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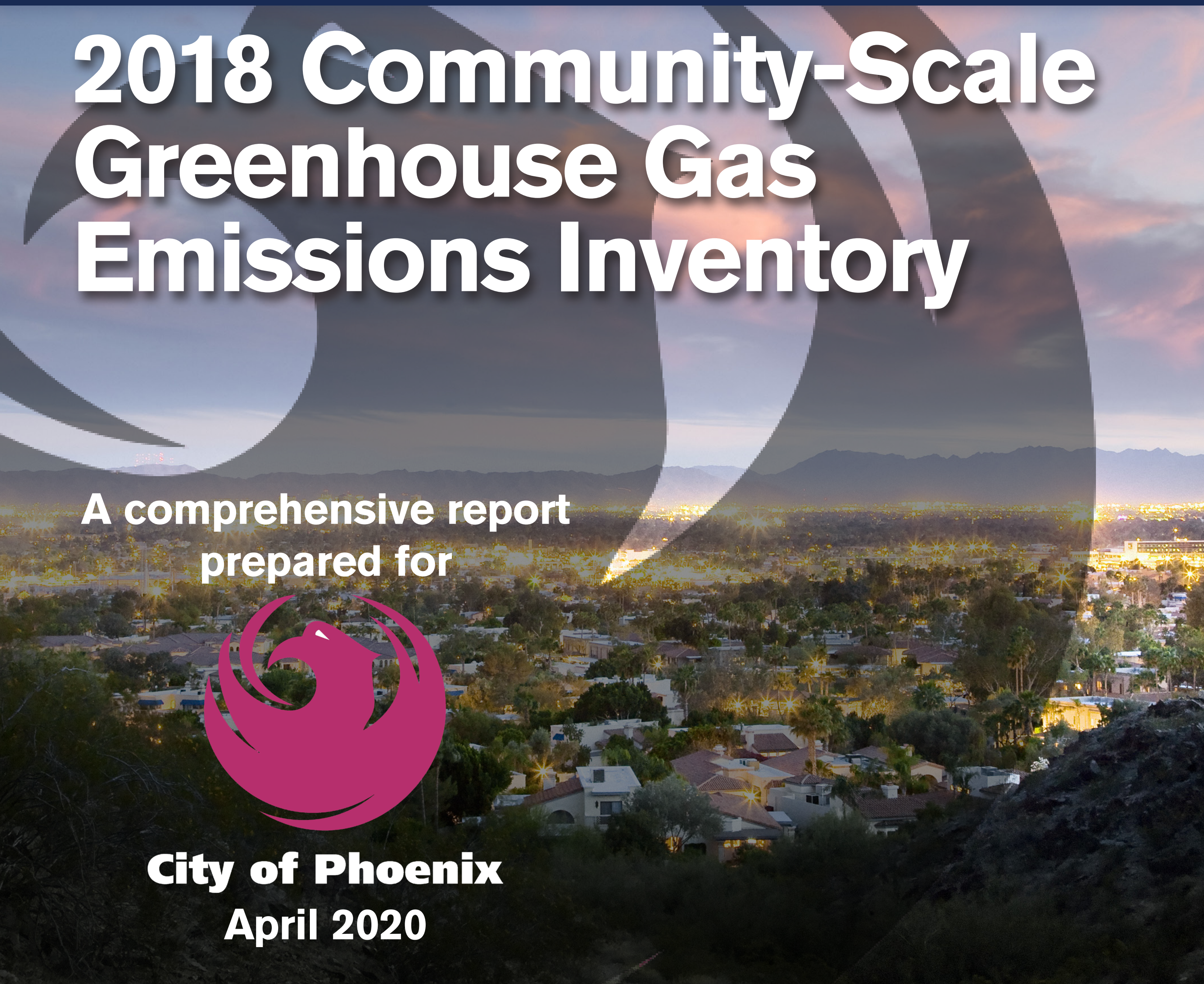

2018 Community-Scale Greenhouse Gas Emissions Inventory

A comprehensive report prepared for

City of Phoenix

April 2020

sustainabilitysolutions.asu.edu

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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
BPEV	Batter Plugin 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
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
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 greenhouse gas (GHG) emissions inventory for calendar year 2018. The 2018 community-scale GHG emissions inventory was conducted 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]. The GPC is also the standard supported by the Global Covenant of Mayors for Climate and Energy, of which the City is a member.

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

- The Stationary Energy Sector includes GHG emissions that occurs 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 2018 community-scale GHG inventory is the third completed by the City following the 2012 and 2016 2018 community-scale GHG inventories. While each of the community-scale GHG inventories completed by the City have followed the GPC, during each inventory process the previous year(s) GHG inventory have been recalculated to reflect updates to source data, data collection and processing methods, GHG global warming potentials, GHG emissions estimation methods. Changes to GHG emissions totals for the 2012 and 2016 calendar years are reported along with the 2018 GHG emissions totals.

[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

Key Findings

- In 2018, community-scale GHG emissions were 16,603,754 metric tons of carbon dioxide equivalents (MT CO_2e)
- 2018 community-scale GHG emissions were 0.5% lower than the 2012 levels of 16,692,626 MT CO_2e (Figure ES-1).
- Stationary Energy Sector GHG emissions totaled 8,550,631 MT CO_2e.
- Transportation Sector GHG emissions totaled 7,748,914 MT CO_2e.
- Waste Sector GHG emissions totaled 304,209 MT CO_2e.
- GHG emissions decreased during a period where the City's population grew 12% and the metro area economy grew 26%. Per capita emissions fell from the 2012 baseline of 11.33 MT CO_2e to 10.00 MT CO_2e in 2018.

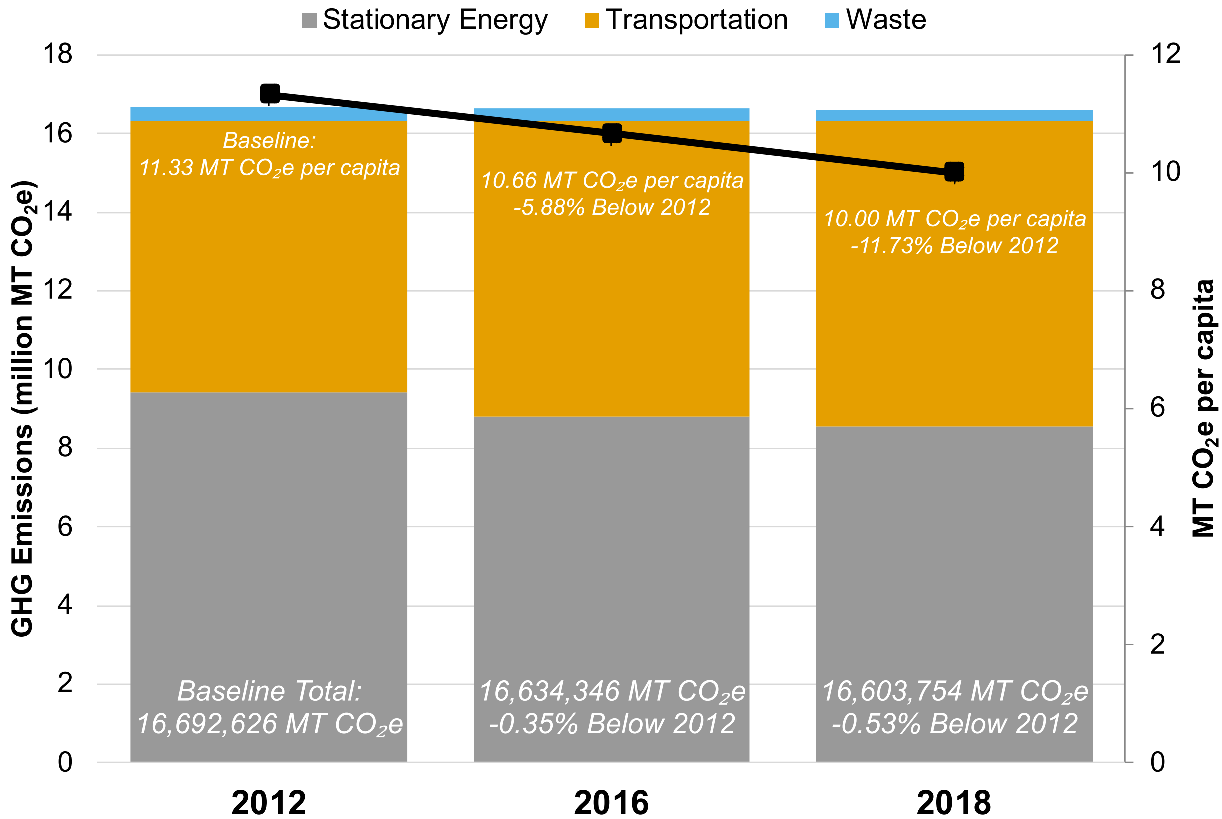


Figure ES-1. GHG emissions by emissions sector for 2012, 2016, and 2018.

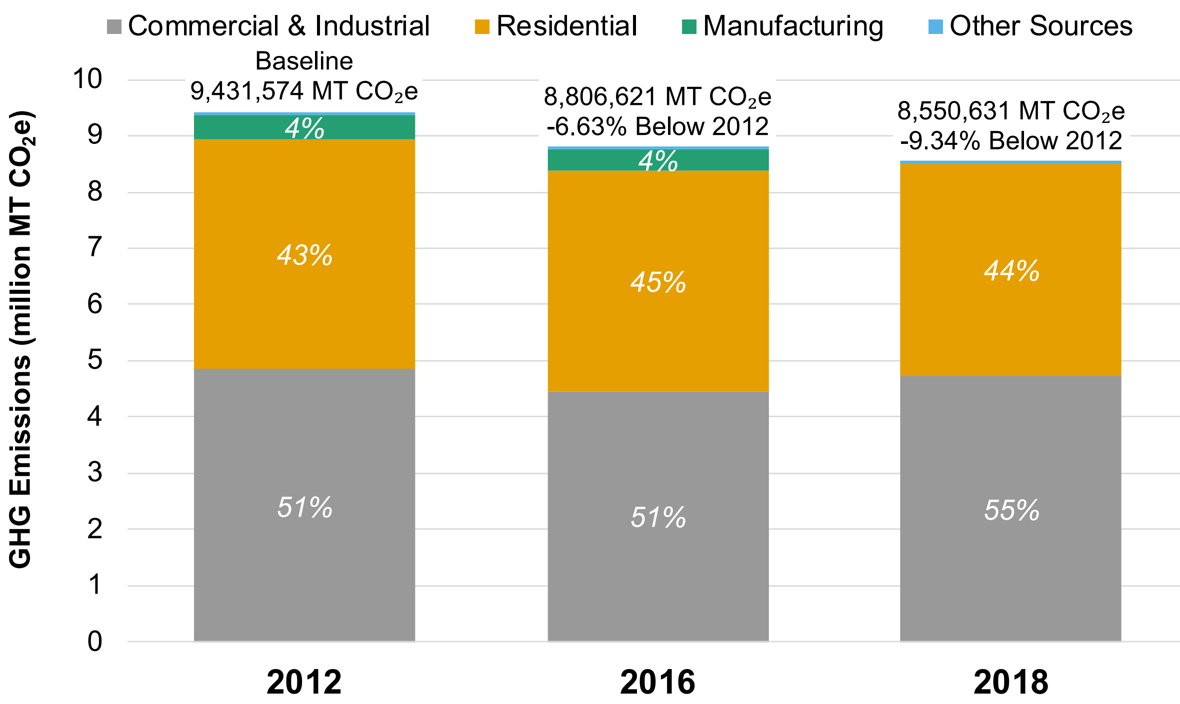
The distribution of GHG emissions between Stationary Energy, Transportation, and Waste Sectors for 2012, 2016, and 2018 is detailed in Table ES-1.

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

Sector	2012	2016	2018	% Change 2012 -2018
Stationary Energy	9,431,574	8,806,621	8,550,631	**-9.3%**
Transportation	6,895,031	7,514,844	7,748,914	**12.4%**
Waste	366,021	312,881	304,209	**-17.6%**
Total	**16,692,626**	**16,634,346**	**16,603,754**	**-0.5%**

Stationary Energy

The Stationary Energy Sector is the largest source of GHG emissions in the City. Stationary energy GHG emissions sources include energy utilized in residential buildings; commercial buildings and facilities; manufacturing industries; agriculture, forestry and fishing energy use; and electricity transmission and distribution energy losses. GHG emissions from natural gas leakages were not included for any reporting year due to a lack of data on leakage rates.



Residential - Residential buildings; Commercial & Industrial - Commercial and institutional buildings and facilities;
Manufacturing - Manufacturing industries and construction; Other Sources - Agriculture, forestry, and fishing activities and Non-specified sources.

Figure ES-2. Stationary Energy GHG emissions for 2012, 2016, and 2018.

Stationary Energy GHG emissions for 2018 were 8,550,631 MT CO_2e, which is a 9% decrease in emissions from 2012. The driving force behind the large reduction in Stationary Energy GHG emissions resulted from a regional increase in clean energy production, which decreased the carbon intensity of what Phoenix consumes, as reflected in the EPA Emissions and General Resource Integrated Database (eGRID) GHG emissions factor. Data to calculate Stationary Energy GHG emissions were obtained from Arizona Public Service (electricity), the Salt River Project (electricity), Southwest Gas (natural gas), and the Energy Information Administration (electricity transmission and distribution loss). Figure ES-2 shows the distribution of GHG emissions between different sub-sectors in the Stationary Energy Sectory for 2012 and 2018 and Table ES-2 details the GHG emissions by subsector.

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

Stationary Energy	2012	2016	2018	% Change 2012-2018
Residential Buildings	4,093,258	3,940,954	3,755,614	-8%
Commercial & Institutional Buildings	4,853,598	4,449,184	4,740,164	-2%
Manufacturing Industries & Construction	415,704	364,647	8,303	-98%
Agriculture, Forestry & Fishing Activities	68,954	51,758	46,477	-33%
Non-Specified Sources	60	78	74	23%
Total	**9,431,574**	**8,806,621**	**8,550,631**	**-9%**

Transportation

The Transportation Sector is the second largest source of GHG emissions in Phoenix. Transportation GHG emissions sources occur from commercial air travel, civil aviation, on-road transportation, non-road vehicle use, light rail, and freight rail. GHG emissions result from the combustion of fossil fuels (gasoline, diesel, CNG, LNG, LPG, aviation gasoline, jet fuel A), blended alternative fuels (B20 biodiesel, E85 Ethanol, E54 Ethanol), or indirectly through the consumption of electricity to charge electric vehicles. Transportation GHG emissions for 2018 were 7,748,914 MT CO_2e, a 12% increase in GHG emissions from the 2012 level of 6,895,031 MTCO_2e (Figure ES-3).

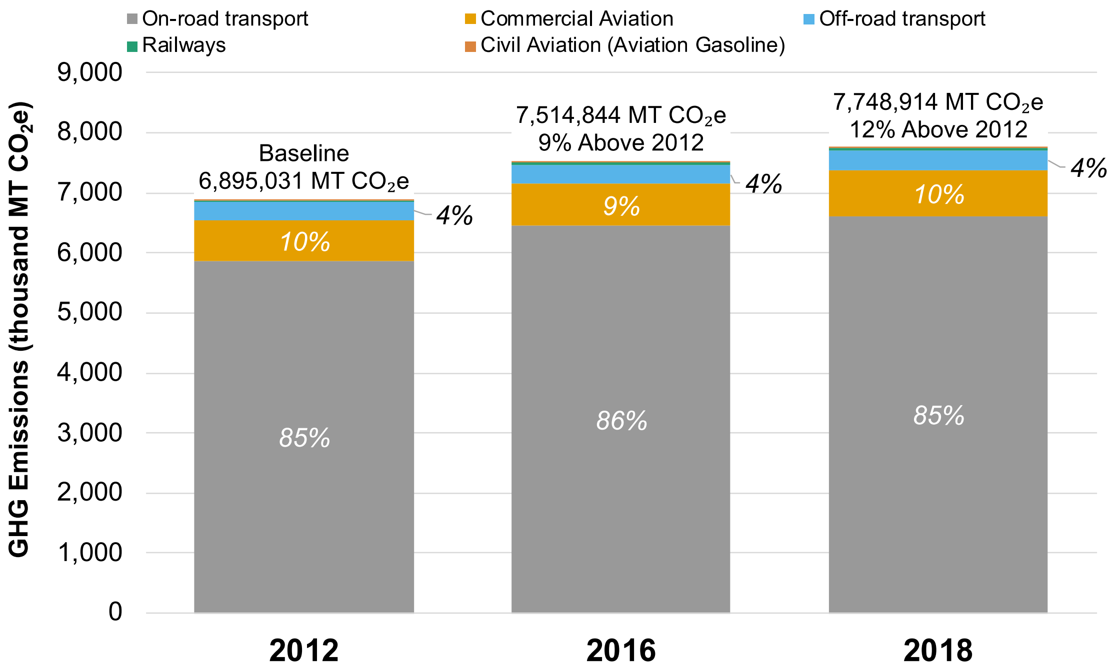


Figure ES-3.Transportation GHG emissions for 2012, 2016, and 2018.

Increased on-road and off-road transportation activity was responsible for the increased emissions. 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 Southwest Gas. Table ES-3 details GHG emissions among Transporation sub-sectors for the years 2012, 2016, and 2018.

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

Transportation	2012	2016	2018	% Change 2012-2018
On-road transport	5,856,023	6,444,711	6,601,864	13%
Railways	29,113	29,300	31,541	8%
Commercial Aviation	698,263	705,643	779,113	12%
Civil Aviation (Aviation Gasoline)	13,394	15,067	10,043	-25%
Off-road transport	298,237	320,122	326,353	9%
Transportation Sector Total	**6,895,031**	**7,514,844**	**7,748,914**	**12%**

Waste

The Waste Sector includes emissions from the current and historic disposal of solid waste generated and treated in Phoenix, the current disposal of solid waste generated in Phoenix that is disposed outside the city, wastewater treated at the 91st Avenue and 23rd Avenue wastewater treatment plants in Phoenix, and the biological treatment (composting) of waste generated and treated in Phoenix. Between 2012 and 2018 there was a 17% decrease in Waste Sector GHG emissions. GHG emissions from solid waste disposal decreased by approximately 19%, similar to the Waste Sector overall (Table ES-4). GHG emissions from wastewater treatment increased by 21% and composting increased 40%. The total GHG emissions from the Waste Sector were 304,209 MT CO_2e in 2018 as compared to 366,021 MT CO_2e reported in the 2012. Waste Sector reductions were driven by solid waste disposal, which is more than 90% of the sector emissions. While Solid Waste GHG emissions will occur from the ongoing disposal of solid waste, historic, closed landfills within the City of Phoenix would produce less GHG emissions over time as the waste decays.

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

Waste	2012	2016	2018	% Change 2012-2018
Solid Waste Disposal	351,780	299,484	285,885	-19%
Wastewater Treatment & Discharge	8,440	9,428	10,199	21%
Biological Waste Treatment (Composting)	5,802	3,968	8,125	40%
Waste Sector Total	**366,021**	**312,881**	**304,209**	**-17%**

Conclusion

In 2018, citywide GHG emissions in Phoenix was 16,603,754 metric tons CO_2e – 0.5% below the 2012 levels of 16,692,626 MT CO_2e. Emissions increased in the Transportation Sector by 853,883 MT CO_2e, which was proportional to population growth. Stationary Energy GHG emissions decreased 880,943 MT CO_2e, driven by a less GHG-intensive regional electricity grid. Waste Sector GHG emissions decreased by 17% between 2012 and 2018, but are small compared to the Stationary Energy and Transportation sectors. While Solid Waste GHG emissions will occur from the ongoing disposal of solid waste, closed landfills within the City produce less GHG emissions as the waste decays.

The Transportation Sector is the second largest source of GHG emissions in Phoenix and grew by 853,883 MT CO_2e between 2012 and 2018. On-road transportation, mainly gasoline consumption, drove Transportation Sector GHG emissions increase. Measures to reduce transportation-related GHG emissions will reduce community-scale GHG emissions. Gasoline-powered motor vehicles used for on-road transportation is the largest single source of transportation-related GHG emissions. An increased adoption of battery electric vehicles (BEVs) or plugin electric hybrid vehicles (PEHVs) is one avenue to reduce transportation-related GHG emissions. Another is higher adoption rate of mass transit options.

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, which only requires an inventory of Stationary Energy, Transportation, Waste sectors. IPPU and AFOLU are not required to be inventoried for BASIC-level reporting under the GPC.

In 2018, community-scale emissions totaled 16,603,754 MT CO2e, 0.5% decrease below the baseline 2012 level of 16,692,626MT CO2e (Table 1). Appendix A contains a detailed breakdown of GPC sector and subsector GHG emissions for 2012, 2016, and 2018. The Stationary Energy and Transportation Sectors account for 99% of the community-scale emissions. The largest source of emissions is from on-road motor gasoline combustion, which comprise 85% Transportation emissions and 36% of all emissions. The next largest source is from electricity consumption from commercial, industrial, and residential areas at 47%. Commercial aviation composed 5% of emissions. Meeting any community-scale goal requires mitigating GHG emissions from these sources.

Table 1. Community- Level GHG Emissions by Sector for 2012, 2016, and 2018

Sector	GHG Emissions (MT CO_2e)			% Change
	2012	2016	2018	2012 -2018
Stationary Energy	9,431,574	8,806,621	8,550,631	**-9.3%**
Transportation	6,895,031	7,514,844	7,748,914	**12.4%**
Waste	366,021	312,881	304,209	**-17.6%**
Total	**16,692,626**	**16,634,346**	**16,603,754**	**-0.5%**

The observed decreases in community-scale GHG emissions were driven by the regional electricity grid becoming less GHG-intensive. GHG emissions from electricity production fell by 855,221 MT CO_2e between 2012 and 2018. The Transportation sector GHG emissions grew by 854,193 MT CO_2e. Waste GHG emissions, which are 1% of community-scale GHG emissions, fell by 61,813 MT CO_2e. Per capita GHG emissions fell by 11.8% from 11.33 to 10.00 MT CO_2e per resident between 2012 and 2018 (Figure 1).

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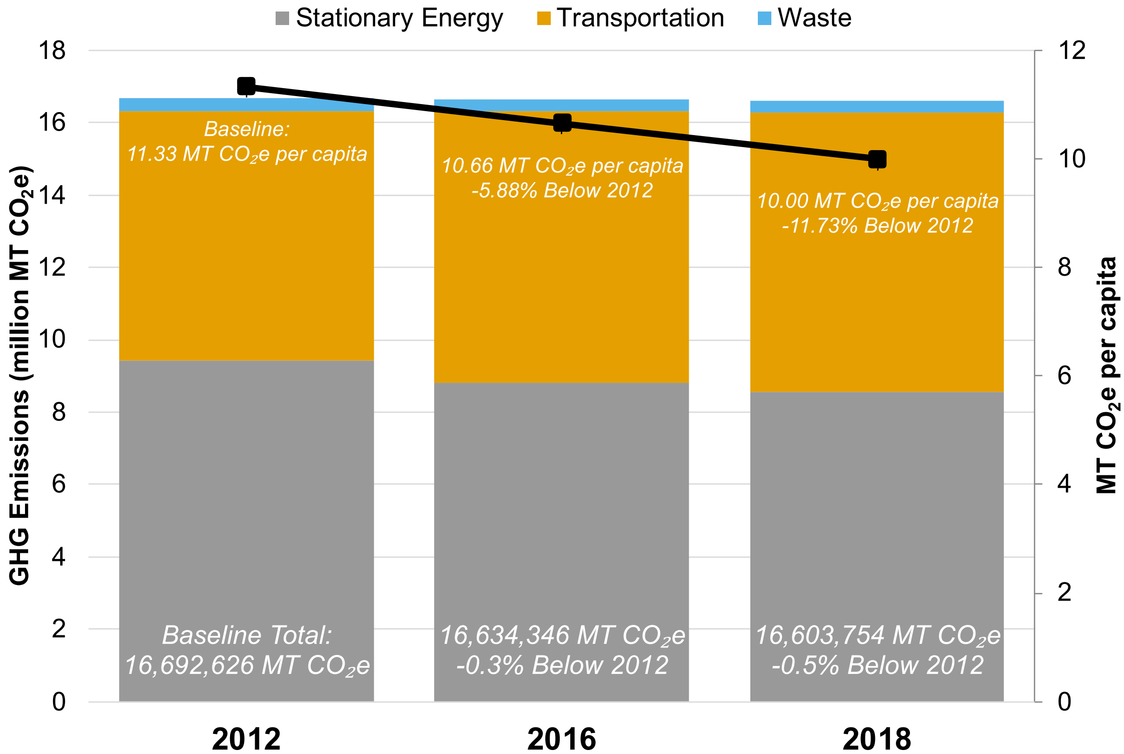

Figure 1. Total GHG Emissions and Per Capita GHG Emissions Since 2012

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 2018, 52% of GHG emissions occurred directly within the city boundary as Scope 1 emissions; 47% occurred indirectly as Scope 2 emissions through the purchase of electricity; and 1% occurred indirectly as Scope 3 emissions from waste disposed of outside the city boundary (Table 2).

Table 2. 2018 Community-Level GHG Emissions by Sector and Scope

Sector	GHG Emissions (MT CO_2e)			
	Scope 1	Scope 2	Scope 3	Total
Stationary Energy	781,000	7,769,631	*310,445**	**8,550,631**
Transportation	7,735,257	13,657	*546**	**7,748,914**
Waste	150,118	0	154,091	**304,209**
Total	**8,666,375**	**7,783,288**	**154,091**	**16,603,754**

**Scope 3 Stationary Energy and Transportation GHG emissions do not count toward the BASIC-level GHG emissions total.*

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In 2018, Stationary Energy activities – GHG emissions resulting from natural gas combustion and electricity consumption – accounted for approximately 51% of community-scale GHG emissions. Transportation activities comprise approximately 47%. Community-scale Transportation Sector GHG emissions have increased relative to Stationary Energy Section GHG emissions since 2012 (Figure 2). Gasoline combustion produced 76% of Transportation GHG emissions within city boundaries. The two largest sources of GHG emissions produced 83% of total community-scale GHG emissions – electricity consumption (47%) and gasoline combustion (36%). Community-level GHG mitigation efforts should prioritize these two sources of GHG emissions to achieve material GHG emissions reductions.

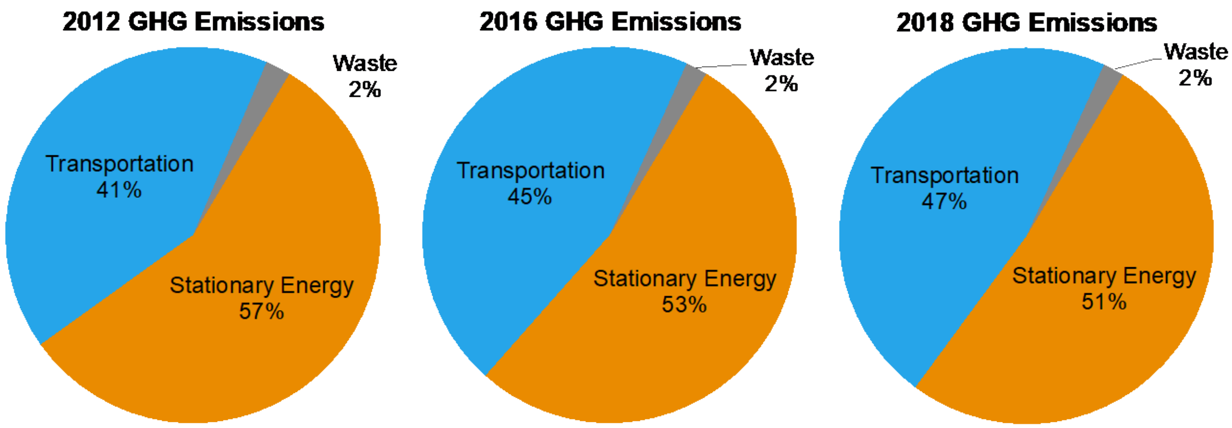

Figure 2. Distribution of GHG Emissions by Sector for 2012, 2016, and 2018.

Recent plant closures and announcements by Arizona Public Service[2] (APS), Salt River Project[3] (SRP) and the Public Service Company of New Mexico[4] (PNM) to retire and replace coal-fired power plants with generation sources that are less carbon intensive 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. This will reduce community-scale GHG emissions significantly and should be measurable in all future inventories.

Motor gasoline consumed for on-road transportation is the single largest GHG emitting activity. These emissions have grown in each GHG inventory. Between 2012 and 2018, GHG emissions from gasoline consumption grew 667,130 MT CO_2e (12.7%).The viability and cost effectiveness of strategies to reduce GHG emissions from

[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

Transportation activities, specifically on-road motor gasoline consumption, will dictate future community-scale GHG emissions and the ability of the City to meet GHG emissions reductions goals.

1. Stationary Energy Sector

Stationary Energy sector GHG emissions occur due to the combustion of natural gas (Scope 1) and the consumption of purchased electricity at residential, commercial, and industrial buildings, in addition to other facilities (Scope 2).

Stationary Energy GHG emissions were predominantly Scope 2 emissions from electricity consumption (Figure 3). Since 2012, the distribution of Stationary Energy GHG emissions between Scope 1 and Scope 2 emissions have been 9% Scope 1 emissions and 91% Scope 2 emissions. Scope 2 Stationary Energy GHG emissions are one of the largest sources of GHG emissions comprising 52% of total community-scale emissions in 2012; 48% in 2016; and 47% in 2018. The decrease in electricity-related GHG emissions has occurred during a period where electricity consumption has increased by 1.5% from 16,428,313 MWh to 16,671,691 MWh. GHG emissions from electricity fell despite consumption growing because of the significant decrease in the carbon intensity of the regional electricity grid.

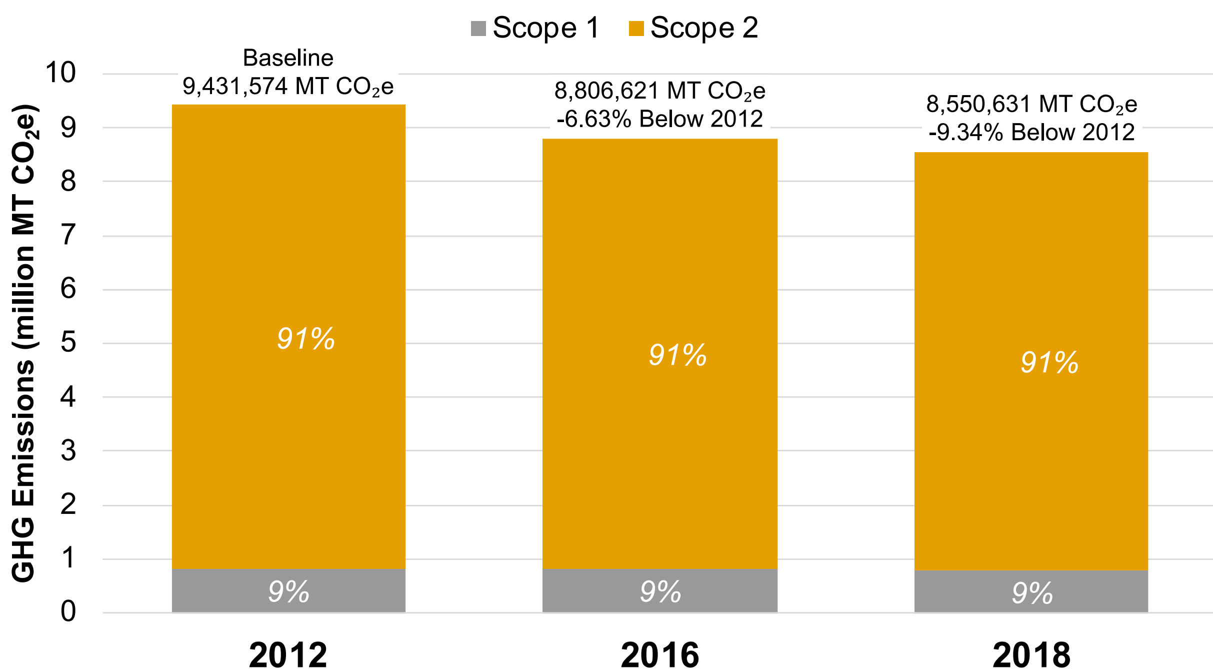

Figure 3. Stationary Energy GHG Emissions by Scope Since 2012

Electricity GHG emissions are calculated using electricity consumption data (activity data) and GHG emissions factors published by the EPA in the eGRID.[5] The Arizona-New Mexico (AZNM) subregion GHG emissions factor is used to calculate electricity GHG emissions. An eGRID subregion emissions factor is not utility-specific, and characterizes the typical GHG profile of electricity generation in that area in CO_2e emissions per MWh of net generation. The AZNM subregion emissions factor includes all regional power plants in Arizona, Western and Central New Mexico, Southern Nevada, and parts of southwestern California. Therefore, GHG emissions reduction activities undertaken by regional utilities – APS, SRP, Tucson Electric Power, and the Public Service Company of New Mexico (PNM) – and municipalities – such as the City-owned solar facilities at the Lake Pleasant water treatment plant and Sky Harbor International Airport – reduce the AZNM subregion GHG emissions factor.

Since 2012, the AZNM subregion GHG emissions factor has decreased 11.2%. This reduction has occurred due to an increase in electricity generation from natural gas and renewable sources, such as wind and solar energy, and, most importantly, a decrease in coal electricity generation. According to eGRID data, the percentage of natural gas production in the AZNM generation portfolio has increased 8%; wind and solar generation has increased 5%; and coal has decreased 11%. Coal still made up 27% of electricity production in the AZNM subregion.

The single largest source of GHG emissions in the AZNM subregion – the Navajo Generating Station operated by SRP – closed in 2019[6]. SRP has a long-term goal of reducing the GHG-intensity of electricity production 62% below 2005 levels by 2035 and 90% by 2050. APS has a carbon neutrality goal for 2050[7]; the utility plans to source 65% of electricity from renewable sources by 2030 and to stop coal-fired electricity generation by 2031[8]. PNM plans to have 100% carbon free electricity by 2040[9]. Therefore, based on how electricity emissions are calculated, the recent coal-fired power plants closures and announcements by regional electric utilities to reduce the

[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 (2019). Navajo Generating Station Permanently Shuts Down. URL: https://media.srpnet.com/navajo-generating-station-permanently-shuts-down/
[7] Arizona Public Service (2020). Stakeholder Perspectives. URL: https://www.aps.com/en/About/Our-Company/Clean-Energy/Stakeholder-Perspectives
[8] Arizona Public Service (2020). Clean Energy. URL: https://www.aps.com/en/About/Our-Company/Clean-Energy
[9] PNM (2020). Our Commitment. URL: https://www.pnm.com/our-commitment

GHG-intensity of electricity generation, or to go carbon neutral, will result in a significant reduction in community-scale GHG emissions. The City of Phoenix recently pledged to become carbon neutral by 2050 and similar efforts by Arizona Public Service (APS) and Salt River Project (SRP) will help the City achieve its GHG reduction goals.

1.1 Scope 1 Stationary Energy

Scope 1 Stationary Energy GHG emissions occur from the combustion of natural gas delivered by Southwest Gas within the city boundary. Citywide natural gas consumption was 3% lower in 2018 than in 2012 (Table 3). Additionally, natural gas consumption in the manufacturing industries and construction subsector has been reclassified to the commercial and institutional buildings and facilities subsector, resulting in a relative increase of natural gas consumption at commercial and institutional buildings and facilities. Future community GHG emissions will consider retroactively combining these two sectors.

Table 3. Summary of Scope 1 Stationary Energy GHG Emissions

Scope 1 Activity Data (kilotherms)	**2012**	**2016**	**2018**
Residential Buildings	58,796	58,946	53,241
Commercial & Industrial Buildings	63,802	69,036	83,367
Manufacturing Industries & Construction	16,289	13,850	1,562
Agriculture, Fishing, and Forestry Activities	12,982	9,737	8,744
Non-specified	11	15	14
Total	**151,881**	**151,584**	**146,927**
Scope 1 GHG Emissions (MT CO_2e)	**2012**	**2016**	**2018**
Residential Buildings	312,298	313,330	283,007
Commercial & Industrial Buildings	338,887	366,966	443,139
Manufacturing Industries & Construction	86,522	73,622	8,303
Agriculture, Fishing, and Forestry Activities	68,954	51,758	46,477
Non-specified	60	78	74
Total	**806,722**	**805,753**	**781,000**

Scope 1 Stationary Energy GHG emissions fell by 25,722 MT CO_2e below 2012 levels (Figure 4). Natural gas consumption at commercial and institutional buildings are the largest source of Scope 1 Stationary Energy GHG emissions. In 2012, Scope 1 Stationary Energy GHG emissions from commercial and institutional buildings and facilities subsector were only slightly higher than the residential buildings subsector, 42% and 39% respectively. In 2018, the commercial and institutional buildings and facilities subsector comprised 57% of Scope 1 Stationary Energy GHG emissions.

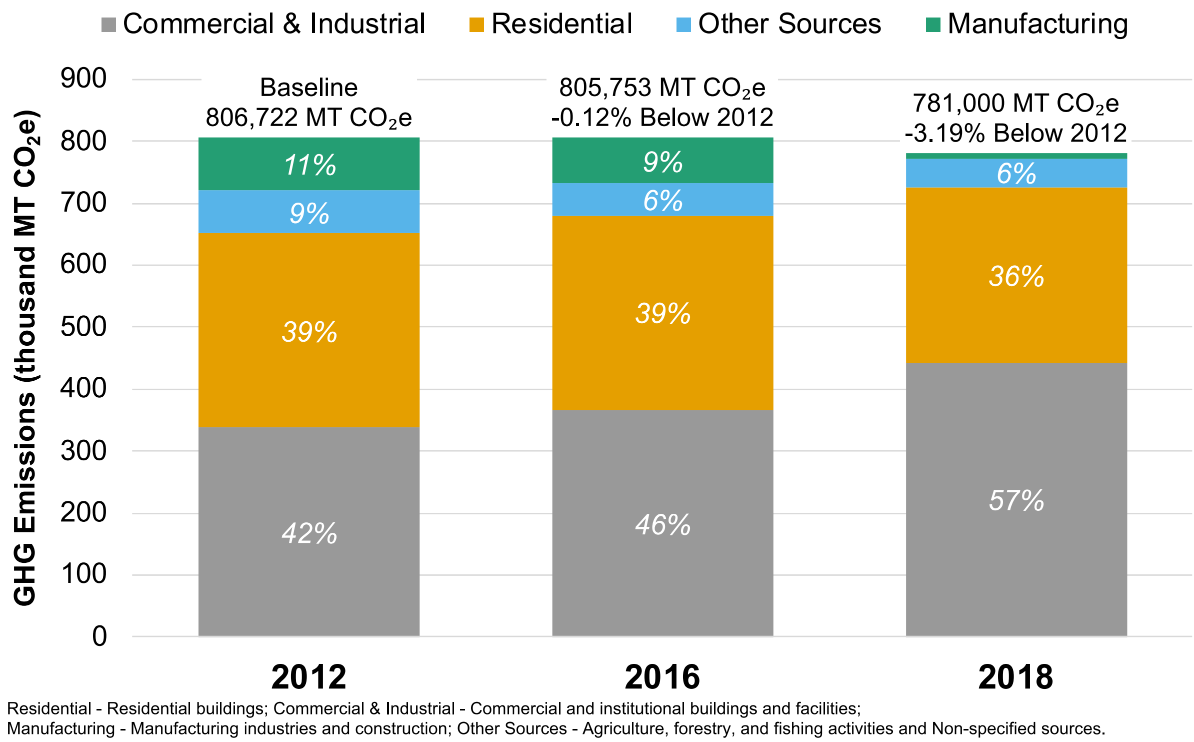

Figure 4. Scope 1 Stationary GHG Emissions Since 2012

1.2 Scope 2 Stationary Energy

Scope 2 Stationary Energy GHG emissions occur from the consumption of electricity purchased from Arizona Public Service (APS) and Salt River Project (SRP) within the city boundary. Between 2012 and 2018, GHG emissions from the consumption of electricity purchased electricity fell by 9.92% (855,221 MT CO_2e) despite consumption levels increasing by 1.5% or 243,378 MWh (Table 4).

Table 4. Summary of Scope 2 Stationary Energy GHG Emissions

Scope 2 Activity Data (GWh)	2012	2016	2018
Residential Buildings	7,202	7,624	7,451
Commercial & Industrial Buildings	8,599	8,579	9,220
Manufacturing Industries & Construction	627	612	IE*
Total	**16,428**	**16,815**	**16,671**
Scope 2 GHG Emissions (MT CO_2e)	**2012**	**2016**	**2018**
Residential Buildings	3,780,960	3,627,624	3,472,607
Commercial & Industrial Buildings	4,514,711	4,082,219	4,297,024
Manufacturing Industries & Construction	329,182	291,025	IE*
Total	**8,624,852**	**8,000,868**	**7,769,631**

**In 2018, Manufacturing industries and construction were IE in Commercial and institutional buildings.*
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 are were NE and, therefore, not included in this table.

In 2018, Scope 2 Stationary Energy GHG emissions were 7,769,631 MT CO_2e, which was 9.92 % below the 2012 levels of 8,624,852 MT CO_2e (Figure 5). Stationary Energy GHG emissions decreased due to the regional electricity grid becoming 11.2% less GHG-intensive from the retirement and replacement of coal-fired power plants with natural gas and renewable (wind and solar) electricity generation.[10] Additionally, residential electricity consumption only grew 3.5% during a period in which population grew approximately 12.6%. The decreased growth in electricity consumption relative to population growth could have occurred for numerous reasons, including energy efficiency retrofits, energy efficient new construction, milder weather, cost, or resident and commercial solar adoption. Further work must be conducted to determine the extent each of these contributed to the decreased growth in electricity consumption.

1.3 Scope 3 Stationary Energy

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 2018, transmission and distribution (T&D) loss in the State of Arizona has

[10] 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. The 11.2% reduction in the GHG intensity of the regional electricity was calculated comparing the 2012 and 2018 emissions factor for the Arizona-New Mexico subregion.

averaged 4.6% ± 0.6% of electricity consumption and has ranged between 3.4% in 2015 up to 5.7% in 1996.[11] Scope 3 Stationary Energy GHG emissions are not within the scope of GPC BASIC-level reporting. They are being presented to show the full extent of GHG emissions from electricity consumption. T&D loss underscores the fact that that on-site renewable energy generation and energy efficiency avoids GHG emissions from the electricity lost during T&D in the electricity grid.

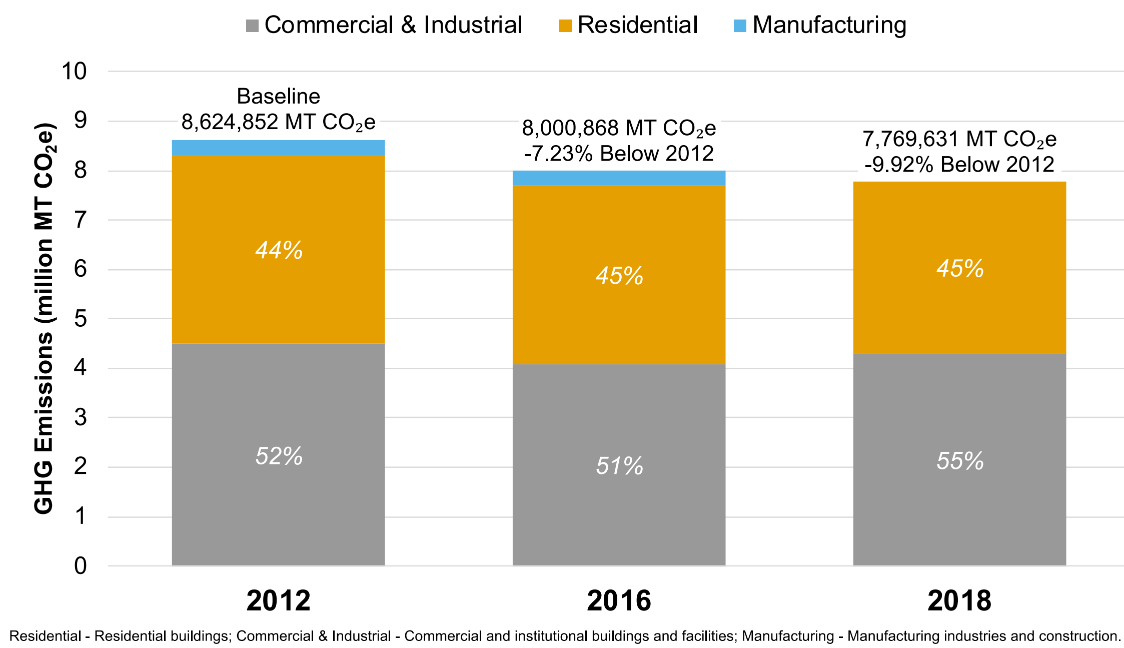

Figure 5. Scope 2 Stationary GHG Emissions Since 2012

Table 5. Summary of Scope 3 Stationary Energy GHG Emissions

Scope 3 Activity Data	**2012**	**2016**	**2018**
Transmission & Distribution Loss (MWh)	613,573	631,792	666,138
Natural Gas Leakage (therms)	NE	NE	NE
Scope 3 GHG Emissions (MT CO2e)	**2012**	**2016**	**2018**
Transmission & Distribution Loss (MWh)	322,125	300,632	310,345
Natural Gas Leakage (therms)	NE	NE	NE
Total	**322,125**	**300,632**	**310,345**

**NE – Not Estimated*

[11] 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 Sector GHG emissions have both Scope 1 and Scope 2 components. Scope 1 Transportation Sector GHG emissions occur due to the combustion of fossil fuels – gasoline, diesel, CNG, LNG, LPG – and biofuel blends – B20 biodiesel and E85 ethanol. Scope 2 Transportation Sector GHG emissions occur from the consumption of electricity to charge plug-in electric vehicles and power electric light rail. In 2018, community-scale Transportation sector GHG emissions totaled 7,748,912 MT CO_2e and were 12.7% greater (853,881 MT CO_2e) than the 2012 levels of 6,895,031 MT CO_2e.

Motor gasoline is the largest source of community-scale Transportation Sector GHG emissions at 76.4% (Figure 6). Community-level gasoline consumption encompasses all gasoline end uses. While some end uses may not be for transportation purposes (e.g., gasoline lawnmowers), emissions from these end uses were assumed to be insignificant compared to gasoline consumption for motor vehicles.[12] GHG emissions from Jet Fuel A (10.1%) and on-road diesel fuel (8.0%) are the next largest sources of transportation GHG emissions, and are much smaller sources than motor gasoline consumption. On-road combustion of motor gasoline alone is responsible for 37% of all community-scale GHG emissions.

Community-level GHG emissions reduction plans must address how to reduce the single largest source of GHG emissions. Transportation Sector GHG emissions have grown since 2012. GHG emissions from gasoline combustion grew on pace with population growth. As growth occurs, viable solutions to reduce gasoline consumption – from plug-in EVs and increased mass transit to creating walkable communities – are critical for meeting GHG emissions reductions goals.

[12] 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

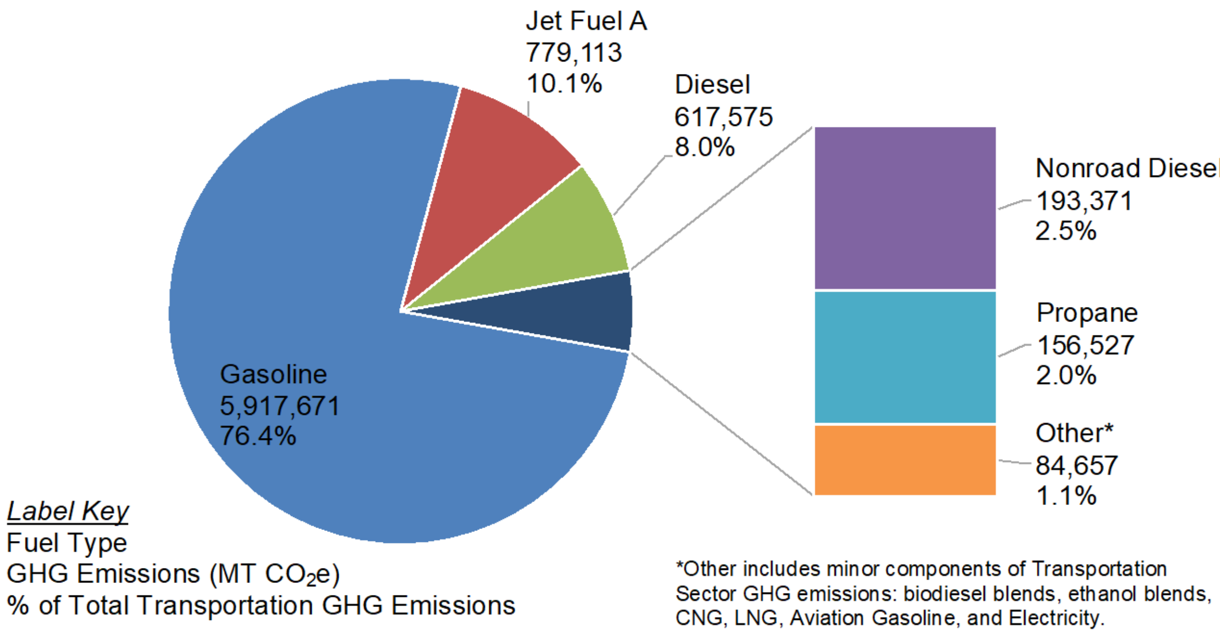

Figure 6. Summary of Transportation Sector GHG Emissions by Fuel Type

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 6). Growth in on-road transport GHG emissions (12.7%) has largely followed population growth (12.7%). 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. Community-level GHG emissions from off-road transport, which is the third largest source community-scale Transportation sector GHG emissions, result from construction equipment, agricultural equipment and mining equipment.

Table 6. Summary of Scope 1 Transportation GHG Emissions (MT CO_2e)

Scope 1 Sources	2012	2016	2018
On-road transport	5,855,292	6,441,344	6,596,202
Railways*	23,545	23,545	23,545
Commercial Aviation	698,263	705,643	779,113
Civil Aviation	13,394	15,067	10,043
Nonroad transport	298,237	320,122	326,353
Total	**6,888,732**	**7,505,722**	**7,735,257**

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

Gasoline consumption is the major driver of Scope 1 Transportation GHG Emissions (Table 7). Between 2012 and 2018, 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. With the City of Phoenix phasing out LNG usage, emissions from this fuel type should reduce to zero. LNG is being replaced by CNG in the City of Phoenix vehicle fleet.

Table 7. Scope 1 Transportation Activity Data and GHG Emissions by Fuel

Scope 1 Activity Data	2012	2016	2018
Gasoline [1]	586,464	652,970	667,093
On-Road Diesel[1]	51,781	57,834	60,435
B20 Biodiesel[1]	3,034	2,701	3,028
E85 Ethanol[1]	287	157	311
E54 Ethanol [1]	0	109	0
CNG[1] – *therms*	4,304	3,484	6,356
LNG[1] – *GGE*	6,222	2,544	543
Jet Fuel A (Commercial Aviation)[2]	71,038	71,788	79,263
Aviation Gasoline (Civil Aviation)[2]	1,569	1,765	1,176
Railways**	NE	NE	NE
Nonroad Diesel[3]	14,528	16,009	16,619
Nonroad LPG[3]	NE	NE	NE

Scope 1 GHG Emissions (MT CO_2e)	2012	2016	2018
Gasoline [1]	5,250,540	5,797,934	5,917,671
On-Road Diesel[1]	529,242	591,063	617,575
B20 Biodiesel[1]	24,785	22,062	24,732
E85 Ethanol[1]	379	207	410
E54 Ethanol [1]	0	441	0
CNG[1] – *therms*	22,595	18,293	33,391
LNG[1] – *GGE*	27,751	11,345	2,423
Jet Fuel A (Commercial Aviation)[2]	698,263	705,643	779,113
Aviation Gasoline (Civil Aviation)[2]	13,394	15,067	10,043
Railways**	23,545	23,545	23,545
Nonroad Diesel[3]	148,488	163,595	169,826
Nonroad LPG[3]	149,749	156,527	156,527
Total	**6,888,732**	**7,505,722**	**7,735,257**

**Activity Data are reported in gallons unless otherwise noted.*
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 sector GHG emissions, which includes the consumption of purchased electricity to charge electric vehicles and to power electric light rail, have increased 117% since 2012 (Table 8). The growth of Scope 2 Transportation sector GHG emissions is primarily from the increased adoption of plug-in electric vehicles; Scope 2 GHG emissions from on-road transport increased 674% since 2012. GHG emissions related to the Valley Metro light rail system increased 2,428 MT CO_2e (44%) largely due to the expansion of the light rail system since 2012.

GHG emissions from electric transport are a small percentage of overall transportation-related GHG emissions (~0.2%). As the regional electricity grid becomes less GHG-intensive over the coming decades, the use of electric personal transport – plugin EVs and plugin hybrid EVs – and electric mass transit – light rail and battery electric buses – will become GHG-saving alternatives to traditional gasoline-powered personal vehicles. Increasing electric-powered transit will require investment in electric mass transit, which is already happening through T2050, battery technology improvements, installing a regional charging station network, and market conditions to change so electric-powered transport becomes more consumer-friendly.

Table 8. Summary of Scope 2 Transportation GHG Emissions

Scope 2 Activity Data (MWh)	2012	2016	2018
On-road transport	1,393	7,075	12,148
Railways (Light Rail)	10,605	12,095	17,157
Total	**11,998**	**19,170**	**29,305**
Scope 2 GHG Emissions (MT CO_2e)	**2012**	**2016**	**2018**
On-road transport	731	3,367	5,661
Railways (Light Rail)	5,568	5,755	7,996
Total	**6,299**	**9,122**	**13,657**

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 9). 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 9. Summary of Scope 3 Transportation GHG Emissions

Scope 3 Activity Data (MWh)	2012	2016	2018
On-road transport	52	266	485
Railways (Light Rail)	396	454	686
Total	**448**	**720**	**1,171**
Scope 3 GHG Emissions (MT CO_2e)	**2012**	**2016**	**2018**
On-road transport	27	127	226
Railways (Light Rail)	208	216	319
Total	**235**	**343**	**546**

3. Waste Sector

The Waste Sector includes GHG emissions from the disposal of municipal solid waste (MSW); wastewater treatment; and compost processing. It is the smallest GHG emissions sector in the community-scale inventory, comprising only 1% of overall GHG emissions.

Community-level emissions from MSW have both Scope 1 and Scope 3 components. Unlike Scope 3 emissions in the Stationary Energy and Transportation sectors, Scope 3 Waste emissions are included within the scope of GPC BASIC-level reporting. Scope 1 MSW emissions include emissions from waste/wastewater generated and treated within the city boundary in addition to waste imported into the city and treated. Wastewater treatment GHG emissions sources include the 23rd Avenue and 91st Avenue wastewater treatment plants. Compost emissions – the biological treatment of waste in – occur at the 27th Avenue Compost Facility, but have historically also occurred at a compost facility co-located at the 27th Avenue Landfill. Emissions from both wastewater treatment and composting are Scope 1 emissions. Scope 3 MSW emissions cover the emissions from all waste exported outside the city boundary. Currently, there are no open landfills within city limits so all Scope 1 MSW emissions are from closed landfills. Over time, these emissions will decrease as the biological processes that generate GHG emissions cease. All solid waste is disposed at a city-owned landfill outside the city-boundary, which is a Scope 3 emissions.

Scope 1 Waste GHG emissions occur from the disposal of solid waste generated within the city. These GHG emissions will continue to decrease, as they have since 2012, because there are no longer any open landfills within the City boundary, and each year there is less waste available for the generation of methane emissions (Table 10). 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. However, as solid waste generated within the City is now primarily disposed of outside the City boundary, Scope 3 Waste GHG emissions will continue to increase in future GHG emissions inventories.

While wastewater treatment GHG emissions have increased since 2012, so too has the population, and these emissions are largely population-dependent. Wastewater treatment GHG emissions are a small fraction of overall community-scale GHG emissions. Scope 1 GHG emissions from the biological treatment of waste generated (compost processing) will likely increase over time with increased organic waste diversion goals. These emissions will be offset by reducing future Scope 3 Waste GHG emissions generated at the SR-85 landfill and Scope 1 Transportation GHG emissions from hauling waste to the landfill.

Table 10. Summary of Scope 1 Waste GHG Emissions

Scope 1 Sources Activity Data (MT CH_4 Emissions)	2012	2016	2018
Disposal of Solid Waste Generated in the City	8,425	5,099	4,707
Biological Treatment of Waste Generated in the City	121	83	170
Wastewater Generated Inside the City	92.00	121.39	134.68
Total	**8,440**	**9,428**	**10,199**
Scope 1 Sources Activity Data (MT N_2O Emissions)	**2012**	**2016**	**2018**
Biological Treatment of Waste Generated in the City	9.09	6.22	12.73
Wastewater Generated Inside the City	22.13	22.75	24.26
Total	**8,440**	**9,428**	**10,199**
Scope 1 GHG Emissions (MT CO_2e)	**2012**	**2016**	**2018**
Disposal of Solid Waste Generated in the City	235,889	142,770	131,794
Biological Treatment of Waste Generated in the City	5,802	3,968	8,125
Wastewater Generated Inside the City	8,440	9,428	10,199
Total	**250,130**	**156,167**	**150,118**

Scope 3 Waste GHG emissions from the disposal of waste generated within the city, but disposed outside the city, will continue to increase (Table 11). This GHG emissions trend will occur as 2018 was the last full GHG inventory year with an operating landfill (Waste Management Lone Cactus Landfill) within the city boundary. As GHG emissions increase at the SR-85 landfill, methane capture and reuse programs may become a viable way to reduce waste related emissions, and offset Scope 1 Stationary Energy GHG emissions from natural gas combustion. The capture of digester gas at the 91st Ave WWTP for processing and sale as renewable natural gas (RNG) by Ameresco, Inc. will reduce Waste Sector GHG emissions from wastewater treatment. The diversion of green-organic waste from waste streams is a viable way to reduce future Waste sector GHG emissions.

Table 11. Summary of Scope 3 Waste GHG Emissions

Scope 3 Sources Activity Data (MT CH_4 Emissions)	2012	2016	2018
Disposal of Solid Waste Generated in the City but Disposed Outside the City at SR-85	295	2,147	2,029
Disposal of Solid Waste Generated in the City but Disposed Outside the City by Private Haulers	3,844	3,450	3,474
Total	**4,139**	**5,597**	**5,503**

Scope 3 GHG Emissions (MT CO_2e)	2012	2016	2018
Disposal of Solid Waste Generated in the City but Disposed Outside the City at SR-85	8,260	60,116	56,820
Disposal of Solid Waste Generated in the City but Disposed Outside the City by Private Haulers	107,631	96,598	97,271
Total	**115,891**	**156,714**	**154,091**

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)			% Change	
			2012	2016	2018	2012 - 2018	2016 - 2018
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	-9%	-10%
I.1.2	2	Emissions from grid-supplied energy consumed within the city boundary	3,780,960	3,627,624	3,472,607	-8%	-4%
I.1.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	141,213	136,308	138,752	-2%	2%
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	31%	21%
I.2.2	2	Emissions from grid-supplied energy consumed within the city boundary	4,514,711	4,082,219	4,297,024	-5%	5%
I.2.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	168,618	153,389	171,693	2%	12%
I.3		**Manufacturing industries and construction**					
I.1.1	1	Emissions from fuel combustion within the city boundary	312,298	313,330	283,007	-9%	-10%
I.1.2	2	Emissions from grid-supplied energy consumed within the city boundary	3,780,960	3,627,624	3,472,607	-8%	-4%
I.2.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	168,618	153,389	171,693	2%	12%
I.4		**Energy Industries**					

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Greenhouse Gas Emissions (metric tons CO_2e)			% Change	
			2012	2016	2018	2012 - 2018	2016 - 2018
I.4.1	1	Emissions from energy used in power plant auxiliary operations within the city boundary	NE	NE	NE	—	—
I.4.2	2	Emissions from grid-supplied energy consumed in power plant auxiliary operations within the city boundary	NE	NE	NE	—	—
I.4.3	3	Emissions from transmissions and distribution losses from grid-supplied energy consumption in power plant auxiliary operations	NE	NE	NE	—	—
I.4.4	1	*Emissions from energy generation supplied to the grid*	986,289	1,200,633	1,391,552	41%	16%
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	-33%	-10%
I.5.2	2	Emissions from grid-supplied energy consumed within the city boundary	IE	IE	IE	—	—
I.5.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	IE	IE	IE	—	—
I.6		**Non-specified sources**					
I.1.1	1	Emissions from fuel combustion within the city boundary	312,298	313,330	283,007	-9%	-10%
I.1.2	2	Emissions from grid-supplied energy consumed within the city boundary	3,780,960	3,627,624	3,472,607	-8%	-4%
I.1.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	141,213	136,308	138,752	-2%	2%
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	—	—

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Greenhouse Gas Emissions (metric tons CO_2e)			% Change	
			2012	2016	2018	2012 - 2018	2016 - 2018
I.8		**Fugitive emissions from oil and natural gas systems**					
I.8.1	1	Emissions from fugitive emissions within the city boundary	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)			% Change	
			2012	2016	2018	2012-2018	2012-2018
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	6,596,202	13%	2%
II.1.2	2	Emissions from grid-supplied energy consumed within the city boundary for on-road transportation	731	3,367	5,661	674%	68%
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	27	127	226	728%	79%
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	0%	0%
II.2.2	2	Emissions from grid-supplied energy consumed within the city boundary for railways	5,568	5,755	7,996	44%	39%
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	319	54%	48%
II.3		**Waterborne navigation**					
II.3.1	1	Emissions from fuel combustion for waterborne navigation occurring within the city boundary	NO	NO	NO	—	—
II.3.2	2	Emissions from grid-supplied energy consumed within the city boundary for waterborne navigation	NO	NO	NO	—	—

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Greenhouse Gas Emissions (metric tons CO_2e)			% Change	
			2012	2016	2018	2012-2018	2012-2018
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	—	—
II.4		**Aviation**					
II.4.1	1	Emissions from fuel combustion for aviation occurring within the city boundary	711,658	720,710	789,156	11%	9%
II.4.2	2	Emissions from grid-supplied energy consumed within the city boundary for aviation	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	—	—
II.5		**Off-road transportation**					
II.5.1	1	Emissions from fuel combustion for off-road transportation occurring within the city boundary	298,237	320,122	326,353	9%	2%
II.5.2	2	Emissions from grid-supplied energy consumed within the city boundary for off-road transportation	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.

Color Key
Sources required for BASIC reporting
Sources required for BASIC+ reporting

NO	Not Occurring	An activity or process does not occur or exist within the city.	Sources included in Other Scope 3
C	Confidential	GHG emissions which could lead to the disclosure of confidential information and can therefore not be reported.	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 GHG Emissions

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Greenhouse Gas Emissions (metric tons CO_2e)			% Change	
			2012	2016	2018	2012-2018	2016-2018
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	142,770	131,794	-44%	-8%

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Greenhouse Gas Emissions (metric tons CO_2e)			% Change	
			2012	2016	2018	2012-2018	2016-2018
III.1.2	3	Emissions from solid waste generated within the city boundary and disposed in landfills or open dumps outside the city boundary	115,891	156,714	154,091	33%	-2%
III.1.3	1	*Emissions from waste generated outside the city boundary and disposed in landfills or open dumps within the city boundary*	NO	NO	NO	—	—
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	40%	105%
III.2.2	3	Emissions from solid waste generated within the city boundary but treated biologically outside of the city boundary	NO	NO	NO	—	—
III.2.3	1	*Emissions from waste generated outside the city boundary but treated biologically within the city boundary*	NO	NO	NO	—	—
III.3		**Incineration and open burning**					
III.3.1	1	Emissions from solid waste generated treated within the city boundary	NO	NO	NO	—	—
III.3.2	3	Emissions from solid waste generated within the city boundary but treated outside of the city boundary	NO	NO	NO	—	—
III.3.3	1	*Emissions from waste generated outside the city boundary but treated within the city boundary*	NO	NO	NO	—	—
III.4		**Wastewater treatment and discharge**					
III.4.1	1	Emissions from wastewater generated and treated within the city boundary	8,440	9,428	10,199	21%	8%

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Greenhouse Gas Emissions (metric tons CO_2e)			% Change	
			2012	2016	2018	2012-2018	2016-2018
III.4.2	3	Emissions from wastewater generated within the city boundary but treated outside of the city boundary	NO	NO	NO	—	—
III.4.3	1	*Emissions from wastewater generated outside the city boundary but treated within the city boundary*	NO	NO	IE	—	—
IV		**Industrial Processes and Product Uses (IPPU)**					
IV.1	1	Emissions from industrial processes occurring within the city boundary	NE	NE	NE	—	—
IV.2	1	Emissions from product use occurring within the city boundary	NE	NE	NE	—	—
V		**Agriculture, Forestry, and Other Land Use (AFOLU)**					
V.1	1	Emissions from livestock within the city boundary	NE	NE	NE	—	—
V.2	1	Emissions from land within the city boundary	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	—	—
VI		**Other Scope 3**					
VI.1	3	Other Scope 3	3,001	715	278	-91%	-61%

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.

Color Key
Sources required for BASIC reporting
Sources required for BASIC+ reporting

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.

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.

Sources included in Other Scope 3
Sources required for territorial reporting
Non-applicable emissions

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 – 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.

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, 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.

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 B4.

Table B4. 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.

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.

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.[13] The APS West Phoenix Power Plant is included in the 2018 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, and 2018 were

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

obtained from the EPA Greenhouse Gas Reporting Program through the Facility Level Information on GreenHouse gases Tool (FLIGHT).[14]

A similar data request process was followed for each of the GHG emissions inventory years. For 2012, APS provided consumption data at the zip code resolution for residential, commercial, and industrial consumers. However, for 2016 and 2018, APS only provided total consumption data for residential, commercial, and industrial consumers for zip codes associated with the City of Phoenix. Unlike APS, SRP only provided total consumption for residential and commercial consumers within the City of Phoenix.

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.

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

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 2012.

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

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[15] emissions factor for the AZNM subregion for GHG emissions factor for CO_2, CH_4, N_2O (*j*) for eGRID reporting year (*y*). y = 2012 (i.e.

[14] 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

[15] 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

electricity emissions from eGRID 2012) for calendar year 2012 data and y = 2016 (i.e. electricity emissions from eGRID 2016) for calendar year 2016 and 2018 data.

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 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*). y = 2012 (i.e. electricity emissions from eGRID 2012) for calendar year 2012 data and y =

(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.

2016 (i.e., electricity emissions from eGRID 2016) for calendar year 2016 and 2018 data.

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*). y = 2012 (i.e. electricity emissions from eGRID 2012) for calendar year 2012 data and y = 2016 (i.e. electricity emissions from eGRID 2016) for calendar year 2016 and 2018 data.

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 from 1990 through 2017.[16] For each inventory year, and using 2017 and proxy for 2018, 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, and 2018 – 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

[16] 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 (Table C1).

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 (kWh)*	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.*

C.5 Impact of Electricity Emissions Factor on GHG Emissions

Community-level GHG emissions are highly sensitive to the emissions factor used to calculate GHG emissions from electricity consumption. Previous GHG emissions inventories – both government operations and community-scale inventories – have used the electricity emissions factor for the Arizona-New Mexico subregion from EPA eGRID. eGRID emissions factors available at multiple scales in addition to the eGRID subregion. These scales include plant (finest resolution), plant operator (utility), balancing authority, state, and NERC region to name a few. Arizona is in the Western Electricity Coordinating Council (WECC) NERC region. The eGRID GHG emissions factors at each of these scales provide a range of GHG emissions intensity for electricity consumption within the city (Table C2).

Table C2. Electricity GHG EFs Derived from Multiple eGRID Decision Boundaries

Electricity EF Boundary	eGRID 2012 (MT CO_2e/MWh)	eGRID 2016 (MT CO_2e/MWh)	eGRID 2018 (MT CO_2e/MWh)
SRP & APS Plant Operator (Utility-Scale)	0.55	0.43	0.47
SRP & APS Balancing Authority	0.53	0.43	0.46
State of Arizona	0.48	0.43	0.44
*AZNM eGRID Subregion**	0.52	0.48	0.47
Western Electricity Coordinating Council (WECC)	0.44	0.40	0.35

In the eGRID 2018 data, the plant operator GHG EF was greater than the AZNM GHG EF; both were greater than the balancing authority and State of Arizona GHG EF. In the eGRID 2012 database this is not the case: the AZNM subregion is less GHG-intensive than SRP & APS plant operator and balancing authority scale, but more GHG-intensive than electricity production in the State of Arizona. For all eGRID years, the local and regional scales are all more GHG-intensive than the WECC as a whole. Using the AZNM eGRID subregion EF for electricity increases emissions inventory by 657,133 MT CO_2e in 2012; 840,710 MT CO_2e in 2016; and 418,274 MT CO_2e in 2018 relative to the State of Arizona GHG EF for electricity consumption (Table C3). Therefore, the boundary used to calculate the EF for electricity consumption is extremely important as minor changes can cause significant changes to GHG emissions totals. Therefore, per existing EPA guidance, it is recommended to use the AZNM eGRID subregion EF until new datasets are produced that provide more detailed information on the carbon-intensity of a locality's electricity supply.

Table C3. Electricity GHG Emissions from Multiple eGRID Decision Boundaries

Electricity EF Boundary	2012 (MT CO_2e)	2016 (MT CO_2e)	2018 (MT CO_2e)
SRP & APS Plant Operator (Utility-Scale)	9,035,572 (492,849)	7,230,104 (-840,710)	7,921,800 (152,169)
SRP & APS Balancing Authority	8,707,006 (164,283)	7,230,104 (-840,710)	7,643,560 (-126,071)
State of Arizona	7,885,590 (-657,133)	7,230,104 (-840,710)	7,351,257 (-418,274)
*AZNM eGRID Subregion**	*8,542,723* —	*8,070,814* —	*7,769,631* —
Western Electricity Coordinating Council (WECC)	7,228,458 (-1,314,265)	6,725,678 (-1,345,136)	5,858,867 (-1,910,764)

*Note: Calculated GHG emissions are the top number in each cell. The change in emissions relative to the AZNM eGRID Subregion EF is shown in parentheses in each cell. Positive parenthetical values indicate an increase in GHG emissions relative to the AZNM eGRID Subregion EF and negative parenthetical values indicate a decrease in GHG emissions.

Due to the interconnectedness of the gird, regional trends and projects to reduce the GHG intensity of electricity production in the AZNM subregion will place downward pressure on the subregion EF. For example, the closure of the Navajo Generating Station in 2019, and additional closures and partial closures of coal-fired electricity generating facilities by APS and PNM, will significantly reduce the AZNM subregion EF. Additionally, further development of utility-scale solar power facilities will also reduce the local and regional GHG EFs for electricity consumption, resulting in additional GHG emissions reductions compared to the 2012 baseline.

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.[17] 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 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 2018 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 for 2012, 2016 and 2018 haven been added to the community-scale inventory. 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[18] used for inventory years 2012 and 2016. 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

[17] Arizona Department of Transportation. Archived Audits and Reports. *Highway User Revenue Fund (HURF).* URL: https://azdot.gov/node/5069.
[18] U.S. Department of Transportation. The National Transit Database. URL: https://www.transit.dot.gov/ntd.

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.

D.3.1 Freight Rail

The National Emissions Inventory (NEI)[19] 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, and 2018. 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 NEI was used to gather data on commercial aviation fuel consumption at Phoenix Sky Harbor International Airport and Phoenix Deer Valley Airport. The 2011 NEI was used as a proxy for 2012 and the 2017 NEI was used as a proxy for 2016 and 2018. Jet Fuel A was assumed to be the primary fuel consumed by commercial aviation.

To estimate Jet Fuel A consumption the following procedure was followed, CO_2 emissions Phoenix Sky Harbor International Airport and Phoenix Deer Valley Airport data for 'Aircraft /Air Taxi /Turbine', 'Aircraft /General Aviation /Turbine', and 'Aircraft/Commercial' processes were obtained from the NEI. Next, the total emissions of CO_2 emissions were converted to gallons of Jet Fuel A using the CO_2 EF for Jet Fuel A. The estimated consumption of Jet Fuel A was then converted back into CO_2 emissions in addition to CH_4 and N_2O emissions.

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

As the NEI is published for 2011 and 2017, estimated Jet Fuel A consumption was scaled to the 2012, 2016, and 2018 calendar years using landing and takeoff operations (LTO) activity data obtained from the City of Phoenix.[20] As Jet Fuel A consumption is strongly tied to commercial aircraft LTO, it was used as an indicator to scale 2011 and 2017 activity data to the inventory calendar year.

D.4.2 Civil Aviation

The NEI was used to gather data on civil aviation fuel consumption at Phoenix Sky Harbor International Airport and Phoenix Deer Valley Airport. The 2011 NEI was used as a proxy for 2012 and the 2017 NEI was used as a proxy for 2016 and 2018. Aviation gasoline was assumed to be the primary fuel consumed by commercial aviation. As aviation gasoline contains lead (Pb), lead emissions reported at Phoenix Sky Harbor International Airport and Phoenix Deer Valley Airport in the National Emissions Inventory is used an indicator of aviation gasoline consumption.

Per EPA guidance documents, the lead emissions from piston-based aircraft is related to aviation gasoline consumption through the following equation.[21]

$$g\ Pb\ = \frac{gallons\ Aviation\ Gasoline\ \times \left(\frac{2.12\ g\ Pb}{gallons\ Aviation\ Gasoline}\right) \times\ 0.95}{907{,}180\ \frac{g}{ton}}$$

Lead emissions obtained from the NEI for Phoenix Sky Harbor International Airport and Phoenix Deer Valley Airport were input to the equation above and used to solve for the gallons of aviation gasoline consumed at each airport. As the NEI is published for 2011 and 2017, estimated aviation gasoline gallons is scaled to 2012, 2016, and 2018 calendar years using LTO activity data obtained from the City of Phoenix[22]. As lead emissions are reported for LTO operations, which is 10% of an aircraft operation, the estimated gallons of Aviation Gasoline are dived by 10%.

[20] Phoenix Sky Harbor International Airport. Airport Statistics. URL: https://www.skyharbor.com/About/Information/AirportStatistics.
[21] U.S. Environmental Protection Agency, 2013. Assessment and Standards Division Office of Transportation and Air Quality. Calculating Piston-Engine Aircraft Airport Inventories for Lead for the 2011 National Emissions Inventory. Report EPA-420-B-13-040.
[22] Phoenix Sky Harbor International Airport. Airport Statistics. URL: https://www.skyharbor.com/About/Information/AirportStatistics.

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”[23] 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.

[23] 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.

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 (Table D1). 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 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. 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 2017. 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.

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 2018 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 2018 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 2012, 2016, and 2018 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 2018 GHG Emissions Inventory of Local Government Operations*. Please refer to the *City of Phoenix 2018 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 2018 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: 1990-2017*.[24]

E.4 GAC Hauling and Regeneration

GHG emissions from GAC hauling and regeneration were obtained from the *City of Phoenix 2018 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.

[24] 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