020	2022
Biological Treatment of Waste Generated in the City	9.09	6.22	12.73	9.96	10.78
Wastewater Generated Inside the City	17.37	17.87	18.13	18.09	17.89
Wastewater Generated Outside the City⁺	*12.37*	*12.50*	*13.22*	*13.26*	*13.66*
Total	**26.46**	**24.09**	**30.86**	**28.06**	**28.67**

Scope 1 GHG Emissions (thousand MT CO_2e)	2012	2016	2018	2020	2022
Disposal of Solid Waste Generated in the City	235.9	142.8	131.8	125.2	134.2
Biological Treatment of Waste Generated in the City	5.80	3.97	8.12	6.36	6.88
Wastewater Generated Inside the City	6.53	6.98	7.04	6.94	6.68
Wastewater Generated Outside the City⁺	*4.21*	*4.28*	*4.51*	*3.66*	*3.68*
Total	**248.2**	**153.7**	**147.0**	**138.5**	**147.8**

⁺ GHG wastewater generated outside the Phoenix that is treated within Phoenix are classified as territorial GHG emissions and do not count toward the Scope 1 total for community GHG emissions.

3.2 Scope 3 Waste GHG Emissions

Scope 3 Waste GHG emissions occur from the disposal of waste generated within the city but disposed outside the city (Table 14). As GHG emissions are expected to increase at the SR-85 landfill, methane capture and reuse programs may become a viable way to reduce waste related emissions and reduce Scope 1 Stationary Energy GHG emissions from natural gas combustion. Additionally, organic waste diversion to the 27th Avenue Compost Facility and other private facilities is a possible way to reduce Scope 1 Transportation GHG emissions by reducing hauling trips to the SR-85 Landfill. Similarly, the capture of digester gas at the 91st Avenue Wastewater Treatment Plant (WWTP) for processing and sale as renewable natural gas (RNG) by Ameresco, Inc. has reduce GHG emissions associated with methane flaring at WWTPs.

Table 14. Scope 3 Waste GHG Emissions

Scope 3 Activity Data (MT CH_4 Emissions)	2012	2016	2018	2020	2022
Disposal of Solid Waste Generated in the City but Disposed Outside the City at SR-85	295	2,147	2,029	2,301	1,931
Disposal of Solid Waste Generated in the City but Disposed Outside the City by Private Haulers	3,845	3,435	3,352	2,861	3,431
Total	**4,140**	**5,582**	**5,381**	**5,162**	**5,362**

Scope 3 GHG Emissions (thousand MT CO_2e)	2012	2016	2018	2020	2022
Disposal of Solid Waste Generated in the City but Disposed Outside the City at SR-85	8.3	60.1	56.8	64.4	54.1
Disposal of Solid Waste Generated in the City but Disposed Outside the City by Private Haulers	107.7	96.2	93.8	80.1	96.1
Total	**115.9**	**156.3**	**150.7**	**144.5**	**150.1**

Appendix A. Detailed GHG Emissions Summary

Appendix A contains tables detailing City of Phoenix community-scale GHG emissions by each GPC sector and subsector.

Table A1. Year-to-Year Comparison of Stationary Energy GHG Emissions

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Greenhouse Gas Emissions (metric tons CO_2e)				
			2012	2016	2018	2020	2022
I		Stationary Energy					
I.1		**Residential Buildings**					
I.1.1	1	Emissions from fuel combustion within the city boundary	312,298	313,330	283,007	321,480	332,016
I.1.2	2	Emissions from grid-supplied energy consumed within the city boundary	3,781,025	3,625,943	3,469,453	3,135,700	2,858,239
I.1.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	141,216	136,245	125,405	131,215	124,597
I.2		**Commercial and institutional buildings and facilities**					
I.2.1	1	Emissions from fuel combustion within the city boundary	338,887	366,966	443,139	349,167	386,989
I.2.2	2	Emissions from grid-supplied energy consumed within the city boundary	4,843,892	4,378,864	4,302,529	3,482,420	3,328,587
I.2.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	180,912	164,535	155,517	145,724	145,100
I.3		**Manufacturing industries and construction**					
I.1.1	1	Emissions from fuel combustion within the city boundary	86,522	73,622	8,303	72,459	80,308
I.1.2	2	Emissions from grid-supplied energy consumed within the city boundary	0	0	IE	IE	IE
I.2.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	0	0	IE	IE	IE
I.4		**Energy Industries**					
I.4.1	1	Emissions from energy used in power plant auxiliary operations within the city boundary	NO	NO	NE	0	0
I.4.2	2	Emissions from grid-supplied energy consumed in power plant auxiliary operations within the city boundary	NO	NO	NE	NE	NE
I.4.3	3	Emissions from transmissions and distribution losses from grid-supplied energy consumption in power plant auxiliary operations	NO	NO	NE	NE	NE
I.4.4	T	*Emissions from energy generation supplied to the grid*	868,700	961,869	968,811	1,100,643	774,664
I.5		**Agriculture, forestry and fishing activities**					
I.5.1	1	Emissions from fuel combustion within the city boundary	68,954	51,758	46,477	45,523	50,454
I.5.2	2	Emissions from grid-supplied energy consumed within the city boundary	IE	IE	IE	IE	IE
I.5.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	IE	IE	IE	NE	NE
I.6		**Non-specified sources**					
I.6.1	1	Emissions from fuel combustion within the city boundary	60	78	74	123	136
I.6.2	2	Emissions from grid-supplied energy consumed within the city boundary	NE	NE	NE	NE	NE
I..3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	NE	NE	NE	NE	NE
I.7		**Fugitive emissions from mining, processing, storage, and transportation of coal**					
I.7.1	1	Emissions from fugitive emissions within the city boundary	NO	NO	NO	NO	NO
I.8		**Fugitive emissions from oil and natural gas systems**					

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Greenhouse Gas Emissions (metric tons CO_2e)				
			2012	2016	2018	2020	2022
I.8.1	1	Emissions from fugitive emissions within the city boundary	NO	NO	NE	NE	NE

Notation Key	Definition	Explanation
IE	Included Elsewhere	GHG emissions for this activity are estimated and presented in another category of the inventory. The category shall be noted in the explanation.
NE	Not Estimated	Emissions occur but have not been estimated or reported; justification for exclusion shall be noted in the explanation.
NO	Not Occurring	An activity or process does not occur or exist within the city.
C	Confidential	GHG emissions which could lead to the disclosure of confidential information and can therefore not be reported.

Color Key
Sources required for BASIC reporting
Sources required for BASIC+ reporting
Sources included in Other Scope 3
Sources required for territorial reporting
Non-applicable emissions

Scope	Definition
Scope 1	GHG emissions from sources within the city boundary.
Scope 2	GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within the city boundary.
Scope 3	All other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary.

Table A2. Year-to-Year Comparison of Transportation GHG Emissions

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Greenhouse Gas Emissions (metric tons CO_2e)				
			2012	2016	2018	2020	2022
II		**Transportation**					
II.1		**On-road Transportation**					
II.1.1	1	Emissions from fuel combustion for on-road transportation occurring within the city boundary	5,855,292	6,441,344	6,366,019	5,907,783	6,492,232
II.1.2	2	Emissions from grid-supplied energy consumed within the city boundary for on-road transportation	666	5,048	8,815	7,674	12,039
II.1.3	3	Emissions from portion of transboundary journeys occurring outside the city boundary, and transmissions and distribution losses from grid-supplied energy consumption	25	190	319	321	525
II.2		**Railways**					
II.2.1	1	Emissions from fuel combustion for railway transportation occurring within the city boundary	23,545	23,545	23,545	23,545	7,427
II.2.2	2	Emissions from grid-supplied energy consumed within the city boundary for railways	5,568	5,755	7,996	5,406	4,351
II.2.3	3	Emissions from portion of transboundary journeys occurring outside the city boundary, and transmissions and distribution losses from grid-supplied energy consumption	208	216	289	226	190
II.3		**Waterborne navigation**					
II.3.1	1	Emissions from fuel combustion for waterborne navigation occurring within the city boundary	NO	NO	NO	NO	NO
II.3.2	2	Emissions from grid-supplied energy consumed within the city boundary for waterborne navigation	NO	NO	NO	NO	NO
II.3.3	3	Emissions from portion of transboundary journeys occurring outside the city boundary, and transmissions and distribution losses from grid-supplied energy consumption	NO	NO	NO	NO	NO
II.4		**Aviation**					
II.4.1	1	Emissions from fuel combustion for aviation occurring within the city boundary	1,639,788	1,459,918	1,511,127	1,055,557	1,369,173
II.4.2	2	Emissions from grid-supplied energy consumed within the city boundary for aviation	NE	NE	NE	NE	NE
II.4.3	3	Emissions from portion of transboundary journeys occurring outside the city boundary, and transmissions and distribution losses from grid-supplied energy consumption	NE	NE	NE	NE	NE
II.5		**Off-road transportation**					
II.5.1	1	Emissions from fuel combustion for off-road transportation occurring within the city boundary	293,823	545,845	540,359	585,134	585,134
II.5.2	2	Emissions from grid-supplied energy consumed within the city boundary for off-road transportation	IE	IE	IE	IE	IE

Notation Key	Definition	Explanation
IE	Included Elsewhere	GHG emissions for this activity are estimated and presented in another category of the inventory. The category shall be noted in the explanation.
NE	Not Estimated	Emissions occur but have not been estimated or reported; justification for exclusion shall be noted in the explanation.
NO	Not Occurring	An activity or process does not occur or exist within the city.
C	Confidential	GHG emissions which could lead to the disclosure of confidential information and can therefore not be reported.

Color Key
Sources required for BASIC reporting
Sources required for BASIC+ reporting
Sources included in Other Scope 3
Sources required for territorial reporting
Non-applicable emissions

Scope	Definition
Scope 1	GHG emissions from sources within the city boundary.
Scope 2	GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within the city boundary.
Scope 3	All other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary.

Table A3. Year-to-Year Comparison of Waste, IPPU, AFOLU, and Other Scope 3 GHG Emissions

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Greenhouse Gas Emissions (metric tons CO_2e)				
			2012	2016	2018	2020	2022
III		**Waste**					
III.1		**Solid waste disposal**					
III.1.1	1	Emissions from solid waste generated within the city boundary and disposed in landfills or open dumps within the city boundary	235,889	142,771	131,794	125,195	134,245
III.1.2	3	Emissions from solid waste generated within the city boundary and disposed in landfills or open dumps outside the city boundary	115,910	156,298	150,665	144,527	150,137
III.1.3	T	*Emissions from waste generated outside the city boundary and disposed in landfills or open dumps within the city boundary*	NO	NO	IE	IE	IE
III.2		**Biological treatment of waste**					
III.2.1	1	Emissions from solid waste generated within the city boundary that is treated biologically within the city boundary	5,802	3,968	8,125	6,360	6,881
III.2.2	3	Emissions from solid waste generated within the city boundary but treated biologically outside of the city boundary	NO	NO	NE	NE	NE
III.2.3	T	*Emissions from waste generated outside the city boundary but treated biologically within the city boundary*	NO	NO	NE	NE	NE
III.3		**Incineration and open burning**					
III.3.1	1	Emissions from solid waste generated treated within the city boundary	NO	NO	NE	NE	NE
III.3.2	3	Emissions from solid waste generated within the city boundary but treated outside of the city boundary	NO	NO	NE	NE	NE
III.3.3	T	*Emissions from waste generated outside the city boundary but treated within the city boundary*	NO	NO	NE	NE	NE
III.4		**Wastewater treatment and discharge**					
III.4.1	1	Emissions from wastewater generated and treated within the city boundary	6,534	6,977	7,040	6,944	6,676
III.4.2	3	Emissions from wastewater generated within the city boundary but treated outside of the city boundary	NO	NO	IE	IE	IE
III.4.3	T	*Emissions from wastewater generated outside the city boundary but treated within the city boundary*	4,210	4,276	4,512	3,655	3,682
IV		**Industrial Processes and Product Uses (IPPU)**					
IV.1	1	Emissions from industrial processes occurring within the city boundary	NE	NE	NE	NE	NE
IV.2	1	Emissions from product use occurring within the city boundary	NE	NE	NE	NE	NE
V		**Agriculture, Forestry, and Other Land Use (AFOLU)**					
V.1	1	Emissions from livestock within the city boundary	NE	98,951	98,951	98,951	98,951
V.2	1	Emissions from land within the city boundary	NE	NE	NE	NE	NE
V.3	1	Emissions from aggregate sources and non-CO_2 emissions sources on land within the city boundary	NE	NE	NE	NE	NE
VI		**Other Scope 3**					
VI.1	3	Other Scope 3	3,001	760	881	946	1,188

Notation Key	Definition	Explanation
IE	Included Elsewhere	GHG emissions for this activity are estimated and presented in another category of the inventory. The category shall be noted in the explanation.
NE	Not Estimated	Emissions occur but have not been estimated or reported; justification for exclusion shall be noted in the explanation.
NO	Not Occurring	An activity or process does not occur or exist within the city.
C	Confidential	GHG emissions which could lead to the disclosure of confidential information and can therefore not be reported.

Color Key
Sources required for BASIC reporting
Sources required for BASIC+ reporting
Sources included in Other Scope 3
Sources required for territorial reporting
Non-applicable emissions

Scope	Definition
Scope 1	GHG emissions from sources within the city boundary.
Scope 2	GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within the city boundary.
Scope 3	All other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary.

Appendix B. Stationary Energy – Natural Gas Documentation

Appendix B describes the data collection and data processing for obtaining natural gas consumption data and calculating GHG emissions from natural gas combustion. Appendix B also describes any changes to data sources and methodologies in the 2018 community-scale GHG emissions inventory.

B.1 Natural Gas Data Collection

Stationary Energy GHG emissions from the combustion of natural gas occur at residential buildings, commercial and institutional buildings and facilities, manufacturing industries and construction, energy industries, agriculture, forestry, and fishing activities, non-specified sources, fugitive emissions from mining, processing, storage, and transport of coal, and fugitive emissions from oil and natural gas systems. Natural gas consumption data were obtained from the Southwest Gas Corporation (Southwest Gas), which is the only natural gas utility that services the city. Natural gas data were obtained for each GHG emissions inventory as the inventory was being compiled.

A similar data request process was followed for each of the GHG emissions inventory years. For 2012 and 2016, Southwest Gas provided consumption data at the zip code resolution for residential buildings, commercial and institutional buildings and facilities, manufacturing industries and construction, energy industries, agriculture, forestry, and fishing activities, and non-specified sources. For 2018 and 2020, Southwest Gas did not provide zip code level data. Southwest Gas provided total annual consumption data for residential buildings, commercial and institutional buildings and facilities, manufacturing industries and construction, energy industries, agriculture, forestry, and fishing activities, and non-specified sources. Consumption data were not available during the 2022 inventory cycle. An ensemble approach was developed to estimate citywide consumption in 2022 (discussed in Section B.4) and will be updated with actual data once it is available.

B.2 Natural Gas Data Processing

For 2012 and 2016, zip code level data were scaled to the percentage of land area in a zip code that was within the city. Natural gas consumption data were scaled only for zip codes which contained a fraction of land within and outside the city boundary. Upon follow up evaluation of the natural gas data previously provided by Southwest Gas; it was found that this scaling of natural gas data by the percent area of a zip code with the City of Phoenix was not necessary. Previously, zip code level natural gas consumption was scaled by percent land area within the City boundary. However, a review of the previous 2012 and 2016 datasets found that if a zip code was associated with more than one Phoenix metropolitan area city the consumption was reported for each city associated with that zip code. To avoid under-reporting natural gas consumption, the zip code scaling factors which were used previously were no longer used. For this reason, 2012 and 2016 community-scale GHG emissions from natural gas combustion were revised upwards (See Section Appendix A.3).

Using the data provided by Southwest Gas, the following equation was used to calculate GHG emissions from Stationary Energy natural gas consumption.

$$GHG_{NG,i,j,y} = NG_{i,y} \times CF \times EF_{NG,j}$$

Where,

$GHG_{NG,i,j,y}$ = The GHG emissions in metric tons from natural gas (NG) consumption from a Stationary Energy sector (*i*) for a GHG (*j*) for a GHG emissions inventory year (*y*).

$NG_{i,y}$ = Natural gas (NG) consumption from a Stationary Energy sector (*i*) for a GHG emissions inventory year (*y*) in therms.

CF = Conversion factor for converting data reported in therms to million British thermal units (mmBTU).

$EF_{NG,j}$ = The natural gas consumption GHG emissions factor for CO_2, CH_4, N_2O (*j*).

Finally, natural gas consumption GHG emissions were converted to metric tons of carbon dioxide equivalent (MT CO_2e) by multiplying $GHG_{NG,i,j,y}$ by global warming potential $GWP_{AR5,j}$ and summed across GHGs (*j*).

B.3 Changes between inventory years

As mentioned in Section Appendix B.1, the natural gas consumption data for 2012 and 2016 in the 2018 GHG emissions inventory were not scaled unlike the previous 2012 and 2016 GHG emissions inventories. A comparison between the scaled (previously reported) and unscaled natural gas consumption for 2012 and 2016 is shown below in Table B1.

Table B1. Changes to Natural Gas GHG Emissions Due to Updated Scaling Methods

Year	Scaled Natural Gas Use (kilotherms)	Scaled GHG Emissions (MT CO_2e)	Unscaled Natural Gas Use (kilotherms)	Unscaled GHG Emissions (MT CO_2e)	ΔGHG Emissions (MT CO_2e)	% Change
2012	122,983	650,267	151,881	806,722	156,455	24%
2016	128,256	678,147	151,584	805,753	127,606	19%

The result of using unscaled natural gas consumption data increases total Stationary Energy GHG emissions by approximately 2% over reported 2012 and 2016 levels.

B.4 Estimating 2022 Natural Gas Consumption

Citywide natural gas consumption from Southwest Gas were not available during the inventory data collection and compilation period. Therefore, citywide natural gas consumption for 2022 were estimated using an ensemble. The ensemble approach projected the ratio between Southwest Gas deliveries to Phoenix customers and all customers in Arizona for 2022 using an averaging method and linear projection method. Data on total Southwest Gas deliveries were obtained from the Arizona Corporation Commission and the EIA Form 176 for calendar years 2012, 2016, 2018, and 2020 and summarized into residential and non-residential customer classes. Previous Southwest Gas data for Phoenix-wide consumption were summarized into the same customer classes. Next, the ratio between deliveries to Phoenix customers and all Arizona customers (hereafter called Phoenix delivery ratio or PDRs) were developed for residential and non-residential customer classes for the previous inventory years for both source datasets.

First, the residential and non-residential Phoenix delivery ratios were averaged over all inventory years. This approach yielded average residential Phoenix delivery ratios of 20.3% +/ 1.3% for ACC data and 20.4% +/- 1.4% for EIA data average non-residential Phoenix delivery ratios of 40.6% +/- 3.1% for ACC data 40.7% +/- 2.6% for EIA data. Next, a simple linear projection was developed to estimate 2022 Phoenix delivery ratios from historic residential and non-residential Phoenix delivery ratio data. This approach yielded estimated residential Phoenix delivery ratios of 18.3% for ACC data and 18.2% for EIA data average non-residential Phoenix delivery ratios of 41.6% for ACC data 41.6% for EIA data. Next, the residential PDRs developed from ACC data averaged (19.3%) and multiplied by residential deliveries reported by Southwest Gas to ACC and the same process was followed for non-residential ACC PDRs. The process was then followed for PDRs developed for EIA Form 176 delivery data. Finally, a third approach was employed using the average utility consumption ratio, defined as natural gas combustion divided electricity consumption, for residential and non-residential accounts over the previous inventory years. After this process, the outputs from ACC and EIA PDR and utility consumption ratio approaches were averaged for residential and non-residential customer classes. Overall, non-residential consumption had a higher level of uncertainty between estimation approaches (Table B2).

Table B2. Output of the 2022 Natural Gas Combustion Estimation Process

Estimation Approach Output	2022 Estimated Natural Gas Combustion (therms)	
	Residential	**Non-Residential**
ACC PDR Approach	63,170,800	108,088,551
EIA PDR Approach	*62,585,439*	107,345,342
Utility Consumption Ratio	61,628,144	94,246,174
Average	*62,461,461*	*103,226,689*
Standard Deviation	*778,765*	*7,786,227*
% Relative Standard Deviation	*1%*	*8%*

Finally, estimated non-residential delivery data were multiplied by the average delivery distribution between Commercial and institutional buildings and facilities; Manufacturing industries and construction; Energy industries; Agriculture, forestry, and fishing activities; Non-specified sources; a deliveries to transportation customers.

Appendix C. Stationary Energy – Electricity Documentation

Appendix C describes the data collection and data processing for obtaining electricity consumption data and calculating GHG emissions from electricity consumption. This appendix also describes any changes to data sources and methodologies in the 2018 community-scale GHG emissions Inventory.

C.1 Electricity Data Collection

Stationary Energy GHG emissions from the consumption of purchased electricity can occur at residential buildings, commercial and institutional buildings and facilities, manufacturing industries and construction facilities, energy industry facilities, agriculture, forestry, and fishing activities, and non-specified sources.

Electricity consumption data for the Community GHG Emissions Inventory were obtained from Arizona Public Service (APS) and the Salt River Project (SRP). APS and SRP are the only electric utilities that provide electricity to consumers within the city boundary. Electricity data were obtained from APS and SRP for each GHG emissions inventory as the inventory was being compiled – i.e., 2012 data were collected while conducting the 2012 community-scale inventory, 2016 data were collected while conducting the 2016 community-scale inventory, and 2018 data were collected while conducting the 2018 community-scale inventory, 2020 data were collected while conducting the 2020 community-scale inventory; and 2022 data were collected while conducting the 2022 community-scale inventory.

Both APS and SRP have electricity generation facilities located within the Phoenix metropolitan area, but only APS has an electricity generation facility within city boundaries – the APS West Phoenix Power Plant. The APS West Phoenix Power Plant is a 997 MW natural gas facility located in southwest Phoenix.[12] The APS West Phoenix Power Plant is included in the 2020 community-scale inventory as emissions from energy generation supplied to the grid (eGRID). Emissions from the APS West Phoenix Power Plant are included in this inventory as an information item (Appendix A, GPC ref. no I.4.4), and are not tabulated as part of the community-scale inventory per GPC guidelines. APS West Phoenix Power Plant emissions for 2012, 2016, 2018, 2020, and 2022 were obtained from the EPA Greenhouse Gas Reporting Program through the Facility Level Information on GreenHouse gases Tool (FLIGHT).[13]

A similar data request process was followed for each of the GHG emissions inventory years. For 2012 and 2020, APS provided consumption data at the zip code resolution

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[12] Pinnacle West Capital Corporation (2019). 2018 Annual Report. URL: http://s22.q4cdn.com/464697698/files/doc_financials/annual/2018/Annual-Report_2018_Web.pdf

[13] U.S. Environmental Protection Agency (2019). EPA Greenhouse Gas Reporting Program through the Facility Level Information on GreenHouse gases Tool URL: https://ghgdata.epa.gov/ghgp/main.do

for residential, commercial, and industrial consumers. However, for 2016, 2018, and 2022 APS only provided total consumption data for residential, commercial, and industrial consumers for zip codes associated with the City of Phoenix. SRP only provided total consumption for residential and commercial consumers within the City of Phoenix for all inventory years.

C.2 Electricity Data Processing

C.2.1 APS Electricity Data Processing

Using the data provided by APS, the following equation was used to calculate GHG emissions from Stationary Energy electricity consumption in 2012 and 2020. Scaling factors were not used for the 2022 as the data was specific to Phoenix city-boundaries.

$$GHG_{APS,i,j,scaled,y} = \sum_{z} EC_{APS,i,z,y} \times SF_{i,z,y} \times CF \times EF_{AZNM,j,y}$$

Where, $GHG_{APS,i,j,scaled,2012}$ = The scaled GHG emissions in metric tons from purchased electricity from APS for a Stationary Energy subsector (*i*) for a GHG (*j*) for inventory year (y) 2012 and 2020.

$EC_{APS,i,z,2012}$ = Purchased electricity from APS for a Stationary Energy subsector (*i*) in zip code (z) for inventory year (y) 2012 and 2020.

$SF_{i,z,y}$ = Scaling factor for zip code (*z*) for inventory year (y) 2012 and 2020.. The scaling factor the % of land area in *z* that is within the city boundary. $SF_{i,z,y}$ ranges from near 0 to 1.

CF = Conversion factor to convert kWh to MWh. If data were reported in the MWh, *CF = 1*. If data were reported in kWh than CF = 0.001.

$EF_{AZNM,j,y}$ = The eGRID[14] emissions factor for the AZNM subregion for GHG emissions factor for CO_2, CH_4, N_2O (*j*) for eGRID reporting year (*y)*.

Zip code level data from APS were not available for calendar years 2016 and 2018. Therefore, the 2012 data (SF_{2012}) were used to develop the scaling factors for 2016 and 2018:

$$SF_{APS,2012} = \sum_{i,z} EC_{APS,i,z,2012} \times SF_{i,z,2012} \Big/ \sum_{i,z} EC_{APS,i,z,2012}$$

Where, $SF_{APS,2012}$ = Is the overall scaling factor for APS data in calendar year 2012. It is the ratio of the total purchased electricity from APS within the city scaled by zip code

[14] The eGRID database inventories plant-level environmental attributes of electric power generation and its effect on air emissions for every power plant in the United States. Phoenix is in the Arizona and New Mexico (AZNM) subregion. The Emissions & Generation Resource Integrated Database (eGRID), developed by the EPA in collaboration with the Energy Information Administration (EIA), the North American Electric Reliability Corporation (NERC), and the Federal Energy Regulatory Commission (FERC), is a comprehensive source of data on the environmental characteristics of almost all electric power generated in the United States. Detailed information can be found at http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html.

specific scaling factors to the reported total unscaled purchased electricity from APS within the city.

$EC_{APS,i,z,2012}$ = Purchased electricity from APS for a Stationary Energy subsector (*i*) in zip code (z) for an inventory year 2012.

$SF_{i,z,2012}$ = Scaling factor for zip code (*z*). The scaling factor the % of land area in *z* that is within the city boundary. $SF_{i,z,2012}$ ranges from near 0 to 1.

Therefore,

$$GHG_{APS,scaled,i,j,y} = \sum_{z} EC_{APS,i,z,y} \times SF_{APS,2012} \times EF_{AZNM,j,y}$$

.

Where, $GHG_{APS,scaled,i,j,y}$ = The scaled GHG emissions in metric tons from purchased electricity from APSY for a Stationary Energy subsector (*i*) for a GHG (*j*) for an inventory year 2016 or 2018 (*y*).

$SF_{APS,2012}$ = Is the overall scaling factor for APS data in calendar year 2012. It is the ratio of the total purchased electricity from APS within the city scaled by zip code specific scaling factors to the reported total unscaled purchased electricity from APS within the city.

$EF_{AZNM,j,y}$ = The eGRID emissions factor for the AZNM subregion for GHG emissions factor for CO_2, CH_4, N_2O (*j*) for eGRID reporting year (*y*).

Next, electricity consumption for the Lake Pleasant Water Treatment Plant (obtained from the City of Phoenix Government Operations GHG Emissions Inventory) was added to the APS electricity total to account its removal during the scaling process. Finally, GHG emissions from APS electricity consumption were converted to metric tons of carbon dioxide equivalent (MT CO_2e) by multiplying $GHG_{i,j}$ by the GHG-specific global warming potential found in the IPCC AR5 report ($GWP_{AR5,j}$).

C.2.2 SRP Data Processing

For each inventory, SRP provided total residential, commercial, and industrial electricity consumption for accounts within the city boundary. As this data consisted of account holders only within the city boundary, no scaling factor was applied to the data.

Using the data provided by SRP, the following equation was used to calculate GHG emissions from Stationary Energy natural gas consumption.

$$GHG_{SRPi,j,y} = EC_{SRP,i,y} \times CF \times EF_{AZNM,j,y}$$

Where, $GHG_{SRP,i,j,y}$ = The GHG emissions in metric tons from purchased electricity from SRP for a Stationary Energy subsector (*i*) for a GHG (*j*) for an inventory year (*y*).

$EC_{SRP,i,y}$ = Purchased electricity from SRP for a Stationary Energy subsector (*i*) for an inventory year (*y*).

CF = Conversion factor to convert kWh to MWh. If data were reported in the MWh, *CF = 1*. If data were reported in kWH than CF = 0.001.

$EF_{AZNM,j,y}$ = The eGRID emissions factor for the AZNM subregion for GHG emissions factor for CO_2, CH_4, N_2O (*j*) for eGRID reporting year (*y*)..

Finally, GHG emissions from SRP electricity consumption were converted to metric tons of carbon dioxide equivalent (MT CO_2e) by multiplying $GHG_{i,j,y}$ by the GHG-specific global warming potential found in the IPCC AR5 report ($GWP_{AR5,j}$).

C.2.3 Total GHG Emissions from Electricity Consumption

After the GHG emissions from electricity consumption (*EC*) in the SRP and APS service territories were calculated, the following equation was summed across inventory sectors (*i*) and GHGs (*j*) to calculate total GHG emissions from electricity consumption within city boundaries.

$$GHG_{EC,i,j,y} = GHG_{APS,i,j,y} + GHG_{SRP,i,j,y}$$

C.3 Transmission and Distribution Loss (T&D Loss)

GHG emissions from T&D loss were estimated using data obtained from the EIA on Arizona's supply and disposition of electricity.[15] For each inventory year, T&D loss is calculated as the ratio between estimated electricity system losses and the difference between total electricity disposition minus direct use of electricity at power plants.

C.4 Changes between inventory years

For each of the inventory years – 2012, 2016, 2018, 2020, and 2022 – electricity consumption has been provided by APS and SRP. SRP data has been provided as an overall total electricity consumption for commercial and residential sectors within City boundaries. For the 2012 community-scale inventory, APS provided zip code level consumption data for commercial, industrial, and residential sectors for zip codes associated with the City. An analysis of this data showed that some of the zip codes with highest reported consumption only had minor portion of the zip code within the City. For example, in the 2012 data the zip code with the highest reported total consumption had less than 1% land area within City boundaries and the zip code with highest reported residential consumption had only 30% land area within City boundaries.

To account for this aspect of the data, a scaling factor was developed to scale reported electricity consumption to City electricity consumption using land area as indicator of electricity consumption. For 2012, a single scaling factor was used, which was a simple ratio of the total area of the City compared to the total area of all zip code for which data was provided. For the 2016 community-scale inventory, the same scaling factor methodology was used because the reported electricity consumption was within 0.5% of

[15] U.S. Energy Information Administration, Form EIA-923, Power Plant Operations Report and predecessor forms. U.S. Energy Information Administration, Form EIA-860, Annual Electric Generator Report. U.S. Energy Information Administration, Form EIA-861, Annual Electric Power Industry Report. Form EIA-111, Quarterly Imports and Exports Report.

2012 levels. For 2018 community-scale inventory, the scaling methodology was updated for the 2012 data and then applied to 2016 and 2018 data. In the updated method, consumption for each zip code is scaled by the percent land area within the City; electricity consumption for some zip codes are scaled, others are not because those zip codes are entirely within City boundaries. Use of this scaling factor assumes that electricity consumption by customer-type within each zip code is constant through the reporting time period from 2012 to 2018. This assumption and scaling approach may need to be revisited in future community-scale GHG emissions inventories. After data from each zip code are scaled, they are summed to arrive at electricity consumption for the City. The result of this methodological change was to increase GHG emissions from electricity consumption in 2012 and 2016. The 2020 inventory was able to follow the approach of the 2012 inventory because zip-code level data were available. The 2022 data were not scaled as data were requested for the city-boundary rather than at the zip code level.

Table C1. Changes to Scaling Methodologies for Electricity Data

Year	Old Scaling Method		New Scaling Method		ΔGHG Emissions (MT CO_2e)	% Change
	APS Electricity Consumption	GHG Emissions (MT CO_2e)	APS Electricity Consumption	GHG Emissions (MT CO_2e)		
2012 (MWh)*	6,429,328,231	3,102,482	9,873,891,733	4,764,661	1,662,179	54%
2016 (MWh)	5,677,762	2,413,206	9,875,762	4,197,472	1,784,266	74%

**kWh data were provided in 2012; MWh data were provided in 2016 and 2018.*

Appendix D. Transportation Sector Documentation

Transportation Sector GHG emissions are generated by a number of different sources and types of fuel. GHG emissions sources include on-road transport, railways, commercial aviation, civil aviation, and off-road transport. Fuel types consumed gasoline, diesel, B20 biodiesel, E85 ethanol, compressed natural gas (CNG), liquified natural gas (LNG), propane (LPG), aviation gasoline, and jet fuel A. Transportation sector GHG emissions also includes the consumption of purchased electricity to charge electric vehicles and to power electric light rail. Appendix D describes data sources and methods by fuel type.

D.1 Transportation Sector Data Processing

Transportation sector GHG emissions are calculated using a generalized formula.

$$GHG_{i,j,y} = FC_{i,y} \times CF \times EF_{i,j,y}$$

Where,	$GHG_{i,j,y}$ =	The GHG emissions in metric tons from a transportation fuel (*i*) for a GHG (*j*) for an inventory year (*y*).
	$EC_{SRP,i,y}$ =	Fuel consumption of a transportation fuel (*i*) for an inventory year (*y*).
	CF =	Conversion factor to convert fuel consumption data to the units of the emissions factor. A CF is only used when necessary and is equal to 1 when not necessary.
	$EF_{i,j,y}$ =	The GHG emissions factor in metric tons from a transportation fuel (*i*) for a GHG (*j*) for an inventory year (*y*).

Finally, GHG emissions from transportation fuel consumption were converted to metric tons of carbon dioxide equivalent (MT CO_2e) by multiplying $GHG_{i,j,y}$ by the GHG-specific global warming potential found in the IPCC AR5 report ($GWP_{AR5,j}$).

D.2 On-Road Transport

D.2.1 Gasoline and Diesel

Gasoline and diesel consumption for Maricopa County were obtained from the Arizona Department of Transportation (ADOT) via a public records request. Gasoline and diesel gallonage data are reported to the ADOT in order to obtain funds through the Highway User Revenue Fund (HURF). Historic HURF monthly distribution reports are available through ADOT. ADOT HURF reports contain county-level monthly gasoline and use oil (diesel) sales data.[16] As these data were for the entirety of Maricopa County, gasoline and diesel sales data were scaled using a ratio of City of Phoenix and Maricopa County populations. Per GPC guidance, population is an acceptable scaling factor for

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[16] Arizona Department of Transportation. Archived Audits and Reports. *Highway User Revenue Fund (HURF).* URL: https://azdot.gov/node/5069.

population-dependent activity data. A future study would be needed to determine if and how driving behaviors differ by Phoenix metropolitan area city.

D.2.2 Alternative Fuel Vehicles – B20 Biodiesel, E85 Ethanol, CNG, LNG

The *City of Phoenix 2022 GHG Emissions Inventory of Local Government Operations* is the primary source of data for alternative fuel consumption and the resulting GHG emissions within the city boundary. It was assumed that local government operations were the largest consumer of these fuels for transportation within the city boundary and other alternative fuel uses were *de minimis*.

D.2.3 Electric Vehicles

GHG emissions from electric vehicles were estimated for the 2012, 2016, 2018, 2020, and 2022 community-scale inventories. National data were used to estimate electric vehicle consumption as local data were not available for estimating these GHG emissions. National-level statistics for annual gasoline consumption and electricity use for mobile transportation were obtained from the EIA Annual Energy Outlook. The ratio between electric energy for transportation and the energy in gasoline usage in the U.S. was used as a proxy to estimate citywide residential electric vehicle usage. GHG emissions from electricity consumption from electric vehicles were calculated according to the method in Appendix C, Section C.2.2.

D.3 Railways

D.3.1 Valley Metro Light Rail

Valley Metro light rail electricity consumption data were obtained from two sources. The National Transit Database[17] used for all inventory years. The National Transit Database is published by the U.S. Department of Transportation and contains various statistics about public transit systems across the United States, including fuel usage. Electricity usage by Valley Metro is reported to the National Transit Database as Valley Metro Rail, Inc. The National Transit Database had not been published for calendar year 2018 during the time in which the 2018 inventory was compiled. Therefore, 2018 electricity consumption by the Valley Metro light rail system was obtained via a public records request of Valley Metro.

For each inventory year, total Valley Metro electricity usage for rail operations were scaled based on ratio of the length of light rail track within the city compared to the overall length of Valley Metro light rail track. GHG emissions from electricity consumption from the Valley Metro light rail were calculated according to the method in Appendix C, Section C.2.2.

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[17] U.S. Department of Transportation. The National Transit Database. URL: https://www.transit.dot.gov/ntd.

D.3.1 Freight Rail

The National Emissions Inventory (NEI)[18] published by U.S. EPA was used to gather data on GHG emissions from freight rail activity in Maricopa County. The 2011 NEI was used as a proxy for 2012, 2016, 2018, and 2020. For 2022, GHG emissions were updated to reflect the latest freight rail emissions data available from the NEI. Please refer to the 2016 community-scale GHG emissions inventory report for a summary of methods to estimate Freight Rail GHG emissions.

D.4 Aviation

D.4.1 Commercial Aviation

The Energy Information Administration (EIA) State Energy Data System (SEDS) was used to gather annual data on Jet Fuel A consumption in the State of Arizona. Next, airport operations data were obtained from the Federal Aviation Administration's (FAA) Operations Network (OPSNET) database for the State of Arizona, Phoenix Sky Harbor Airport, and the Phoenix Deer Valley. The FAA OPSNET data were used to calculate the proportion of commercial airport operations that occurred at the Phoenix Sky Harbor and Phoenix Deer Valley airports relative the State of Arizona. Once this annual scaling factors were calculated, they were multiplied by the annual state-level Jet Fuel A consumption to arrive at estimated Jet Fuel A consumption at the two Phoenix airports. This number was then divided by two to only account for takeoffs. It should be noted that EIA SEDS data are subject to revision from year-to-year. In 2022, Commercial Aviation GHG emissions were revised with the latest aviation fuel estimates from EIA for all inventory years.

D.4.2 Civil Aviation

The Energy Information Administration (EIA) State Energy Data System (SEDS) was used to gather annual data on Aviation Gasoline consumption in the State of Arizona. Next, airport operations data were obtained from the Federal Aviation Administration's (FAA) Operations Network (OPSNET) database for the State of Arizona, Phoenix Sky Harbor Airport, and the Phoenix Deer Valley. The FAA OPSNET data were used to calculate the proportion of non-commercial airport operations that occurred at the Phoenix Sky Harbor and Phoenix Deer Valley airports relative the State of Arizona. Once this annual scaling factors were calculated, they were multiplied by the annual state-level Aviation Gasoline consumption to arrive at estimated Aviation Gasoline consumption at the two Phoenix airports. This number was then divided by two to only account for takeoffs. It should be noted that EIA SEDS data are subject to revision from year-to-year.

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[18] U.S. Environmental Protection Agency. National Emissions Inventory (NEI). URL: https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei.

D.5 Off-Road Transportation

D.5.1 Nonroad Diesel

Consumption data for nonroad diesel (dyed diesel) were obtained via a public records request of the Arizona Department of Transportation for dyed diesel sales in Maricopa County. Nonroad (dyed) diesel is only permitted for use in "vehicles and equipment used in agriculture (farming and ranching), mining and roadway construction"[19] and illegal for on-road transportation uses. Public records requests were submitted for two different points in time. The public records request for nonroad diesel consumption for calendar year 2016 was submitted in 2017 and data were obtained in 2017. These data had contained origin-destination flows of dyed diesel sales – from the terminal to point of sale – at the city level for Maricopa County. The second public records request for dyed diesel sales in Maricopa County for 2012 and 2018 (submitted as one public records request) yielded aggregate sales in Maricopa County for each calendar year requested. Therefore, the ratio of dyed diesel sales in Phoenix compared to Maricopa County was used as scaling factor for 2012 and 2018 data.

GHG emissions for dyed diesel were calculated using the following equation.

$$GHG_{NonRoadDiesel,Phoenix,j,y} = \begin{cases} DyedDiesel_{Gallons,Phoenix,y} \times EF_{diesel,j} & if\ y = 2016 \\ DyedDiesel_{Gallons,MaricopaCounty,y} \times SF_{Phoenix,2016} \times EF_{diesel,j} & if\ y = 2012, 2018 \end{cases}$$

Where,

$GHG_{NonRoadDiesel,Phoenix,j,y}$ = the GHG emissions from red-dyed diesel sold within the city for a GHG (*j*) and an inventory year (*y*).

$DyedDiesel_{Gallons,Phoenix,y}$ = The gallons of red-dyed diesel sold at pumps located within the city in an inventory year (*y*).

$EF_{diesel,j}$ = The diesel emissions factor (*EF*) for a GHG (*j*).

$DyedDiesel_{Gallons,MaricopaCounty,y}$ The gallons of red-dyed diesel sold at pumps located within the Maricopa County in an inventory year (*y*).

$SF_{Phoenix,2016}$ = The ratio between total red-dyed diesel gallons sold at pumps located in the city to the total red-dyed diesel gallons sold in pumps located in Maricopa County for year 2016.

For 2012 and 2016, the 2011 and 2014 US EPA National Emissions Inventory (NEI) were the sources of nonroad diesel GHG emissions, respectively. However, a follow up analysis showed that the amount of CO_2 emissions associated within nonroad diesel use reported in the NEI was equivalent to the volume diesel sold in both 2012 and 2016 in Maricopa County as reported by ADOT. Therefore, it was concluded there was double counting of diesel no. 2 sales for nonroad purposes included in the nonroad diesel GHG emissions in the 2012 and 2016 community-scale GHG emissions inventories. To correct for this double-counting, red-dye diesel consumption data for the City (2016) and Maricopa County (2012, 2018) were obtained from ADOT. Red-dye

[19] Arizona Department of Transportation (2019). Red-Dyed Diesel Fuel in Arizona. URL: https://azdot.gov/motor-vehicles/professional-services/fuel-tax-information/red-dyed-diesel-fuel-arizona.

diesel consumption was used as a proxy for nonroad diesel emissions because it is illegal for purchase for on-road transportation. ADOT provided city-specific data for Maricopa County for 2016 and county-level data for 2012 and 2018, so 2016 data was used to scale 2012 and 2018 county-level data to the city-level. Additionally, 2018 data was used as a proxy for 2020 data. With this updated method for estimating non-road diesel consumption, on-road diesel GHG emissions may contain diesel purchased for nonroad purposes, but nonroad diesel GHG emissions only contains GHG emissions for nonroad purposes.

Table D1. Changes to Non-Road Diesel Consumption and GHG Emissions

Year	NEI Data Nonroad Diesel	ADOT Dyed Diesel Sales	ΔGHG Emissions ($MT\ CO_2e$)	% Change in GHG Emissions
	GHG Emissions ($MT\ CO_2e$)	GHG Emissions ($MT\ CO_2e$)		
2012	1,864,570	148,488	-1,716,082	-92%
2016	1,992,217	149,749	-1,842,468	-92%

D.5.2 Other Nonroad GHG Emissions

The NEI was used to gather data on GHG emissions from other nonroad fuel consumption in Maricopa County. The 2011 NEI was used as a proxy for 2012 and the 2014 NEI was used as a proxy for 2016, 2018, and 2020. Other nonroad fuel consumption data were scaled from Maricopa County to the city boundary. These data primarily cover the combustion of propane for nonroad uses.

D.5.3 Nonroad GHG Emissions Estimation Updates for 2022

The NEI was used to gather data on GHG emissions from other nonroad fuel consumption in Maricopa County. Nonroad emissions were updated to utilize the 2017 NEI for 2018 and the 2020 NEI for both 2020 and 2022 inventory years.

Appendix E. Waste Sector Documentation

Waste Sector GHG emissions occur from numerous sources: solid waste, wastewater treatment, compost processing, and granulated activated carbon (GAC) hauling and regeneration. Much of these GHG emissions occur due to city's local government operations and as such a description of the methods to calculate these GHG emissions are found in the *City of Phoenix 2022 GHG Emissions Inventory of Local Government Operations*.

E.1 Solid Waste

Solid Waste GHG emissions occur at landfills owned and operated by the city within city boundary, a landfill owned and operated by the city outside city boundary, a privately-owned landfill within the city boundary, and privately-owned landfills outside the city boundary.

GHG emissions from landfills owned and operated by the city were obtained from the *City of Phoenix 2022 GHG Emissions Inventory of Local Government Operations*. Of the seven landfills owned and operated by the city, six are located within the city boundaries – these landfills are closed and no longer accept waste – and the only open landfill is located outside city boundaries. The names of these landfills, the data source, method of GHG emissions calculation, and GPC subsector are described in Table E1.

Table E1. Data and Method Documentation for City-Owned Landfills

Landfill	Activity Data	Source	Method	Active?	GPC Subsector
Skunk Creek	CH_4 Monitoring	City of Phoenix	ICLEI LGOP	No	Disposal of solid waste generated in the city
27th Avenue	CH_4 Monitoring	City of Phoenix	ICLEI LGOP	No	Disposal of solid waste generated in the city
Del Rio	CH_4 Monitoring	City of Phoenix	ICLEI LGOP	No	Disposal of solid waste generated in the city
Deer Valley	CH_4 Monitoring	City of Phoenix	ICLEI LGOP	No	Disposal of solid waste generated in the city
19th Avenue	CH_4 Monitoring	City of Phoenix	ICLEI LGOP	No	Disposal of solid waste generated in the city
Estes	EPA LandGEM Model	City of Phoenix	First Oder Decay	No	Disposal of solid waste generated in the city

SR-85	CH_4 Monitoring	City of Phoenix	ICLEI LGOP	Yes	Disposal of solid waste generated in the city but disposed outside the city

The City of Phoenix only collects municipal solid waste from single family residences within city boundaries. Residents in the city that live in multi-family housing in addition to commercial and industrial establishments are serviced by private haulers. There is one landfill within the city boundary – the Lone Cactus Landfill – owned by a private waste management company. GHG emissions from the Lone Cactus Landfill are reported by Waste Management, Inc. to the EPA Greenhouse Gas Reporting Program. Therefore, GHG emissions from the Lone Cactus Landfill were obtained from the EPA Facility-Level Information on Greenhouse Gas Emissions Tool (Table E2).

Table E2. Data Documentation for Privately-Owned Landfills

Landfill	Activity Data	Owner	Active?	GPC Subsector
Lone Cactus	EPA GHGRP	Waste Management	Yes	Disposal of solid waste generated in the city
Private Haulers	EPA GHGRP/Population	Multiple	Yes	Disposal of solid waste generated in the city but disposed outside the city

Since solid waste is also collected by private haulers and disposed of in privately-owned landfills outside of the city boundary, an additional estimation method was employed to estimate GHG emissions from the landfills attributable to solid waste generated within the City of Phoenix. First, a per capita GHG emissions from solid waste calculated for Maricopa County. To do this, all landfill emissions data reported to the EPA GHGRP within Maricopa County was pulled from EPA FLIGHT for all inventory years and converted to a per capita metric using population data obtained from the U.S. Census and City of Phoenix. Next, the number of residents living in multi-family housing in city was estimated using data obtained from the U.S. Census American Housing Survey. Finally, the population data were converted to GHG emissions using the per capita GHG emissions rate, as shown in the equation below.

$$GHG_{PrivateMSW,y} = \frac{\sum_l GHG_{SW,l,Maricopa,y}}{Pop_{Maricopa,y}} \times \left[\left(1 - \frac{\#\ Single\ Family\ Detached\ Housing}{All\ Dwellings}\right)_{PHX\ MSA,y} \times Pop_{Phoenix,y}\right]$$

Where, $GHG_{PivateMSW,y}$ = the GHG emissions from solid waste picked up by private haulers (PrivateHaulers) in an inventory year (*y*).

$\Sigma_l\ GHG_{SW,l,Maricopa,y}$ = The total reported GHG emissions by all landfills in Maricopa County, Arizona.

$Pop_{Maricopa,y}$ = The population of Maricopa County, Arizona in an inventory year (*y*).

 # Single Family Detach Housing = The number of single-family detached housing units in the Phoenix metropolitan area in an inventory year (*y*).

 # All Dwellings = The number of housing units in the Phoenix metropolitan area in an inventory year (*y*).

$Pop_{Phoenix,y}$ = the population of Phoenix, Arizona in an inventory year (*y*).

E.2 Wastewater Treatment

GHG emissions from wastewater treatment were obtained from the *City of Phoenix 2022 GHG Emissions Inventory of Local Government Operations*. Please refer to the *City of Phoenix 2022 GHG Emissions Inventory of Local Government Operations* for details about monitoring data and method. A summary table is presented below (Table E3).

Table E3. Data Documentation for Wastewater Treatment Plants

Wastewater Treatment Plant	Service Area	GHG Emissions	Data Source	GHG Emissions Methodology	GPC Subsector
23rd Avenue	City of Phoenix	CH_4, N_2O	City of Phoenix CH_4 and effluent monitoring data	ICLEI LGOP	Wastewater generated in the city
91st Avenue	All or Portions of Glendale, Mesa, Phoenix, Scottsdale and Tempe	CH_4, N_2O	City of Phoenix CH_4 and effluent monitoring data	ICLEI LGOP	Wastewater generated in the city

E.3 Compost Processing

GHG emissions from compost processing were obtained from the *City of Phoenix 2022 GHG Emissions Inventory of Local Government Operations*. The city provided data on the total tons of green organic waste diverted to be processed as compost from FY 2005-2006 to FY 2018-19. Using these data, GHG emissions from composting were calculated according to the methodology employed by the EPA to estimate national-level emissions from composting in Section 7.3 of the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022.*[20] While there are private composting operations within the city of Phoenix, their processing tonnages, and associated greenhouse gas emissions, are proprietary and unavailable at this time.

E.4 GAC Hauling and Regeneration

GHG emissions from GAC hauling and regeneration were obtained from the *City of Phoenix 2022 GHG Emissions Inventory of Local Government Operations*. The city provided data on the vehicle miles driven to the GAC recharging facility and the amount and type of energy used at the recharging facility. GHG emissions from GAC Hauling and Regeneration are included as Other Scope 3 GHG emissions.

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[20] U.S. EPA. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017. URL: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2017