Report

Greenhouse Gas Systems Analysis

Ramsey/Washington County Resource Recovery Project

Project I.D.: 15R002.00

Prepared For Ramsey/Washington County Resource Recovery Project Board Maplewood, Minnesota

April 2015

RAMSEY/WASHINGTON COUNTY
RESOURCE RECOVERY PROJECT
RAMSEY AND WASHINGTON COUNTIES, MINNESOTA

In Association With

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April 9, 2015

Mr. Zack Hansen
Ms. Judy Hunter
Ms. Kate Bartelt
Ramsey/Washington Counties Resource Recovery Project Board
2785 White Bear Avenue, Ste 350
Maplewood, MN 55109-1320

Dear Mr. Hansen, Ms. Hunter, and Ms. Bartelt:

RE: Greenhouse Gas (GHG) Systems Analysis
for Residential and Commercial Waste Management

This letter transmits the Greenhouse Gas (GHG) Systems Analysis for the scenarios analyzed for residential and commercial waste management. The report details the analysis of GHG emissions and the comparison of options for various waste management scenarios that could occur in Ramsey and Washington Counties. This report is intended to be a comparative analysis of different systems and not an all-inclusive life cycle GHG analysis of specific waste management systems. Items that generated the same GHG emissions between the systems were not accounted for in the GHG systems analysis such as the life cycle of a collection truck.

This report analyzes 400,000 tons of MSW managed in different systems or scenarios. Scenarios analyzed in this report include:

- **Processing Only** (Base Case) – Model the current system of processing all MSW (400,000 tons) into RDF and all RDF going to Xcel for combustion;
- **Phase 1-SSO/SSR** – Increased Source Separated Organics (SSO) and Source Separated Recycling (SSR), with all MSW (remaining tons of the 400,000) delivered to the Newport Facility for processing into RDF with combustion by Xcel;
- **Phase 2-SSO/SSR/MWP/AD** – Phase 1 plus the use of Mixed Waste Processing (MWP) to increase recycling and organics quantities and sending the organics offsite to an Anaerobic Digester (AD);
- **Phase 3-Gasification/SSO/SSR/MWP/AD** – Phase 1 and 2 plus the use of Gasification to manage all RDF instead of combustion by Xcel;
- **Alternative 1 – Processing and Gasification Only** – The Processing Only case with the RDF going to Gasification instead of combustion by Xcel (does not include SSO/SSR, MWP, and AD);

- **Existing System – Extended** – "status quo" for waste delivery, managed in same manner at the Newport Facility and existing landfills – processed RDF to combustion by Xcel, with the Newport Resource Recovery Facility (Newport Facility) continuing under private ownership;
- **Alternative 2-Processing, AD, and MWP** – RDF processing with the addition of MWP and AD (does not include SSO/SSR).

In order to analyze the major components of residential and commercial collection, as well as the various processes, GHG analysis was analyzed by modules. Using this method of modules allowed for input changes to a module but retained the basic calculations to ensure comparable results.

Major modules developed for this GHG analysis included:

- Collection and Hauling, including adding SSO/SSR
- Transportation
- Materials Management
  - RDF Processing (including recyclables, bulky waste and residue)
  - RDF Combustion
  - RDF Disposal (Ash, bulky waste and processing residue)
  - Mixed Waste Processing (MWP)
  - Anaerobic Digestion (AD)
  - Gasification
- RDF Combustion Plant Shut Down (gasification only)
- Ethanol Offset (gasification only)
- Electrical Offset (gasification only)

This report includes components completed with the assistance of Great Plains Institute (GPI). GPI was consulted to provide GHG emissions estimates used in the modeling as well as to provide data for electrical offsets for closing the Xcel combustion facilities (Red Wing and Wilmarth) and for ethanol production using gasification. GPI's report *Market, Policy and GHG Implications of MSW/RDF to Ethanol Production at Newport* is included in Appendix C.

Thank you for the opportunity to provide this GHG analysis.

Sincerely,

Foth Infrastructure & Environment, LLC

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Greenhouse Gas Systems Analysis

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Greenhouse Gas Systems Analysis
Contents

Tables within the Report

Tables behind the Tables Tab

Figures within the Report

Figures behind the Figures Tab

Appendices

Greenhouse Gas Systems Analysis

Executive Summary

This *Greenhouse Gas Systems Analysis* estimates and compares the greenhouse gas (GHG) emissions of options for various waste management scenarios that could occur in Ramsey and Washington Counties. Each system was modeled for GHG emissions based on 400,000 tons per year of MSW in the system.

This report is a comparative analysis of different waste management systems that could occur in the Counties. It is intended to be comparative and not an all-inclusive life cycle GHG analysis. Items that generated the same GHG emissions between the systems were not accounted for in the GHG systems analysis such as the life cycle of a collection truck. Figures to depict the waste flows for each system modeled are located in Section 2.

The different systems analyzed in this *Greenhouse Gas Systems Analysis* parallel the systems analyzed in the *Life Cycle Financial Analysis*, February, 2015. Each system has a process flow diagram to visually depict waste flows for each system. The process flow assigned various tons of materials to different material management options. The systems analyzed include:

- **Processing Only** (Base Case) – Model the current system of processing all MSW (400,000 tons) into RDF and all RDF going to Xcel for combustion;
- **Phase 1-SSO/SSR** – Increased Source Separated Organics (SSO) and Source Separated Recycling (SSR), with all MSW (remaining tons of the 400,000) delivered to the Newport Facility for processing into RDF with combustion by Xcel;
- **Phase 2-SSO/SSR/MWP/AD** – Phase 1 plus the use of Mixed Waste Processing (MWP) to increase recycling and organics quantities and sending the organics offsite to an Anaerobic Digester (AD);
- **Phase 3-Gasification/SSO/SSR/MWP/AD** – Phase 1 and 2 plus the use of Gasification to manage all RDF instead of combustion by Xcel;
- **Alternative 1 – Processing and Gasification Only** – The Processing Only case with the RDF going to Gasification instead of combustion by Xcel (does not include SSO/SSR, MWP, and AD);
- **Existing System – Extended** – “status quo” for waste delivery, managed in same manner at the Newport Facility and existing landfills – processed RDF to combustion by Xcel, with the Newport Resource Recovery Facility (Newport Facility) continuing under private ownership;
- **Alternative 2-Processing, AD, and MWP** – RDF processing with the addition of MWP and AD (does not include SSO/SSR).

All systems modeled are considered mature systems. No modeling was completed during the phase in of systems or processes. Modeling GHG emissions for each system was broken into modules. The GHG modules included:

- Collection and Hauling, including adding SSO/SSR
- Transportation
- Materials Management
  - RDF Processing (including recyclables, bulky waste and residue)
  - RDF Combustion
  - RDF Disposal (Ash, bulky waste and processing residue)
  - Mixed Waste Processing (MWP)
  - Anaerobic Digestion (AD)
  - Gasification
- RDF Combustion Plant Shut Down (gasification only)
- Ethanol Offset (gasification only)
- Electrical Offset (gasification only)

GHG emissions models for each module were developed using data for emissions for diesel fuel (collection, hauling and transportation), electric use (RDF processing, MWP), anaerobic digestion and composting (Canadian model), recycling (EPA WARM model) and gasification using direct emissions data.

To provide data for electrical offsets for closing the Xcel combustion facilities (Red Wing and Wilmarth) and for ethanol production using gasification, Great Plains Institute (GPI) was consulted to provide GHG emissions estimates used in the modeling.

Specific inputs and modeling results are in the Tables located after the Tables tab in the back of this report.

Table ES-1 provides a summary of the results developed in Section 4.

Table ES-1
GHG Emissions Summary (MtCO₂e)

	Processing Only (Base Case)	Phase 1 - SSO/SSR	Alternative 1 - Processing, AD, and MWP	Phase 2 - SSO/SSR/ MWP/AD	Alternative 2 - Processing and Gasification Only	Phase 3 - Gasification/SSO /SSR/MWP/AD	Existing System - Extended
Collection	**13,502**	**14,684**	**13,502**	**14,684**	**13,502**	**14,684**	**13,502**
Transportation	**9,384**	**8,770**	**8,771**	**8,419**	**5,414**	**5,114**	**11,342**
RDF Processing	**5,393**	**4,969**	**9,048**	**8,957**	**5,393**	**8,957**	**4,341**
Material Management							
♦ Recycling	(32,190)	(58,813)	(71,550)	(76,937)	(32,190)	(76,937)	(25,910)
♦ Anaerobic Digestion (AD)	0	(4,934)	(10,060)	(11,044)	0	(11,044)	0
♦ RDF Combustion	72,198	65,860	60,714	58,909	0	0	58,119
♦ Gasification	0	0	0	0	61,075	48,343	0
♦ Landfill	5,372	5,057	4,871	4,828	5,372	4,828	15,244
Material Management Subtotal	**45,380**	**7,170**	**(16,024)**	**(24,244)**	**34,257**	**(34,810)**	**47,454**
RDF Combustion Plant Shut-down	0	0	0	0	(170,538)	(141,967)	0
Ethanol Offset	0	0	0	0	(80,523)	(69,987)	0
Electrical Offset	0	0	0	0	100,641	83,780	0
Total GHG	**73,659**	**35,592**	**15,296**	**7,816**	**(91,855)**	**(134,229)**	**76,636**

Figure ES-1 graphically presents the total GHG emissions

The modeled system that most closely represents today's MSW management in the Counties is Existing System – Extended with most MSW processed but also some landfilled. The Processing Only (Base Case) assumes all 400,000 tons of Ramsey and Washington County waste is processed and none direct landfilled. GHG analysis indicates that as the waste is utilized in different ways through the various systems beyond Processing Only (Base Case), GHG emissions are reduced. Adding SSO/SSR to the Processing Only (Base Case) system resulted in a GHG reduction of 52%. If the Counties only added MWP and AD to the Base Case, the GHG reduction is estimated to be 79%. If both SSO/SSR and MWP/AD are added, GHG reduction is estimated to be 89% in comparison to the Base Case.

Gasification of RDF rather than combustion was compared in two of the systems. If gasification technology is proven to convert RDF to ethanol, the GHG emission change is significant. By adding gasification to the Processing Only (Base Case) system, GHG emissions become negative (or a GHG credit) with a GHG emissions reduction of 225% when compared to the base case. If a gasification system is added along with SSO/SSR/MWP and AD, the reduction in GHG emissions is 282% when compared to the base case.

The addition of the various recycling (MWP, SSO/SSR) and AD to the systems has considerable GHG reductions resulting in comparably less GHG generation than the Processing Only (Base Case). It is important to note that the addition of gasification to the system results in a net negative GHG emissions generation.

The Greenhouse Gas Systems Analysis with its separate modules allows a GHG impact analysis to determine the activities that have the greatest impact on GHG emissions. The following items of note come from the comparisons of the GHG emissions of the seven (7) waste management scenarios.

Conversion of Waste to a Resource has the Greatest Impact on GHG Emissions

Each of the systems analyzed indicate that the more you do with the waste, the greater the GHG emission reduction impact. Comparatively speaking the following items indicate how GHG emissions are impacted:

1) **Collection and transportation have the least GHG emission impacts of all other activities**

   Collection and transportation, while the most visible component of the waste management system to the households and businesses, are a small component of GHG emissions in the overall waste management scenarios. Changing collection and transportation has minimal impact on GHG emissions.

2) Conversion of waste to recyclables has the greatest reduction impact on GHG Emissions

The addition of the various recycling (MWP, SSO/SSR) and AD to the system has considerable GHG emissions reductions resulting in comparably less GHG generation than the Processing Only (Base Case) scenario.

The system most similar to today's waste management activity in the Counties is Existing System - Extended. The Processing Only (Base Case) assumes all Ramsey and Washington County waste is processed and not some of it direct landfilled as currently occurs. GHG emissions analysis indicates that as the waste is utilized in different ways through the various systems beyond Processing Only (Base Case), GHG emissions are reduced.

3) Gasification significantly increases the change from "waste" management to "resource" management

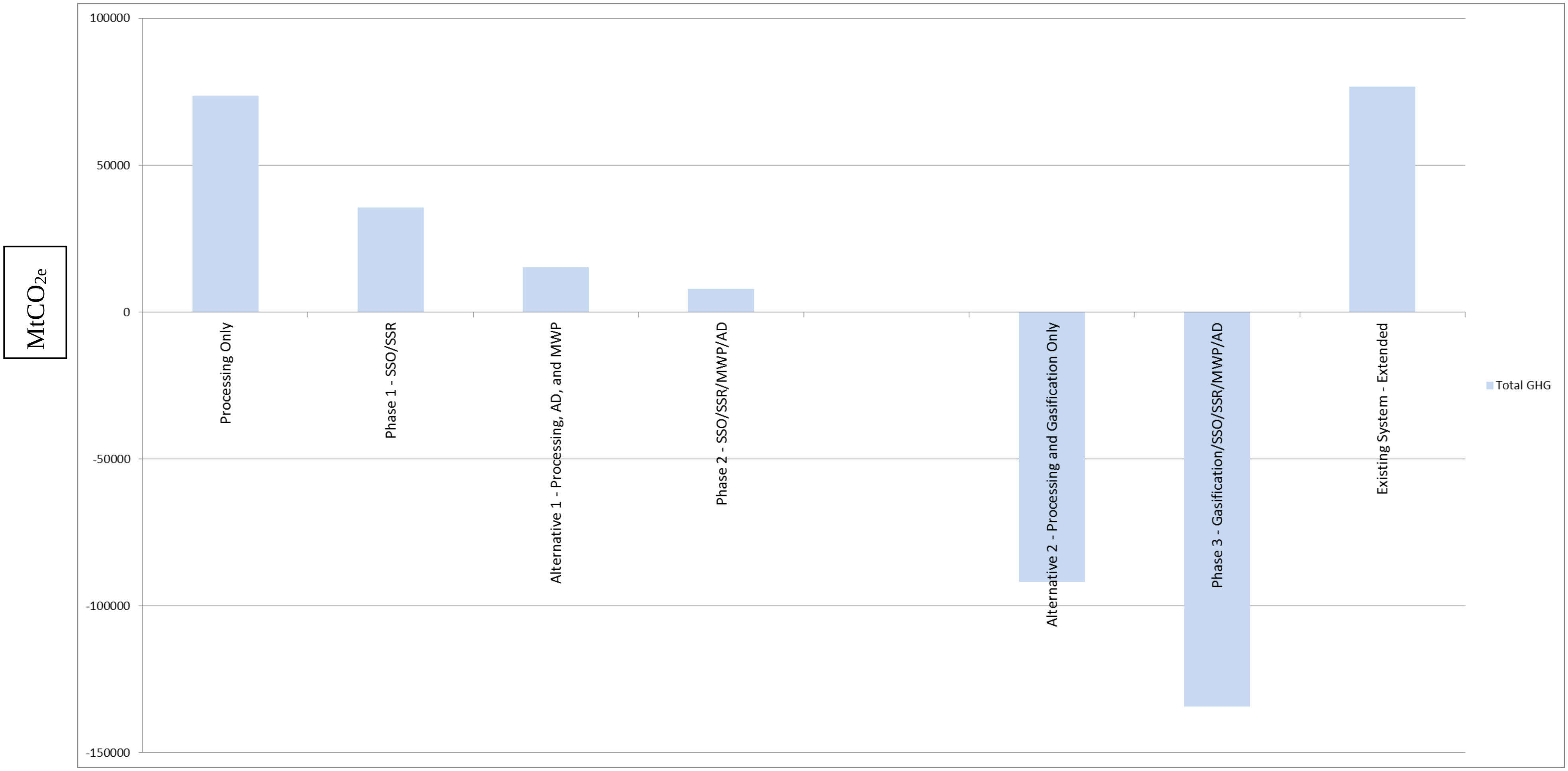
It is important to note that the addition of gasification to the system results in a net negative GHG emission generation. Converting to gasification extends the changes of the "waste" management system to a "resource" management system.

Gasification of RDF rather than combustion was compared in two of the systems. If gasification technology is proven to convert RDF to ethanol, the GHG emission change is significant. By adding gasification to the Processing Only (Base Case) system, GHG emissions become negative (or a GHG credit). The ethanol replaces the use of gasoline, reducing GHG emissions.

4) Greenhouse Gas is one metric of the waste management systems for consideration

This analysis reviews one metric of the waste management system: Comparative GHG emissions. It is important to consider the impact of the system on other metrics (e.g. safety, traffic concerns, and cost). Other research has been done on financial costs of implementing each of the systems (*Life Cycle Financial Analysis*, February, 2015). This should all be part of a larger consideration of the waste management system options.

Figure ES-1
Total GHG Emissions Summary by System (MtCO2e)



Greenhouse Gas Systems Analysis

List of Abbreviations, Acronyms, and Symbols

AD	Anaerobic Digestion
Biogenic	CO_2 emissions-related to the natural carbon cycle
BMP	Biomethane Potential
C & D	Construction and Demolition
Carbon Cycle	The movement of carbon as it is recycled and reused in the biosphere
CH_4	Methane
CO_2	Carbon Dioxide
EPA	Environmental Protection Agency
Foth	Foth Infrastructure & Environment, LLC
GHG	Greenhouse Gas
GPI	Great Plains Institute
HDPE	High Density Polyethylene
LFG	Landfill Gas
mpg	Miles per Gallon
MSW	Municipal Solid Waste
$MtCO_{2e}$	Metric Tons of Carbon Dioxide Equivalent
MWP	Mixed Waste Processing
N_2O	Nitrous Oxide
Newport Facility	Newport Resource Recovery Plant
Non-biogenic	CO_2 emissions-not related to the natural carbon cycle
OCC	Old Corrugated Containers
PET	Polyethylene Terephthalate
Project Board	Ramsey/Washington Counties Resource Recovery Project Board
R/W	Ramsey/Washington
RDF	Refuse Derived Fuel
Red Wing	Xcel Red Wing RDF Combustion Plant
RRT	Resource Recovery Technologies, LLC
SSO	Source Separated Organics
SSR	Source Separated Recyclables
tpy	Tons per Year
WARM	EPA's Waste Reduction Model
Wilmarth	Xcel Wilmarth RDF Combustion Plant

1 Introduction

The purpose of this Greenhouse Gas Systems Analysis is to develop, analyze, and compare the estimated greenhouse gas (GHG) emissions from several different potential municipal solid waste (MSW) management scenarios under consideration by the Ramsey/Washington Counties Resource Recovery Project Board (Project Board). The Project Board conducted this analysis to evaluate and compare the potential environmental impacts of each of the scenarios using GHG emissions as an indicator.

This comparative analysis was completed with a goal of using the same assumptions for each scenario and using readily available data including its inherent limitations. The intent was to treat each scenario equally such that the results are comparable. This is not intended to be an all-inclusive GHG life cycle analysis of each scenario.

The MSW management scenarios analyzed for a one-year period in this report include:

- ♦ **Processing Only** (Base Case) – Model the current system of processing all MSW (400,000 tons) into RDF and all RDF going to Xcel for combustion;
- ♦ **Phase 1-SSO/SSR** – Increased Source Separated Organics (SSO) and Source Separated Recycling (SSR), with all MSW (remaining tons of the 400,000) delivered to the Newport Facility for processing into RDF with combustion by Xcel;
- ♦ **Phase 2-SSO/SSR/MWP/AD** – Phase 1 plus the use of Mixed Waste Processing (MWP) to increase recycling and organics quantities and sending the organics offsite to an Anaerobic Digester (AD);
- ♦ **Phase 3-Gasification/SSO/SSR/MWP/AD** – Phase 1 and 2 plus the use of Gasification to manage all RDF instead of combustion by Xcel;
- ♦ **Alternative 1 – Processing and Gasification Only** – The Processing Only case with the RDF going to Gasification instead of combustion by Xcel (does not include SSO/SSR, MWP, and AD);
- ♦ **Existing System – Extended** – “status quo” for waste delivery, managed in same manner at the Newport Facility and existing landfills – processed RDF to combustion by Xcel, with the Newport Resource Recovery Facility (Newport Facility) continuing under private ownership;
- ♦ **Alternative 2-Processing, AD, and MWP** – RDF processing with the addition of MWP and AD (does not include SSO/SSR).

The analysis assumes 400,000 tons per year (tpy) of MSW in each of the scenarios. The report describes the material flows in the various scenarios.

The report describes the framework and modules used to develop the data to estimate the various GHG emissions: from different collection systems through various processing systems to final disposal. There is an extensive mathematical analysis using various computer models and calculations to develop the appropriate emission factors for each system.

Advice was sought from the Great Plains Institute (GPI) to review the processes used to conduct the GHG analysis to ensure validity. Additionally, GPI provided additional higher level analysis regarding the potential impact of producing ethanol via the gasification technology being considered. The analysis considered the potential impacts on ethanol markets and impacts and outcomes for the existing Xcel Energy plants.

Finally, the emissions factors for each component of each scenario and the tons managed are multiplied together to provide the estimates for GHG emissions. Each scenario was compared to the other potential management scenarios.

2 Materials Management Systems

For purposes of comparison, seven (7) management systems or scenarios were developed for this Greenhouse Gas System Analysis.

- **Processing Only** (Base Case) – Illustrate the current system of processing all MSW (400,000 tons) into RDF and all RDF going to Xcel for combustion;
- **Phase 1-SSO/SSR** – Increased Source Separated Organics (SSO) and Source Separated Recycling (SSR), with all MSW (remaining tons of the 400,000) delivered to the Facility for processing RDF with combustion by Xcel;
- **Phase 2-SSO/SSR/MWP/AD** – Phase 1 plus the use of Mixed Waste Processing (MWP) and sending the organics offsite to an Anaerobic Digester;
- **Phase 3-Gasification/SSO/SSR/MWP/AD** – Phase 1 and 2 plus the use of Gasification to manage all RDF instead of combustion by Xcel;
- **Alternative 1 – Processing and Gasification Only** – The processing only case with the RDF going to Gasification instead of combustion by Xcel (does not include SSO/SSR, MWP, and AD);
- **Existing System – Extended** – "status quo" for waste delivery, managed in same manner at the Newport Facility and existing landfills – processed RDF to combustion by Xcel, with the Newport Resource Recovery Facility (RRF) continuing under private ownership;
- **Alternative 2-Processing, AD, and MWP** – RDF processing with the addition of Mixed Waste Processing (MWP) and Anaerobic Digestion (does not include SSO/SSR).

Each of the scenarios is described in detail below. For consistent comparison, all systems assume the waste stream is comprised of 400,000 tons per year of MSW. The MSW is recovered or processed differently in each system described below. Each system processes and separates different types of materials that can then be analyzed for GHG emissions

2.1 Processing Only (Base Case)

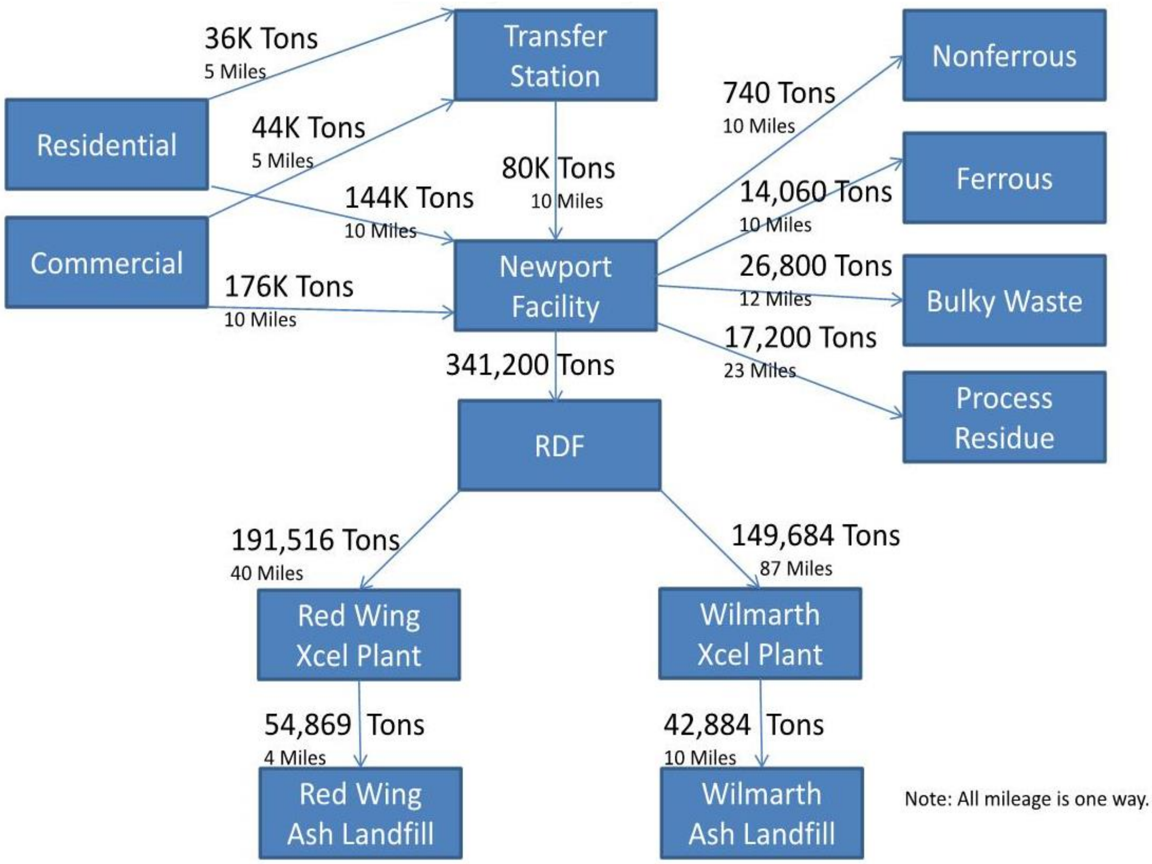
All 400,000 tons are assumed to be processed at the Newport Facility for RDF combustion at one of the Xcel Energy facilities. 2013 data was used to generate the material flows to and from the Newport Facility.

The Processing Only (Base Case) scenario assumes all waste is collected and delivered to either a transfer station or directly to the Newport Facility. The Processing Only system assumes 80,000 tons (20%) are delivered to a transfer station prior to delivery to the Newport Facility. The remaining 320,000 tons (80%) are assumed to be direct hauled to the Newport Facility. The bulky waste is assumed to be removed from the system at the Newport Facility prior to processing MSW into RDF. Bulky waste, along with process residue, is modeled as being landfilled.

The remaining material is processed at the Newport Facility and results in ferrous, nonferrous, process residue and RDF. The tons of each material type is the actual average tons historically reported at the Newport Facility, including the tons of RDF delivered to the Red Wing and Wilmarth Xcel Energy facilities. The amount of ash resulting from RDF combustion is 28.65% of the RDF delivered and is assumed to be the "wet" ash weight. That is, the ash is cooled with water prior to shipping to a landfill for disposal.

Figure 2-1 provides a flow diagram for Processing Only (Base Case).

Figure 2-1
Processing Only (Base Case w/o Collection)



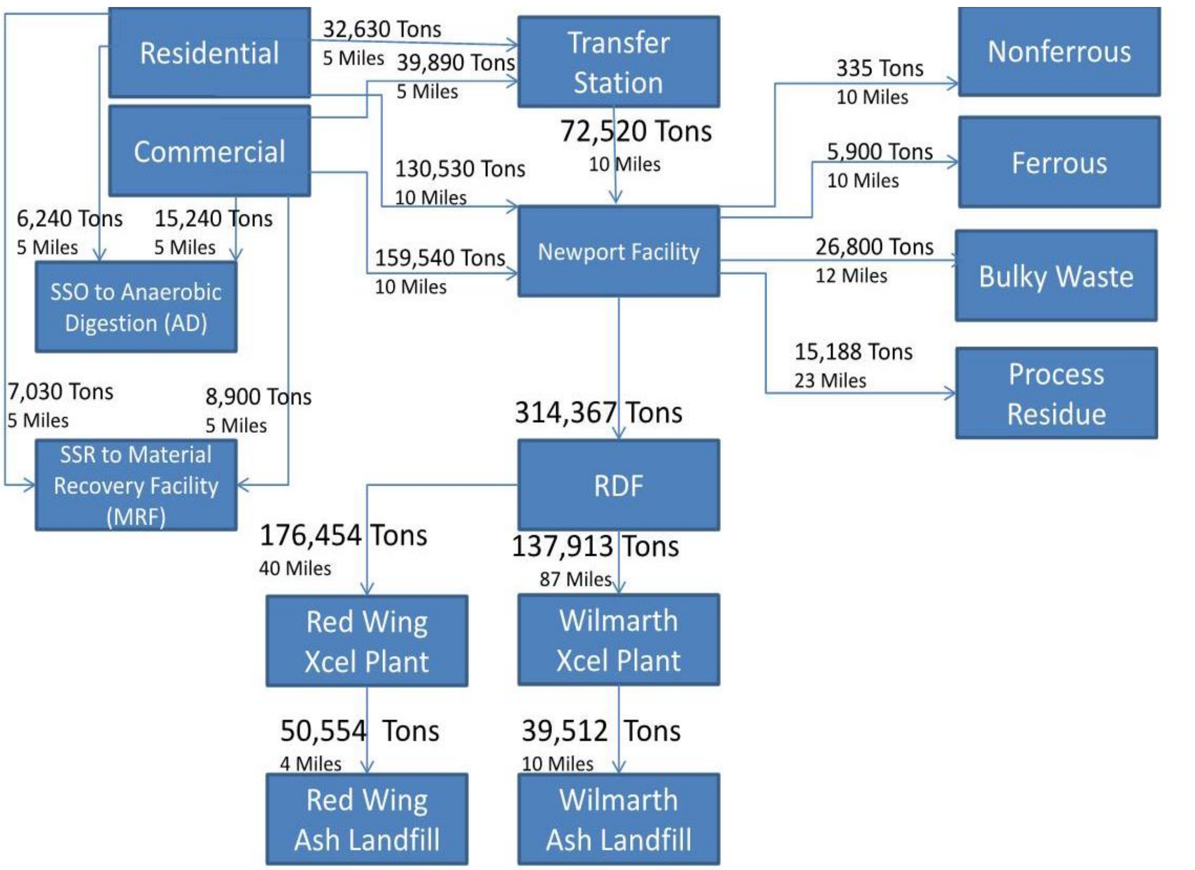
2.2 Phase 1 – Increased SSO/SSR with Processing Only

Phase 1- increased SSO/SSR scenario assumes increased source separated recycling (SSR) and source separated organics (SSO) recycling with all remaining MSW delivered to the Newport Facility or to a transfer station. Phase 1 assumes that increased SSO and SSR are separated at the household and business level prior to the MSW being sent to the Newport Facility or transfer station. Estimates for SSO and SSR tons removed from the waste stream are assumed to be in a mature system.

Phase 1 estimates additional collection vehicles for SSO, since there is not a well-established collection system for that material currently in the Counties. SSR and MSW collection vehicles remained the same as materials are transferred from one collection system vehicle to the other.

Figure 2-2 provides a flow diagram for Phase 1.

Figure 2-2
Phase 1 – Increased SSO/SSR with Processing Only (Base Case)



Note: All mileage is one way.

The addition of SSO/SSR to Processing Only (Base Case) results in reduced MSW delivered to the Newport Facility. The SSO/SSR tons recovered prior to delivery to the Newport Facility or transfer station were determined based on the "new" tons available as presented in the *Estimated Calculations of Additional SSR/SSO Tons* memorandum[1].

The memorandum presents the projected tons recovered via SSO/SSR based on the total waste managed of 921,500 tons. The traditional recyclables (paper, glass, metal, and plastic) were

[1] *Estimated Calculations of Additional SSR/SSO Tons* memorandum Foth Infrastructure & Environment, LLC. September 15, 2014.

combined to represent SSR and the food waste and compostable paper were combined as SSO. SSO and SSR tons are based on a mature program.

A ratio between the GHG modeling system tons (400,000) and the total tons managed (921,500) was applied to the SSO and SSR tons (i.e. 400,000/921,500 = 0.434). The result is 21,480 tons of SSO and 15,930 of SSR removed from the waste stream prior to delivery to the transfer station or the Newport Facility. The tons remaining (362,590) are modeled at 20% from the transfer station and 80% direct to Newport. The addition of SSO/SSR will have no effect on the tons of bulky waste so the number of tons (26,800) remained the same as the Processing Only (Base Case) scenario.

The remaining material after SSO/SSR and bulky waste removal (335,790 tons) is processed at the Newport Facility and results in ferrous, nonferrous, process residue and RDF. The tons of each material were determined as follows:

- Tons of recovered nonferrous are calculated from the tons available after SSO/SSR (1,450 tons as presented in Table 8-1 of the memorandum *Analysis of Mixed Waste Processing*[2]) times the fraction recovered at the Newport Facility in the Base Case divided by the total nonferrous system tons as estimated in the 2014 Waste Composition Study[3].
- Tons of recovered ferrous are calculated from the amount available after SSO/SSR with 100% recovery. (Note: Complete recovery was modeled because the actual reported ferrous recovery exceeded the calculated ferrous tons available based on the 2014 Waste Composition Study data[4]).
- Tons of process residue are calculated from total tons being processed after SSO/SSR, bulky waste, and recycled material tons are removed times the ratio of the actual process residue tons (17,200 tons) to the material processed in the base case (400,000 tons – 26,800 tons), which results in 4.6% process residue. Process residue is landfilled.
- Tons of RDF are calculated from incoming waste after SSO/SSR minus material removed (bulky, recyclables, process residue).

Similar to the existing system, 56.13% of the RDF is delivered to Red Wing and 43.87% of the RDF is delivered to Wilmarth and the amount of ash resulting from RDF combustion is 28.65% of the RDF delivered, which is assumed to be the "wet" ash weight.

2.3 Alternative 1 – Processing, AD, and MWP

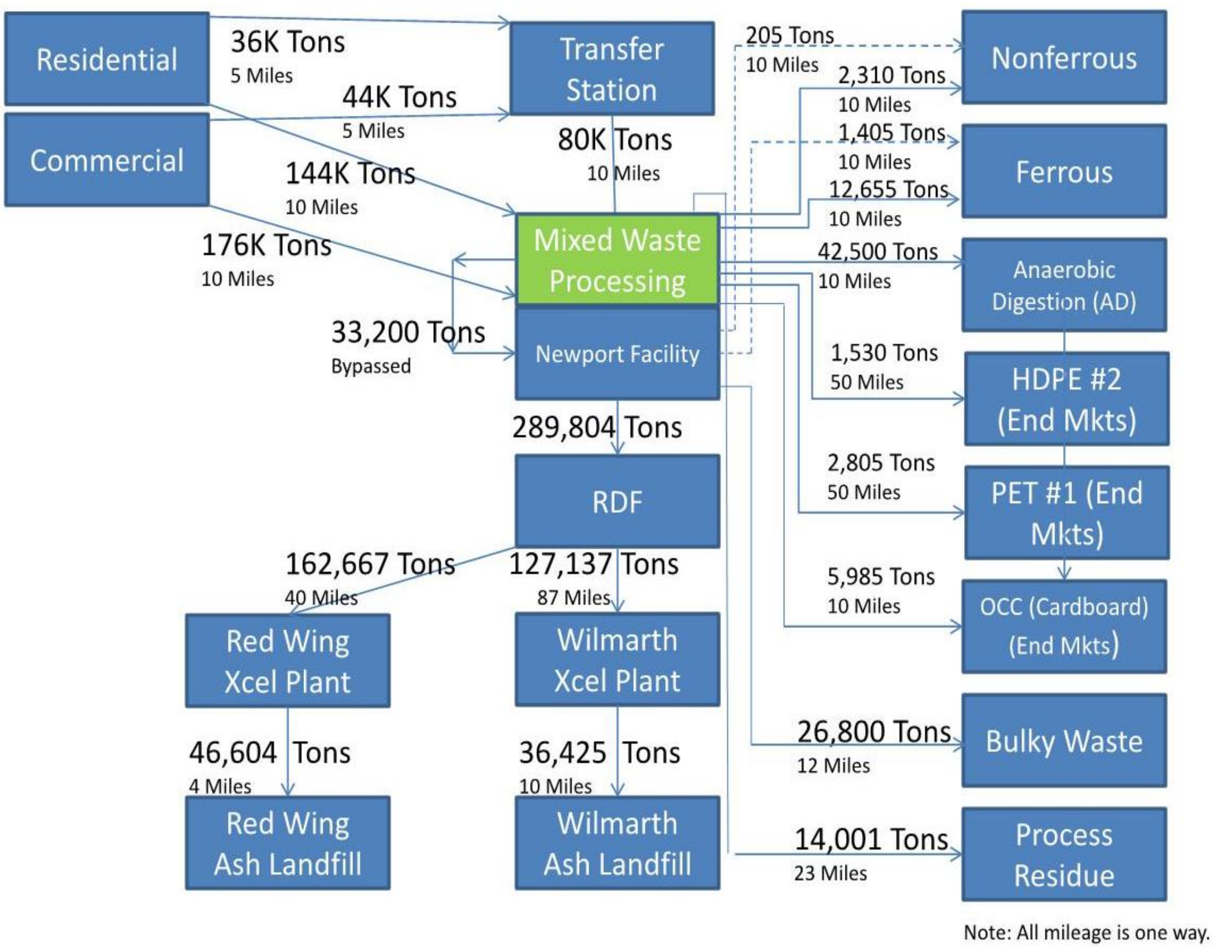
Alternative 1 - Processing, AD, and MWP system includes no additional SSO/SSR at the household or business level and that collection of these materials continue as those programs exist today. Recyclables are captured through the addition of MWP at the Newport Facility. Organics are also separated by MWP and sent to an offsite AD facility. The addition of

[2] *Analysis of Mixed Waste Processing* memorandum. Foth Infrastructure & Environment, LLC. September 2014
[3] i.e. 740 tons /3,200 tons = 23.1%
[4] *Waste Composition Study.* Foth Infrastructure & Environment, LLC. August, 2014

MWP/AD to the Processing Only (Base Case) system estimates 80,000 tons (20%) are delivered to a transfer station then delivered to the Newport Facility and the remaining 320,000 tons (80%) are modeled to be direct hauled to the Newport Facility. The bulky waste is estimated to be removed from the system at the Newport Facility prior to processing the material through the MWP system. Removal of the bulky waste (26,800 tons) results in 373,200 tons of material for MWP. However, the MWP system design has a total processing capacity of 340,000 tons per year so the remaining 33,200 tons is bypassed directly into the Newport RDF processing equipment.

Figure 2-3 provides a flow diagram of Alternative 1.

Figure 2-3
Alternative 1: Addition of AD and MWP with RDF Processing



Note: All mileage is one way.

The materials targeted with the MWP equipment include ferrous, nonferrous, organics, HDPE, PET, and cardboard. The tons of each material estimated to be recovered with the MWP equipment were determined as follows:

- Tons of recovered nonferrous materials are calculated from the nonferrous tons available based on the 2014 Waste Composition Study (3,200 tons). A reduction was applied to account for the MWP system design capacity limitation (85% of the incoming material is processed by MWP, the bulky waste and bypassed waste is not sent to MWP). Additionally, the MWP system is estimated to have an 85% recovery rate for nonferrous materials, which is applied to the nonferrous tons processed (i.e. (3,200 tons x 85%) x 85%) = 2,310 tons). In addition to the nonferrous recovered by MWP with the MWP equipment, there is a fraction recovered during material processing into RDF. This tonnage is calculated from the tons remaining after MWP (3,200 tons - 2,310 tons = 890 tons) times 23.1% recovery based on estimated recovery rates for the RDF process.
- Tons of recovered ferrous are the actual average tons historically reported at the facility multiplied by the estimated percent recovery of the MWP system for ferrous materials (90%). In addition to the ferrous recovered with the MWP equipment, there is a fraction recovered during material processing into RDF. This tonnage is estimated to be 100% of the ferrous material remaining in the system since the material is readily recovered with magnetic equipment.
- Tons of recovered organics are calculated from the tons of organics available based on the 2014 Waste Composition Study (100,000 tons). A reduction was applied to account for the MWP system design capacity (85% of the incoming material is processed by MWP). Additionally, the MWP system is estimated to have a 50% recovery rate for organic material, which is applied to the tons processed (i.e. (100,000 tons x 85%) x 50%) = 42,500 tons).
- Tons of recovered HDPE are calculated from the tons of HDPE available based on the 2014 Waste Composition Study (2,400 tons). A reduction was applied to account for the MWP system design capacity (85% of the incoming material is processed by MWP). Additionally, the MWP system is estimated to have a 75% recovery rate for HDPE, which is applied to the tons processed (i.e. (2,400 tons x 85%) x 75%) = 1,530 tons).
- Tons of recovered PET are calculated from the tons of PET available based on the 2014 Waste Composition Study (4,400 tons). A reduction was applied to account for the MWP system design capacity (85% of the incoming material is processed by MWP). Additionally, the MWP system is estimated to have a 75% recovery rate, which is applied to the tons processed (i.e. (4,400 tons x 85%) x 75%) = 2,805 tons).
- Tons of recovered cardboard (OCC) are calculated from the tons of cardboard available based on the 2014 Waste Composition Study (25,600 tons). Operation of the MWP system is estimated to target cardboard only in the commercial waste, which accounts for 55% of the incoming waste. Therefore the total available cardboard for the MWP equipment is calculated to be 14,080 tons. A reduction was applied to account for the MWP system design capacity (85% of the incoming material is processed by MWP).

Additionally, the MWP system is estimated to have a 50% recovery rate for cardboard, which is applied to the tons processed (i.e. (14,080 tons x 85%) x 50%) = 5,985 tons).

- Process residue tons are calculated from total tons being processed after bulky waste and recycled material tons are removed times 4.6%; which is the historical percentage of process residue generated by the Newport Facility. Process residue is landfilled.

Material leaving the MWP system is combined with the bypass material and further processed into RDF. The RDF tons are calculated from incoming waste minus materials removed (bulky, recyclables, process residue, organics).

The breakdown of materials going to the Red Wing and Wilmarth facilities and the resulting ash generation are detailed in Section 2.1.

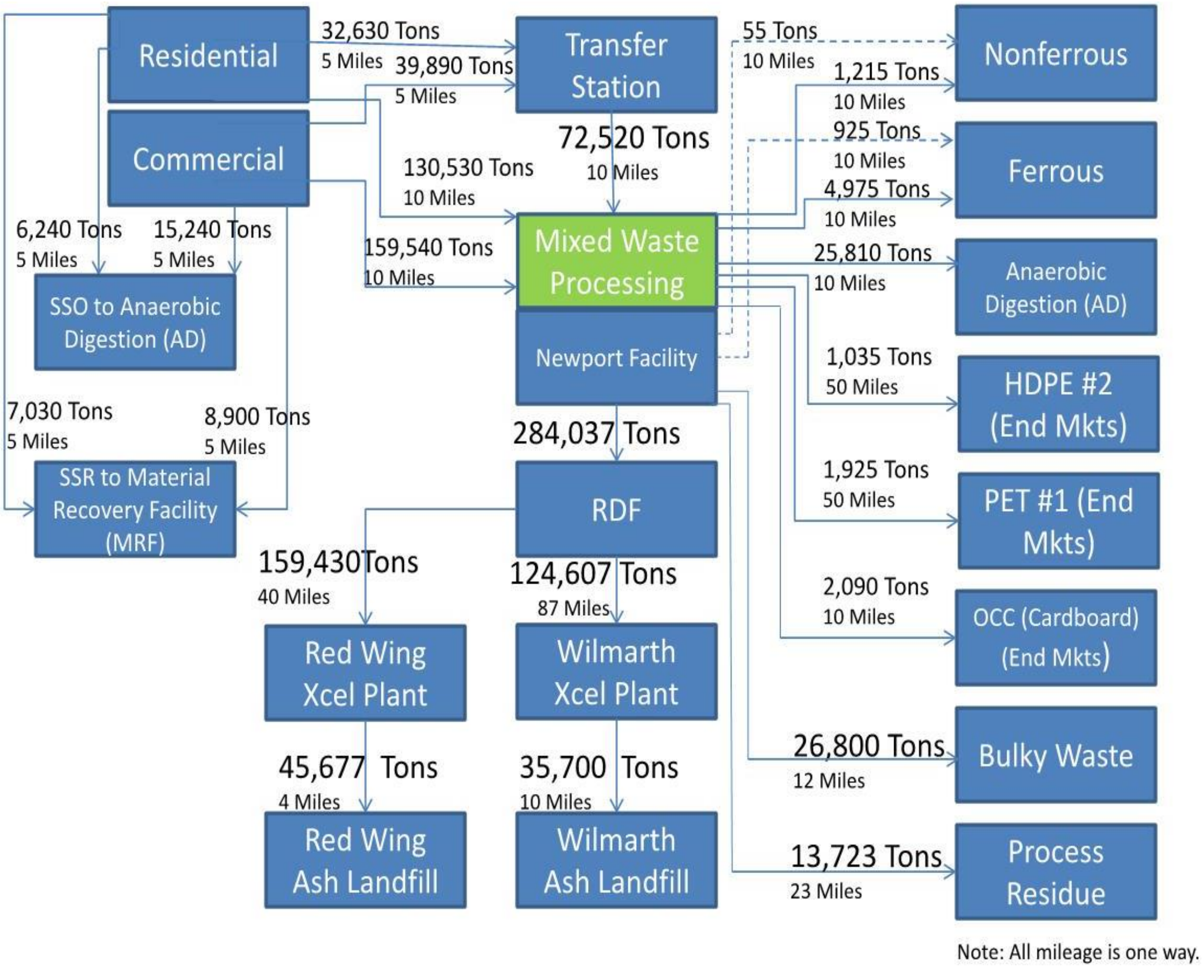
2.4 Phase 2 – SSO/SSR/MWP/AD

Phase 2-SSO/SSR/MWP/AD scenario combines Processing Only (Base Case) and Phase 1 with MWP and AD. Phase 2 results in additional materials being processed and separated for recycling by adding MWP and AD to the system. Subtracted from the base of 400,000 tons are the tons recovered by increased SSO/SSR, which occurs at the household and business. The tons of SSO/SSR Are assumed to be in a mature system. The material remaining after the SSO/SSR is subtracted and then processed through a MWP system to separate additional recyclables for shipping to an end market and organic material that is shipped to an AD facility. The material remaining after SSO/SSR/MWP/AD is processed at the Newport Facility to generate RDF for combustion at the Xcel Energy facilities.

Combining SSO and SSR with AD and MWP, results in a decrease in the number of tons entering the MWP system and Newport Facility. The number of tons delivered is calculated as discussed in the Phase 1 System (Section 2.2) and resulted in 362,590 tons. The bulky waste tonnage stays constant at 26,800 which results in 335,790 tons available for MWP, which is within the design capacity of the MWP system.

Figure 2-4 provides a flow diagram for the Phase 2 System.

Figure 2-4
Phase 2 – SSO/SSR, Mixed Waste Processing (MWP) and AD with Processing



The tons of each material estimated to be recovered with the MWP equipment were determined as follows:

- Tons of recovered nonferrous are calculated from the tons available after SSR recovery (1,450 tons). A reduction factor of 98.7% was applied to material tonnage sent to MWP to account for the unused MWP system design capacity (e.g. the MWP system will not be at capacity). As discussed previously, the MWP system is estimated to have an 85% recovery rate for non-ferrous materials, which is applied to the tons processed (i.e. (1,450 tons x 98.7%) x 85%) = 1,215 tons). In addition to the nonferrous recovered with the MWP equipment, there is a fraction recovered during the processing of material into RDF.
- Tons of recovered ferrous are calculated from the amount available after SSR recovery multiplied by the estimated percent recovery of the MWP system of 90% for ferrous materials. In addition to the ferrous recovered with the MWP equipment, there is a

fraction assumed to be recovered during the processing of material into RDF. The RDF processing capture for percentage ferrous materials is modeled at 100%.

- Tons of recovered organic materials are calculated from the tons of organic materials available after SSO collection (52,300 tons). The MWP system is processing at 98.7% of the design capacity and is modeled to have a 50% recovery rate for organic material. Therefore, the tons of organic materials separated by MWP are 25,810 tons.
- Tons of recovered HDPE are calculated from the tons available after SSR collection (1,400 tons). The MWP system is processing 98.7% of the design capacity and is modeled to have a 75% recovery rate for HDPE containers. This is applied to the HDPE tons available to estimate tons captured at 1,035 tons. (i.e. (1,400 tons x 98.7%) x 75%) = 1,035 tons).
- Tons of recovered PET are calculated from the tons available after SSR collection (2,600 tons). The MWP system is processing 98.7% of the design capacity and is estimated to have a 75% recovery rate for PET. This is applied to the tons of PET processed to provide an estimate of PET recovered at 1,925 tons. (i.e. (2,600 tons x 98.7%) x 75%) = 1,925 tons).
- Tons of recovered cardboard (OCC) are calculated from the tons available after SSR collection (7,710 tons). Operation of the MWP system is modeled to target cardboard only from the commercial waste, which accounts for 55% of the incoming waste. The total available cardboard for the MWP system is estimated to be 4,240 tons. The MWP system is processing 98.7% of the design capacity and is modeled to have a 50% recovery rate, which is applied to the tons of cardboard processed which yields 2,090 tons of cardboard recovered for recycling (i.e. (4,240 tons x 98.7%) x 50%) = 2,090 tons).
- Process residue tons are calculated from total tons being processed after bulky waste and recycled material tons are removed times 4.6%. Process residue is sent to the landfill for disposal with MWP, process residue is reduced 11% from the Base Case system.

Material not recovered by the MWP system is further processed into RDF. The RDF tons are calculated from incoming waste minus material removed (bulky, recyclables, process residue and organics).

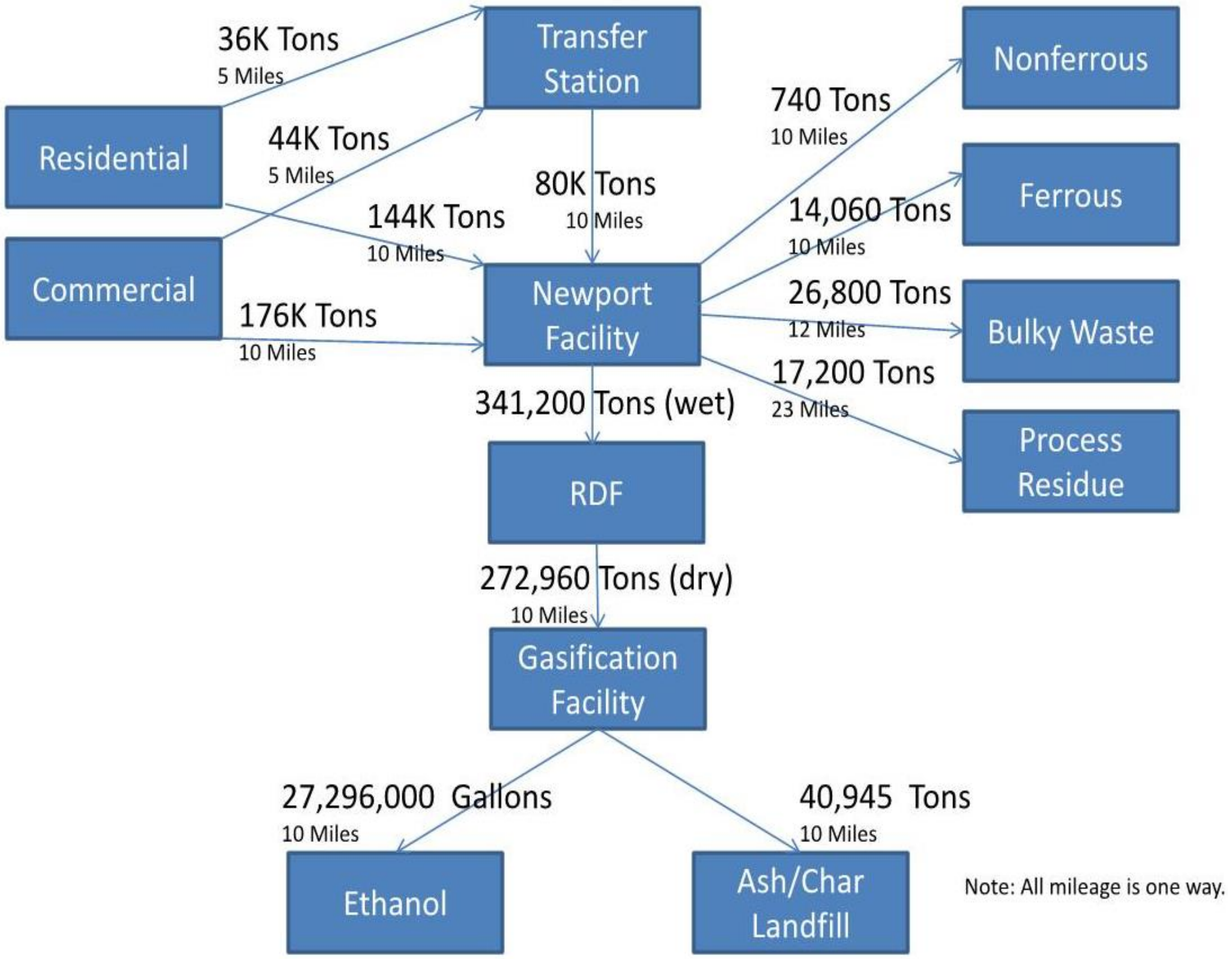
The breakdown of material going to the Red Wing and Wilmarth facilities and the resulting ash use the same percentage as the Processing Only system analysis in Section 2.1.

2.5 Alternative 2 – Processing and Gasification Only

Alternative 2 includes Processing Only (Base Case) with all RDF generated going to Gasification rather than the Xcel Energy facilities. Simply, this system is exactly like the system described in Section 2.1 except the RDF is converted to ethanol in a gasification process.

Figure 2-5 provides a flow diagram of Alternative 2.

Figure 2-5
Alternative 2: Processing and Gasification



The addition of gasification to Processing Only (Base Case) does not change the amounts of bulky waste, ferrous, nonferrous or process residue described in the Processing Only (Base Case) system in Section 2.1. The main difference is the RDF is delivered to a gasification facility. The gasification process is estimated to result in a lower percentage of ash equal to 15%. The ash is also "dry" rather than "wet" as in combustion. No additional programs such as SSO/SSR/MWP/AD are modeled in this scenario. Gasification is estimated to produce 100 gallons of ethanol for each dry ton of RDF that is gasified. This scenario also requires the shutdown of both Red Wing and Wilmarth RDF combustion plants. Electric power generated by RDF combustion is replaced on the grid in this scenario.

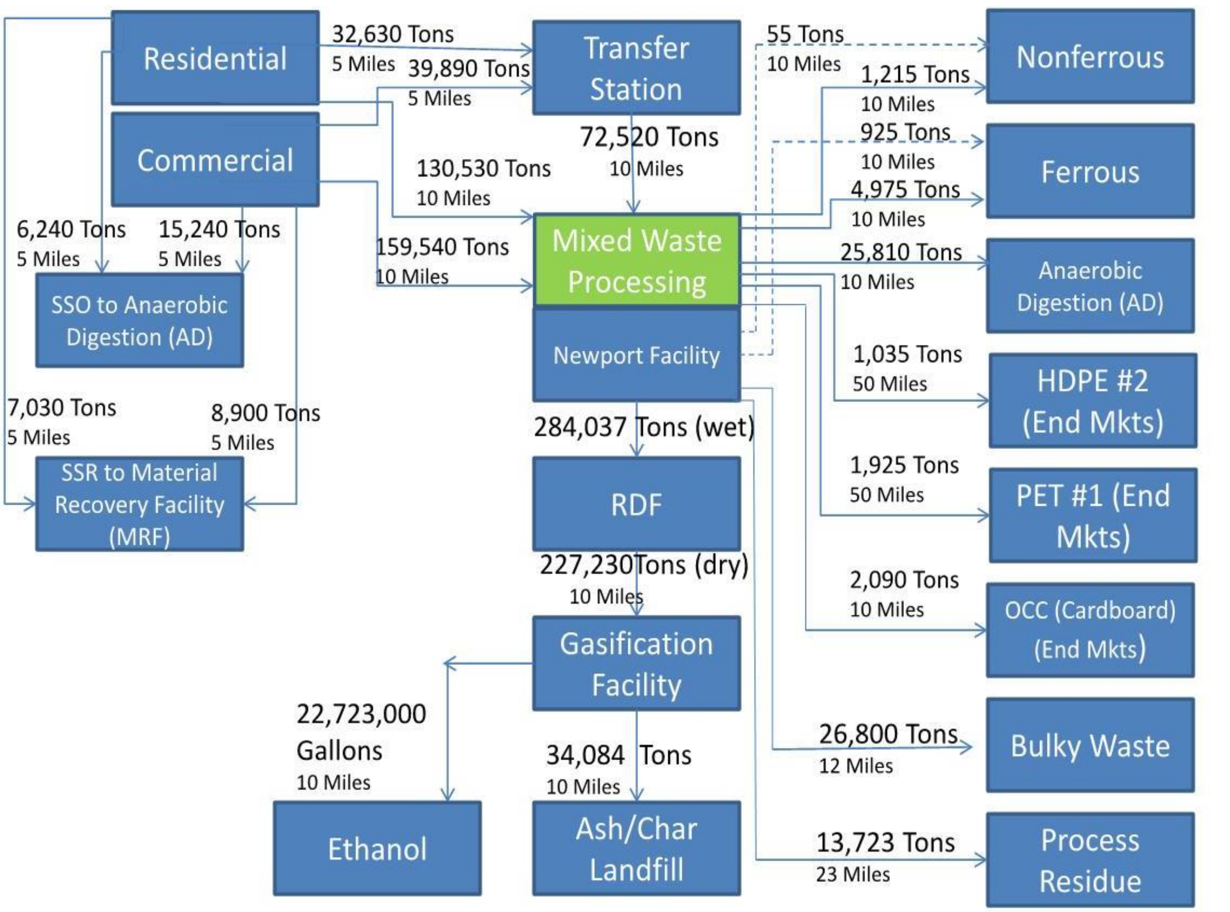
2.6 Phase 3 – Gasification/SSO/SSR/MWP/AD

Phase 3-Gasification/SSO/SSR/MWP/AD scenario combines Processing Only, Phase 1, Phase 2, and Gasification This system is the "All In" system analysis where every option considered is combined. The change in the system is the RDF is converted to ethanol at a gasification facility rather than converted to electricity at the Xcel Energy facilities. Using RDF with gasification has the same tonnage breakdown as previously described in Phase 2 System (Section 2.4) and is shown on Figure 2-6.

Combining SSO and SSR with AD and MWP, results in a decrease in the number of tons entering the MWP system and Newport Facility. The number of tons delivered is calculated as discussed in the Phase 1 System (Section 2.2) and resulted in 362,590 tons. The bulky waste tonnage stays constant at 26,800 which results in 335,790 tons available for MWP, which is within the design capacity of the MWP system.

Figure 2-6 provides a process flow diagram for the Phase 3 system.

Figure 2-6
Phase 3 – SSO/SSR, Mixed Waste Processing (MWP), AD, and Gasification



Note: All mileage is one way.

The gasification process is estimated to result in a lower percentage of ash than combustion. The percentage ash is 15%, and the ash is also "dry" rather than "wet" as in combustion.

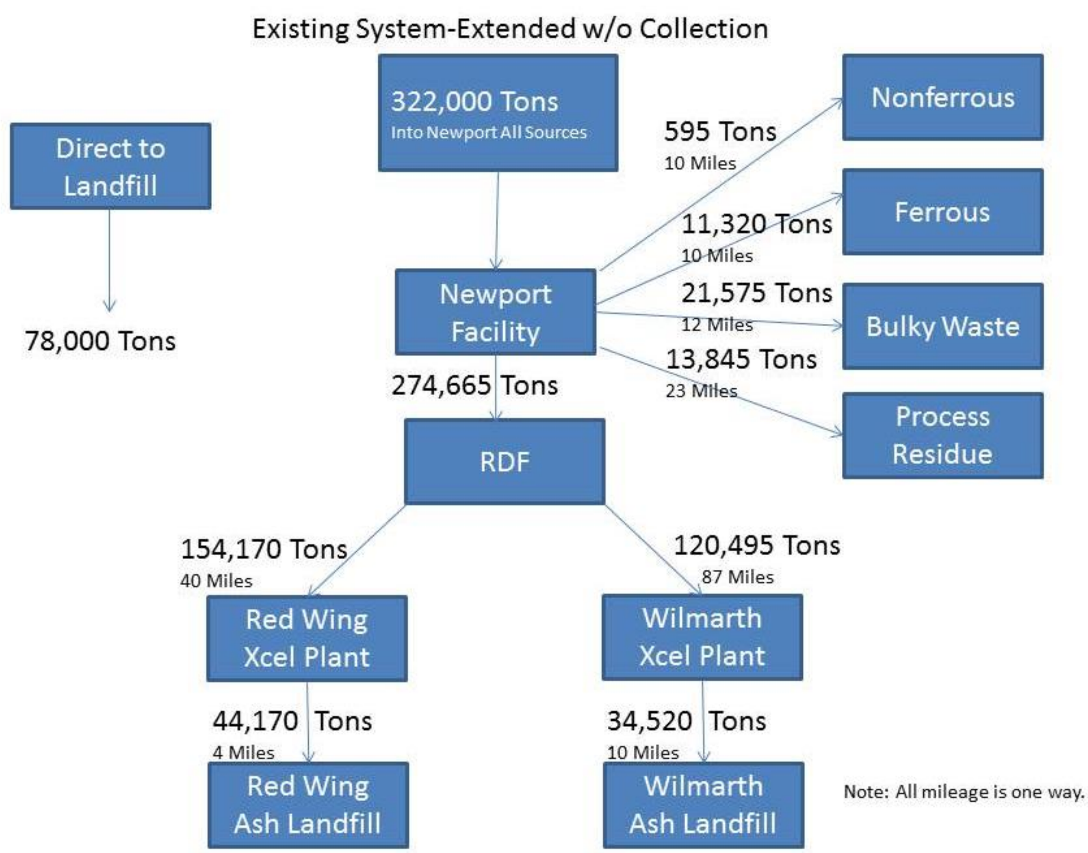
Gasification is not a proven technology for converting RDF to ethanol. This system is provided to demonstrate impacts of the gasification technology to GHG emissions when compared to the existing and enhanced RDF to electricity process. With gasification, the RDF combustion plants are modeled to close with the electricity they generate replaced with conventional systems.

2.7 Existing System-Extended

The Existing System-Extended scenario includes collection and hauling that remain the same as they exist in 2015 and delivery and collection continue as they are today. Waste is delivered through a system of transfer stations and direct delivery to the Newport Facility and five (5) landfills. The existing system estimates 78,000 tons of MSW is delivered to five (5) landfills and the remaining 322,000 tons are delivered to the Newport Facility either direct haul or through transfer stations. These estimates are based on the 400,000 tons used in all the systems analyzed in this report.

Figure 2-7 provides a flow diagram of the Existing System – Extended.

Figure 2-7
Existing System – Extended



The five (5) landfills currently utilized for Ramsey/Washington County waste all have landfill gas recovery which is converted to electricity for the grid. Only waste delivered to the Newport Facility is estimated to be processed into RDF. The bulky waste is removed from the waste stream at the Newport Facility prior to processing the waste into RDF. Processing the waste delivered to the Newport Facility results in ferrous, nonferrous, process residue and RDF. The amount of each material was determined by estimating a ratio of total system material to tons delivered to Newport (i.e. 322,000/400,000 = 0.805) and applying the resulting percentage to the actual tons reported by RRT for each material category (i.e., actual nonferrous reported by RRT was 740 tons x 0.805 = 595 tons recovered).

The RDF delivered to Red Wing and Wilmarth was determined based on historical RDF delivered to the respective facility. The historic data indicates that 56.13% of the RDF is delivered to Red Wing and 43.87% of the RDF is delivered to Wilmarth. Finally, the amount of ash from RDF combustion was determined based on historical data pertaining to the ash generation at the combustion plants. The result is 28.65% ash generation from RDF combustion that is sent to the landfill. RDF ash is assumed to be the “wet” since the ash is “quenched” with water prior to transport to the landfill.

3 GHG Modeling Framework

In order to analyze the major components of the residential and commercial collection, as well as the various processes, GHG analysis was categorized by modules. Using this method of modules allowed for input change to a module but retained the basic calculations to ensure comparable results. Each of the major GHG modules is described in this section.

Major module development for this analysis included:

- Collection and Hauling, including adding SSO/SSR
- Transportation
- Materials Management
  - RDF Processing (including recyclables, bulky waste and residue)
  - RDF Combustion
  - RDF Disposal (Ash, bulky waste and processing residue)
  - Mixed Waste Processing (MWP)
  - Anaerobic Digestion (AD)
  - Gasification
- RDF Combustion Plant Shut Down (gasification only)
- Ethanol Offset (gasification only)
- Electrical Offset (gasification only)

3.1 Collection and Hauling

The collection and hauling GHG model originated in a 2009, Foth study for the MPCA, *Analysis of Waste Collection Service Arrangements* (MPCA study)[5].

Ramsey and Washington Counties have a combination of open hauling and contracted "organized" systems for residential households and open hauling for commercial businesses. Open hauling systems allow residents to subscribe to the licensed hauler of their choice and generally result in multiple haulers serving the same geographic area. Contract or "organized" hauling systems typically require 100 percent of the route to be served by only one hauler. Open hauling systems have additional route truck miles traveled and fuel consumed that contributes to GHG emissions due to the multiple haulers serving the same geographic area. As the percentage of households served/collected (or "route density") increases, there is greater efficiency in collection and less drive time (time spent driving without performing collections).

To estimate these fuel efficiencies for the MPCA study, Foth measured fuel consumption for collection services while actually on a collection route. This data allowed Foth to determine the amount of fuel used per household collected. To estimate GHG emissions, a CO_2 emission factor of 10.21 kg CO_2 per gallon of diesel fuel (22.51 pounds of CO_2 per gallon) was used, as

[5] MPCA report, *Analysis of Waste Collection Service Arrangements* prepared by Foth Infrastructure & Environment, LLC (June 2009): http://www.pca.state.mn.us/index.php/view-document.html?gid=4514

well as other factors for N_2O and CH_4, based on an EPA emission factors[6]. These factors are used for all on-road diesel fuel use. (Note: The EPA has different factors for diesel fuel use in the Mandatory GHG Reporting Rule which are applied to stationary sources)

As part of the MPCA study, Foth prepared a model to estimate the GHG emissions for collection vehicles based on the following variables:

- The number of households or businesses receiving collection service.
- Percent of households or businesses participating in a collection service.
- Frequency of pick up.
- Number of haulers collecting a material in the system.
- Percentage of market share of each hauler.
- Estimated distance between each household or business.
- Estimated fuel consumption rates.

The model calculates the total annual fuel consumption and total annual GHG emissions.

The residential collection model includes no net change in greenhouse gas generation when material is collected as SSR instead of MSW (Phase 1, Phase 2, and Phase 3). In the case of additional SSR, the MSW collection GHG emissions are estimated to remain the same as trucks would be less full, but no trucks could be removed from the system. There is a net additive effect of GHG generation when additional collection routes are added for increased SSO (Phase 1, Phase 2, and Phase 3).

The commercial collection models include the current MSW collection at 1.5 times per week. With adding SSO/SSR there is a decrease in MSW collection service to once per week. Adding SSO/SSR results increased participation which leads to additional collection time and GHG emissions due to additional stops. Appendix A contains copies of each of the collection models developed.

3.1.1 Number of Households or Businesses Receiving Collection Service

Ramsey and Washington Counties have an estimated 300,000 households. 70,000 households are estimated to be multi-units and are considered part of commercial collection. 230,000 households are estimated as single units and are considered in the residential collection model.

Ramsey and Washington Counties have an estimated 20,000 businesses, including the multi-unit dwellings, considered in the commercial collection model. The 20,000 businesses include shared collection points such as those utilized by the 70,000 multi-unit dwellings.

[6] EPA (2014) Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2012. All values calculated from Table A-107. http://www.epa.gov/climateleadership/documents/emission_factors.pdf Accessed 2/15/2015. Last modified 4/4/2014.

3.1.2 Percent of Households or Businesses Participating In a Collection Service

Households in Ramsey and Washington Counties are modeled to have MSW and SSR collection service. SSO is not currently provided curbside to households in either County. SSO is added to the collection system in several phases with an estimated participation rate of thirty (30) percent for the program at maturity.

Twenty thousand (20,000) businesses in Ramsey and Washington Counties are modeled to have MSW collection service. This includes shared collection points utilized by multi-unit dwellings. Twenty-five percent (25%) of businesses are currently estimated to have SSR and 12.5 percent (12.5%) are estimated to currently have SSO collection. This data is from County staff currently involved with business recycling. With aggressive SSR and SSO programs, both are estimated to double participation (50% SSR and 25% SSO participation) at program maturity.

3.1.3 Frequency of Pick Up

The estimated households in Ramsey and Washington Counties are modeled to have weekly MSW collection service. County staff conducted a survey of cities in the two counties to estimate the frequency of pick up for recycling (SSR). Weekly SSR collection services are provided to approximately 110,000 households and every other week SSR collection services are provided to approximately 120,000 households. SSO collection is anticipated to be weekly in the collection models.

The estimated number of businesses in Ramsey and Washington Counties are modeled to have 1.5 collections per week in the systems without additional SSO and SSR. The estimate for MSW collections decreases to one (1) time per week when additional SSO and SSR collection programs are added. SSO and SSR collections are estimated to be provided one (1) time per week in the business collection analysis.

3.1.4 Number of Haulers Collecting

A review was completed of the cities in Ramsey and Washington Counties to estimate the number of licensed haulers in each City and the number of households serviced. The City of Saint Paul has significant impact on the number of residential haulers collecting waste. Approximately forty percent (40%) of the households in the two counties are in Saint Paul which has seventeen (17) licensed residential haulers. Based on the data, modeling was based on the following inputs.

Residential market share accounts for the differing markets in the two counties as well as the number of licensed haulers collecting waste. Residential MSW market share was divided into:

- Three (3) haulers at twenty-five percent (25%) market share each.
- Two (2) haulers at ten percent (10%) market share each.
- Three (3) haulers lumped at five percent (5%) total market share.

Residential SSR market share was calculated to be 1.4 haulers with equal market share. The SSR market share is due to the large number of households in Ramsey County serviced by single hauler contracts.

Residential SSO market share was estimated to be 1.4 haulers identical to SSR. This reflects that SSO, like SSR, may be primarily single hauler contracts in the two counties.

Commercial MSW market share is modeled the same as residential market share.

- Three (3) haulers at twenty-five percent (25%) market share each.
- Two (2) haulers at ten percent (10%) market share each.
- Three (3) haulers lumped at five percent (5%) total market share.

Commercial SSR market share is modeled as five (5) haulers with equal twenty percent (20%) market share. The equal percentages are based on current nodes of businesses participating in recycling programs. Businesses are modeled as "nodes" or clusters rather than individually like residential collection. It is estimated that, with additional SSR, the hauler market share will remain the same.

Commercial SSO market share was modeled using Washington County data on current organics collection types and was applied to both counties. Current market share is:

- One (1) hauler at seventy-five percent (75%) market share.
- Two (2) haulers at ten percent (10%) market share each.
- One (1) hauler at five percent (5%) market share.

3.1.5 Calculated Distance between Each Household or Business

Estimated distances between households were calculated using average distances across both counties. A distance of 115 feet per household was used as the average. This distance includes "dead heading" sections of road traveled between stops. In the collection model calculations, if a hauler has twenty-five percent (25%) market share they drive past four (4) households or 460 feet for each stop collected.

Estimated distance between businesses for MSW and SSR collection is modeled at 500 feet. In the collection model calculations, if a hauler has twenty-five percent (25%) market share they drive past four businesses or 2,000 feet for each stop collected.

Enhanced SSO is modeled to occur in nodes of service (i.e. nodes of businesses in particular geographic areas). An estimated distance between businesses of 4,000 feet per serviced business is modeled.

3.1.6 Calculated Fuel Consumption Rates in the Model

Fuel consumption rates for collection vehicles were taken from the MPCA study. Foth measured fuel consumption for collection services while actually on a collection route. This data allowed Foth to determine the amount of fuel used per household collected. To estimate GHG emissions, a CO_2 emission factor of 10.21 kg CO_2 per gallon of diesel fuel (22.38 pounds of CO_2 per gallon) was used and other factors for N_2O and CH_4 based on an EPA technical reference[7]. This factor is used for all on-road diesel fuel use. Fuel is first estimated in ounces per stop and then converted to annual gallons which are used to calculate GHG emissions on an annual basis.

The Collection model is primarily impacted by increased residential SSO and increased commercial SSO and SSR.

1) Increased residential SSO results in additional collection vehicles added to the system. Due to volumes, residential MSW collection vehicles are not able to be removed from the system. A net increase in GHG emissions occurs due to additional vehicles on the road.
2) Increased commercial SSO and SSR results in additional collection vehicles being added to the system. However, the model estimates MSW service frequency will reduce from 1.5 times per week to one (1) time per week with the addition of SSO/SSR to commercial businesses. Therefore, an overall decrease in commercial collection results in a reduction in GHG emissions.

Estimates of GHG emissions for the current system and increased SSO/SSR are provided in Table 3-1.

Table 3-1
Summary of Impact of Increased SSO/SSR
on Collection and Hauling
($MtCO_{2e}$/year)

	Current Collection Hauling System	Increased SSO/SSR Collection and Hauling System
Commercial	4,063	3,027
Residential	9,439	11,657
Total GHG Impact	13,502	14,684

Collection and hauling model outputs are provided in Appendix A.

3.2 Transportation

The transportation model addresses the GHG emissions from the time the MSW collection vehicle leaves the route to unload at either a transfer station or at the Newport Facility; loads taken from the transfer station to the Newport Facility; materials leaving Newport (i.e., recyclables, organics to AD, RDF to Xcel plants or gasification, process residue and bulky waste to landfill.); and materials like ash or ethanol destined for final uses. The goal of this model is to

[7] Ibid

quantify GHG emissions for material movements within the R/W Counties system and account for diesel emissions as they pertain to GHG for the material movements. All transportation is modeled using on-road diesel fuel trucks.

The model was developed based on the total tons of the material being moved. The total tons of material being moved were modeled to be trucked. Truck capacity was estimated to be 7 tons for materials hauled direct to a facility by the collection vehicle. Truck capacity was estimated to be 19 tons per load for transfer loads, recyclable loads to end use, RDF transport, ethanol transport and ash/residuals transport. Bulky waste transfer from Newport to a landfill was estimated to be 13 tons per load since bulky waste loads would likely be limited by the capacity of the truck and not the weight. Furthermore, 13 tons per load for bulky waste transport to a landfill correlates with historic operations at the Newport Facility.

Having the total tons of each material and the estimated truck weights per load, the total number of trips was calculated for each part of the material transport. (e.g., MSW to Newport, ferrous metals to recyclers, RDF to Red Wing, etc.) Each trip was assigned an estimated mileage based on general information about distance to facilities and estimates about future systems. Where accurate mileage information was available (e.g., distance to transport RDF from Newport to Red Wing and Wilmarth) it was used in the transportation model.

Estimated miles were used for future options; such as transport of organic material to an anaerobic digester was estimated to be ten (10) miles each way. Where there may be multiple transportation scenarios for recycling materials, a general estimated mileage to the recycler was used in the model. For example, when HDPE is separated from the wastes using MWP, the model input for transportation of the HDPE to end markets was fifty (50) miles one way. While there may be markets closer for this material, the final destination of recycling materials depends on pricing and other business relationships. The estimated mileage was selected to provide a basic understanding of the GHG transportation emissions. The mileage for transportation remained constant for each option analyzed so there is a consistency of GHG emissions across options.

For this analysis, a general miles per gallon (mpg) per truck was used based on the type of truck being used to transport the material. For residential collection, a side loader type truck was modeled. Side loader type trucks have a typical fuel efficiency rating of 2.9 mpg[8]. For trucks that transport commercial wastes directly to a facility, a front loader type waste truck was modeled. These trucks typically have a rating of 2.6 mpg[9]. For transfer haul trucks and trucks that transport commodities to market, bulky waste and residuals to landfills and RDF to Red Wing, Wilmarth or gasification, a large semi-tractor trailer mpg was used. For a semi-tractor trailer an estimated 4.5 mpg was used[10].

[8] Sandhu, Gurdas, et. al. *"Real World Authority and Fuel Use of Diesel and CNG Refuse Trucks."* Presented at 2014 PEMS International Conference and Workshop. April 3-4, 2014. Riversdale, California. Slide 31.
[9] IBID
[10] IBID

Using the estimated miles traveled and the estimated miles per gallon per truck, the total annual gallons of diesel fuel use was calculated. Since this is a calculated field, rounding may have occurred. However, the estimated fuel use per transportation item was consistent in each model. Rounding did not impact the comparison of GHG emissions between the systems analyzed.

The amount of GHG's emitted from on-road diesel fuel consumption is based on data provided by EPA for mobile combustion sources[11]. For diesel fuel use, the GHG emissions factors were:

- 10.21kg of CO_2 per gallon
- 0.0048g of N_2O per mile
- 0.0051g of CH_4 per mile

To convert the N_2O emissions to CO_{2e} required the emissions to be multiplied by the global warming potential (GWP). The GWP for CO_2 is 1, for N_2O the GWP is 298; and for CH_4 the GWP is 25[12]. Therefore, all transportation GHG emission was converted to carbon equivalents (CO_{2e}) by the use of the GWP.

The transportation model is not intended to provide a GHG lifecycle emissions of the vehicles used in transport. Rather it looks at fuel usage and compares the GHG generated from fuel usage between the systems. The transportation model outputs are provided in Appendix B for each of the systems analyzed. All emissions are based on the annual tonnage of 400,000 tons. Outputs are in $MtCO_{2e}$ per year.

3.3 RDF Processing

GHG emissions for RDF processing were calculated using the annual electric use at the Newport Facility in addition to the annual fuel used for onsite equipment (loaders and yard trucks).

To estimate the GHG emissions associated with RDF production, Foth used the available data based on historic records for electric use for the Newport Facility from 2005 and 2006 to determine the estimated kilowatt hours (Kwh) needed per ton of processed waste. The electrical usage of the plant has remained fairly consistent year to year, so the estimate of electrical use for the Newport Facility is valid for the systems modeled. Based on the information, an estimate of 25.27 Kwh is required per ton of material processed.

To estimate GHG emissions for electrical consumption at the Newport facility, Great Plains Institute (GPI) calculated an average GHG intensity for Xcel Energy upper Midwest electric system[13]. The calculated GHG emission factor was 511.07 kg CO_{2e} per Mwh in 2010, which is used in the model. GPI also calculated future GHG intensity of Xcel Energy's system based in

[11] EPA (2014) Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2012. All values calculated from Table A-107. http://www.epa.gov/climateleadership/documents/emission-factors.pdf Accessed 2/15/2015. Last modified 4/4/2014.
[12] IPCC Fourth Assessment Report. 2.10.2 Direct Global Warming Potentials. Table 2.14. 100 Year Time Horizon.
[13] Great Plains Institute report. See Appendix C.

resource plans developed by Xcel Energy[14]. In the future, Xcel Energy's electrical production becomes less GHG intense due to the addition of wind and solar power to the energy grid.

For example, by 2015, the GHG intensity is expected to be 405.38 kg CO_{2e} per Mwh (a 21% decrease from 2010 to 2015) and by 2030, the GHG intensity is expected to be 325.18 kg CO_{2e} per Mwh (a 36% decrease from 2010 to 2030).

Therefore, for the various options analyzed, the total tons processed were used to determine the total electric use which was then converted to GHGs using the GPI calculated value for 2010.

Diesel emissions for equipment used at the Newport Facility were estimated from records and other previous reports. For this analysis, Newport equipment includes three (3) Caterpillar 966H loaders. Two loaders are operated a total of 460 hours per week. One loader is considered a backup and is used if one of the two loaders is being serviced.

Fuel consumption for the loaders at Newport was estimated from the Caterpillar Performance Handbook 44[15]. For a 966H Caterpillar estimates, the low fuel consumption is 2.5-3.6, medium is 3.6-4.5, and high is 4.5 – 5.5 gallons per hour. For this analysis, the fuel use for the loaders was modeled to be 4.05 gallons per hour, the average medium fuel consumption rate for the 966H loader.

There are also four (4) yard tractors at the Newport Facility that are used to move transfer trailers. Two (2) yard tractors operate 140 hours per week. The other two tractors are estimated to operate 30 hours per week each. The yard tractors are Capacity brand tractors. Typical yard tractors have turbo diesel engines rated at 200-220 horsepower with an estimated average fuel consumption rate of 2.10 gallons per hour[16].

GHG emissions for diesel use in equipment was calculated using EPA emission factors for CO_2 (10.21 kg CO_2/gallon), N_2O (0.26 g/gal) and CH_4 (0.57 g/gal)[17]. Use of the yard tractors was reduced based on the amount of RDF produced in each option. Likewise, loader use was adjusted based on the amount of waste received at Newport. With the addition of MWP, one additional loader was added to account for increased material management to support MWP. Electricity consumption was also increased as a result of MWP.

[14] Xcel Energy, Inc. 2016-2030 Resource plan. January 2, 2015. http://www.xcelenergy.com/Company/Rates_&_Regulations/Resource_Plans/Upper_Midwest_2016-2030_Resource_Plan Accessed February 10, 2015.
[15] *Caterpillar Performance Handbook 44*. Caterpillar, Peoria, Illinois, January 2014. Page 25-35.
[16] *"Hybrid Yard Hustler Demonstration and Commercialization Project."* Final Report. CALSTART. March 2011. Table 2.
[17] EPA (2014) Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2012. All values calculated from Table A-107. http://www.epa.gov/climateleadership/documents/emission-factors.pdf Accessed 2/15/2015. Last modified 4/4/2014.

The other GHG emission for the Newport Facility is the fuel used for comfort heat in the office and plant. Since the amount of fuel used for comfort heat is anticipated to remain constant, regardless of the system modeled, GHG emissions for comfort heat were not included in the analysis of the Newport Facility.

RDF Processing GHG emissions increase with the addition of MWP at the Newport Facility due to increased electricity usage for the MWP system and increased fuel consumption in the additional loader added to the system. There is an impact of mitigating GHG by removing recyclables from the system.

3.4 EPA Warm Model and Other Source Emission Factors

The USEPA WARM model[18] was created as a tool to estimate GHG emissions and reductions for various solid waste management scenarios. WARM estimates GHG emissions for baseline solid waste systems and various alternative scenarios. Emission factors for various solid waste materials and options are available in WARM in $MtCO_{2e}$.

The WARM model provides emission factors for the various materials and scenarios. WARM also can consider transportation of the materials. Since GHG emissions from transportation are analyzed in the transportation module, the WARM model travel distances were set to zero so the emission factors presented would represent GHG emissions not including any transportation.

The WARM model was used for the various systems for recycling materials and landfill materials. For the landfill option, WARM model was set to include landfill gas (LFG) recovery which would be converted to energy (electricity). LFG system parameters were set to WARM model defaults (typical LFG) collection. The default means phased-in collection with an improved cover, judged to represent the average U.S. landfill, although every landfill is unique. A typical landfill is an approximation of reality and national average decay coefficient (values used in the model) to account for variations in landfills that may receive R/W waste. All landfills that would receive R/W waste currently have active LFG collection with conversion to energy. The WARM model emission factor also accounts for soil oxidation of methane not collected by the collection system. The WARM model estimated emissions from the landfill as 0.14 $MtCO_{2e}$ per ton of mixed MSW disposed.

The emission factor used to estimate GHG from bulky waste disposal in landfills was based on work completed by Hunsacker[19] based on construction and demolition (C&D) waste emission factors. C&D waste emissions closely represent the bulky waste stream from the Newport Facility for GHG emissions. Emission factors for C&D waste from residential customers are 0.705 $MtCO_{2e}$/ton and C&D waste from commercial customers is 0.248 $MtCO_{2e}$/ton. Since the waste stream at the Newport Facility is estimated to be 45% residential and 55% commercial, a

[18] U.S.E.P.A. WARM Model. Available at http://epa.gov/epawaste/conserve/tools/warm/index.html Accessed 2/17/2015

[19] Hunsaker, Larry. Personal communication. Referenced in *Climate Action Team Green Building Sector Subgroup Scoping Plan Measure Development and Cost Analysis.* December 2008. Table 7. Page 9. http://www.climatechange.ca.gov/climate_action_team/reports/ Accessed 1/31/2015.

combined emission factor for bulky waste was calculated to be 0.45365 $MtCO_{2e}$/ton of bulky waste. Since the bulky waste is destined for landfilling, the emission factor was adjusted for active LFG collection (assume a 75% collection efficiency) and cover soil oxidation (10%), so the emitted GHG for bulky waste is 0.10207 $MtCO_{2e}$/ton of bulky waste.

The emission factor used for process residue was based on previous laboratory testing of process residue. In 2009, R/W Counties conducted Biomethane Potential (BMP) testing on process residue collected from the Newport Facility[20]. Testing was conducted by the University of Florida under the direction of Dr. Tim Townsend. Test results provided by the University of Florida indicated the BMP for the process residue was 0.045 liters of methane per gram of process residue. Since it is typical for LFG generated from organic materials to also contain about the same amount of CO_2 as methane (LFG is typically 50% methane and 50% CO_2 with some trace gases), CO_2 is also generated when process residue is landfilled. However, the CO_2 generated is considered part of the natural carbon cycle (biogenic[21]) so it is not counted in GHG emissions.

For process residue, the BMP rate was converted into the GHG emission factor by converting the BMP results to $MtCO_{2e}$ per ton of process residue. Since the process residue is placed in a landfill, the emission factor was adjusted for LFG system collection efficiency and oxidation in the cover soils. The resulting emissions factor for process residue that is landfilled is 0.1565 $MtCO_{2e}$ per ton.

The GHG emissions factors for anaerobic digestion followed by composting were developed using a Canadian model[22]. The Canadian model addresses expected GHG emissions from composting and anaerobic digestion of food scraps and yard trimmings. The composting GHG emissions rate addresses the long term carbon storage that compost can achieve. Transportation of raw materials to a compost area (or AD facility) and transportation of the compost to the final disposition were not included in the Canadian model. Those GHG emissions for transportation were addressed in the transportation module. Additionally, compost turning emissions were not considered in the model for this analysis.

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[20] Biochemical Methane Potential Assay Results. Hwidong Kim, PhD. University of Florida. August 31, 2009. Unpublished.

[21] Biogenic "Of non-fossil, biological origin" The EPA Air Program states "Biogenic CO_2 emissions are defined as emission of CO_2 from a stationary source directly resulting from the combustion or decomposition of biologically-based materials other than fossil fuels and mineral sources of carbon. Examples include, but are not limited to CO_2 from:

- Combustion of biogas collected from biological decomposition of waste in landfills, wastewater treatment plants or manure management processes;
- Fermentation during ethanol production;
- Combustion of the biological fraction of MSW or biosolids;
- Combustion of the biological fraction of tire-derived fuels; and,
- Combustion of biological material, including all types of wood and wood waste, forest residue, and agricultural material.

[22] *Determination of the Impact of Waste Management Activities on Greenhouse Gas Emissions.* 2005 Update. Final Report. ICF Consulting. October 31, 2005. Exhibit 6-4.

Given the variation of turning processes and the concept that compost emissions would be after an AD process, the analysis only accounts for some minimal storage of the material (finishing) after an AD process. Food scraps and yard trimmings were treated equally in regards to the emission factors since the Canadian Model did not make a distinction between the two materials in regards to an emission factor for GHG emissions for composting. For composting, GHG emissions factor is (0.22) $MtCO_{2e}$ per ton.

In the AD model, much like composting, two basic material types were identified; food scraps and yard trimmings. However, the model for AD uses two distinct GHG emission factors for the two materials. The difference between food scraps and yard trimmings in regards to GHG emissions is the carbon sink possibilities from AD of yard trimmings versus food waste.

For the analysis, SSO collected was modeled as food scraps in the AD model. The GHG emissions factor for food scraps in AD is (0.10) $MtCO_{2e}$ per ton. For organic materials obtained when MWP is used at the Newport facility, the AD model was adjusted to account for the yard waste component in the waste stream being delivered to the Newport Facility. To estimate the amount of yard waste that would be part of the total organics recovered using MWP, the 2014 waste composition analysis was used. In the waste composition analysis, yard waste was determined to be 3.7% of the total waste stream. Yard waste was estimated to be 14% of the organic waste stream that would be retrieved using mixed waste processing with the remaining 86% estimated to be food scrap for modeling purposes. Using the estimated percentage of yard trimmings and food scraps from MWP, an emissions rate of (0.107) $MtCO_{2e}$ per ton was applied for AD of organics obtained using MWP.

The AD model included converting the methane produced into electricity that would offset grid electricity. This offset is included in the overall emissions rate for AD process. Transportation of food scraps to the AD facility was not accounted for in this model since they were accounted for in the transportation model. Finally, gasification was modeled based on estimated emissions from a proposed MSW gasification plant in Mississippi. Further details on specific modeling for gasification is in Section 3.11 "Gasification".

3.5 RDF Conversion

RDF conversion is the process of burning the material at the Xcel plants to make electricity. Previous studies have used the WARM model and modeled the WARM mixed MSW material type to estimate the potential GHG emissions for combustion of RDF. For this analysis, three approaches were analyzed to determine the GHG emissions from the burning of the RDF at Red Wing and Wilmarth. Approach 1 was to use the WARM model using the mixed MSW waste material types as done in previous studies. Approach 2 adjusted the WARM model GHG emission rate to account for the differences in non-biogenic wastes in the Newport Facility RDF waste stream. The third approach modeled GHG emissions from Red Wing and Wilmarth using actual emissions data provided to the EPA by Xcel Energy and GHG electrical offsets based on Xcel Energy's grid GHG intensity. The approaches are discussed in detail below.

3.5.1 Approach 1

For Approach 1, the WARM model default value for combustion of mixed MSW was used. This simplified approach includes many assumptions inherit to the WARM model, including a non-biogenic waste composition of 10%, metal recovery from the ash, and grid offset power production based on regional factors. The assumptions in the WARM model for mixed MSW that is combusted resulted in a GHG emission factor of (0.07) $MtCO_{2e}$ per ton combusted.

3.5.2 Approach 2

For Approach 2, the WARM model assumptions were adjusted to account for actual non-biogenic material in the waste stream accepted at the Newport Facility and the metals recovery being conducted as part of the RDF process rather than from the ash material as modeled in WARM; the RDF versus mass burn emissions factors in WARM; and the transportation factors were removed since transportation of GHG emissions were accounted for in the transportation model.

WARM calculates the emissions from combusting mixed MSW as 0.43 $MtCO_{2e}$ per ton combusted. This emission estimate includes a transportation emission of 0.03 $MtCO_{2e}$ per ton to account for transport of the waste and ash material. Since this analysis accounts for transportation separately, GHG emissions for transportation were removed from the emission factor. The emission factor without the transportation component is 0.40 $MtCO_{2e}$ per ton.

The mixed MSW emission factor in WARM only considers those emissions from non-biogenic sources such as plastics, textiles, leather, rubber, etc. The WARM model assumes that mixed MSW contains 10% non-biogenic waste[23].

To account for the non-biogenic waste stream that is sent for combustion at Red Wing and Wilmarth data from the 2014 waste sort completed at the Newport Facility[24] was used to determine an estimate of non-biogenic waste in the RDF. The following components in the mixed MSW waste stream were considered non-biogenic:

Table 3-2
Non-Biogenic Components

Material	Percentage
Plastics	15.9%
Textiles/Leather	4.2%
Diapers/Sanitary Napkins	2.1%
TOTAL	**22.2%**

[23] WARM Model Documentation. Combustion. http://epa.gov/epawaste/conserve/tools/warm/SWMGHGreport.html Accessed 2/4/2015. Page 3

[24] Waste Composition Study. Foth MSW. Prepared for Ramsey/Washington Resource Recovery Project Board. August 2014.

To account for the increased non-biogenic waste stream at the Newport Facility, the GHG emission factor was increased linearly based on the percentage of non-biogenic wastes. The calculated GHG emissions from the non-biogenic waste stream that is combusted based on the Newport waste sort data was calculated to be 0.888 $MtCO_{2e}$ per ton (0.40 $MtCO_{2e}$ x 0.222/0.10). It is important to note the waste composition data is a snapshot in time and may not represent the long term waste composition. Variations in non-biogenic materials in the waste stream directly impact the GHG emission factor for combustion processes given the WARM emissions factors for various plastic wastes ranging from 1.25 to 3.01 $MtCO_{2e}$/ton combusted.

The WARM model also considers the electrical generation from combusting waste materials. WARM default values utilize emissions factors for electric offsets from mass burn facilities and allow adjustments to the emission factor based on the region the waste combustion takes place. These factors consider the amount of fossil fuel derived electrical generation that occurs in the specific region. Thus, the electrical offset is based on offsetting fossil fuel electric generation.

WARM model documentation also provides GHG emission estimates for RDF combustion[25]. The GHG emission factor for mixed MSW combustion electrical generation offset for mass burn is (0.39) $MtCO_{2e}$ per ton. WARM considers regional electrical generation to determine electrical generation offsets. For this analysis, the regional factor for the West North Central region (Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska and Kansas) was used to adjust the electrical generation offset GHG emission factor[26]. The adjusted GHG emission factor for combustion of RDF at Red Wing and Wilmarth was calculated to be (0.40) $MtCO_{2e}$ per ton combusted.

WARM also considers a GHG emission factor for metals recycling from the ash at mass burn facilities[27]. This emissions factor is small, (0.05) $MtCO_{2e}$ per ton for mixed MSW, and was not considered in this analysis. Metals recovery is conducted in the RDF process and GHG emissions for the recovery is addressed in the RDF processing analysis.

For GHG emissions from RDF combustion, the emissions from the non-biogenic portion of the waste stream accepted at Newport was calculated to be 0.888 $MtCO_{2e}$ per ton of waste combusted. The electrical generation offset for the specific plants in Minnesota was calculated to be (0.40) $MtCO_{2e}$ per ton combusted. Therefore, the net GHG emission factor is 0.488 $MtCO_{2e}$ per ton.

If SSR is implemented, it is anticipated the plastics percentage in the waste stream would be reduced. To account for this reduction, the non-biogenic waste percentage was estimated to be 21.2% with SSR. Since a portion of the non-biogenic waste is not plastics and only select plastic material would be targeted with SSR, the total impact to the non-biogenic waste percentage was estimated to be 1%. This would reduce the GHG emission factor for combustion of RDF in Minnesota to 0.448 $MtCO_{2e}$ per ton.

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[25] Ibid. Page 6
[26] Ibid. Page 9
[27] Ibid. Page 12

If both MWP and SSR are implemented, the GHG emission factor is estimated to be 0.408 $MtCO_{2e}$ per ton combusted. These factors were applied to the estimated tonnage for the systems analyzed.

It is important to note that the non-biogenic content from Newport RDF (22.2%) is significantly higher than the average in the WARM model (10%). This is due to the higher than average content of mixed plastic in the waste stream. Mixed plastics are not targeted in increased SSO/SSR or MWP/AD. These systems typically target specific plastics like HDPE and PET used in bottles and containers. The mixed plastics remain in the waste stream to be made into RDF in the proposed systems. The high percentage of plastics increases the projected GHG emissions significantly when combusted.

3.5.3 Approach 3

A third option analyzed GHG emissions from RDF combustion using reported data from EPA on actual GHG emissions[28]. Data for Red Wing and Wilmarth plants was obtained from 2011 to 2013. The data is summarized below:

Table 3-3
EPA Reported GHG Emissions (Non-Biogenic Sources)
($MtCO_{2e}$ per year)

Plant	Year		
	2013	**2012**	**2011**
Red Wing	87,146	84,341	75,827
Wilmarth	83,041	78,846	78,968

This information was divided by the tonnage delivered to the facilities based on Newport reporting data.

EPA GHG emissions are based on both biogenic and non-biogenic material classification. Biogenic waste composition analysis is conducted using two test methods; ASTM D7459 and ASTM D6866. These test methods take a sample and analyze it using radio carbon analysis.

The Mandatory Reporting Rule requires a quarterly sample be collected and analyzed for the biogenic portion of the exhaust (stack) from combustion. The test method measures carbon 14 in the sample which is present in biogenic sources but not in non-biogenic sources. Combustion facilities are required to submit information to the EPA each year on the GHG emissions from biogenic and non-biogenic sources. For this approach, the emission factor for combustion of RDF was 0.5065 $MtCO_{2e}$ per ton of RDF.

Since actual GHG emissions were used in this approach, electrical offsets for electric power generated at Red Wing and Wilmarth was also determined. GPI provided 2010 GHG intensities based on the fuel mix for Xcel Energy's upper Midwest electric system. For 2010, the GHG intensity was calculated as 511.07 kg CO_{2e}/Mwh. This translates to an effective offset for Red

[28] EPA GHG data located EPA database. http://www.epa.gov/ghgreporting/ghgdata/reportingdatasets.html

Wing as (0.2614) MtCO2e per ton and for Wilmarth (0.3379) $MtCO_{2e}$ per ton. Using tonnage information for both RDF combustors, the average GHG offset for electrical production would be (0.2949) $MtCO_{2e}$ per ton.

Table 3-4 provides a summary of the three approaches to determine the GHG factors for RDF combustion.

Table 3-4
RDF Combustion Calculation Summary
($MtCO_{2e}$/ton)

Item	WARM Default Value of Mixed MSW	R/W Calculated Value	EPA Data for Actual Emissions
Gross GHG Emissions for MSW Combustion	0.40	0.888[1]	0.5065[5]
Avoided Electrical GHG Emissions	(0.45)	(0.40)[2]	(0.2949)
Transportation Emissions for MSW and Ash	0.03	0.00[3]	0.00[3]
Metals Recycling from Ash	(0.05)	0.00[4]	0.00[4]
TOTAL	**(0.07)**	**0.488**	**0.2116**

1. Adjusted emission factor to account for increases in non-biogenic material in R/W waste stream. WARM default non-biogenic material is 10%. R/W waste sort non-biogenic material is 22.2%. Only non-biogenic emissions are included.
2. Adjusted for RDF combustion versus mass burn for the West North Central Grid power offset per WARM model documentation for combustion. For actual emissions, GHG intensity for Xcel's upper Midwest grid was used.
3. Transportation GHG emissions included in the transportation model.
4. Metals recycling in the ash is addressed for R/W prior to RDF processing and during RDF processing. No credit provided for R/W metals recovered from the ash material post combustion.
5. Average actual GHG emissions for Red Wing and Wilmarth using EPA GHG reporting database averaged for 2010, 2011, 2012 for both plants. Tonnage for plants taken from NRG data.

For modeling the various systems analyzed in this report, actual emissions data and electrical offsets based on Xcel Energy's upper Midwest grid power for 2010 (Approach 3) was used. This provides an estimate of GHG emissions from both plants and considers actual plant outputs. Since this is a comparative study, the options that utilize RDF combustion will be using local data to determine GHG impacts by changes to the systems. This approach is consistent with the approach used to model gasification in section 3.11.

3.6 Ash Disposal

Ash disposal as a result of RDF combustion and RDF gasification was to be modeled using the WARM model. In the WARM model, ash GHG emissions are only associated with the transportation of the ash to the landfill. Transportation of ash to the landfill was accounted for in the transportation model and, therefore, was not accounted in the WARM modeling for ash disposal.

3.7 Increased SSO Collection

A Foth memorandum[29] examined data presented in the 2014 Waste Composition Study[30] as well as data from the 2013 MPCA SCORE reports for Ramsey and Washington Counties to determine the amount of "available" recyclable materials remaining in the waste stream, including organics. Data presented in the memorandum were used to determine the amount of material recovered through implementation of an increased SSO program.

3.7.1 Residential

The amount of SSO collected from residential homes in Ramsey and Washington Counties was calculated based on the data presented in Table 5 of the Foth memorandum[31]. Table 5 is based on managing the entire two county waste stream of 921,000 tons. Therefore, a ratio between the total waste stream tons and the number of tons used in this GHG analysis (400,000 tons) was determined and applied to the number of tons presented in Table 5. The organics estimated to be collected through increased SSO for this analysis are "Food Waste" and "Compostable Paper" for a total of approximately 6,240 tons.

3.7.2 Commercial/Industrial/Institutional

The SSO collected from commercial sources were calculated similar to described for residential sources and included "Food Waste" and "Compostable Paper" from commercial sources. The same ratio was applied to the commercial SSO to account for the study tonnage of 400,000 tpy compared to the entire waste stream of 921,000 tons. A total of 15,240 tons of commercial SSO is used in this analysis.

3.8 Increased SSR Collection

The Foth technical memorandum[32] was also used to determine the SSR tons collected through implementation of an increased SSR program. The same ratio (0.4343) was applied to the tons presented in Table 5 of the technical memorandum for the "Traditional Recyclables" to model SSR based on 400,000 tpy.

3.8.1 Residential

The traditional recyclables (paper, plastic, metal, and glass) from residential homes presented in the Foth memorandum[33] estimated a total of 16,200 tons available for this analysis. An estimate of 7,035 tons of recyclables is used in the systems analyzed.

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[29] Foth prepared a technical memorandum, *Estimated Calculations of Additional SSR/SSO Tons*. 2014

[30] Waste Composition Study. Foth MSW. Prepared for Ramsey/Washington Resource Recovery Project Board. August 2014.

[31] Ibid, Table 5.

[32] Ibid.

[33] Ibid.

3.8.2 Commercial/Industrial/Institutional

The traditional recyclables (paper, plastic, metal, and glass) from commercial sources presented in Table 5 of the Foth memorandum[34] result in an estimate of 20,500 tons available for this analysis. An estimate of 8,900 tons of recyclables is used in the systems analyzed.

Table 3-5
Net Effect Tons and GHG of Increased SSO/SSR

	Net Tons Recovered	Net GHG Produced
SSO	21,480 Tons	(2,148) $MtCO_{2e}$
SSR	15,930 Tons	(45,082) $MtCO_{2e}$

It is important to note that tons managed as SSO/SSR are directly removed in all scenarios including Newport production of RDF or landfilling. Tons collected and managed through increased SSO/SSR collection have negative GHG impact. In Table 3-5 the impact of increased SSO/SSR is detailed.

3.9 Mixed Waste Processing (MWP)

MWP plant emissions were determined using data from an equipment vendor for electrical consumption for MWP equipment. Recycling rates for MWP processing were estimated based on previous studies[35].

GHG plant emissions were estimated based on the electric use for the equipment. Electric use estimates for MWP equipment were provided by an equipment vendor[36]. For a 35 ton per hour MWP system, the estimated electric use is 800 to 1,000 Kwh. This would calculate to an effective energy use of 25.71 Kwh/ton processed (900Kwh/35tons).

The electric use GHG emissions rate was provided by GPI as 511.07 kg CO_{2e}/Mwh for the Xcel Energy upper Midwest electric system. Using the data presented, emissions for MWP were calculated based on the total tonnage that would be sent to MWP. Further detail on the actual MWP materials targeted and recovered is provided in Section 2.3. GHG Emissions for recovered materials were estimated using the WARM model.

The model estimated GHG emissions reductions ($MtCO_{2e}$ /ton) for recycled materials as:

Non-Ferrous Metals	(1.81) WARM Model-Steel Cans
Ferrous Metals	(9.11) WARM Model-Aluminum Cans
HDPE	(0.88) WARM model - HDPE
PET	(1.13) WARM model - PET
Cardboard	(3.12) WARM Model - OCC
Mixed Recyclables	(2.83) Used for SSR Tons

[34] Ibid.
[35] Estimated Calculations of Additional Material Capture based on Foth technical memorandum, Estimated Calculations of Additional SSR/SSO Tons. 2014
[36] Personal Communication with Jeff Draper. 12/29/2014.

The MWP system will also generate organic wastes for AD. The emissions for AD are separately addressed in Section 3.10. GHG emissions factors for mixed recyclables were used to estimate total GHG emissions for tons of recyclables collected as part of SSR. In WARM, mixed recyclables includes approximately 1% aluminum cans, 3% steel cans, 6% glass, 1% HDPE, 2% PET, 54% OCC, 7% magazines, 1l% newspaper, 8% office paper, 5% lumber and less than 1% textbooks and phone books.[37] This report did not adjust the mixed recyclables based on waste stream analysis or specific data.

Using the amount of material recovered through MWP, the WARM emission factors were applied along with electric use estimates to calculate GHG emissions as a result of MWP.

3.10 Anaerobic Digestion (AD)

For this report, AD was modeled using the Canadian Method[38] that has emission factors for AD systems. The model used anticipated AD emissions for food scraps only with SSO and both food scraps and yard trimmings for MWP. Transportation of raw materials to an AD facility was included in the Canadian model. However, this was excluded in this analysis since transportation was accounted for in the transportation model. The model, therefore, only includes GHG emissions from the actual AD process. The methane generated from AD is modeled to be converted to electricity that would offset fossil fuel generated electricity. For food scraps anaerobically digested, the expected GHG emissions are (0.10) $MtCO_{2e}$ per ton of material. For yard trimmings, the estimated GHG emissions are (0.15) $MtCO_{2e}$ per ton of material.

After the AD process, the residual is composted to stabilize the material and to provide for a marketable product for the residual materials. For this analysis, the Canadian Model was used[39] to estimate GHG emissions from composting the residuals from an AD process. As with the AD analysis, only food scraps are assumed to be used in the process for SSO and both food scraps and yard trimmings for MWP. Additionally, the emission factor was adjusted to only consider static pile (no turning) of the compost. This is likely in an AD facility since the purpose of the residuals processing is to stabilize the material prior to shipment. Composting emissions for both food waste and yard trimmings is estimate to be (0.24) $MtCO_{2e}$ per ton.

Consideration of the end use of the compost or end product was extremely conservative in this analysis. GHG emissions for delivery of product to its final destination were not counted, nor was the final use of the compost analyzed (i.e. land applied as a soil amendment or land stabilization). The GHG emissions may likely be a higher credit once the final end use of the compost is included , however that determination was not made for purposes of this analysis.

[37] WARM Documentation. *WARM Background and Overview*. WARM Version 13. Page 9. http://epa.gov/epawaste/conserve/tools/warm/SWMGHGreport.html Accessed 2/4/2015
[38] *Determination of the Impact of Waste Management Activities on Greenhouse Gas Emissions.* 2005 Update. Final Report. ICF Consulting. October 21, 2005.
[39] Ibid

Modeling of the AD process was completed in two distinct steps. The first was the actual AD process and the tons entering the process. The second was the composting process of the residuals remaining after the AD process on food waste. The amount of residuals remaining with AD is dependent on the process being used. Results from European AD processes[40] indicate residue production of 415 kg/Mg for the Valorga process to 680 kg/Mg for the Kompogas process.

The Valorga process is a single phase mesophilic process while the Kompogas process is a single phase thermophilic process. It is reported[41] that the Valgora process is ill suited for relatively wet waste that is likely to be digested in an AD process in the study. The Kompogas system is a horizontal plug flow digester that retains the material for 20 days at thermophilic conditions. Other systems analyzed included the BTA system (wet system for food waste); biocell process that uses a high solids batch process to convert organic material to methane and the SUBBOR (Super Blue Box Recycling) process that uses thermophilic vessels with steam injection in a two stage process.

For this report, the Kompogas system was used to determine the amount of residuals. An AD process in the Twin Cities is anticipated to be a plug flow system or similar; thus the residuals yield that will be composted is anticipated to be similar to the data on the Kompogas system.

The study predicted residue production for an input of 80% kitchen waste and 20% garden waste to be 5,995 kg/Mg of input for the Kompogas system[42]. For the systems analyzed in the report, the total waste entering an AD process was used to estimate the amount of residuals. The residuals fraction modeled was 0.595 tons of residuals per ton of waste entering the AD process. The AD process is assumed to only take SSO (food waste) and MWP (food and yard waste).

Using the ratio presented; the total GHG emission from AD plus composting the residual material was calculated. An AD of the type that could process material sorted at the Newport Facility along with SSO is not currently sited in the Twin Cities area. Therefore, the estimated GHG emissions are based on similar systems likely to be used in the Twin Cities.

3.11 Gasification

For the analysis conducted, gasification of the RDF is assumed to yield ethanol that is used as a motor fuel. Ethanol produced is assumed to offset gasoline use in the analysis. For modeling purposes, emissions from the gasification plant are estimated followed by emissions from ethanol use. Furthermore, if gasification is initiated to utilize the RDF, then the existing RDF combustion facilities are modeled to close which would require the electric power to be replaced. A discussion of the GHG impact from closure of Red Wing and Wilmarth is also provided.

[40] *Evaluation of the Performance of Different Anaerobic Digestion Technologies for Solid Waste Treatment.* Chavez-Vazquez, Mariana and David M. Bagley. CSCE/EWRI of ASCE Environmental Engineering Conference. Niagara 2002. Table 2.
[41] Ibid, Page 4.
[42] Ibid, Table 3, Page 11.

3.11.1 Direct Plant Emissions

Gasification plant emissions were based on emissions estimates provided for a proposed gasification plant in Pontotoc, Mississippi[43]. The proposed plant was based on a throughput of 330 dry tons of MSW per day.

GHG emissions were estimated to be[44]:

CO_2 – 64,767 Mt/year
CH_4 – 103 Mt/year
N_2O – 21.6 Mt/year

GHG emissions were based on the plant operating 365 days per year, 24 hours a day for all waste received. No adjustment was made for biogenic versus non-biogenic sources.

To evaluate the GHG emissions from gasification of RDF at Newport, the evaluation of emissions from biogenic versus non-biogenic sources was estimated. As in the WARM model[45], CO_2 generated from biogenic sources is not counted as GHG emissions. CO_2 emissions from non-biogenic materials in the waste stream (e.g. plastics, textiles, rubber, etc.) do contribute to GHG emissions and are counted.

To determine the amount of potential materials that would enter a gasification process and its non-biogenic waste quantity, the waste sort data from the June 2014 waste sort conducted at Newport was used[46]. Waste source data indicated that for the current mix of materials being sent to Newport, the non-biogenic portion is 22.2% of the waste stream. This includes the material presented in Table 3-6[47].

Table 3-6
Non-Biogenic Waste Stream – Newport Facility

Material	Percent
Plastics	15.9%
Textile/Leather	4.2%
Diapers/Sanitary Napkins	2.1%
Total	**22.2%**

[43] *Construction and Operation of a Heterogeneous Feed Biorefinery, Environmental Assessment.* DOE/EA-1790. U.S. Department of Energy. September 2010
[44] Ibid, Page 2-13.
[45] WARM Version 13. *Management Practices and Background. Combustion.* http://epa.gov/epawaste/conserve/tools/warm/SWMGHGreport.html Accessed 2/1/2015
[46] *Waste Composition Study.* Foth MSW. Prepared for Ramsey/Washington Resource Recovery Project Board. August 2014. Table 3-7
[47] Ibid.

Methane emissions and N_2O emissions were not adjusted based on the biogenic content of the waste stream of the gases. Therefore, gasification plant emissions for methane and N_2O were calculated to be 0.061 $MtCO_{2e}$/per wet ton of RDF.

For gasification direct emissions using RDF from the Newport facility, the calculated GHG emission factor would be 0.179 $MtCO_{2e}$ per wet ton of materials, including all gases.

3.11.2 Ethanol Production

In order to quantify GHG impacts from ethanol production by gasification of RDF, Foth teamed with Great Plains Institute (GPI) to estimate the GHG impacts of cellulosic ethanol production via gasification of RDF.

GPI provided data and information on ethanol markets and production to help assess potential GHG emissions results if gasification of RDF produces approximately 27 million gallons of ethanol each year. The GPI report is provided in Appendix D.

Ethanol GHG impacts can vary depending on the source of feedstock used to produce ethanol. Furthermore, if ethanol is produced to displace gasoline, GHG offsets vary depending on the source of the oil used to produce the gasoline (e.g. gasoline produced from oil sands crude oil has a higher GHG emissions than other gasoline produced from oil fields). GPI examined the energy equivalent displacement by an advanced biofuel (D-5). Using a D-5 designation provided some conservative values rather than D-3 designation for cellulosic. The actual designations for ethanol produced would be determined during plant permitting.

GPI estimated the gasoline displacement by advanced biofuels as (3.80) kg CO_{2e} per gallon. Since a percentage of the RDF waste stream contains non-biogenic wastes (22.2%), the ethanol displacement was adjusted to consider the non-biogenic wastes. For the model, the ethanol offset was estimated to be 0.00295 $MtCO_{2e}$/gallon. If SSR is implemented, the ethanol offset is (0.00299) $MtCO_{2e}$/gallon. If MWP and SSR are implemented, the factor would be (0.00303) $MtCO_{2e}$/gallon. This GHG offset for ethanol production is used in the systems where gasification produces ethanol. Gasification is estimated to produce 100 gallons of ethanol for each dry ton of RDF sent to the gasifiers. For modeling, RDF produced at the Newport Facility contained 20% moisture.

3.11.3 RDF Combustion Offset

If gasification is implemented, RDF would not be combusted at either Red Wing or Wilmarth. To determine the GHG impacts of closing Red Wing and Wilmarth, GPI researched the GHG emissions from each facility and impacts to overall GHG emissions. Specifically, if Red Wing and Wilmarth close due to the implementation of gasification, would the loss of electrical power be replaced with more carbon intensive generation (e.g. make it worse from a GHG perspective) or would the electricity generated not be replaced in the system?

The GPI study found that closing the Red Wing and Wilmarth RDF combustion plants would not require Xcel Energy to bring additional electrical production on line. The electricity the plants were producing would be replaced elsewhere on the Xcel Energy grid.

GPI estimated that Red Wing generated 605 kg CO_{2e} per Mwh and Wilmarth 594 kg CO_{2e} per Mwh (2010 data). This calculates to an effective GHG emission rate of 0.324 CO_{2e} per ton for the Red Wing Plant and 0.417 CO_{2e} for the Wilmarth plant. However, previous calculations indicate the actual emissions from Red Wing and Wilmarth based on EPA reported information on non-biogenic GHG emissions were 0.452 $MtCO_{2e}$ per ton of RDF for Red Wing and 0.561 Mt CO_{2e} per ton of RDF for Wilmarth. Closing these plants would result in the emissions not occurring. Thus, there would be a GHG credit for closing the RDF combustion plants.

The GHG credit for closing Red Wing and Wilmarth would be reduced since the electrical power the RDF combustors currently produce would need to be replaced in the Xcel Energy's grid system for the upper Midwest. GPI estimated that in 2010, the GHG intensity of the Xcel Energy upper Midwest grid was 0.511 $MtCO_{2e}$ per Mwh. Using the estimated Mwh production at Red Wing and Wilmarth plants in 2010 provided an estimated electrical replacement GHG emissions factor of 0.2614 $MtCO_{2e}$ per ton at Red Wing and 0.3379 $MtCO_{2e}$ per ton for Wilmarth. The emissions factor was applied in the models based on the historical percentage of RDF going to each of the RDF combustors applied to the estimate of RDF going to the gasification facility instead of the RDF combustors.

Therefore, closing both plants would cause a GHG credit to be included based on the total tons that would have been sent to the facilities in the absence of gasification. For this analysis, a GHG emission factor of (0.324) $MtCO_{2e}$ per ton for the Red Wing facility and (0.417) $MtCO_{2e}$ per ton for the Wilmarth plant was used.

3.11.4 Gasification GHG Emissions Summary

Gasification emissions included emissions from the plant, the ethanol produced and the loss of emissions as a result of the closure of Red Wing and Wilmarth. The specific emissions summary is provided in Table 3-7

Table 3-7
Gasification GHG Emissions Summary

Option	Plant	Ethanol	Electricity	
	$MtCO_{2e}$/wet ton	$MtCO_{2e}$/gallon	$MtCO_{2e}$/ton	
			Red Wing	Wilmarth
Gasification only	0.179	.00295	(.1906)	(.2231)
Gasification + SSR	0.174	.00299	(.1906)	(.2231)
Gasification + SSR + MWP	0.1702	.00308	(.1906)	(.2231)

It is important to note that there is not currently a gasification facility generating ethanol from MSW or RDF. Enerkem in Edmonton, Alberta, Canada is currently being tested, but gasification is not yet a proven technology.

4 Results and Observations

Comparative tables have been developed to allow further discussion of the impacts of each scenario. Summary tables are provided after the Tables tab in this report and are discussed below. The tables provided correlate to the figures which are provided after the Figures tab in this report.

Table 4-1 provides the specific emissions factors for the Material/Category and what is happening with the materials (e.g. recycling, combustion, AD, etc.). The emissions factors for the materials were generated from various sources using readily available data and were normalized to provide a factor that could be multiplied by the input tonnage (or in the case of ethanol, gallons produced) to obtain the estimate of GHGs emitted in $MtCO_{2e}$ per year. The actual source of each of the factors is detailed in Section 3 of the report.

Table 4-2 provides the estimated tons and how they are managed in each of the scenarios modeled. Table 4-2 is divided into scenarios shown as boxes of data in the Table. One box is for the existing combustion plants system continuing to operate and the other set of boxed data is for gasification implementation. Where the gasification system operates, the RDF combustion plants are assumed to be shut down and the electricity they were producing would be replaced on the Xcel Energy grid. The replacement electricity has a slightly better GHG emissions factor because the Xcel power production mix has changed to include additional wind, solar and natural gas power production which lowers the GHG intensity for the replacement power. Since the gasification plant produces ethanol, there is also a GHG reduction for the production of ethanol. This reduction is based on an offset of fossil fuel derived motor fuels and examines the difference in life cycle GHG emissions. It is important to note that implementation of gasification changes the GHG emissions significantly and converts “waste” to “resource.”

Table 4-3 includes the information in Tables 4-1 and 4-2 to estimate the annual GHG emissions that would occur with implementation of the scenarios. Table 4-3 does not include collection or transportation GHG emissions, the emissions from processing the waste into RDF or the emissions from sorting the waste in an MWP process. These emissions are added in Table 4-4.

Table 4-3 is also divided into the two basic options of continuation of RDF combustion as compared to implementation of gasification technology in lieu of combustion of RDF. It is interesting to note in Table 4-3 that as programs such as SSO/SSR and MWP are implemented, the GHGs are reduced. Starting from the Processing Only (Base Case) scenario and implementing SSO/SSR would result in a GHG reduction of 84%. If only AD and MWP are added to the Processing Only (Base Case) option, the GHG reduction would be 135%. Finally, if SSO/SSR/MWP and AD are implemented (the “all in” option) the GHG reduction would be 153%.

Table 4-4 builds upon Table 4-3 by adding in transportation and collection of the materials along with the estimated emissions from electric use to convert the material to RDF and the machinery and electricity needed for a MWP system. As with Table 4-3, Table 4-4 also demonstrates as enhanced recovery and recycling activities are implemented, the GHG emissions are reduced.

Starting from the Processing Only (Base Case) option, implementing SSO/SSR would reduce system wide GHG emissions by 52%. If only MWP and AD are added to the Processing Only (Base Case) option, the reduction is 79%. Finally, the “all in” option of adding SSO/SSR/MWP and AD to the Processing Only (Base Case) scenario reduces GHG emissions by 89%. The larger reduction by adding MWP and AD when compared to just adding SSO/SSR (89% reduction versus 79%) is directly attributable to the increased recycling and AD that would occur if MWP with AD is implemented.

It is interesting to note, that the collection and transportation GHG estimates with or without SSO/SSR are only minor (2%) but the increase in AD materials and recyclables by using MWP in lieu of SSO/SSR resulted in a GHG reduction of 79% overall. Thus, from a GHG perspective, it would be better to implement MWP with AD rather than SSO/SSR if only one program were to be implemented.

Table 4-4 also shows the significant change in GHG emissions by implementing gasification to ethanol. While adding gasification to the Processing Only (Base Case) scenario resulted in GHG reduction of 225% and a significantly negative GHG emission (credit), the adding of SSO/SSR/MWP and AD with gasification improved GHG emissions by 282% when compared to the Base Case. Therefore, from a GHG perspective, emissions improve significantly when adding gasification due to the GHG impacts of ethanol production from gasification that turns waste into resources.

5 Items of Note

The GHG Systems Analysis with its separate modules allows a GHG impact analysis to determine the activities that have the greatest impact on GHG emissions. GHG emissions are one metric in the overall system analysis. This analysis is intended to be comparative and is not inclusive of all life cycle GHG emissions. Items that generated the same GHG emissions between the systems were not accounted for in the GHG systems analysis such as the life cycle of a collection truck. The following items of note come from the comparisons of the GHG emissions of the seven (7) waste management scenarios.

It is understood that each system will take time to implement with the exception of the current Existing System - Extended. The systems compared in the Greenhouse Gas Systems Analysis are compared at program maturity for each component. Each scenario is assumed to have all components and modules in place and functioning at full capacity at the time of GHG emission comparisons.

5.1 Conversion of Waste to a Resource has the Greatest Impact on GHG Emissions

Each of the systems analyzed indicate that the more you do with the waste (e.g. recycle, compost, AD) there is a reduction of GHG impact. The following items indicate how GHG emissions are impacted:

1. **Collection and transportation have the least GHG emission impacts of all other activities**

   Collection and transportation, while the most visible component of the waste management system to the households and businesses, they are a small component of GHG emissions in the overall waste management scenarios. Changes to collection and transportation of MSW and recyclables have a minimal impact on GHG emissions.

2. **Conversion of waste to recyclables has the greatest reduction impact on GHG Emissions**

   The addition of recycling (MWP, SSO/SSR) and AD to the systems has considerable GHG reductions resulting in comparably less GHG generation than the Processing Only (Base Case) scenario.

   The system most similar to today's waste management activity in the Counties is Existing System - Extended. The Processing Only (Base Case) assumes all Ramsey and Washington County waste is processed and not some of it direct landfilled as currently occurs. GHG analysis indicates that as the waste is utilized in different ways through the various systems beyond Processing Only (Base Case), GHG emissions are reduced. Adding SSO/SSR to the Processing Only (Base Case) system is estimated to reduce GHG emissions by 52%. If the Counties only added MWP and AD to the Base Case, the estimated GHG reduction would be 79%. If both SSO/SSR and MWP/AD are added, GHG reduction is estimated to be 89% in comparison to the Base Case.

3. Gasification changes "waste" management to "resource" management

It is important to note that the addition of gasification to the waste management system results in a net negative GHG generation (a GHG credit). Converting to gasification instead of combustion changes the "waste" management system to a "resource" management system.

Gasification of RDF rather than combustion was compared in two of the systems. If gasification technology is proven to convert RDF to ethanol, the GHG emission reduction is significant. By adding gasification to the Processing Only (Base Case) system, GHG emissions become negative (or a GHG credit) with an estimated GHG reduction of 225%. If a gasification system is added along with SSO/SSR/MWP and AD, the reduction in GHG emissions is estimated to be 282% when compared to the base case.

4. Greenhouse Gas is one metric of the waste management systems for consideration

This analysis reviews one metric of the waste management system: Comparative GHG emissions. It is important to consider the impact of the system on other metrics (e.g. safety, traffic concerns, and cost). Other research has been done on financial costs of implementing each of the systems[48]. This should all be part of a larger consideration of next steps.

[48] Life Cycle Financial Analysis, February, 2015

Figures

Figure 4-1
Total GHG Emissions Summary by System (MtCO2e)

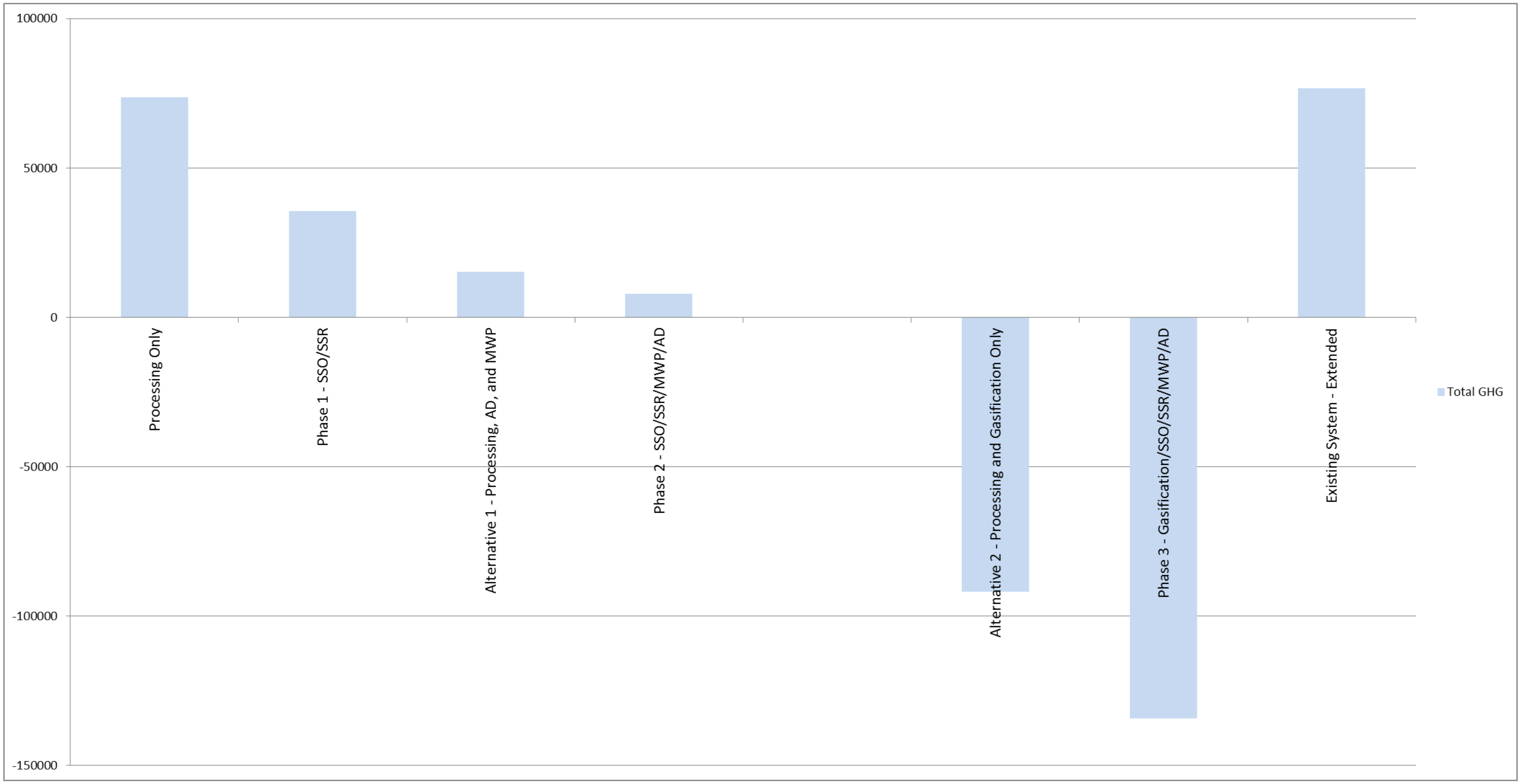


Figure 4-2a
GHG Summary of Projected Emissions (MtCO2e) by Module (Selected Systems)

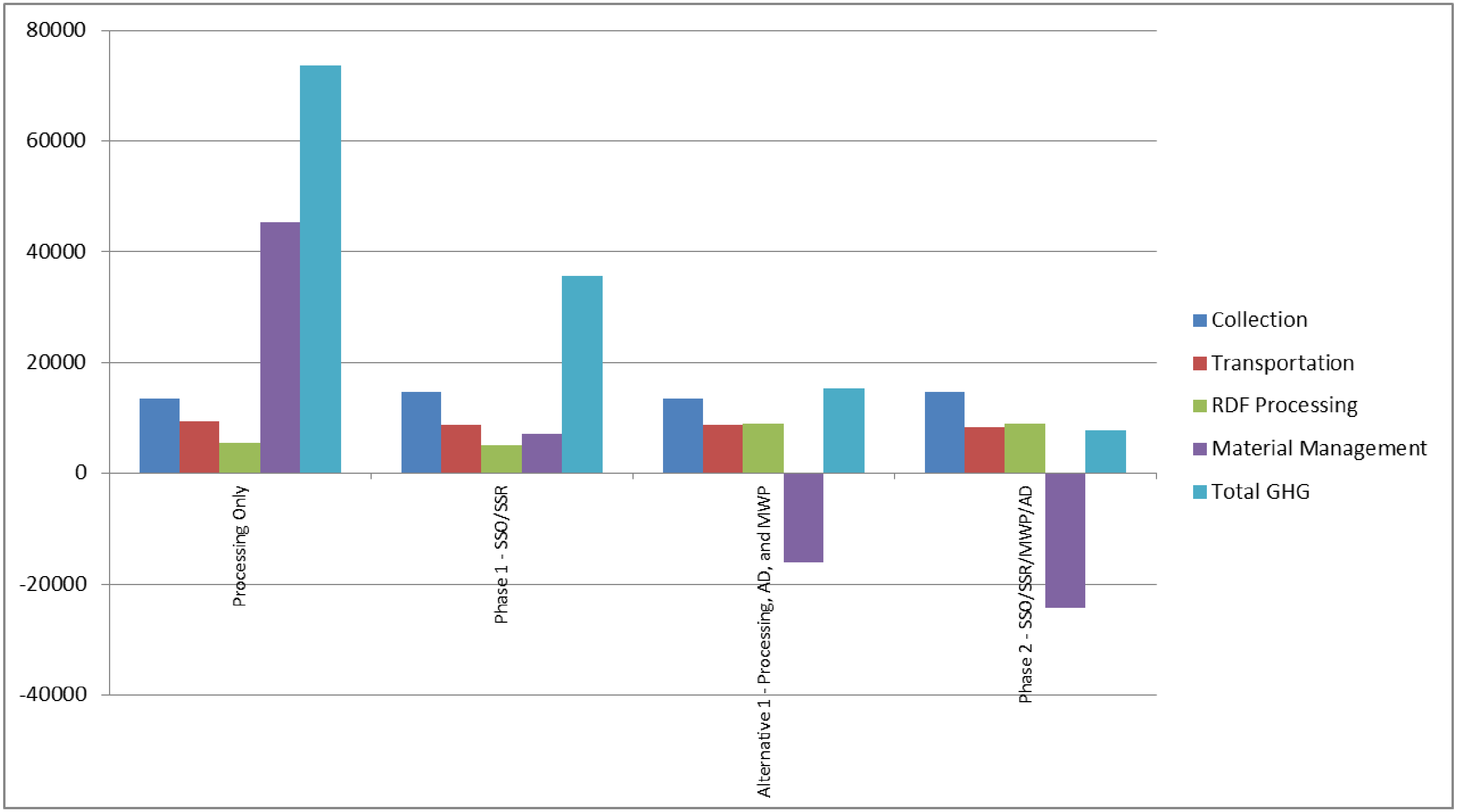


Figure 4-2b
GHG Summary of Projected Emissions (MtCO2e) by Module (Selected Systems), Continued

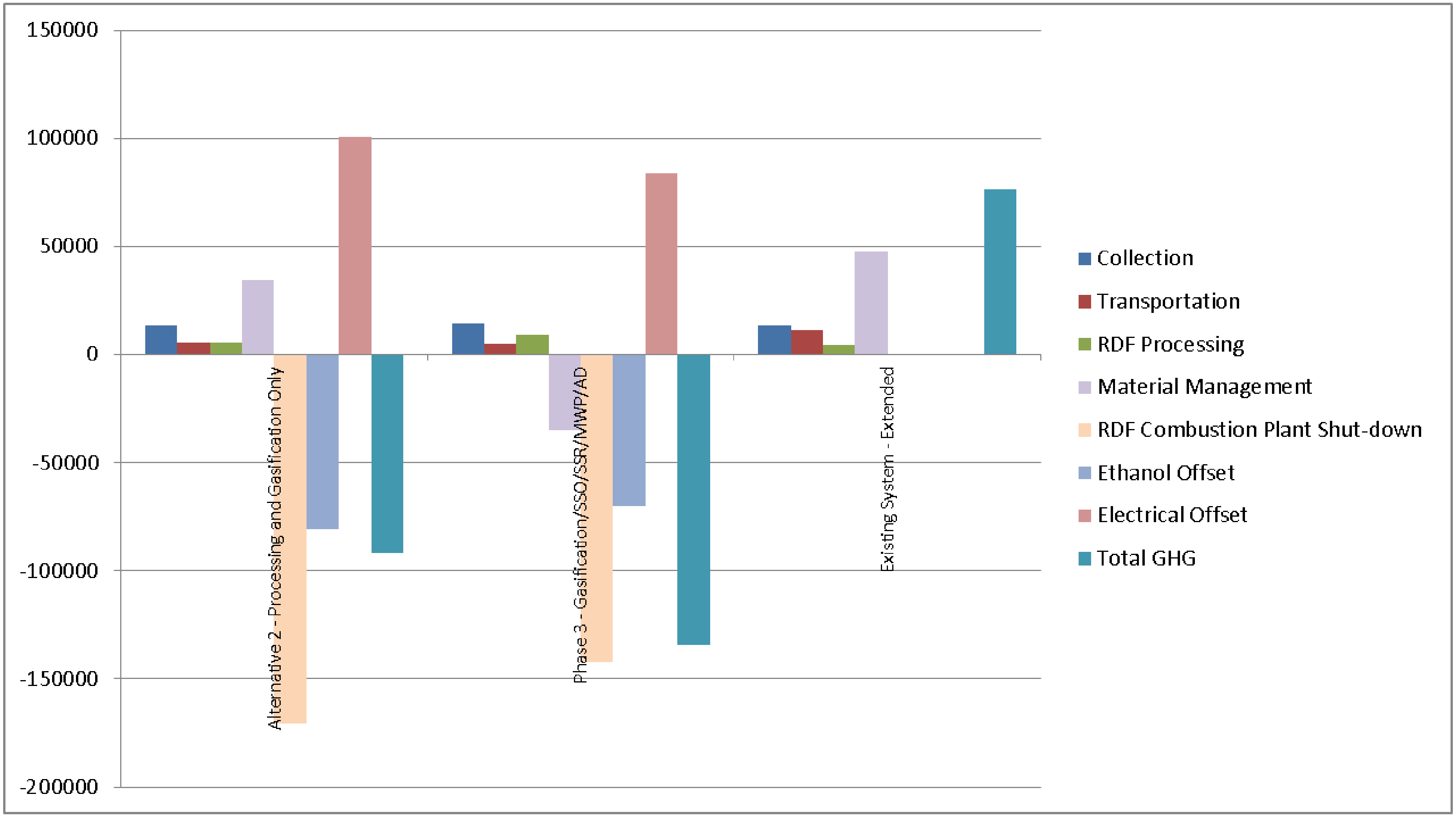
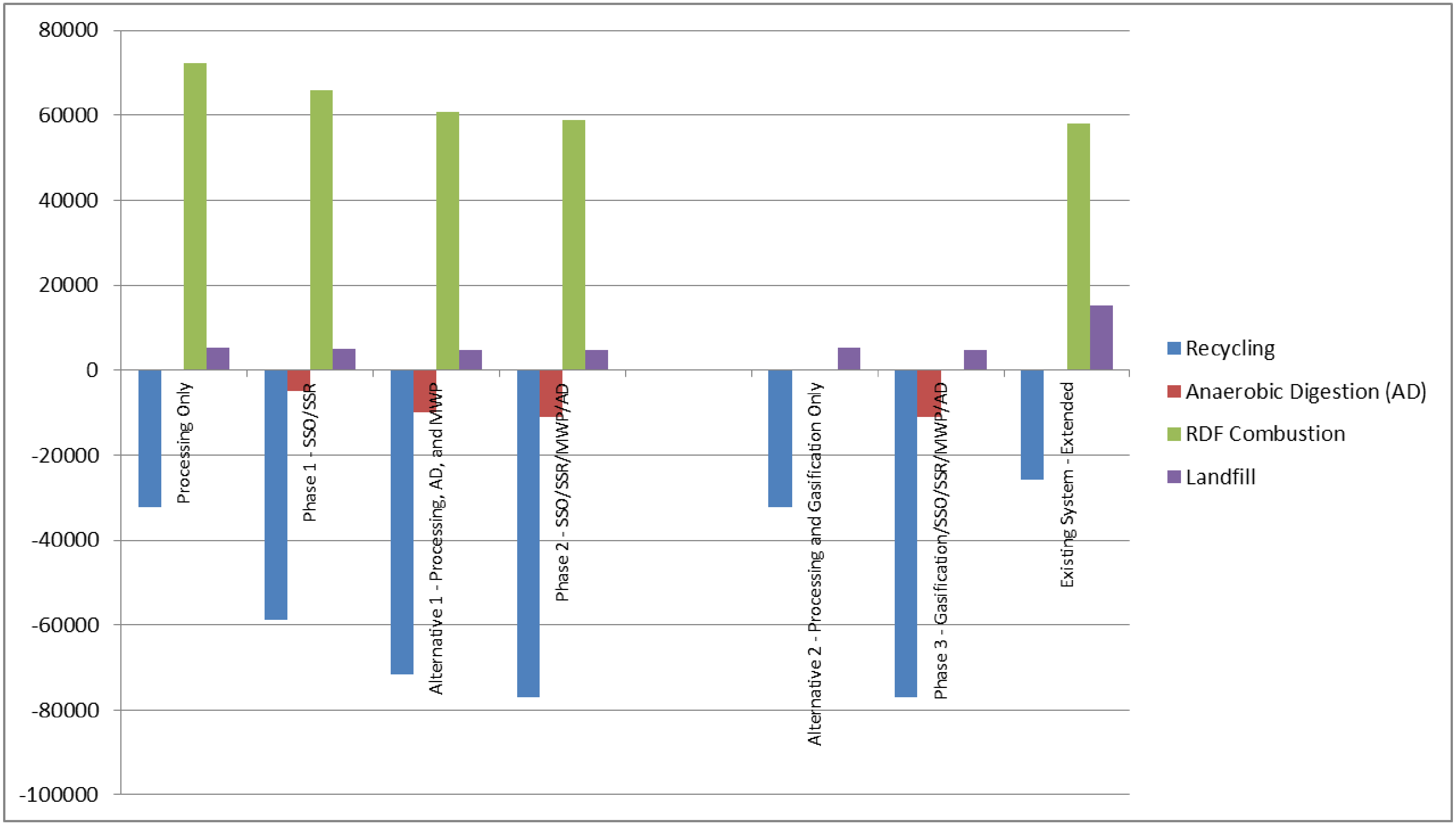


Figure 4-3
GHG Summary of Projected Emissions from Material Management (MtCO2e)



Tables

Appendix

Appendix A – Collection and Hauling Model

Appendix B – Transportation Model

Appendix C – Great Plains Institute Report:

Market, Policy and GHG Implications of MSW/RDF to Ethanol Production at Newport

Appendix D –GHG Implications of Combustion