UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Comparison of End of Life Options for Waste Paper Towel at the University of British Columbia

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CHBE 484

April 20, 2013

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Acknowledgements

We would like to express our appreciation to Brenda Sawada for her support and insight into this project. We would also like to recognize the UBC Department of Alternative Energy and the Department of Municipal services for their cooperation.

Executive Summary

In this paper, three paper towel disposal options were evaluated – landfill, compost and gasification (Nexterra Plant). The seed office would like to find that if it is feasible that UBC collects the paper towel waste and sends it to Nexterra Plant to produce syngas. Below is the summarized of the findings. Economy: $0.073/kgPT landfill, $0.079/kg compost, and -0.062 gasification; thus, gasification is economic feasible. Environement: 1.882kgCO_2/kg PT landfill, 0.7577 kgCO_2/kg PT, and 1.15kg CO_2/kg PT; thus, the compost option is the most environmental- friendly option. Social impact: 9.243 kg/year/mg/m^3,5.85 kg/year/mg/m^3,and 332 kg/year/mg/m^3; thus, the composting option also has the lowest health impact. Based on the finding, the compost option is the best based on the overall consideration in this paper; however, the gasification gives economic savings; even though it is not as environmental-friendly as the compost option, it is feasible.

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1.0 Introduction

1.1 Background

UBC currently purchases 2.82 km^2 of White Swan Long Roll paper towel (PT) per year. This is approximately 70.5 tons. It can be assumed that the quantity of paper towel disposed of is directly proportional to the quantity of paper towel purchased (SEEDS paper). The paper towel is purchased from Kruger and is 100% recycled fiber and 88% post-consumer fiber (Kruger 2013). This brand is FSC and Ecologo certified making it an excellent environmental choice for UBC. Currently, the UBC compost program only accepts food services paper towel waste and sanitary paper towels are sent to a landfill 17 km from the university. UBC Operates an in-vessel compost unit and a biomass gasifier (Nexterra) both of which could be suitable for sanitary paper towel disposal. This study will explore these options relative to sending the waste paper towel to landfill. The end of life options will be evaluated from economic, environmental and health impact perspectives. Finally this study will recommend the best disposal process with relative to the assessment parameters.

1.2 Scope

The purpose of this report is to compare three disposal options for paper towels and recommend the best strategy to manage waste paper towel. This analysis focuses of the transportation of waste paper towel to the disposal sites and the disposal process. It excludes all procurement activities and the use of the disposal process products (if any). This study also excludes the offset credits from the production consumer fertilizers and wood pellets Figure 1: System Boundary Diagram illustrates the system boundaries that are within the scope of this study.

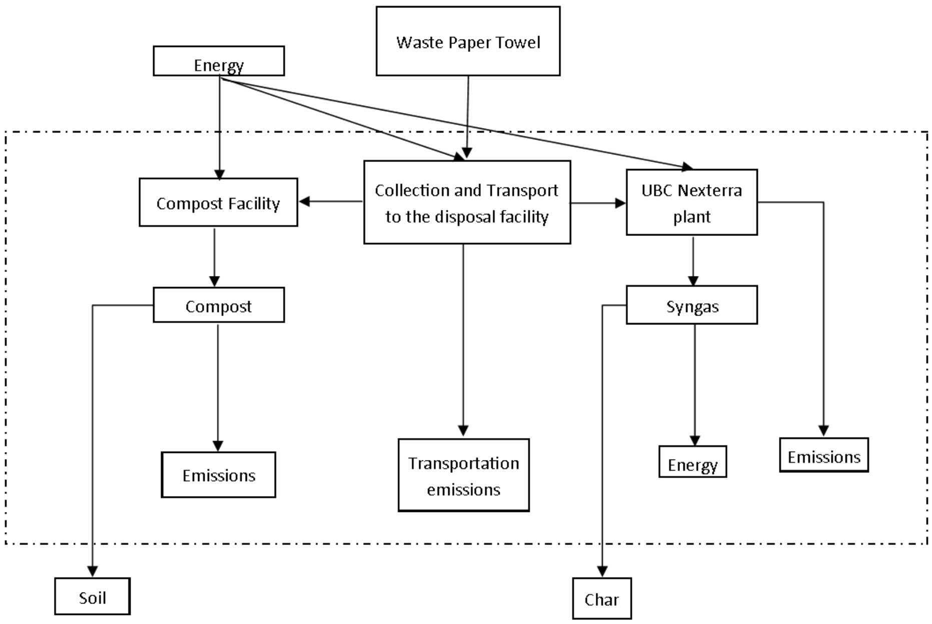

Figure 1: System Boundary Diagram

This study assumes that the manufacturing and acquisition of paper towel is the same regardless of the waste disposal method. End of life options will be compared based on their carbon equivalent emissions and on the cost or savings associated with implementation.

1.3 Functional Unit

The comparison categories will be compared on a per-kilogram of paper towel basis to be able to compare between processes. The functional units for this project will be $Kg_{PT.}$

2.0 End of Life Options

2.1 Landfill

Landfilling is the do-nothing option. The waste is sent to a landfill for disposal by decomposition. Anaerobic bacteria consume the waste and break the organic matter into cellulose, amino acids, and sugars. Methane (CH_4) and carbon dioxide (CO_2) are produced by the process. Although this process produces greenhouse gasses, landfilling also stores a fraction of the gasses when organic waste is not fully decomposed. On-site biogas contains methane, carbon dioxide nitrogen and oxygen as shown in Table 1: Composition of landfill biogas.

Table 1: Composition of landfill biogas

Composition of on-site biogas	Percentage
Methane (CH_4)	41%
Carbon dioxide (CO_2)	34%
Nitrogen (N_2)	22%
Oxygen (O_2)	3%
(U.S.EPA, 2008).	

This study will evaluate the impacts associated with sending waste paper towel produced at UBC to the Ecowaste landfill located 22 km away from the university. Figure 2: Landfill System Diagram describes the path of the paper towel as it is sent to landfill.

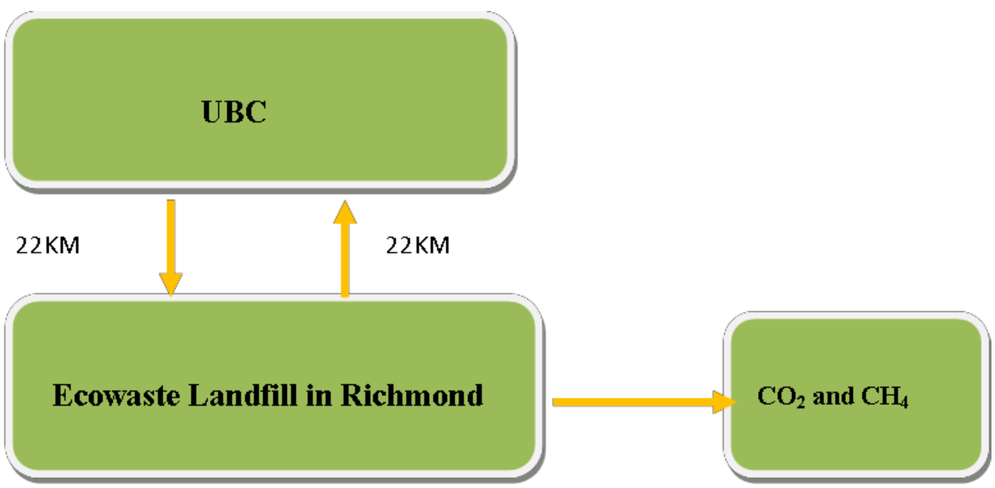

Figure 2: Landfill System Diagram

2.2 Composting

Composting is the aerobic digestion of organic matter. In a solid waste facility or composting machine, the organic matter must be mixed with water, exposed to air and mixed. Given enough time, the organic matter starts to break down. The time required for the organic matter to decompose is dependent on the composting vessel used. The aerobic digestion of organic matter produces CO_2 and CH_4. Composting of waste paper towel is beneficial because it can improve the nutrient quality and destruct pathogen, and reduce the production of odor.

UBC municipal services do not currently compost sanitary paper towel. This analysis considers off-site composting at the Harvest power 17 km from the university. Transportation of the waste to the facility will incur monetary and GHG emission costs. Figure 3 summarized the composting process considered.

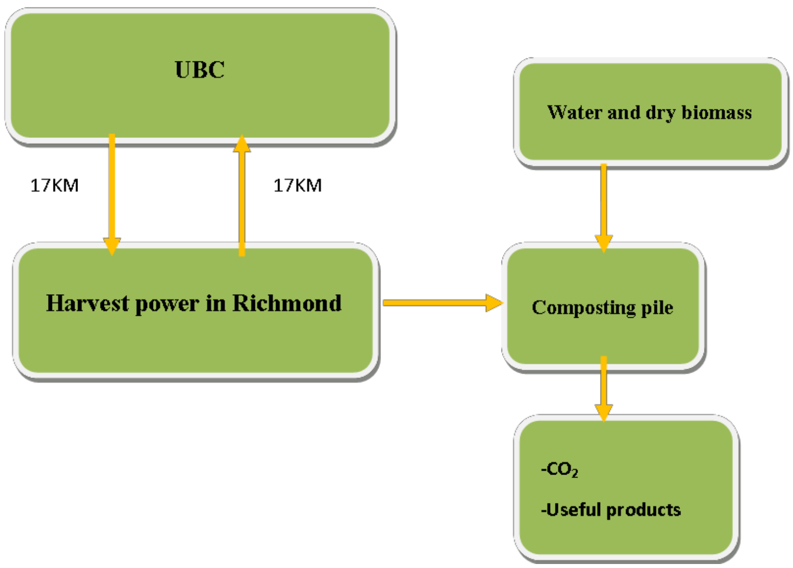

Figure 3: Compost System Diagram

2.3 Gasification

The Nexterra plant at UBC uses an updraft gasification unit to produce syngas from biomass. In the gasification unit, the feedstock is subjected to drying, pyrolysis and is reduced to ash. Pyrolysis is the conversion of a carbonaceous solid to a combustible gas. This reaction takes place in a low oxygen environment producing CO_2, CO, H_2, CH_4 and H_2O. Contaminants such as ash particles and tars are also formed but can be removed with further processing (Belgiorno 2002). This process produces syngas which is separated into two streams. The first is injected into an oxidizer where the reaction energy can be collected by a boiler to produce steam and hot water. The second stream is cleaned with a thermal cracking process to remove tars; then fed into a natural gas combustion engine to generate electricity. Flue gas containing CO, CO_2, H_2O, and

NOx is emitted by this process. Gasification is considered to be more environmentally friendly than incineration because corrosive contaminants can be more easily removed. Syngas has a higher energy density than raw feedstock and is therefore economically preferable to incineration (RMS Ross Corporation 2013). Paper towel used as a fuel source would travel a distance of 10 km while being collected. This was estimated based on the distance a single vehicle must travel to visit the major buildings on campus. Figure 4: Gasification System Diagram summarizes the path of the paper towel during the gasification process.

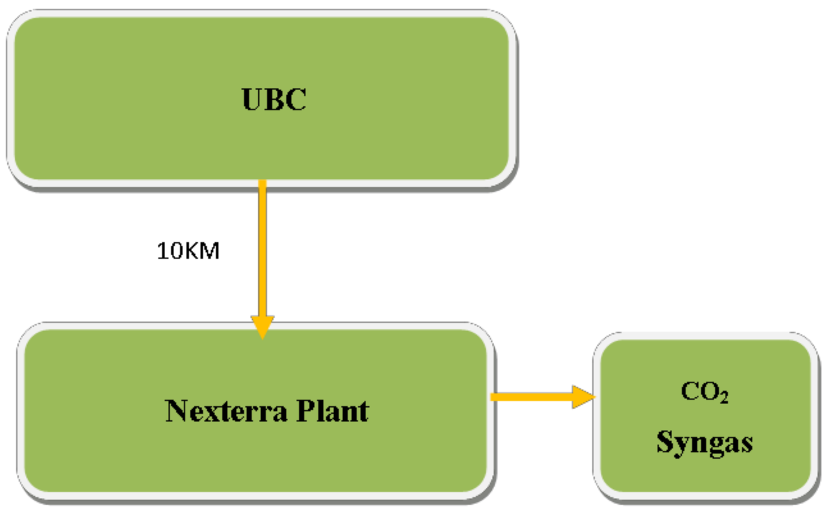

Figure 4: Gasification System Diagram

3.0 Comparison

3.1 Economy

The three considered processes incur transportation and operational costs. This section assumes that transportation was done by a front loading diesel waste disposal vehicle with a paper towel capacity of 1815 kg and a fuel efficiency of 0.2 l/km. The disposal costs associated with each process are explored in the following sections.

3.1.1 Landfill

As shown in Table3, the total cost of Landfill is $0.073/kg$_{PT}$; this cost includes the transportation cost and landfill rates. To calculate the transportation cost, students assumed a light truck is used to transport the waste, and roundtrip is required for transportation of the waste. With the distance, students could calculate the number trips, which gave the fuel cost; the cost of landfill was found by the rate of the waste; the rate of the waste is $63/ton. In short, the cost is higher than the Nexterra plant and lower than the composting site; however, one can see that the cost of landfilling is close to the cost of composting.

3.1.2 Compost

The method to calculate the transportation cost for compost is basically the same of the one of landfill; since the distance from UBC to the compost facility is longer than to landfill, it would have a higher transportation cost. To calculate, students used the horsepower of the composting machine to estimate the electricity, which is the main the cost of the process. In this part, some uncertainties exist because some hidden costs were uncovered; however, it shows that the cost of the composting is already the highest; thus, conclusion could be drawn at this point; composting option is the most expensive of the three.

3.1.3 Gasification

The UBC Nexterra plant economics are summarized in Table 2: Economics of the UBC Nexterra Plant:

Table 2: Economics of the UBC Nexterra Plant

Cost	CAD$/year
Start up	27,000,000[1]
Fuel	800,000[2]
Operators	600,000[2]
Maintenance	200,000[2]
Total	1,600,000
$/ GJ	8.27
[1]The Ubyssey 2012 **[2]Interview with Jeff Giffon**	

Neglecting the cost of the initial investment the operational cost per year is 1.6 million dollars. The Nexterra plant consumes 13 thousand tons of woodchips annually. The specific heat of wood is 14.89 MJ/kg. From this it can be calculated that the energy cost of biomass gasification at UBC is $8.27/ GJ. The price of natural gas is approximately $8/ GJ. Despite this, UBC Nexterra projects a savings of $ 850,000/year in natural gas costs (Staley 2012). Given that the paper towel would be disposed of regardless of the nature of the disposal, the cost of purchasing the PT can be neglected and gasifying paper towel can actually provide a savings to the Nexterra plant. Gasifying paper towel would offset 1043 GJ of the plant's energy demand annually. This is a savings of $4,310 per year or $0.061/kg$_{PT}$ in

The disposal vehicle would require 39 trips and 78 l of fuel to move the annual quantity of waste paper towel. The current price of diesel fuel is $1.40/l Therefore the cost of transporting the paper towel to the gasification centre is $109/year.

Using paper towel as biomass at Nexterra also offsets the transport of 70 tons of woodchips from Cloverdale Fuel in Langley (120 km round trip) would offset 8 woodchip shipments (kcxi.com). This results in a $235.2/year savings in fuel costs or $0.0033/kg$_{PT}$.

3.1.4 Summary of Disposal Economics

Table 3: Summary of disposal economics shows that disposal by gasification yields the greatest economic advantage. Gasifying waste paper towel would save on fuel costs for transportation and for the Nexterra plant. However, the savings are almost negligible; $4,310/year.

Table 3: Summary of disposal economics

Process	**Landfill** (CAD$/kg$_{PT}$)	**Compost** (CAD$/kg$_{PT}$)	**Gasification** (CAD$/kg$_{PT}$)
Transportation	0.01	0.002	-0.001
Disposal	0.063	0.077	-0.061
Total	0.073	0.079	-0.062

3.2 Environment

3.2.1 Landfill

Landfill is the worst option based on the concerns of environment because it produces the largest amount of CO_2 comparing with the other two options. To calculate the production of CO_2, given UBC purchased 9500 cases of paper towel from Kruger, which had a total weight of 70.5 ton. The area of an individual paper towel is 20 cm^2; with this value, the weight of paper towel is found. Then, the total number of each pull can be calculated. The reason to calculate the total number of pull because each pull of paper towel produced 10g CO_2. Then the amount of CO_2 can be calculated. Landfill also produces CH_4; thus, it has the highest global warming impact of the three options.

3.2.2 Compost

The compost option produces the least amount of CO_2 of the three options; based on the environmental concern, this option seems the best because it produces less CO_2 and CH_4; even though CH_4 is not compared here, the compost option indeed produces less methane. Some uncertainties occur here because the contaminated paper towel could not be composted due to the health reasons. Contamination of the paper towel has been neglected in the rest of this study

3.2.3 Gasification

Paper towel is primarily composed of cellulose. For this study it was assumed that the specific energy of paper towel is approximately that of wood (14.89 MJ/kg). The density of paper towel was shown to be 0.025 kg/m^2 (see appendices). Therefore the energy density of paper towel assuming a constant thickness is calculated to be 0.37 MJ/m^2. UBC can extract 678 GJ/year from the gasification of paper towel.

The Energy Department at Sao Paulo State University showed that for syngas produced using eucalyptus biomass with a moisture content of 20% the total carbon equivalent emission factor is 0.080228 $kg_{CO2}/ MJ_{produced}$. This indicates that gasifying waste paper towel at UBC would produce 83.7 tons of CO_2 equivalent gasses per year or 1.19 kg_{CO2}/kg_{PT}.

As shown above, the paper towel will travel 10 km during the collection process. For consistency of comparison it will be assumed that the PT will be transported by the same vehicle that would bring the waste to landfill. In practice this vehicle could be replaced with light capacity biodiesel or electric vehicle from the municipal services fleet. Table 4: Emission Factors for Diesel Fuel from Environment Canada shows the emission factors for diesel fuel. These values result in 217 kg_{CO2} emissions per year. This is 0.0031 kg_{CO2}/kg_{PT}.

Gasifying paper towel would also offset 7 shipments of fuel from the Cloverdale Fuel facility in Langley. This would result in an emissions savings of 469 kg_{co2} per year or 0.0067 kg_{CO2}/kg_{PT}.

Table 4: Emission Factors for Diesel Fuel

	CO2 (g/L)	CH4 (g/L)	N02 (g/L)
Diesel	2663	0.133	0.4

3.2.4 Summary of Environmental Impacts

Table 5: Summary of disposal emissions compares the carbon equivalent emissions from each of the three considered processes. From an emissions perspective it is clear that a compost facility equipped with emission recovery is the best option offering GHG reduction of 60%.

Table 5: Summary of disposal emissions

Process	Landfill (kg_{CO2}/kg_{PT})	Compost (kg_{CO2}/kg_{PT})	Gasification (kg_{CO2}/kg_{PT})
Transportation	0.013	0.01	-0.004
Disposal	1.869	0.7477	1.19
Total	**1.882**	**0.7577**	**1.15**

	Global warming Impact(tons CO_2 equivalent)
Nexterra	83.19
Composting	52.7
Landfilling	3468

Table6: Global warming impact

3.3 Society

3.3.1 Landfill

According to Table 7, this option has the highest health impact because it produces CH_4 and CO_2. Students used the course note to calculate these values. The threshold limit values are provided in the course notes. The total production of emissions were found and shown in the sections above; thus, the toxicity index and health impact could be calculated.

3.3.2 Compost

As shown in Table7, composting has the lowest health impact, which is considered the best option based on this value. This value is important for the workers and people around the facility. Bothe the compost option and gasification have low values; however, the gasification option is still 36% higher than that of the composting option.

3.3.3 Gasification

Jeff Giffon, Head of Alternative Energy at UBC believes that dry paper towel could be introduces to the current feedstock provided there were no harmful additives. Chlorine would be particularly harmful to the process as it would be converted to hydro chloric acid (HCL) and damage the oxidizer and turbines. The UBC Nexterra plant is not equipped with the wet scrubber process required to remove the HCl from the syngas.

Although the paper towel purchased by UBC is FSC and Ecologo certified; neither certification mandates the use of chlorine free processes. For this reason the sanitary waste could not be processed by the UBC Nexterra plant without further evaluation of the chlorine content of the paper towel and the feasibility of adding a wet scrubber to the Nexterra process. Operators at the plant are reluctant to modify the process at the moment as it is still undergoing trials (Giffon 2013).

3.3.4 Summary of Social Impacts

Table 7: Summary of disposal health impacts indicates that landfilling has a high health impact when compared with alternatives. Based on this data, landfilling is not considered as a good option for disposal. The best disposal option relative to health impacts is composting.

Table 7: Summary of disposal health impacts

	Health Impact
Nexterra	9.243
Composting	5.85
Landfilling	332

4.0 Recommendations

Biomass gasification showed the greatest potential from both an economic and greenhouse gas emission perspective, however the UBC plant is not equipped to process the harmful acidic by-products that would form as a result of the bleach used to white the paper towel.

Although UBC compost does not currently accept waste sanitary paper towel, this was shown to also be beneficial in terms of greenhouse gas reduction. This would result in a reduction of 78 tons of GHG gasses annually at a cost of $5,500/year.

This study recommends that UBC explore the opportunity of composting waste sanitary paper towel as part of their greenhouse gas reduction initiative.

5.0 Conclusion

This study compared the possible end of life options for the waste sanitary paper towel at the University of British Columbia. It was shows that, although gasification of the paper towel resulted in an economic savings and a GHG reduction of 70 tons/year, the plant does not have the capacity to accept the current brand of paper towel as a fuel. Based on this fact it was concluded that composting is the most viable option for the end of life disposal of waste sanitary paper towel. This would result in a GHG reduction of 55 tons per year. The UBC compost program does not currently accept waste sanitary paper towel. The waste would therefore need to be shipped off campus to a nearby compost facility. More important GHG reductions could be achieved if gasification were a viable option or the UBC compost program allowed sanitary paper towel into the process.

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Appendices

Appendix A: Calculations

A.1 Gasification Emissions

Assumptions

- Wood, paper towel and eucalyptus leaves have similar composition
- Specific energy of wood is 14.89 MJ/kg
- Emission factor for gasification of eucalyptus leaves is 0.080228 kg_{CO2}/ MJ
- UBC orders 70.5 tons of paper towel annually with an area of (from Kruger website)

$$\rho_{PT} = \frac{1g}{0.04m^2} = 0.025\frac{kg}{m^2}\ Empirical\ values$$

$$\bar{q}_{PT} = 0.025\frac{kg_{fuel}}{m^2} \cdot 14.89\frac{Mj}{kg_{fuel}} = 0.37\frac{Mj}{m_{PT}^2}$$

Energy Content

$$Q = \ \bar{q} \cdot A = 0.37\frac{Mj}{m_{PT}^2} \cdot 2.82x10^6\ m_{PT}^2 = 1043\ Gj$$

$$With\ a\ 65\%\ heat\ efficiency, this\ is\ 678\ Gj\ of\ useful\ energy$$

Greenhouse Gas emitted

$$\dot{m}_{CO2} = 0.080228\frac{kg_{CO2}}{Mj} \cdot 1043\frac{Gj}{year} = 83.67\frac{ton_{CO2}}{year}$$

$$m' = 83.67\frac{ton_{CO2}}{year} \div 70.5\frac{ton_{PT}}{year} = 1.19\frac{kg_{CO2}}{kg_{PT}}$$

A.2 Gasification Economics

Assumptions:

- Cost of wood is \$800,000/year
- Nexterra uses 13,000 tons/year
- Specific heat of wood is 14.89 MJ/kg

- Paper towel produces 1043 GJ annually

Cost of Energy

$$C = \frac{1{,}600{,}000}{13000} \cdot \frac{\$}{ton} \cdot \frac{1}{1000} \cdot \frac{ton}{kg} \cdot \frac{1}{14.89} \cdot \frac{kg}{Mj} \cdot 1000 \cdot \frac{Mj}{Gj} = \frac{\$8.27}{Gj}$$

Savings

Paper towel would offset 1043 GJ

Cost of wood (by same calculation as above) is $4.13/ GJ

$$S = 1043 \cdot \frac{Gj}{year} \cdot \frac{\$4.13}{Gj} = \frac{\$4310}{year}$$

CO_2 production of transportation:

Landfill(22km)

22km*0.621 mile/km = 13.6mile

Light truck fuel economy: 7mile/gallon

136 mile / 7mile/gallon = 1.95 gallon required.

Round trip: 1.95*2= 3.905 gallon=17.73L diesel required

17.73L*2.68kg diesel/ kg = 47.51 kg CO_2

Paper towel weight: 70500kg.

About 20 times of transporting

47.51*20/ 70500 = 0.015kgCO^2/kgPT

Compost(17km)

17km*0.621miel/km=10.563 mile

Same truck

10.563/7 = 1.51 gallon diesel

Round trip = 1.51*2=3.01 gallon = 13.638 L diesel required

13.638 L * 2.68 kg/L = 36.55kg CO_2

36.55*20/70500 = 0.01036 kgCO_2/kg PT

CO_2 production

Annual CO2production:

Landfill: 9500 cases purchased=70500 kg of paper towel

10 g CO2 produced per paper towel goes to landfill

Each pull of paper towel: 20cm*20cm

Paper density: 134g/m^2

Each paper towel weight:

134g/m^2/(0.2*0.2)m2=5.36 g

Total CO2 produced: (70500kg/0.00536kg)*0.01kg=131775.7 kgCO^2/year

Landfill: 131775.7kg/70500 kg=1.869 kgCO^2/Kg paper towel

Composting: CO2 is found to be 2.5 times less than landfill production.

Thus, Total CO2 produced=137892.02 kg

Composting=0.747 $kgCO^2$/kg paper towel

COST:

Composting: machine horsepower:200,000KWh/year

Electricity=0.07$/KWh

Cost=200,000KWh/year*0.07$/KWh=$14000/year

Capacity: 5 tonnes/day*365=1825 tonnes/year =1825000kg/year

($14000/1825000)*(70500) =$5408/year

5408/70500=$0.077/kg Paper towel

Landfill: ($63/tonnes*70500kg)/ (1000kg*70500kg) =$0.063/kg paper towel

Total environmental impact

CO2 e=∑(GHG*GWPi)

CO2 e: emissions in carbon dioxide equivalents

GHGi: emissions of GHG pollutant

GWPi: GWP of GHG pollutant "i"

N: number of GHG emitted from the source

NOTE:In this LCA only main emission sources are considered.

Nexterra plant: (1.18kg CO2/Kg pt)*(70500/1000)=83.19tonnes CO^2 equivalent

Composting: 0.7477*(70500/1000)=52.71285tonnes CO2 equivalent

Landfilling: ((1.869*70500)+(1.869*70500*0.41/0.34))/((1000))=3468.5 CO^2 eq

According to EPA CO2:CH4

34%:41%

Human health risk assessment:

TLV(mg/m3)

CO^2 :9000→1/TLV=0.00111

CH4:500 --→1/TLV=0.002

Health impact or toxicity potential=∑Ei/TLVi

Ei-→emission rate

Nexterra plant: health impact=(83190/9000)=9.24kg/year/mg/m^3

Composting: Health impact=(52712.85/9000)=5.857kg/year/mg/m^3

Landfill: Health impact=(131764.5/9000)+(158892.49/500)=332kg/year/mg/m^3