Technical Appendix

GHG Reduction Calculation Method

To estimate the magnitude of greenhouse gas emissions reduced through the implementation and operation of USATEN, we use EPA, EIA, and EnergyStar data to estimate annual carbon dioxide, nitrous oxide, and methane emissions from the consumption of grid electricity, from the combustion of fossil gas, and from the production and delivery of fossil gas. We focus this analysis on the end-uses that USATEN will power: space heating and cooling end-uses at Union Station, and space heating, cooling, and water heating at Union Square. We use State of Connecticut greenhouse gas reduction targets to forecast grid emissions, an EIA forecast of fossil gas production to forecast production emissions, and EPA emissions factors to forecast combustion emissions, all through 2050. We perform this analysis both assuming the conditions of USATEN—the "Ground-Source Heat Pump (GHP)" scenario—and assuming the conditions of a "Business-as-Usual (BAU)" reference scenario. We calculate the sum of annual GHG emissions (MT CO_2e) between 2025 and 2030 and between 2025 and 2050 under each scenario, and then find the difference between those sums for each reference period (see table below). We do not use any external models or tools to conduct these calculations.

Summary of Cumulative GHG Emissions Reductions

Site	End-Use	Old System	Fuel Type	BAU Emissions 2025-2030	BAU Emissions 2025-2050	GHP Emissions 2025-2030	GHP Emissions 2025-2050	Difference in Emissions, 2025-2030	Difference in Emissions, 2025-2050
Union Station	Space Heating	3 Gas Boilers	Gas	1,454	6,212	940	1,009	-514	-5,203
	Space Cooling	Chiller	Electric	265	523	225	416	-39	-107
	ALL			1,719	6,735	1,165	1,425	-553	-5,310
Multifamily	Space Heating	Furnaces	Gas	12,727	54,381	8,574	11,141	-4,153	-43,240
	Water Heating	Boilers	Gas	3,953	16,890	2,656	3,415	-1,297	-13,475
	Space Cooling	Central Air	Electric	2,876	5,680	2,516	4,433	-360	-1,247
	ALL			19,556	76,951	13,747	18,989	-5,810	-57,962
Total Emissions Reductions	**Total (MT CO_2e)**	***ALL***		**21,275**	**83,686**	**14,912**	**20,414**	**-6,363**	**-63,272**
	% Change					**-30%**	**-76%**		

Summary of Annual GHG Emissions Reductions (MT CO_2e)

Year	Union Square	Union Station	Total Annual Reductions
2025	0	0	0
2026	0	0	0
2027	0	0	0

2028	-1,147	-113	-1,260
2029	-2,326	-203	-2,529
2030	-2,337	-237	-2,574
2031	-2,370	-237	-2,607
2032	-2,400	-237	-2,637
2033	-2,434	-237	-2,671
2034	-2,467	-237	-2,704
2035	-2,500	-238	-2,738
2036	-2,530	-238	-2,768
2037	-2,563	-238	-2,801
2038	-2,596	-238	-2,834
2039	-2,628	-238	-2,866
2040	-2,660	-238	-2,898
2041	-2,667	-238	-2,905
2042	-2,675	-238	-2,913
2043	-2,682	-238	-2,920
2044	-2,690	-238	-2,928
2045	-2,697	-238	-2,935
2046	-2,704	-238	-2,942
2047	-2,711	-238	-2,949
2048	-2,718	-238	-2,956
2049	-2,726	-238	-2,964
2050	-2,734	-238	-2,972
Total 2025-2030	-5,810	-553	-6,363
Total 2025-2050	-57,962	-5,310	-63,272

Reference Case Scenario: Calculations and Assumptions

The Business-As-Usual (BAU) scenario for these emissions reductions estimates does not include the effect of non-CPRG federal incentives. Even for projects that receive 9% Low-Income Housing Tax Credits and take advantage of Inflation Reduction Act (IRA) geothermal incentives, cost pressures around the development of new affordable housing make it infeasible for them to include additional capital costs for a shared thermal energy network than can serve Union Station and the surrounding neighborhood. Thus, we assume that the project will not proceed without CPRG funding, and so the BAU scenario focuses on the current heating and cooling systems at Union Station, and assumes that the Union Square development will be constructed with gas space and water heaters and an electric central air conditioning system according to minimum requirements of the State of Connecticut building code, the Energy Star Multifamily New Construction National Program Requirements, and the Connecticut Housing Finance Authority's Construction Guidelines for Energy Conservation and Sustainability.

Union Square

The Housing Authority of New Haven, Elm City Communities (ECC) has received a U.S. Department of Housing and Urban Development Choice Neighborhoods planning grant to transform the Robert T. Wolfe Apartments complex and the recently acquired parcels around it, now called "Union Square." The significant redevelopment planned by the Housing Authority plans to include 1,000 units of new residential construction with an average square footage of 900 square feet (a two-bedroom apartment) and an additional common area space of roughly 20% of each unit's area. In total, the Housing Authority estimates that the new residential construction will include 1,080,000 square feet of residential space built to Energy Star standards of efficiency.

Given the Housing Authority's plan to construct the new development to the Energy Star standard of efficiency, we based our calculations on the site energy data available through the Energy Star website as well as source-site ratios available through the Energy Star website. Energy Star reports that the median Energy Star site energy use intensity for multifamily housing is 59.6 kBtu per square foot. This figure was applied to the total projected square footage of the Union Square development (resulting in a total of 64,368 MMBtu of energy consumed annually) and then segmented into end uses for space heating, water heating, and air conditioning, utilizing the Energy Information Administration's annual household site end-use consumption the Northeast to allocate energy use by end type. These figures were then multiplied by the Energy Star program's source-site ratio according to energy source. For example, to estimate energy use for gas-powered space heating, we used the site energy use intensity, multiplied by the portion of the end use's consumption of 55% and the source-site factor of 1.05 (55% x 1.05 x 59.6 kBtu/ft^2 = 34.43 kBtu/ft^2). Thus we are able to arrive at an end use specific source energy use intensity, which represents the total amount of raw fuel that is required to operate the given end use system.

Using the efficiencies of the space heating, cooling, and water heating systems and each system's estimated annual energy consumption, we calculated the amount of energy required for each end-use, and then used the USATEN efficiency to determine the amount of energy the GHP system would require to provide the necessary amount of energy for space heating, cooling, and water heating. This calculation allowed us to estimate the emissions from USATEN's consumption of grid-supplied electricity.

1. $Total\ Building\ Energy\ Use\ (MMBtu) * End\ Use\ Share\ (\%) * \frac{Source}{Site} Adjustment\ = \boldsymbol{BAU\ System\ Energy\ Consumption}\ (MMBtu)$
2. $BAU\ System\ Energy\ Consumption\ (MMBtu) * \ Assumed\ BAU\ System\ Efficiency = \boldsymbol{Amount\ of\ Energy\ Required\ for\ End\ Use}\ (MMBtu)$
3. $\frac{Amount\ of\ Energy\ Required\ for\ End\ Use}{GHP\ System\ Efficiency} = \boldsymbol{GHP\ System\ Energy\ Consumption\ (MMBtu)}$

Union Square: BAU vs. GHP Scenarios Technical Summary				
	BAU Space Heating	**BAU Cooling**	**BAU Water Heating**	**GHP**
Assumed System Type	Furnaces	Air Conditioning	Gas Water Heater	Geothermal Network
System Fuel	Gas	Electricity	Gas	Electricity
System Efficiency (COP)	0.95	4.1	0.90	6
Rationale for Assumed Efficiency	Energy Star Multifamily New Construction National Program Requirements			Conservative estimate, based on NREL
Share of Building Energy Consumption	55%	4%	17%	76%
Source-Site Adjustment Factor	1.05	2.80	1.05	2.8

Annual Energy Consumption (MMBtu)	37,505.33	6,485.56	11,648.41	4,433.96
Kind of Emissions Released	Combustion, Production	Grid	Combustion, Production	Grid

Union Station

USATEN will meet Union Station's primary space heating and cooling needs, replacing the station's three gas-powered hot water boilers, as well as its chilled water pump ("chiller"). Annual gas consumption for space heating is assumed to be equivalent to Union Station's 2023 gas consumption, 100% of which was used for space heating. Annual lectricity consumption for cooling (from the chiller) is estimated according to the capacity and estimated efficiency of the chiller at Union Station. USATEN will not affect Union Station's water heating system, since water is heated via a collection of electric resistance units distributed throughout the building.

Union Station: BAU vs. GHP Scenarios Technical Summary			
	BAU Space Heating	**BAU Cooling**	**GHP**
System Type	3 Boilers	1 Chiller	Geothermal Network
System Fuel	Gas	Electricity	Electricity
System Efficiency (COP)	0.895	4.4	6
Rationale for Assumed Efficiency	Average of 3 Boilers' AFUE, converted to COP	Median efficiency of Trane's CGAM Air-Cooled Scroll Chillers:	Conservative estimate, based on NREL
Annual Energy Consumption	4,284 MMBtu	174,891 kWh	129,426 kWh
Rationale for Assumed Annual Energy Consumption	2023 Gas Consumption	100 ton (351.7 kW) capacity chiller Assume 2,208 hours running in 2023 $\frac{351.7\ kW}{4.4} * 2{,}208\ hrs$	*See below.*
Kind of Emissions Released	Combustion, Production	Grid	Grid

We calculated GHP energy consumption for space heating and cooling at Union Station according to the following method:

1. $BAU\ System\ Energy\ Consumption\ (MMBtu) *\ Assumed\ BAU\ System\ Efficiency = \boldsymbol{Amount\ of\ Energy\ Required\ for\ End\ Use}\ (MMBtu)$
2. $\frac{Amount\ of\ Energy\ Required\ for\ End\ Use}{GHP\ System\ Efficiency} = \boldsymbol{GHP\ System\ Energy\ Consumption\ (MMBtu)}$

GHG Emissions Reductions: Calculations and Assumptions

The USATEN project will replace three gas boilers and one electric chiller at Union Station, and it will avoid the installation of gas heating, gas domestic hot water, and conventional air conditioning systems at the Union Square multifamily development. The proposal assumes that new construction at Union Square would utilize these systems as they are minimally compliant with the Connecticut building code, the Energy Star standard, and the Connecticut Housing Finance Authority (CHFA) Construction Guidelines for Energy Conservation and Sustainability. This project therefore will yield both direct reductions in greenhouse gas emissions at Union Station, as well as avoided emissions at the proposed 1,000-unit multifamily building.

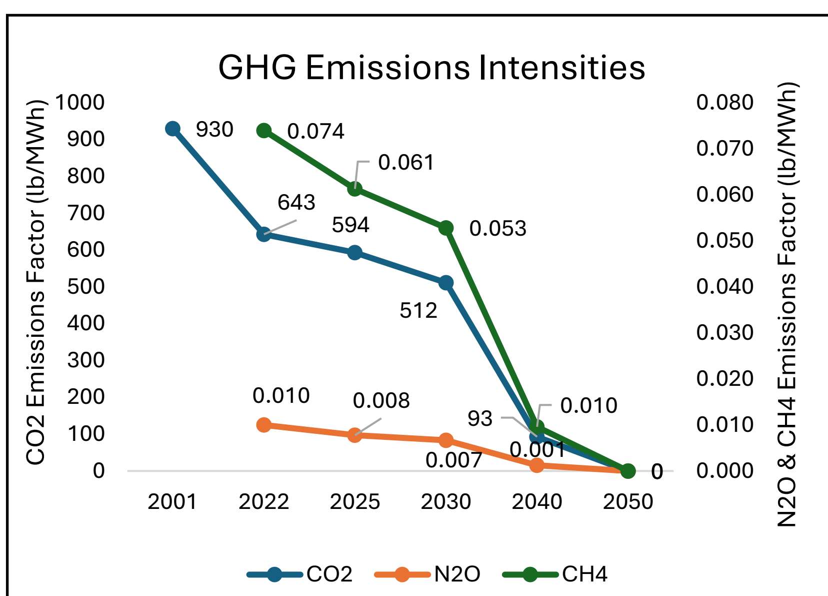
To estimate the cumulative emissions reductions in the 2025-2030 and 2025-2050 periods, we consider emissions released in fossil gas production and delivery, emissions released from gas combustion, and emissions from the grid. The analysis focuses on emissions of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), all converted into CO_2e. We also provide rough estimates of the magnitude of local Criteria Air Pollution (CO, CH_4, NO_x, filterable and primary PM, and SO_2) that is avoided by relying on a geothermal heat pump system at Union Square and Union Station instead of systems that rely on gas combustion.

Grid Emissions

We estimate the grid emissions of the USATEN heat pump network, as well as the electric cooling systems in both properties (Union Station and Union Square). We assume that grid emissions intensities are declining over time according to Connecticut Public Act 18-82, which calls for a 45% decrease in annual greenhouse gas emissions relative to 2001 levels by 2030, as well as Connecticut Public Act 22-5, which sets the goal of providing carbon-free electricity by 2040. However, since the state forecasts that some amount of electricity supplied to the ISO-NE grid in 2040 will still be derived from fossil fuels, it is more likely that in 2040, the grid will continue to release some amount of greenhouse gas emissions, and emissions will not be fully eliminated until 2050 (for example, Connecticut's "Base Balanced Blend" scenario estimates that 19 TWh of ~135 TWh in ISO-NE will come from fossil fuels in 2040, or 14%). As a result, we assume that in 2040, grid emissions will be 10% of their levels in 2001.

Grid Emissions Intensity (lbs/MWh)				
	CO_2	N_2O	CH_4	CO_2 Factor Source
2001	930			ISO-NE
2022	643	0.010	0.074	ISO-NE
2025	594	0.008	0.061	2022-2030 Linear Regression
2030	512	0.007	0.053	45% Below 2001 Levels
2040	93	0.001	0.010	90% Below 2001 Levels
2050	0	0	0	Assume 0 GHGs
Contribution to BAU 2025-2050 Emissions	7%	0.03%	0.02%	
Contribution to GHP 2025-2050 Emissions	96%	0.2%	3%	

To forecast CO_2 grid emissions between 2025 and 2050, we use the 2001 CO_2 emissions intensity reported by ISO-New England (930 lb/MWh) as our reference value. We then calculate the 2030 emissions intensity (512 lb/MWh) based on the assumption that the 2030 value will be 45% smaller in magnitude than the 2001 emissions intensity, and the 2040 emissions intensity (93 lb/MWh) based on the assumption that the 2040 value is 90% smaller in magnitude than the 2001 emissions intensity. We then assume linear



reductions in emissions between 2001 and 2022, 2022 and 2030, 2030 and 2040, and 2040 and 2050. We include the 2022 grid CO_2 emissions intensity in this analysis because 2022 is the most recent year for which data is available, and thus serves as the best available baseline for a linear model of grid emissions between intensities for the 2025-2030 period.

To estimate N_2O and CH_4 grid emissions between 2025 and 2050, we adopt the 2024 Northeast Power Coordinating Council New England grid emissions intensities reported by the EPA's Emissions Factors Hub as our reference values. We then calculate the annual percent change in CO_2 emissions between 2025 and 2050, and assume that N_2O and CH_4 emissions change annually by the same percentage, mirroring changes in CO_2 emissions. We forecast that N_2O and CH_4 will mirror changes in CO_2 emissions between 2025 and 2050 based on the assumption that as state greenhouse gas reduction goals are met, related emissions from these three gasses will be reduced proportionally. EPA does not publish 2001 N_2O and CH_4 emissions intensities, and N_2O and CH_4 grid emissions comprise a small contribution to overall emissions (0.03% and 0.02% of BAU 2025-2050 emisisons, 0.2% and 3% of GHP 2025-2050 emisisons). Thus, although it is unlikely that N_2O and CH_4 grid emissions will exactly mirror the annual percent change in CO_2 emissions between 2025 and 2050, this method is an adequate estimation. We multiply these emissions intensities by the sites' annual electricity consumptions—in two scenarios, one in which USATEN is built and the other in which Union Station and Union Square rely on fossil fuel-based heating and cooling (and water heating, for Union Square)—and appropriate Global Warming Potentials (GWPs) to determine annual GHG emissions from the grid in MT CO_2e.

Combustion Emissions

Burning fossil gas for space heating in both properties and water heating in the proposed Union Square multifamily development will release greenhouse gas emissions. We assume that Union Station and Union Square consume the same amount of gas every year (Union Station: based on 2023 levels; Union Square: based on the proposed development's energy requirements), so these emissions will remain constant between 2025 and 2050. We adopt 2021 CO_2, N_2O, and CH_4 emissions intensities from fossil gas combustion from the EPA's Emissions Factors hub. We multiply these emissions intensities by the sites' annual fossil gas consumptions and appropriate Global Warming Potentials (GWPs) to determine annual GHG emissions from combustion in MT CO_2e.

Production Emissions

Every year between 2025 and 2050, some amount of greenhouse gas emissions will be released in the course of producing and delivering fossil gas to Union Station and the multifamily development, once it is built. We adopt 2021 values for CO_2, N_2O, and CH_4 emissions from fossil gas production, derived from the 1990-2021 Inventory of U.S. Greenhouse Gas Emissions and Sinks, as our reference values. To model production emissions (CO_2e) from 2022-2050, we use the EIA's forecast of annual gas production through 2050 and assume that "production emissions" are a function of gas production, so as gas production varies, CO_2 and N_2O production emissions will vary by the same factor. We assume that CH_4 emissions from gas production will also correlate with the quantity of fossil gas produced annually, but starting in 2024, will be further reduced according to the EPA's 2023 standards for methane emissions (NSPS OOOOb and EG OOOOc). EPA provides projections for annual methane reductions between 2024 and 2038 as a result of the rule in Table 3-2 of "Regulatory Impact Analysis of the Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review." This table ends at 2030, so we forecast the impact of the rule from 2038-2050 by assuming that methane reductions will plateau at 4.7 MMT in 2038 and remain constant through 2050. Annual methane emissions from 2022-2050 from fossil gas production is therefore calculated as follows:

$$\big((\%\ Change\ in\ Annual\ Gas\ Production * Previous\ Year\ CH_4\ Emissions) + Previous\ Year\ CH_4\ Emissions\big) - Methane\ reductions\ due\ to\ EPA\ Rule$$

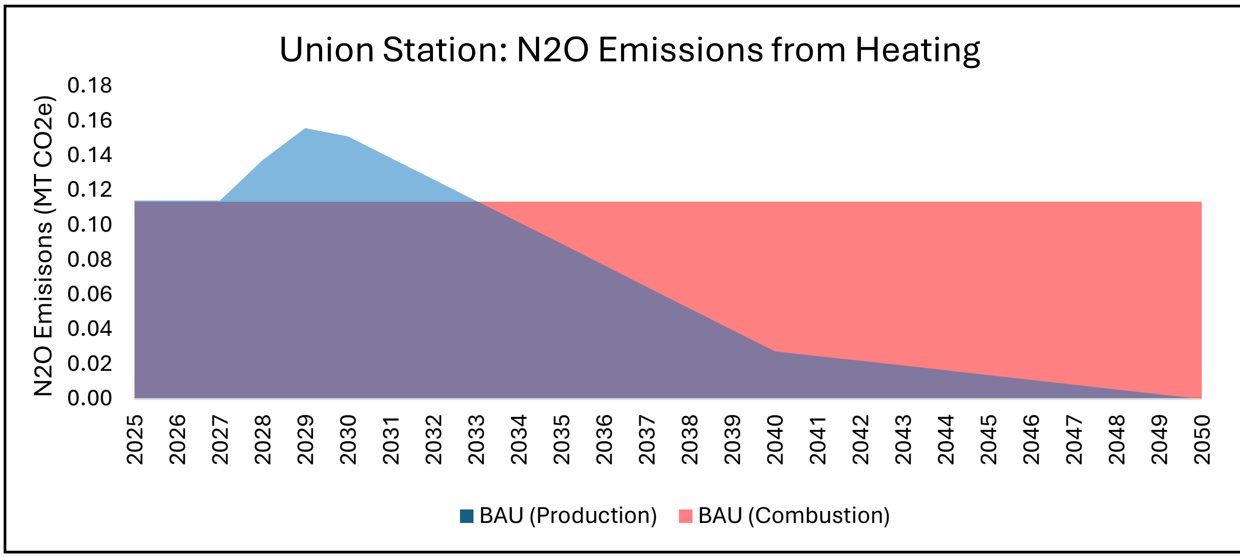
We then divide annual GHG emissions (MMT) from fossil gas production (MMT) by the annual quantity of fossil gas produced to calculate the GHG's emissions as a percentage of gas production. We apply these percentages to the site's annual fossil gas consumption (both BAU and GHP) and appropriate Global Warming Potentials (GWPs) to determine annual GHG emissions from production in MT CO_2e.

Cumulative GHG Emissions Reductions

To estimate cumulative emissions reductions under the BAU scenario, we first calculate the sum of annual emissions from 2025 to 2030 and then from 2025 to 2050 according to the kind of BAU emission (grid/combustion/production), end-use (space heating/cooling/water heating), greenhouse gas (CO_2/N_2O/CH_4, all in MT CO_2e), and site (Union Square/Union Station). Then, we calculate the sum total by period by end use by site, and then the sum total by period across both sites.

We conduct the corresponding calculations for the GHP scenario with nearly the same method, but with a variation for 2025 through 2028. For the years 2025, 2026, and 2027, we assume that USATEN will still be under development, so we adopt the sum of BAU grid, BAU combustion, and BAU production emissions for each end use and GHG. We assume that the project will be completed in June of 2028, halfway through the year. Accordingly, we divide the sum of BAU grid, BAU combustion, and BAU production emissions by 2, and add it to the GHP grid emissions value for 2028, also divided by 2 to reflect the project start being halfway through the year.

We calculate the magnitude of cumulative emissions reductions for the 2025-2030 and 2025-2050 periods by calculating the difference between the sum total of cumulative emissions under BAU conditions and the sum total of cumulative emisisons under GHP conditions. In the attached emissions calculations spreadsheet, we have also calculated GHP vs. BAU differences according to greenhouse gas, end-use, site, and period. It is important to note that the cumulative emissions estimates for GHP include three and a half years of BAU data, so the 2025-2030 period only includes 2.5 years of data in which USATEN is operational. Additionally, in cases where a very small amount of the greenhouse gas is released through combustion and production, grid emissions from USATEN may temporarily exceed the sum of BAU emissions until the grid has decarbonized sufficiently so as to release less of the pollutant than is released through production and combustion. For example, whereas N_2O emissions are 15% higher under a GHP scenario than a BAU scenario for the 2025-2030 period, the annual grid emissions rate is projected to drop below the combustion rate in 2033 to remain on track to meet statewide greenhouse gas reduction goals, leading to GHP N_2O emissions to be 41% lower than BAU for the 2025-2050 period.



CAP & HAP Emissions Reductions

We roughly estimate the magnitude of Criteria Air Pollutant (CAP) and Hazardous Air Pollutant (HAP) emissions reductions based on the sample CAP and HAP emissions reductions estimates for a networked geothermal project provided in "Appendix I: Near-Term Implementation-Ready Climate Action Measures" of the Connecticut Priority Climate Action Plan (PCAP). CT DEEP's summary of HAP and CAP emissions reductions on page 111 of the PCAP is based on a networked geothermal system installed in a newly constructed neighborhood which utilizes gas furnaces for space heating. Though CT DEEP makes similar assumptions to those made here regarding the heating systems for the Union Square development, CT DEEP's modeling of HAPs and CAPs only focuses on space heating and does not include emissions related to water heating or space cooling. Therefore, in relying on CT DEEP's modeling, the estimates of HAP and CAP emissions reductions are conservatively low.

CT DEEP's 375 ton modeled geothermal system is 3.8 times smaller than the estimated 1,425 tons (285 boreholes with an average of 5 tons per borehole) USATEN system. By multiplying the annual emission reductions for CT DEEP's system by the 3.8, the HAP and CAP values below were calculated on an annual basis. These reductions were then applied to over the 21.5 years the USATEN system is projected to be operational through 2050. Note that the methane emissions in the table below are only those emissions directly related to heating system combustion at the project site.

Modeling CAP Emissions Reductions				
	Pollutant	**CT PCAP: 2030 Annual Emissions Reductions in Newly Constructed Neighborhood (lbs)**	**USATEN Annual Emissions Reductions (lbs)**	**USATEN Emissions Reductions, 2025-2050 (lbs)**
Criteria Air Pollutants (CAP)	CO	194	737	15,850
	CH_4	*Emissions calculated separately for GHG reduction estimates for multifamily – space heating.*		2,150.18
	NO_x	457	1,737	37,337
	PM (filterable)	9	34	735

	PM (primary)	37	141	3,023
	SO_2	3	11	245
Total Urban Toxics HAP		12	45.6	980.4
Total		**723**	**2,747**	**59,069**