Sankey Diagram

Natural Gas Utilization Analysis

Group 4

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1 Problem Set Scope and Methodology

Evaluate the use energy resources to reduce natural gas consumption by creating an eco-industrial park consisting of a manufacturing facility, a power plant, a wastewater treatment plant, and an energy-from-waste facility.

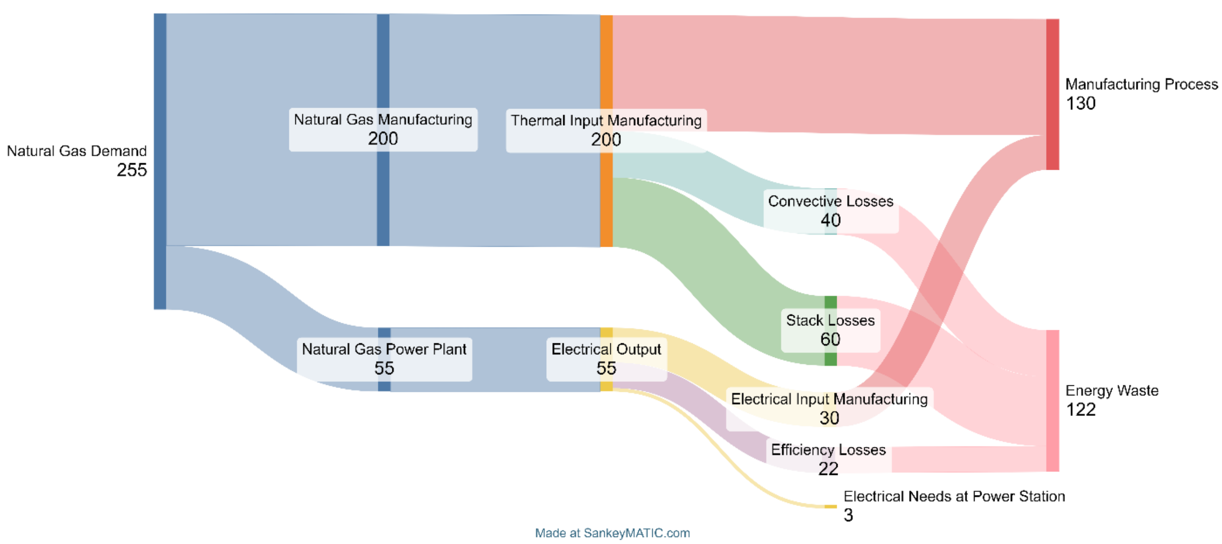
This analysis uses Sankey Diagram to visualize the energy flow per hour in each option. The unit used in the analysis is GJ.

The analysis neglects all transmission losses between facilities. Assuming every hour is identical within each Scenario.

2 Basic Scenario

Manufacturing Facility and Power Plant.

2.1 Sankey Diagram



2.2 Code

'Base case is power plant and manufacturing facility (considering scope of natural gas use)

'Thermal needs for manufacturing facility

Natural Gas Manufacturing [200] Thermal Input Manufacturing

Thermal Input Manufacturing [100] Manufacturing Process

Thermal Input Manufacturing [40] Convective Losses

Thermal Input Manufacturing [60] Stack Losses

'Electrical needs for manufacturing facility

Electrical Input Manufacturing [30] Manufacturing Process

'Power Station

'Balanced to what the manufacturing facility needs as long as it does not impact efficiency

'Making sure within constraints of 50 GJ output capacity (output needed is 33 GJ)

Natural Gas Power Plant [55] Electrical Output

Electrical Output [30] Electrical Input Manufacturing

Electrical Output [3] Electrical Needs at Power Station

Electrical Output [22] Efficiency Losses

'Combining my totals up front to have a overall input

Natural Gas Demand [200] Natural Gas Manufacturing

Natural Gas Demand [55] Natural Gas Power Plant

'Combining my totals at back end for overall energy waste

Convective Losses [40] Energy Waste

Stack Losses [60] Energy Waste

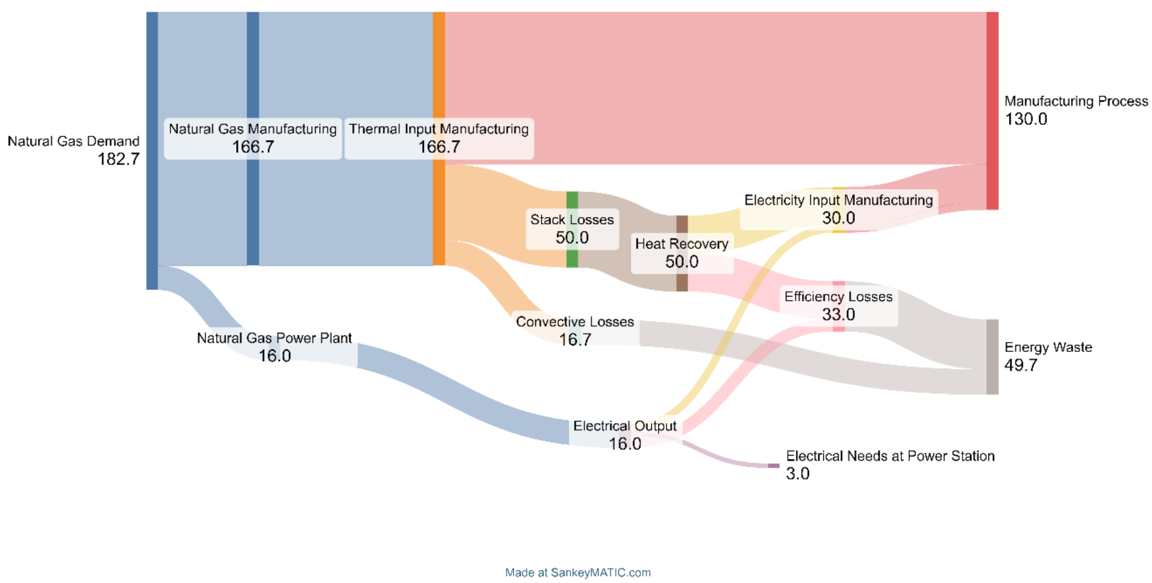
Efficiency Losses [22] Energy Waste

3 Scenario A:

At manufacturing site: Insulate chemical processing and piping reducing convective losses by 50% and recover heat from stack losses converting to electricity (install turbine with 50% efficiency)

- At Manufacturing Site, through insulation, convective losses reduced to 10%, manufacturing efficiency increased to 60%. Keep manufacturing process's thermal energy requirement as 100GJ. Convective losses are 16.7GJ and Stack losses are 50GJ. Stack losses (50GJ) heat recovered energy is converted to electrical energy, yielding 25GJ for the manufacturing process with a 25GJ efficiency loss.
- At Power Plant, needs 5GJ Electricity input Manufacturing and 3 GJ for the power plant. The total electricity used is 8 GJ which is below 50% of the full load, the average efficiency is 50%. Therefore, Natural Gas needed in the Power Plant are 16GJ. 5GJ Electricity input Manufacturing, 3GJ for the Power Station, and 8GJ efficiency waste.

3.1 Sankey Diagram



3.2 Code

'Scenario A is reducing convective losses by 50% and recover heat from stack losses (50% efficiency)

'Thermal needs for manufacturing facility

Natural Gas Manufacturing [166.7] Thermal Input Manufacturing

Thermal Input Manufacturing [100] Manufacturing Process

Thermal Input Manufacturing [16.7] Convective Losses

Thermal Input Manufacturing [50] Stack Losses

'Electricity needs for manufacturing facility

Electricity Input Manufacturing [30] Manufacturing Process

'Heat recovery from Stack Losses to electricity with 50% efficiency

Stack Losses [50] Heat Recovery

Heat Recovery [25] Electricity Input Manufacturing

Heat Recovery [25] Efficiency Losses

'Electrical needs for manufacturing facility

'Power Station

'Balanced to what the manufacturing facility needs as long as it does not impact efficiency

'Making sure within constraints of 50 GJ output capacity (output needed is 33 GJ)

Natural Gas Power Plant [16] Electrical Output

Electrical Output [5] Electricity Input Manufacturing

Electrical Output [3] Electrical Needs at Power Station

Electrical Output [8] Efficiency Losses

'Combining my totals up front to have an overall input

Natural Gas Demand [166.7] Natural Gas Manufacturing

Natural Gas Demand [16] Natural Gas Power Plant

'Combining my totals at back end for overall energy waste

Convective Losses [16.7] Energy Waste

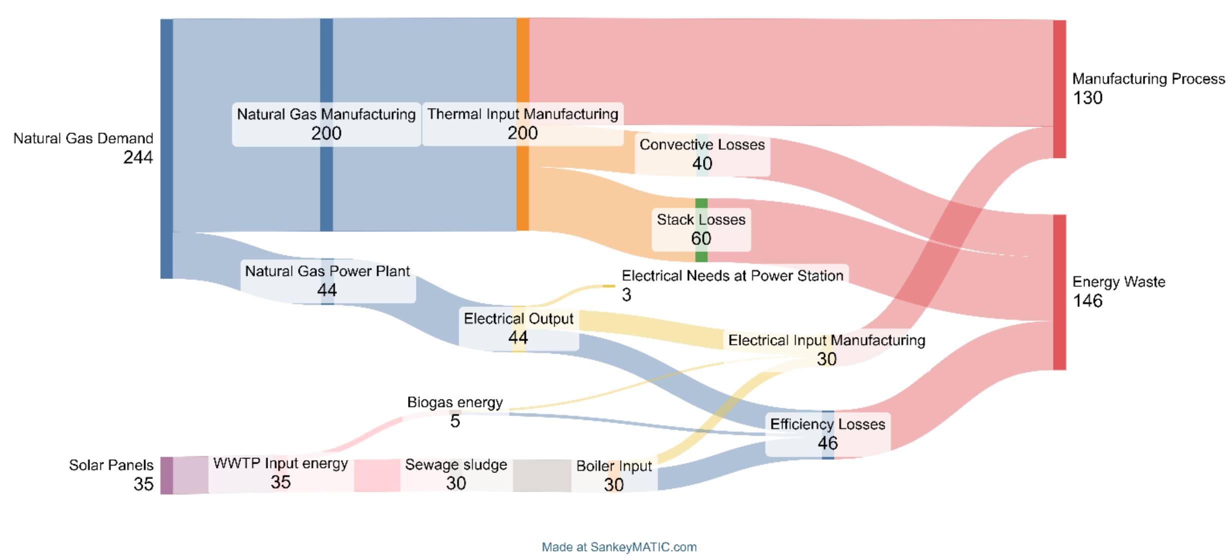
Efficiency Losses [33] Energy Waste

4 Scenario B:

At WWTP: Install turbine to convert flared biogas to electricity at WWTP (running an engine that would be 40% efficient) and using sewage sludge as feedstock in power plant (sewage sludge can be used in the idled coal boiler at the same efficiency as coal).

- At the Wastewater Treatment Plant (WWTP), solar energy is employed to produce biogas 5GJ and sewage sludge 30GJ. The biogas is converted to 2GJ electrical energy with 3GJ efficiency losses.
- At Power Plant, utilize 30GJ of sewage sludge as feedstock in its boiler. The boiler operates with 30% efficiency, resulting in an electrical energy output of 9GJ, along with 21GJ in efficiency losses.
- At Manufacturing Site, the electrical needed 30GJ comes from biogas (2GJ), sewage sludge (9GJ) and power plant (19GJ).
- The electrical output in power station (without boiler) is 3GJ electrical needed, 19GJ manufacturing input, and efficiency losses 22GJ. The natural gas needed in power plant is 44GJ (efficiency is 50%).

4.1 Sankey Diagram



4.2 Code

'Scenario B is power plant, WWTP and manufacturing

'Thermal needs for manufacturing facility

Natural Gas Manufacturing [200] Thermal Input Manufacturing

Thermal Input Manufacturing [100] Manufacturing Process

Thermal Input Manufacturing [40] Convective Losses

Thermal Input Manufacturing [60] Stack Losses

'Electrical needs for manufacturing facility

Electrical Input Manufacturing [30] Manufacturing Process

'WWTP

Solar Panels [35] WWTP Input energy

WWTP Input energy [5] Biogas energy

WWTP Input energy [30] Sewage sludge

Biogas energy [2] Electrical Input Manufacturing

Biogas energy [3] Efficiency Losses

'Power Station

Natural Gas Power Plant [44] Electrical Output

Sewage sludge [30] Boiler Input

Boiler Input [9] Electrical Input Manufacturing

Boiler Input [21] Efficiency Losses

Electrical Output [19] Electrical Input Manufacturing

Electrical Output [3] Electrical Needs at Power Station

Electrical Output [22] Efficiency Losses

'Combining my totals up front to have a overall input

Natural Gas Demand [200] Natural Gas Manufacturing

Natural Gas Demand [44] Natural Gas Power Plant

'Combining my totals at back end for overall energy waste

Convective Losses [40] Energy Waste

Stack Losses [60] Energy Waste

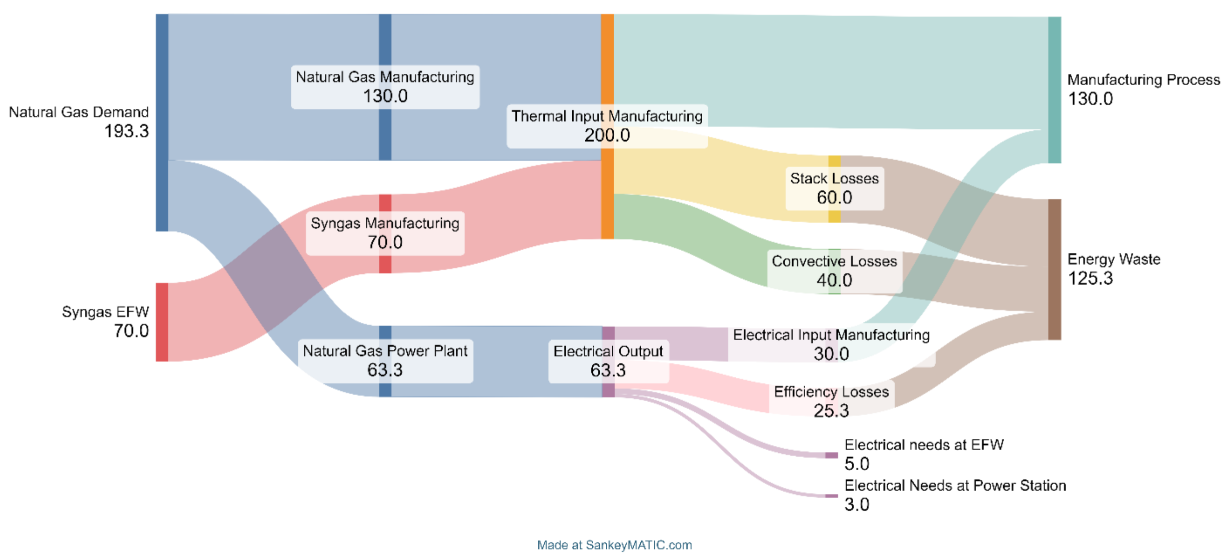
Efficiency Losses [46] Energy Waste

5 Scenario C:

Build an energy-from-waste facility to generate syngas that can be used to replace natural gas thermal needs at manufacturing facility.

- An Energy-from-Waste (EFW) facility is constructed to generate syngas amounting to 70GJ, replacing a portion of the natural gas required for thermal energy. An additional 5GJ of electrical energy is necessary at the EFW facility.
- At power plant, additional 5GJ electrical needs at EFW, so the total Electrical needed to be produced is 38 GJ with the efficiency is 60%. Therefore, the natural gas needs in power plant are 63.3GJ and the efficiency losses is 25.3GJ.

5.1 Sankey Diagram



5.2 Code

'Scenario C is power plant, EFW and manufacturing facility (considering scope of natural gas use)

'Thermal needs for manufacturing facility

Natural Gas Manufacturing [130] Thermal Input Manufacturing

Syngas EFW [70] Syngas Manufacturing

Syngas Manufacturing [70] Thermal Input Manufacturing

Thermal Input Manufacturing [100] Manufacturing Process

Thermal Input Manufacturing [40] Convective Losses

Thermal Input Manufacturing [60] Stack Losses

'Electrical needs for manufacturing facility

Electrical Input Manufacturing [30] Manufacturing Process

'EFW

Electrical Output [5] Electrical needs at EFW

'Power Station

'Balanced to what the manufacturing facility needs as long as it does not impact efficiency

'Making sure within constraints of 50 GJ output capacity (output needed is 33 GJ)

Natural Gas Power Plant [63.3] Electrical Output

Electrical Output [30] Electrical Input Manufacturing

Electrical Output [3] Electrical Needs at Power Station

Electrical Output [25.3] Efficiency Losses

'Combining my totals up front to have an overall input

Natural Gas Demand [130] Natural Gas Manufacturing

Natural Gas Demand [63.3] Natural Gas Power Plant

'Combining my totals at back end for overall energy waste

Convective Losses [40] Energy Waste

Stack Losses [60] Energy Waste

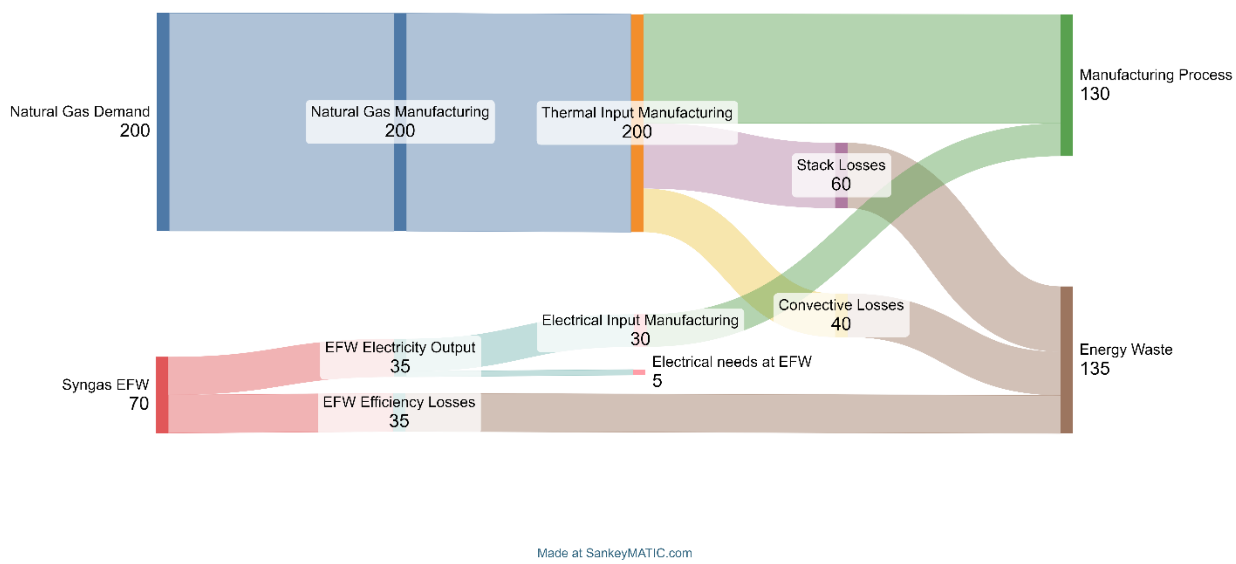
Efficiency Losses [25.3] Energy Waste

6 Scenario D:

Build an energy-from-waste facility to generate electricity (syngas turbine available is 50% efficient)

- An Energy-from-Waste (EFW) facility is constructed to generate syngas amounting to 70GJ. Syngas is used to generate electricity with efficiency of 50%, so 35 GJ electrical energy and 35GJ efficiency losses. The electrical energy can be distributed to manufacturing 30GJ and EFW 5GJ.

6.1 Sankey Diagram



6.2 Code

'Scenario D is EFW and manufacturing facility (considering scope of natural gas use)

'Thermal needs for manufacturing facility

Natural Gas Manufacturing [200] Thermal Input Manufacturing

Thermal Input Manufacturing [100] Manufacturing Process

Thermal Input Manufacturing [40] Convective Losses

Thermal Input Manufacturing [60] Stack Losses

'Electrical needs for manufacturing facility

Electrical Input Manufacturing [30] Manufacturing Process

'EFW

Syngas EFW [35] EFW Electricity Output

Syngas EFW [35] EFW Efficiency Losses

EFW Electricity Output [30] Electrical Input Manufacturing

EFW Electricity Output [5] Electrical needs at EFW

'Combining my totals up front to have an overall input

Natural Gas Demand [200] Natural Gas Manufacturing

'Combining my totals at back end for overall energy waste

Convective Losses [40] Energy Waste

Stack Losses [60] Energy Waste

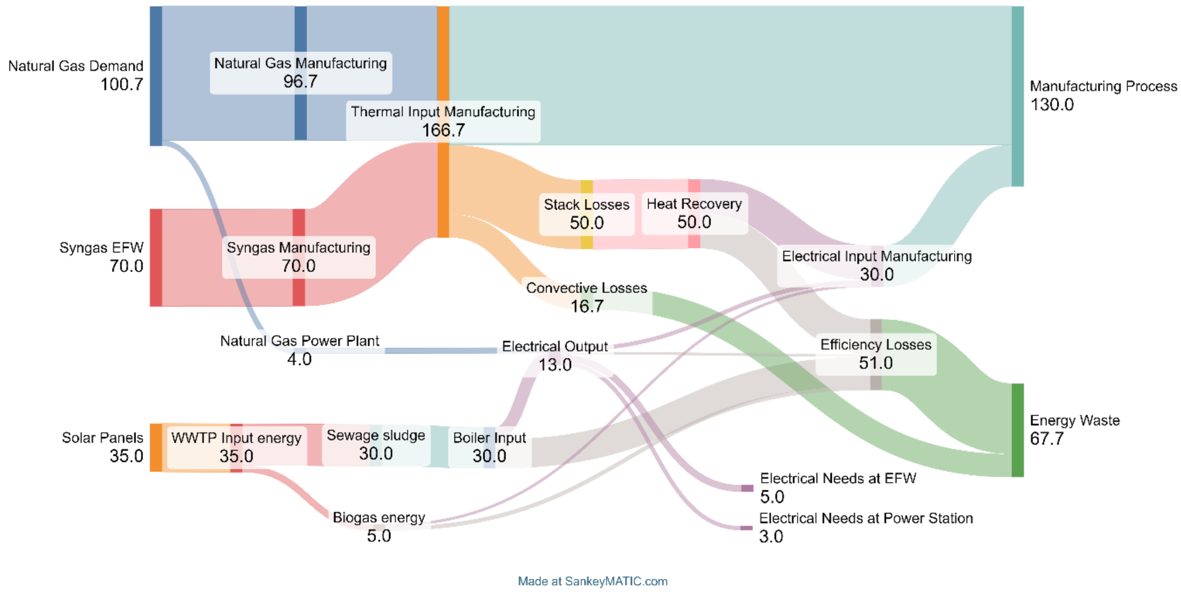
EFW Efficiency Losses [35] Energy Waste

7 Scenario E:

Evaluate another scenario that you think might be effective to achieve your objective of reducing natural gas consumption by combining any of the Scenarios provided.
Combine Scenario A, B and C:

- At Manufacturing Site, through insulation, convective losses reduced to 10%, manufacturing efficiency increased to 60%. Keep manufacturing process's thermal energy requirement as 100GJ, Convective losses are 16.7GJ and Stack losses are 50GJ. Therefore, the thermal energy needed in manufacturing site are 166.7GJ.
  Stack losses (50GJ) heat recovered energy is converted to electrical energy, yielding 25GJ for the manufacturing process with a 25GJ efficiency loss.
- An Energy-from-Waste (EFW) facility is constructed to generate syngas amounting to 70GJ, replacing a portion of the natural gas required for thermal energy at manufacturing facility. An additional 5GJ of electrical energy is necessary at the EFW facility.
- At the Wastewater Treatment Plant (WWTP), solar energy is employed to produce biogas 5GJ and sewage sludge 30GJ. The biogas is converted to 2GJ electrical energy with 3GJ efficiency losses.
- At Power Plant, needs 5GJ Electricity input Manufacturing, 3 GJ for the power plant, and 5GJ for the Energy-from-Waste (EFW) facility. Utilize 30GJ of sewage sludge as feedstock in its boiler. The boiler operates with 30% efficiency, resulting in an electrical energy output of 9GJ, along with 21GJ in efficiency losses. Utilize 4GJ of Natural Gas to produce 2GJ (below 50% of the full load, the average efficiency is 50%), with 2GJ efficiency losses.

7.1 Sankey Diagram



7.2 Code

'Scenario E is power plant, WWTP, EFW and manufacturing site

Natural Gas Manufacturing [96.7] Thermal Input Manufacturing

Syngas Manufacturing [70] Thermal Input Manufacturing

Thermal Input Manufacturing [100] Manufacturing Process

Thermal Input Manufacturing [16.7] Convective Losses

Thermal Input Manufacturing [50] Stack Losses

'Electricity needs for manufacturing facility

Electrical Input Manufacturing [30] Manufacturing Process

Heat Recovery [25] Electrical Input Manufacturing

Electrical Output [3] Electrical Input Manufacturing

Biogas energy [2] Electrical Input Manufacturing

'EFW

Syngas EFW [70] Syngas Manufacturing

'Heat recovery from Stack Losses to electricity with 50% efficiency

Stack Losses [50] Heat Recovery

Heat Recovery [25] Efficiency Losses

'Power Station

Natural Gas Power Plant [4] Electrical Output

Boiler Input [9] Electrical Output

Electrical Output [2] Efficiency Losses

Electrical Output [3] Electrical Needs at Power Station

Electrical Output [5] Electrical Needs at EFW

'WWTP

Solar Panels [35] WWTP Input energy

WWTP Input energy [5] Biogas energy

WWTP Input energy [30] Sewage sludge

Biogas energy [3] Efficiency Losses

Sewage sludge [30] Boiler Input

Boiler Input [21] Efficiency Losses

'Combining my totals up front to have a overall input

Natural Gas Demand [96.7] Natural Gas Manufacturing

Natural Gas Demand [4] Natural Gas Power Plant

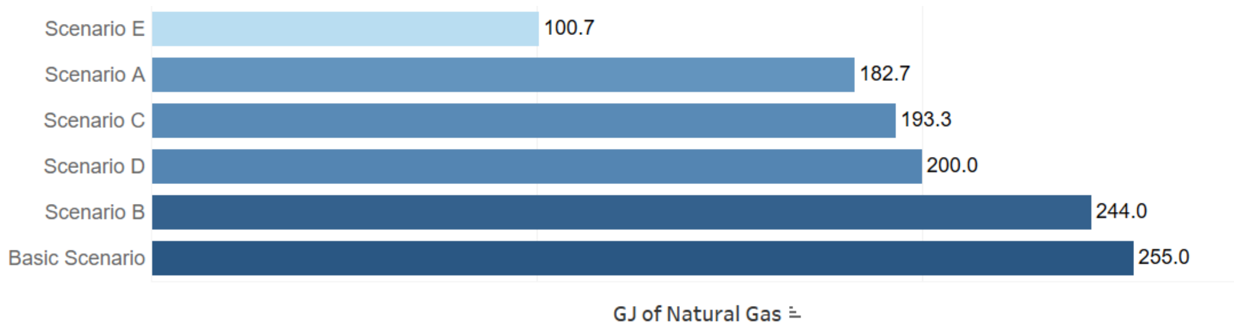
'Combining my totals at back end for overall energy waste

Convective Losses [16.7] Energy Waste

Efficiency Losses [51] Energy Waste

8 Comparison of Scenarios

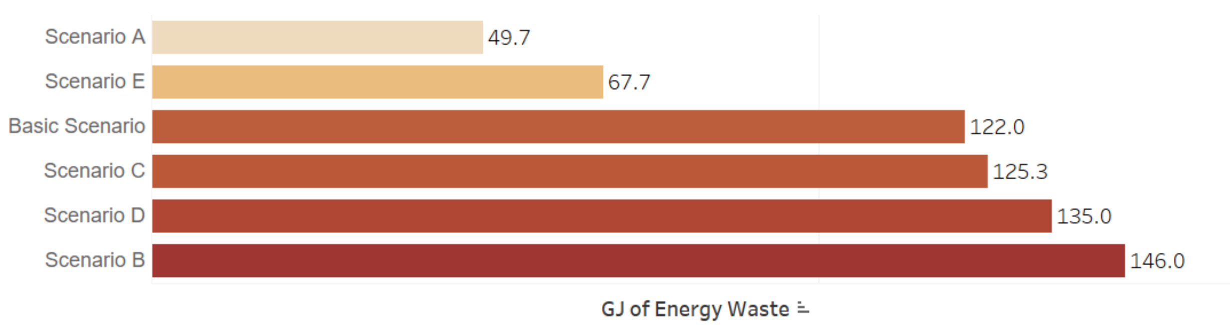
8.1 Natural Gas Utilization



Considering the consumption of Natural Gas, the Basic Scenario consumes the most Natural Gas (255GJ). The other five scenarios can all reduce the consumption of natural gas. Among them, Scenario B reduces the least and still requires 244GJ. This scenario produces electricity through the Wastewater Treatment Facility, thereby reducing the use of Natural Gas in Power Plant (from 55GJ to 44GJ).

Scenario E is the most significant, which combines scenarios A, B, and C. In terms of heat energy, manufacturing efficiency is improved by reducing the consumption of convective losses and using Syngas instead of Natural Gas to reduce the use of Natural Gas. In terms of electric energy, by reusing Stack Losses and using Sewage Sludge as Power Plant Feedstock, the Natural Gas required for electrical energy is reduced. In this case, only 100.7GJ of Natural Gas is required.

8.2 Energy Waste



When comparing the energy wasted in each of the cases, scenario B causes the most energy waste. This can be attributed to the fact that the coal-powered boiler at the power plant operates at an efficiency of only 30%. It is also important to note that the power plant is fed by using processed sewage as feedstock. Scenario D produces the second-largest amount of energy waste. In this scenario, municipal waste is converted to electricity with an efficiency of 50%, which is lower than the base-case scenario, which operates with an efficiency of 60%. The base case and scenario C produce a similar level of energy waste of around 125 GJ. The best-case scenarios for minimizing the wasted energy are A and E. In both cases, the convective thermal losses are reduced by the manufacturing process. Even though the losses in scenario E are higher than those in scenario A, scenario E uses electricity that is produced from the WWTP, which is a more effective approach for minimizing energy waste.

9 Limitations

- Geographical Constraints: While the analysis assumes seamless installation of connections between facilities, in reality, there may be geographical challenges such as varying terrains, environmental restrictions, or other physical obstacles that could impede the installation process.
- Transmission Loss Variability: The analysis assumes negligible transmission losses due to close proximity between facilities. However, actual transmission losses may vary, influenced by factors such as weather conditions, maintenance requirements, and the specific technologies employed.
- Energy Consumption and Production Dynamics: The assumption of constant energy consumption and production in each hour oversimplifies the scenario. Real-world situations involve dynamic and fluctuating energy demands, influenced by factors like seasonality, operational changes, and unforeseen events, which can impact the accuracy of the analysis.