Technical Appendix

Recipient Name:	City of Saint Paul
Project Title:	Clean Heat Saint Paul

The objective of this analysis is to estimate the magnitude of the cumulative greenhouse gas (GHG) emissions reduction that could be achieved by the Clean Heat St. Paul Project. The project entails recovering waste heat from the effluent of the largest wastewater treatment plant in the State of Minnesota, the Metro Plant, and using the recovered waste heat in an existing hot water district heating system to distribute the energy to the 33 million square feet of buildings it serves. The recovered waste heat would be used to reduce natural gas and fuel oil being combusted in boilers connected to the district heating network. Buildings served by the hot water district heating network use it for space heating, domestic hot water and process heating.

The modeling also reflects that District Energy is currently in the process of extending a power purchase agreement (PPA) with Xcel Energy, enabling it to continue operation of the biomass cogeneration plant (COGEN) through 2030. The actual terms and conditions of that agreement must be approved by Minnesota's Public Utility Commission (MNPUC), which is anticipated to occur late 2024. Changes to the terms of that agreement that occur during the approval process could impact the magnitude of GHG emissions reductions achieved in the initial years of operation of the CHStP Project and the cumulative totals. The MNPUC could reduce the extension of the PPA to less than 2030, which would increase the operational hours of the heat recovery system implemented during the CHStP Project. This is unlikely to occur. It is possible given the important role COGEN plays in managing regional tree waste, that the PPA is extended past 2030 to mid 2030s. That is unlikely to occur during this review of the PPA, but could occur in future reviews of the PPA by the MNPUC, which would reduce the amount of energy HRS would recover. For this analysis, it is assumed that COGEN's PPA is extended by the MNPUC through 2030, and COGEN discontinues operation in 2031.

GHG Reduction Estimate Method:

- Scenario comparison between reference and proposed scenarios
- Reference yearly historical fuel usage and reported GHG-Emissions
- Averaged annual hourly heating load conditions as the heating load baseline for all scenarios
- Empiric availability and fuel efficiency of existing equipment
- Manufacturer specifications and assumed availability for proposed equipment
- Emission factors and historical fuel usage was used to determine GHG-Emissions
- Proposed implementation timeline for the scenarios
- Yearly and cumulative GHG-Emission Reduction compared to reference
- Energy units presented in this narrative and GHG emission calculation are in metric

Model/Tools Used:

- Historical plant data and emissions reports for District Energy St. Paul
- Historic hourly data points for the Metro Plant from 2017-2023
- Microsoft Excel for:
    - Creation of averaged load duration curve
    - Calculation of hourly and yearly heating load share from each fuel source based on historical data and input assumptions for future operating scenarios
    - Calculation of scenario dependent fuel consumption with equipment performance data
    - Calculation of scenario dependent GHG emission reduction based upon emission factors of the fuel sources

Measure Implementation Assumptions:

The implementation timeline for the CHStP Project is based upon the best information available from manufacturers on material and equipment lead times, information provided by construction contractors and engineering consultants, generally accepted practices and a variety of past and current project experiences. The project schedule and key milestones are described in the Project Narrative. The implementation timeline assumes notification on selection by July 1, 2024 and Funding Award on October 1, 2024, and a project schedule that spans 39 months for engineering/design, permitting, procurement, construction, commissioning and start-up to be completed. The modeling to determine the magnitude of cumulative GHG emissions reduction resulting from the proposed project is based upon the CHStP Project being fully operational on January 1, 2028, and the following data and assumptions.

GHG Reduction Estimate Assumptions:

- Performance data:

Equipment Perforcance Data

		Fuel Efficiency/COP	Availability
Natual Gas Boilers		78%	100%
COGEN	*Biomass*	73.1%	87%
	Nat. Gas	82%	
Heat Recovery System		3 *(avg.)*	95%
Electric Boiler		100%	50%

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    - 100% Natural gas boiler availability for redundancy
    - Biomass cogeneration plant (COGEN) off-line for planned maintenance period of 30 days
    - 50% Electric boiler availability based upon off-peak operation in tandem with thermal storage
- Emission factors:

GHG-Emission Factors

	CO_2-emission		CO_2-e (CH_4-emission)		CO_2-e (NO_X-emission)		Total CO_2-e emission		
	[kg/MMBtu]	[kg/MWh]	[kg/MMBtu]	[kg/MWh]	[kg/MMBtu]	[kg/MWh]	[kg/MMBtu]	[kg/MWh]	Source
Natual Gas	53.06	181.0	0.025	0.085	0.030	0.102	**53.11**	**181.24**	*EPA CO2-Emission Factors*
Electricity 2020	80.28	273.9	0.395	1.349	0.673	2.298	**81.35**	**277.57**	*Xcel Energy 2022*
Electricity 2030	32.11	109.6	0.158	0.540	0.269	0.919	**32.54**	**111.03**	*MN Clean Energy Standard*
Electricity 2040	0.00	0.0	0.000	0.000	0.000	0.000	**0.00**	**0.00**	*MN Clean Energy Standard*
Biomass **renew.*	0	0	0.180	0.614	1.073	3.661	**1.25**	**4.27**	*EPA CO2-Emission Factors*
Biomass	93.80	320.1	0.180	0.614	1.073	3.661	**95.05**	**324.33**	*EPA CO2-Emission Factors*
			100y-GWP: 25		100y-GWP: 298				

   - Electricity emission factor was assumed to decrease linearly in between MN Clean Energy Standard milestones
- GHG Emission calculation:
   - GHG emissions are calculated for each type of equipment depending on the amount of thermal energy produced
   - Emissions of CH_4 and NO_x are weighted by their 100 year global warming potential as shown in the table above
   - The equipment GHG emissions are added up for yearly total emissions

$$\boldsymbol{m_{CO2-e} = Q * \eta * (\varepsilon_{CO2} + \varepsilon_{CH4} * 25 + \varepsilon_{NOx} * 298)}$$

$$\begin{aligned}
&with: \\
&m_{CO2-e} = GHG\ Emission \\
&Q = Themal\ energy\ production\ of\ equipment \\
&\eta = equipment\ fuel\ efficiency \\
&\varepsilon_{CO2} = CO_2 - emission\ factor \\
&\varepsilon_{CH4} = Methane - emission\ factor \\
&\varepsilon_{NOx} = Nitrogen\ oxide - emission\ factor
\end{aligned}$$

- Other input assumptions:
   - Due to natural gas curtailment fuel oil replaces part of the natural gas load. Input data based on actual yearly averages (2015-2022)
   - Electricity used to supplement and supply heating equipment and pumps is based upon actual yearly averages (2015-2022)
   - District Energy St. Paul will be purchasing renewable energy credits to offset the GHG emissions from the electricity used to operate the heat recovery system from 2028 to 2040, when Minnesota's Clean Energy Standard mandates the electricity grid be 100% carbon free. District Energy currently purchases renewable energy credits (RECS) to offset GHG emissions from the electricity used to produce chilled water for its district cooling network.

Reference Case Scenario (GHG-Emissions or Activity Level):

- Historic hourly data points from 2019-2023 were collected including:
   - Heating Loop System Load
   - Heating Loop Supply & Return Temperature
   - St. Paul Cogeneration (COGEN) Thermal & Electric Production
   - District Energy St. Paul Natural Gas Usage

- The hourly system loads of each year were sorted then averaged to create an averaged load duration curve as a baseline for the reference and proposed operating scenarios
- Reference case scenario modelled to match historic fuel source load share and consumption data for natural gas, fuel oil, biomass and electricity
- The cogeneration system is prioritized to fulfill electric output according to an existing PPA and maximized for system heating load coverage
- A maintenance period of 30 days is scheduled in summertime during low system heating loads to not exaggerate GHG reductions of proposed future scenarios
- The resulting load duration curve and the equipment specific heating load coverage of the reference scenario are shown in Fig. 1
- The reference case scenario is used until operation of the heat recovery system and the electric boiler in the beginning of 2028

Measure Specific Activity Data:

a) Scenario for the years 2028-2030

- COGEN still in operation
  - The cogeneration system is operated under the same assumptions as in the reference scenario
- Heat Recovery System and electric boiler in operation
  - Used for thermal production during peak system heating loads
  - Heat Recovery System with higher efficiency prioritized over electric boiler
- The existing District Heating St. Paul natural gas boilers are used for safety through redundancy as well as coverage of extreme peak system heating loads
- Calculation of recoverable thermal energy from effluent
  - Historic hourly data points from 2017-2023 were collected including:
    - General Effluent Total Mass Flow Rate
    - General Effluent Strainer Discharge Temperature
  - Low daily temperature fluctuation/higher daily mass flow fluctuation
  - Minimum heat exchanger effluent temperature assumed at 40°F to cover from potential freezing issues
  - The heat recovery systems peak load was chosen at 60 MW to optimize long term system load coverage and heat pump utilization. Resulting in:
    - 79 % potential system load coverage
    - > 50 % system utilization
  - An availability the HRS of 95% was assumed to account for random outages and system faults resulting in 57 MW effective HRS peak thermal production
  - Needed heat exchanger effluent flow calculated with converted specific heat formula:

$$\dot{m} = \frac{\dot{Q}}{c_p * (t_{eff} - t_{min})}$$

$with$:
$\dot{m} = mass\ flow\ rate$

$\dot{Q} = intended\ thermal\ energy\ recovery$
$c_p = specific\ heat\ capacity\ of\ water$
$t_{eff} = effluent\ temperature$
$t_{min} = minimum\ heat\ exchanger\ effluent\ temperature$

  - On average only 10 % of effluent flow needed to cover intended thermal heat recovery, 25% as maximum
- Heat Recovery System output temperature assumed to be up to 230°F maximum
  - To be blended into district energy heating loop
  - Analysis revealed no restriction on heat recovery system output:
    - Heating loop supply temperatures rarely surpasses 230°F (3.23%)
    - In times it does the system heating exceeds 80MW
    - The temperature ratio (230°F - return / supply – 230°F) is never lower than the system demand ratio allowing the loop supply temperature to be blended to with other heat production means
- Assumptions on electric boiler and thermal storage
  - 30 MW peak thermal production of electric boiler
  - Operating during electricity off-peak hours (50%)
  - Electricity off-peak charging of thermal storage to be utilized during heating on-peak hours
  - Resulting in 15 MW effective average heating production
- The load duration curve and the equipment specific heating load coverage of the measure scenario for the years 2028-2030 are shown in Fig. 2

b) Scenario starting in 2031

- COGEN PPA terminated end of 2030, operation discontinues
- Heat Recovery System now used for system base load coverage
  - Same assumptions apply to availability and 5thermal production
- Electric Boiler used for thermal production during peak system heating loads
- The existing District Heating St. Paul natural gas boiler are used for safety through redundancy as well as extreme peak system heating load
- The load duration curve and the equipment specific heating load coverage of the measure scenario starting in 2031 are shown in Fig. 3

GHG Emissions Reduced:

- Fig. 4 shows an overview of the historic and projected yearly GHG emissions from 2014 to 2050.
  - The GHG emissions are separated by equipment and heating fuel source
  - Only projected annual and cumulative GHG emissions reductions are inlcuded in this application.
- Fig. 5a and 5b show the yearly and cumulative yearly reduction in GHG emissions in comparison to the reference case scenario

- From 2028-2030 up to 33,500 metric tons GHG emissions/year can be reduced. The reduction increases to approximately 37,000 metric tons starting 2031
- From 2025 - 2030 the estimated cumulative GHG emission reduction is cumulates to a total of 100,500 metric tons. Totaling at 842,500 metric tons until 2050

Fig. 1 Distict Energy St. Paul Heating Load Duration Curve 2024-2027

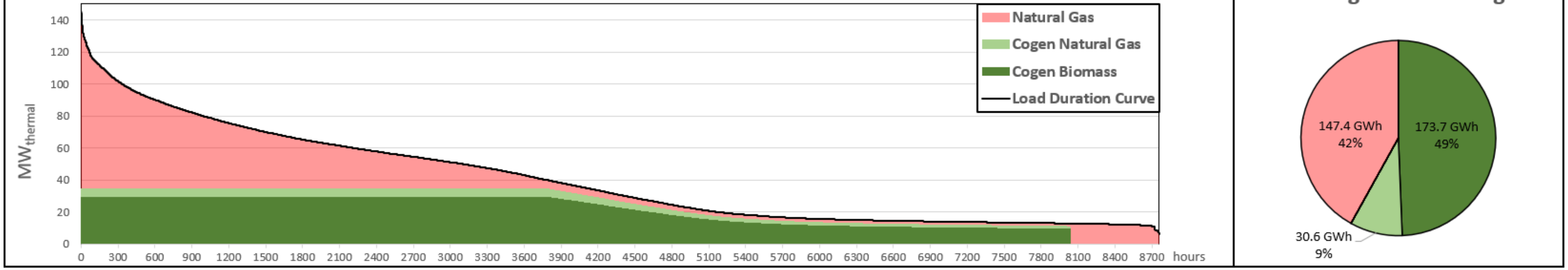


Fig. 2 Distict Energy St. Paul Heating Load Duration Curve 2028-2030

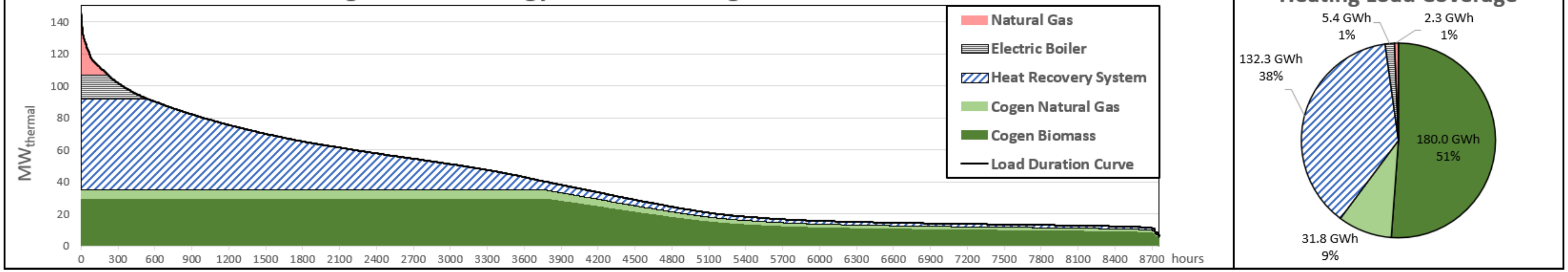
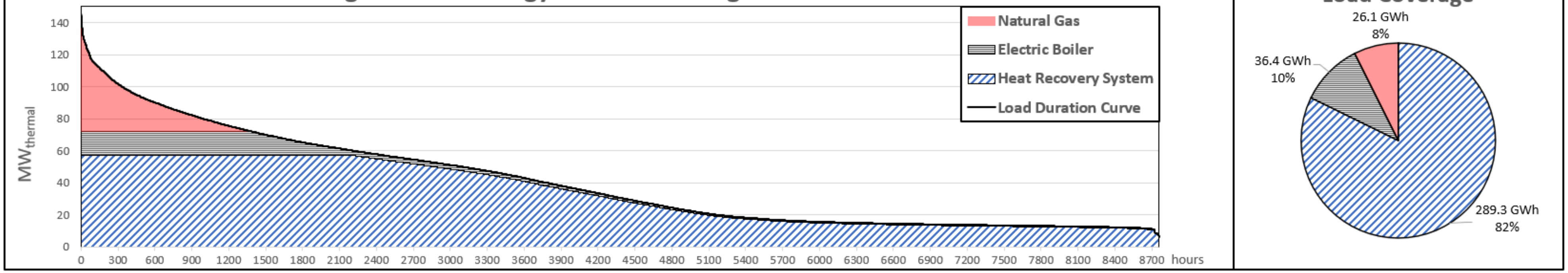


Fig. 3 Distict Energy St. Paul Heating Load Duration Curve 2031-2050



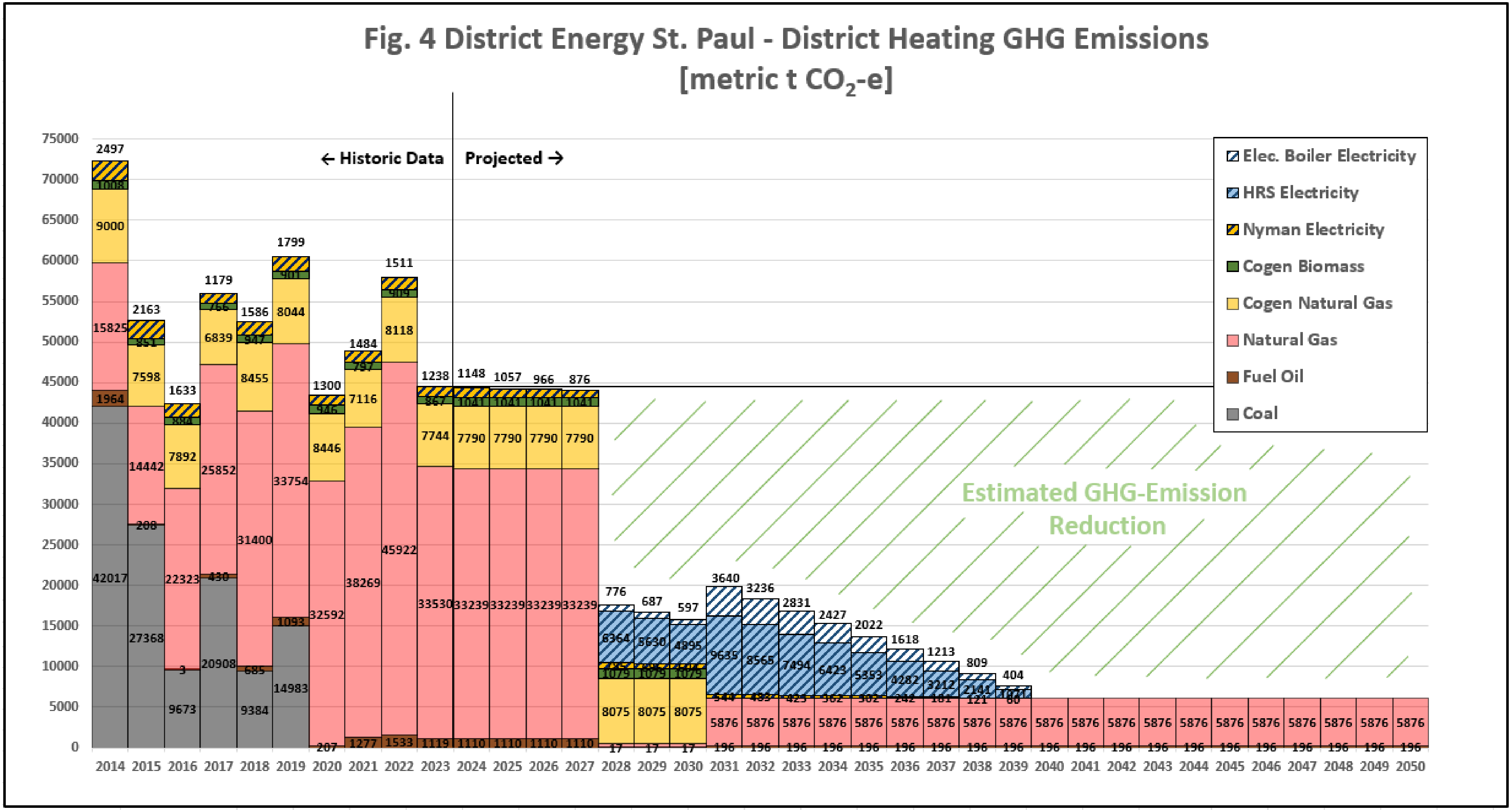


Fig. 4 District Energy St. Paul - District Heating GHG Emissions
[metric t CO_2-e]
← Historic Data
Projected →
Elec. Boiler Electricity
HRS Electricity
Nyman Electricity
Cogen Biomass
Cogen Natural Gas
Natural Gas
Fuel Oil
Coal
Estimated GHG-Emission Reduction

Fig. 5a Clean Heat St. Paul Project - Yearly GHG Emissions Reduction [metric t CO_2-e]

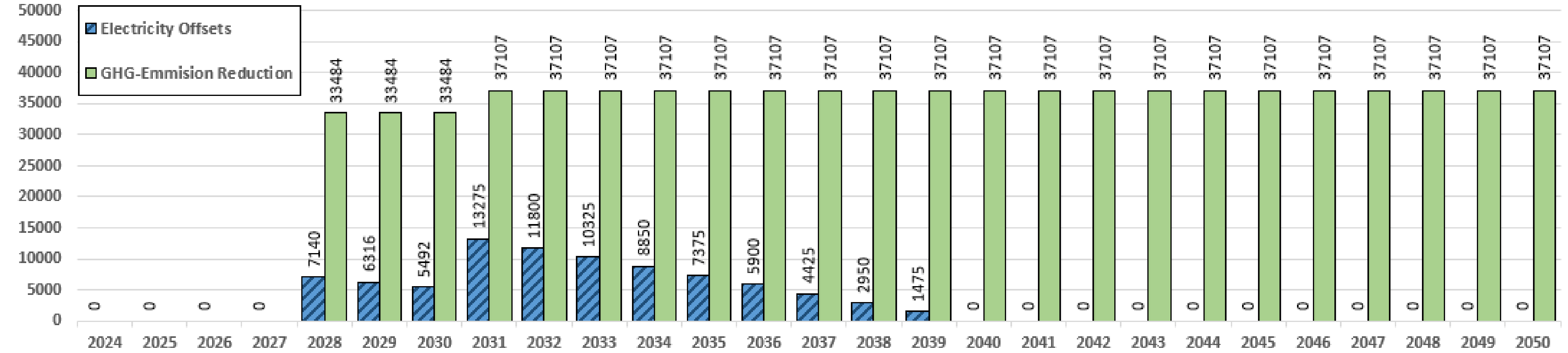


Fig. 5b Clean Heat St. Paul Project - Cumulative GHG Emissions Reduction [metric t CO_2-e]