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SCHOOL OF SUSTAINABLE ENGINEERING AND THE BUILT ENVIRONMENT

CESEM

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Attributional Life Cycle Assessment: Emissions, Greenhouse Gas, and Costs for Palm Fronds Attributed to the City of Phoenix

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ALCA: Emissions, Greenhouse Gas, and Costs for Palm Fronds Attributed to the City of Phoenix

Executive Summary:

Urban landscaping palm tree waste in the form of palm frond trimmings and bark shavings currently handled as municipal solid waste by the City of Phoenix, and other major municipalities, can be more cost effective and lead to reductions in emissions and greenhouse gases. While many cities have green organics collection and diversion programs, they always exclude palm tree waste due to its unique properties. As a result, an unknown tonnage of palm tree waste is landfilled as municipal solid waste annually. Additionally, as the tonnage is unknown, so are the associated emissions, greenhouse gases and costs. An attributional life-cycle assessment was conducted in the City of Phoenix from the perspective responsibility of the City of Phoenix's Public Works Department. Three potential inputs for palm tree tonnage were proposed as possible annual collection values, and were based on collected green organic tonnages. These values were 17,572 tons, 35,144 tons and 70,288 tons.

Three disposal solution systems were evaluated using these three inputs. They were the business as usual model currently utilized by the City of Phoenix, an envisioned mulching operation owned and operated by the City of Phoenix, and a conceptual technological solution instituted by a private third party. Calculations for all solutions focused solely on facility operations, equipment, fuel, vehicles, transportation, and landfilling directly interacting with palm tree waste.

The multitude of calculated results were as follows: **Carbon Monoxide: 9.25** tons of CO/FY for PF, and **1.0x10^-3** tons of CO/tonPF/FY for the lowest case scenario, **18.95** tons of CO/FY for PF, and **1.0x10^-3** tons of CO/tonPF/FY for the medium case scenario, and **37.02** tons of CO/FY for PF, and **1.0x10^-3** tons of CO/tonPF/FY for the high case scenario. Comparatively, the disposal of palm tree waste via alternative one results in the following CO emissions: **6.23** tons of CO/FY for PF, and **7.3x10^-4** tons of CO/tonPF/FY for the lowest case scenario, **12.76** tons of CO/FY for PF, and **7.3x10^-4** tons of CO/tonPF/FY for the medium case scenario, and **24.94** tons of CO/FY for PF, and **7.3x10^-4** tons of CO/tonPF/FY for the high case scenario.

Nitrous Oxides: 2.82 tons of NOx/FY for PF, and **3.3x10^-4** tons of NOx/tonPF/FY for the lowest case scenario, **5.77** tons of NOx/FY for PF, and **3.3x10^-4** tons of NOx/tonPF/FY for the medium case scenario, and **11.27** tons of NOx/FY for PF, and **3.3x10^-4** tons of NOx/tonPF/FY for the high case scenario. Comparatively, the disposal of palm tree waste via alternative one results in the following NOx emissions: **2.01** tons of NOx/FY for PF, and **2.3x10^-4** tons of NOx/tonPF/FY for the lowest case scenario, **4.13** tons of NOx/FY for PF, and **2.3x10^-4** tons of NOx/tonPF/FY for the medium case scenario, and **8.06** tons of NOx/FY for PF, and **2.3x10^-4** tons of NOx/tonPF/FY for the high case scenario.

Hydro-Carbons: .74 tons of HC/FY for PF, and **8.8x10^-5** tons of HC/tonPF/FY for the lowest case scenario, **1.52** tons of HC/FY for PF, and **8.8x10^-5** tons of HC/tonPF/FY for the medium case scenario, and **2.98** tons of HC/FY for PF, and **8.8x10^-5** tons of HC/tonPF/FY for the high case scenario. Comparatively, the disposal of palm tree waste via alternative one results in the following HC emissions: **.58** tons of HC/FY for PF, and **6.6x10^-5** tons of HC/tonPF/FY for the lowest case scenario, **1.19** tons of HC/FY for PF, and **6.6x10^-5** tons of HC/tonPF/FY for the medium case scenario, and **2.33** tons of HC/FY for PF, and **6.6x10^-5** tons of HC/tonPF/FY for the high case scenario.

Particulate Matter: .06 tons of PM/FY for PF, and **7.1x10^-6** tons of PM/tonPF/FY for the lowest case scenario, **.12** tons of PM/FY for PF, and **7.1x10^-6** tons of PM/tonPF/FY for the medium case scenario, and **.24** tons of PM/FY for PF, and **7.1x10^-6** tons of PM/tonPF/FY for the high case scenario. Comparatively, the disposal of palm tree waste via alternative one results in the following PM emissions: **.04** tons of PM/FY for PF, and **5.1x10^-6** tons of PM/tonPF/FY for the lowest case scenario, **.09** tons of PM/FY for PF, and **5.1x10^-6** tons of PM/tonPF/FY for the medium case scenario, and **.18** tons of PM/FY for PF, and **5.1x10^-6** tons of PM/tonPF/FY for the high case scenario.

Greenhouse Gases C02 Equivalence: 5,405 tons of C02 Eq/FY for PF, and **.32** tons of C02 Eq/tonPF/FY for the lowest case scenario, **11,071**tons of C02 Eq/FY for PF, and **.32** tons of C02 Eq/tonPF/FY for the medium case scenario, and **21,633** tons of C02 Eq/FY for PF, and **.32** tons of C02 Eq/tonPF/FY for the high case scenario. Comparatively, the disposal of palm tree waste via alternative one results in the following GHG emissions: **56** tons of C02 Eq/FY for PF, and **7.2x10^-3** tons of C02 Eq/tonPF/FY for the lowest case scenario, **115** tons of C02 Eq/FY for PF, and **7.2x10^-3** tons of C02 Eq/tonPF/FY for the medium case scenario, and **225** tons of C02 Eq/FY for PF, and **7.2x10^-3** tons of C02 Eq/tonPF/FY for the high case scenario.

Costs: -**$374,512**/FY for PF, and **-$40.35**/tonPF/FY for the lowest case scenario, **-$767,235**/FY for PF, and **-$40.35**/tonPF/FY for the medium case scenario, and **-$1,498,903**/FY for PF, and **-$40.35**/tonPF/FY for the high case scenario. Comparatively, the disposal of palm tree waste via alternative one results in the following costs: -**$22,470**/FY for PF, and **-$17.26**/tonPF/FY for the lowest case scenario, **-$46,181**/FY for PF, and **-$17.26**/tonPF/FY for the medium case scenario, and **-$90,329**/FY for PF, and **-$17.26**/tonPF/FY for the high case scenario.

Although the mulching alternative reduces annual emissions, greenhouse gases, and costs, uncertainty in the mulching market advises for a policy that continues BAU, expands the study of palm tree waste, studies palm tree mulch and the mulching market, and invests in startup solutions either monetarily or with knowledge.

1. Introduction

In Western and Southwestern regions of the United States, environmental and aesthetic norms have established the palm tree, and its variety of species, as one of the standards of urban landscaping despite its not being a native species to the United States. Specifically, in the City of Phoenix, and other major cities with noticeable quantities and climates suitable for palm trees, an approximate value of the total number of palm trees within the city is unknown. As with all landscaping, promoting the health and growth of these trees requires attention, resources and maintenance. For palm trees, part of this takes the form of regular trimming and shaving of the trees' fronds and bark by specialized landscaping companies. Consequently, as the number of palm trees is unknown, so is the resultant quantity or any approximation of palm tree waste produced annually within the City of Phoenix.

As a general rule, most trees, bushes and yard trimmings can easily be chipped, mulched or composted together, and with the increasing adoption of sustainable culture by cities and their citizens, municipal disposal methods are being guided in this direction in the form of low-capital and low infrastructure investment "green organics" collection programs. However, it is important to specify that despite the rollout of such programs in the City of Phoenix and other cities, as it exists today, palm tree trimmings and shavings still require processing and disposal as municipal solid waste. The rationale for this is that the fronds and bark of the palm tree are unlike other yard trimmings in their composition and properties. By comparison, their fibrous nature, high salt content, high holocellulose content, and high flashpoint do not allow their trimmings to be chipped, mulched, composted, or incinerated in a commingled system without ruining machinery, damaging end products, or losing capturable energy. This reality and lack of solution therefore create an obstacle in municipal strategies and legislation emphasizing the utilization of valuable waste streams and the requirement of diverting waste streams from landfills.

In the City of Phoenix, where a plan of action to increase total solid waste diversion from 18%, 14% below the national average of 33.8% (1), to 40% by the year 2020 is beginning to take shape, every divertable material becomes valuable and isolatable for study. Therefore, in order for a solution to be created and a diversion strategy implemented pertaining to palm tree waste, it would benefit the City of Phoenix to understand the impacts associated with the disposal of palm tree waste, as such knowledge appears to not have been previously isolated or studied by any outside entity. Thus, this is a comparative attributional life-cycle assessment of palm tree waste in the City of Phoenix to determine the emissions, greenhouse gases, and costs directly attributable to a business as usual solid waste disposal practice ad two alternatives performed by the City of Phoenix.

2. Background

From a global perspective, the attention and importance of palm trees is largely focused on the African oil palm species, which produces the fruits used in the creation of palm oil, a popular and booming commodity found in foreign markets. As such, research and life-cycle assessments related to palm trees are largely focused on palm oil production processes and land allocation requirements for major producing nations such as Indonesia and Malaysia (2,3). Additionally, research exists pertaining to the possibility of bio-diesel conversion from palm oil (4), with one study examining the pulping possibility of palm fronds as an industrial byproduct in Malaysian palm oil production (5). However, as all of these studies are related to foreign palm oil production, no information exists related to the quantity and disposal of palm trees as landscaping in domestic municipalities. Furthermore, an additional contributing factor is the successful public education program known as the three r's; reducing, reusing and recycling, which for over twenty years has centered the concept of national waste diversion and research on consumer commodities, transportation, energy, water and food. As such, less publicized waste streams, such as palm fronds, have avoided attention and in depth study of their environmental impacts.

3. Methodological Approach

A business as usual (BAU) and two improvement alternatives were examined. Each scenario was a cradle to grave analysis within City of Phoenix disposal facilities. That is, although disposal is usually considered an end of life process in life-cycle assessment, when specifically examining the components of waste disposal, the entrance of waste into the transfer station is considered the cradle, and the landfilling and subsequent digestion and emissions portion is considered the grave. Thus, although examined palm tree waste is only coming from within the flow boundaries, which are defined by the literal 516 square miles that compose the City of Phoenix; the respective revenues, costs, and environmental impacts associated with vehicles, facilities, administration, labor, residents, maintenance, collection, fuel production, and electricity usage by the City of Phoenix Public Works Department are ignored. Instead, the system boundaries used to summate emissions, greenhouse gases, and costs pertaining to palm tree waste are defined from the City of Phoenix's perspective, referring to the first moment palm tree waste interacts with and becomes a City of Phoenix responsibility. This occurs at the entrance to both the 27th Avenue and North Gateway Transfer Stations, and ends at the State Route 85 Landfill. Thus, impacts attributable to the City of Phoenix are assessed only from City of Phoenix owned or contracted facilities, vehicles, transportation, and operations that directly interact with palm tree waste. A diagram illustrating these system boundaries can be found in Figure 1.

Additionally, per City of Phoenix green organics collection data, 80-90% of green organics are brought into the transfer stations via self-hauling residents and landscapers. As a unique process with specialty tools and requirements, it can be assumed that 90-99% of palm tree waste brought into transfer stations would be delivered via private self-haul. However, while there are environmental impacts associated with these private services and hauling, this life-cycle assessment was conducted for the City of Phoenix Public Works Department, and was therefore simplified to only reflect and report responsible costs and impacts associated with the disposal of palm tree waste in the City of Phoenix by the governmental City of Phoenix body.

As previously mentioned, the quantity of palm tree waste produced annually is unknown, nor is it tracked by the City of Phoenix. This poses a challenge, as the functional unit utilized for this life-cycle assessment is tons of palm tree waste per City of Phoenix fiscal year. As palm tree waste is handled with all other municipal solid waste, the only known factor is that it composes some percentage of the 900,000 tons of municipal solid waste (MSW) disposed of annually by the City of Phoenix. Interviews with disposal and transfer station administration could only offer guesses as to the percentage of MSW it composes, with guesses ranging from 5% (45,000 tons per fiscal year) to 10% (90,000 tons per fiscal year). With no foundational support for such guesses, the tonnage of palm tree waste used in each scenario was derived from a relatable tonnage that is tracked, green organics. It is known that per the 2012 fiscal year, the City of Phoenix collected 35,144 tons of green organics. Therefore, the assumption was made that as a green organic itself; palm tree waste could have a value near this number. To cover the potential that the actual number is lower or higher, assumed total palm tree waste was determined to be half of this value (17,572 tons per fiscal year), the same value (35,144 tons per fiscal year), and double this value (70,288 tons per fiscal year), with all three possibilities used as the palm tree waste tonnage inputs to calculate the three associated potential emission, greenhouses gase (GHG), and cost impacts of each solution.

3.1 Business as Usual. For BAU, palm tree waste was examined at the first process, the transfer station entrance. Here the cost of operations and labor for just solid waste services at each transfer station facility was input, meaning all recycling and materials recovery facility (MRF) associated staff, vehicles and operations were excluded. The reported facilities costs were rounded audit values of $10.2M and $8M for the 27th Avenue and North Gateway (NG) transfer stations, respectively. Next the revenue generated from a 2012 city rate charge of $20 per ton to personal waste haulers at each transfer station entrance was input for the three possible tonnages.

Assessment then moved to the second process, the transfer station tipping floor. Here the quantity and type of B20 biodiesel vehicles used to sort and load all MSW was inventoried. Their respective costs of annual fuel usage and resultant emissions and GHGs were calculated.

Analysis then moved to process three, which consisted of contracted private hauling totaling 3,963,390 annual miles traveled to and from each transfer station to the City of Phoenix owned and operated State Route 85 Landfill (SR85). A $10.26 per ton cost of contracting with a private hauler and the resultant emissions and GHGs from the diesel semi-trailer trucks was attributed to the City of Phoenix.

Finally, process four, landfill operations, included a $5.8M rounded audit of SR85 facilities costs, and inventory of the quantity and type of B20 biodiesel vehicles used to move and compact all MSW in the landfill. The respective costs of annual fuel usage, resultant emissions and GHGs of each vehicle were calculated, as well as the emissions and GHG impacts related to the flaring of landfill gas produced from landfilling 900,000 tons of MSW at SR85 annually per the Environmental Protection Agency's (EPA) Waste Reduction Model (WaRM). All values were then normalized per activity and again per functional unit to obtain final costs and impacts reported as total costs per fiscal year attributed to palm fronds ($USD/FY for PF), costs per ton of palm fronds per FY ($USD/tonPF/FY), total emissions tons per fiscal year attributed to palm fronds (tons/FY for PF), emissions tons per ton of palm fronds per FY (tons/tonPF/FY), total GHG C02 equivalent tons per fiscal year attributed to palm fronds (C02 Eq tons/FY for PF), and GHG C02 equivalent tons per ton of palm fronds per FY (C02 Eq tons/tonPF/FY).

3.2 Alternative 1: Independent Mulching. In selecting alternatives, the specialized and lone processes of mulching and incineration were considered. Not to be confused with the understanding that palm tree waste cannot be mulched or incinerated with usual green organics, the distinction is that lone processes with palm tree waste as the only feedstock are possible, but require an investment in specialized equipment, technology, and infrastructure as well as consistent quantities and qualities of feedstock.

The ideal system for a mulching operation would be an unsaturated mulching market that would purchase all produced palm tree mulch, whereas the ideal system for incineration would be a closed-loop that supplied energy back to City of Phoenix waste disposal operations. As it is assumed that the City of Phoenix would be more likely to adopt the alternative with the lowest cost of entry and quickest return on investment, a palm tree mulching operations was evaluated, and the incineration alternative disregarded due to high initial capital investment.

The mulching alternative maintains the same flow boundaries as BAU, as it is approached from the perspective of the City of Phoenix the moment palm tree waste becomes its responsibility. System boundaries for this alternative are also similar to BAU, and can be seen in Figure 2. Process one is again the transfer station entrance. Here the cost of operations and labor for just solid waste services at each transfer station facility were input. The reported facilities costs were rounded audit values of $10.2M and $8M for the 27th Avenue and North Gateway (NG) transfer stations, respectively. Next the revenue generated from a 2012 city rate charge of $20 per ton to personal waste haulers at each transfer station entrance was input for the three possible tonnages.

Assessment then moved to the second process, an envisioned lone palm tree mulching operation to be located at the 27th Avenue transfer station. The process is modeled after the current mulching operation located at the 27th Avenue transfer station and contracted with Gro-Well Company to mulch the City of Phoenix's green organics. In this alternative, the mulching operation uses the same quantity of vehicles and grinders inventoried in Gro-Well's operation, except ownership and responsibility now fall under the City of Phoenix. Thus, there is an implied initial investment in equipment, however this assessment takes place after the initial investment has been recouped, and represents repeatable annual contributions of emissions, GHGs, and costs. The initial cost is not included as part of the cost impact. Here the quantity and type of B20 biodiesel vehicles and equipment used to load and mulch all palm tree waste at the 27th Avenue transfer station was inventoried. The respective costs of annual fuel usage and resultant emissions and GHGs were calculated. In this process the quantity and type of B20 biodiesel vehicles used to load collected palm tree waste at the NG transfer station was inventoried separately. The respective costs of annual fuel usage, resultant emissions and GHGs were calculated.

Process three follows what would happen to palm tree waste only collected at the NG transfer station. As the mulching facility is located at the 27th Avenue transfer station, it is assumed that the City of Phoenix would ship all palm tree waste from NG to 27th Avenue for mulching using private hauling contracted at a rate of $10.26 per ton, and traveling potential annual mileages there and back of 7,617 for the lowest case 17,572 tons per fiscal year scenario, 15,622 miles for the medium case 35,144 tons per fiscal year scenario, and 30,537 miles for the high 70,288 tons per fiscal year scenario.

Finally, process four tracked the sale and distribution of palm tree mulch from the 27th Avenue transfer station. Sale price was estimated to be $17 per ton, as it is the current rate the City of Phoenix pays Gro-Well to process their green organics. Traveling potential mileages there and back were calculated as 7,226 miles for the lowest case 17,572 tons per fiscal year scenario, 14,799 miles for the medium case 35,144 tons per fiscal year scenario, and 28,917 miles for the high 70,288 tons per fiscal year scenario.

All values were then normalized per functional unit to obtain final costs and impacts reported as total costs per fiscal year attributed to palm fronds ($USD/FY for PF), costs per ton of palm fronds per FY ($USD/tonPF/FY), total emissions tons per fiscal year attributed to palm fronds (tons/FY for PF), emissions tons per ton of palm fronds per FY (tons/tonPF/FY), total GHG C02 equivalent tons per fiscal year attributed to palm fronds (C02 Eq tons/FY for PF), and GHG C02 equivalent tons per ton of palm fronds per FY (C02 Eq tons/tonPF/FY).

3.3 Alternative 2: Third Party Solution. The processes and technology related to alternative 2 were left undefined. Conceptually this alternative involves a third party palm tree waste solution, which intercepts and collects all palm tree waste from the City of Phoenix. An illustration of the system boundaries pertaining to this alternative can be seen in Figure 3. In approaching system boundaries from the perspective of the moment palm tree waste becomes the City of Phoenix's responsibility, it is apparent that in this alternative the third party lies outside of the system boundaries. Meaning, palm tree waste will never enter the transfer stations, nor becomes a City of Phoenix responsibility. As such, the need to inventory and track processes within this alternative were ignored. Instead, the emission, GHG, and cost impacts attributed to the City of Phoenix were reportable as the inverse of calculations from BAU. As an example, total private hauling of 3,963,390 annual miles in BAU becomes a savings of 3,963,390 annual miles traveled by the City of Phoenix in alternative 2.

4. Results

For BAU, raw transfer station data accessed from the City of Phoenix was the cost of waste operations, the types of vehicles operating, the quantity of vehicles operating, the hours of operation, as well as the frequency, capacity, and cost of contracting with private haulers. I coupled this data with EPA B20 biodiesel emissions data (6), MBI company semi-trailer properties, and Caterpillar (CAT) company reported properties to determine impacts from within the transfer station and from hauling to the SR85 landfill. The collected data can be seen in Figure 4.

Additionally, raw SR85 Landfill data was accessed from the City of Phoenix in the form of facilities costs, types of vehicles, quantity of vehicles, hours of operation, and coupled with EPA and industry data to determine city emissions, GHGs, and costs from vehicles (6). To determine emissions from landfill digestion, I utilized the EPA's WARM model (7), input annual City of Phoenix municipal solid waste tonnage and normalized it for palm tree waste. The collected data can be seen in Figure 4. After normalization of every piece of data, an aggregate of the impacts was created for BAU, and can be seen in Figure 5. The entire process of inventorying, normalizing and aggregating was repeated for alternative one of a City owned and operated palm tree waste mulch operation.

The individual results pertaining to the three potential palm tree waste tonnages allow for a breakdown and comparison between aggregate BAU and alternative one. All results are related to palm tree waste solely in the infrastructure that directly interacts with them. As such, emissions, GHGs and emissions are not compounded or offset by fleet services, collection, or residential municipal solid waste fees.

Carbon Monoxide. From the completed attributional life-cycle assessment, the disposal of palm tree waste via BAU results in the following CO emissions: **9.25** tons of CO/FY for PF, and **1.0x10^-3** tons of CO/tonPF/FY for the lowest case scenario, **18.95** tons of CO/FY for PF, and **1.0x10^-3** tons of CO/tonPF/FY for the medium case scenario, and **37.02** tons of CO/FY for PF, and **1.0x10^-3** tons of CO/tonPF/FY for the high case scenario. Comparatively, the disposal of palm tree waste via alternative one results in the following CO emissions: **6.23** tons of CO/FY for PF, and **7.3x10^-4** tons of CO/tonPF/FY for the lowest case scenario, **12.76** tons of CO/FY for PF, and **7.3x10^-4** tons of CO/tonPF/FY for the medium case scenario, and **24.94** tons of CO/FY for PF, and **7.3x10^-4** tons of CO/tonPF/FY for the high case scenario. A graphical display of the results with a breakdown by source can be seen in figures 6 and 7.

Nitrous Oxides. The disposal of palm tree waste via BAU results in the following NOx emissions: **2.82** tons of NOx/FY for PF, and **3.3x10^-4** tons of NOx/tonPF/FY for the lowest case scenario, **5.77** tons of NOx/FY for PF, and **3.3x10^-4** tons of NOx/tonPF/FY for the medium case scenario, and **11.27** tons of NOx/FY for PF, and **3.3x10^-4** tons of NOx/tonPF/FY for the high case scenario. Comparatively, the disposal of palm tree waste via alternative one results in the following NOx emissions: **2.01** tons of NOx/FY for PF, and **2.3x10^-4** tons of NOx/tonPF/FY for the lowest case scenario, **4.13** tons of NOx/FY for PF, and **2.3x10^-4** tons of NOx/tonPF/FY for the medium case scenario, and **8.06** tons of NOx/FY for PF, and **2.3x10^-4** tons of NOx/tonPF/FY for the high case scenario. A graphical display of the results with a breakdown by source can be seen in figures 8 and 9.

Hydro-Carbons. The disposal of palm tree waste via BAU results in the following HC emissions: **.74** tons of HC/FY for PF, and **8.8x10^-5** tons of HC/tonPF/FY for the lowest case scenario, **1.52** tons of HC/FY for PF, and **8.8x10^-5** tons of HC/tonPF/FY for the medium case scenario, and **2.98** tons of HC/FY for PF, and **8.8x10^-5** tons of HC/tonPF/FY for the high case scenario. Comparatively, the disposal of palm tree waste via alternative one results in the following HC emissions: **.58** tons of HC/FY for PF, and **6.6x10^-5** tons of HC/tonPF/FY for the lowest case scenario, **1.19** tons of HC/FY for PF, and **6.6x10^-5** tons of HC/tonPF/FY for the medium case scenario, and **2.33** tons of HC/FY for PF, and **6.6x10^-5** tons of HC/tonPF/FY for the high case scenario. A graphical display of the results with a breakdown by source can be seen in figures 10 and 11.

Particulate Matter. The disposal of palm tree waste via BAU results in the following PM emissions: **.06** tons of PM/FY for PF, and **7.1x10^-6** tons of PM/tonPF/FY for the lowest case scenario, **.12** tons of PM/FY for PF, and **7.1x10^-6** tons of PM/tonPF/FY for the medium case scenario, and **.24** tons of PM/FY for PF, and **7.1x10^-6** tons of PM/tonPF/FY for the high case scenario. Comparatively, the disposal of palm tree waste via alternative one results in the following PM emissions: **.04** tons of PM/FY for PF, and **5.1x10^-6** tons of PM/tonPF/FY for the lowest case scenario, **.09** tons of PM/FY for PF, and **5.1x10^-6** tons of PM/tonPF/FY for the medium case scenario, and **.18** tons of PM/FY for PF, and **5.1x10^-6** tons of PM/tonPF/FY for the high case scenario. A graphical display of the results with a breakdown by source can be seen in figures 12 and 13.

Greenhouse Gases C02 Equivalence. The disposal of palm tree waste via BAU results in the following GHG emissions: **5,405** tons of C02 Eq/FY for PF, and **.32** tons of C02 Eq/tonPF/FY for the lowest case scenario, **11,071**tons of C02 Eq/FY for PF, and **.32** tons of C02 Eq/tonPF/FY for the medium case scenario, and **21,633** tons of C02 Eq/FY for PF, and **.32** tons of C02 Eq/tonPF/FY for the high case scenario. Comparatively, the disposal of palm tree waste via alternative one results in the following GHG emissions: **56** tons of C02 Eq/FY for PF, and **7.2x10^-3** tons of C02 Eq/tonPF/FY for the lowest case scenario, **115** tons of C02 Eq/FY for PF, and **7.2x10^-3** tons of C02 Eq/tonPF/FY for the medium case scenario, and **225** tons of C02 Eq/FY for PF, and **7.2x10^-3** tons of C02 Eq/tonPF/FY for the high case scenario. A graphical display of the results with a breakdown by source can be seen in figures 14 and 15.

Costs. Finally**,** the disposal of palm tree waste via BAU results in the following costs: -**$374,512**/FY for PF, and **-$40.35**/tonPF/FY for the lowest case scenario, **-$767,235**/FY for PF, and **-$40.35**/tonPF/FY for the medium case scenario, and **-$1,498,903**/FY for PF, and **-$40.35**/tonPF/FY for the high case scenario. Comparatively, the disposal of palm tree waste via alternative one results in the following costs: -**$22,470**/FY for PF, and **-$17.26**/tonPF/FY for the lowest case scenario, **-$46,181**/FY for PF, and **-$17.26**/tonPF/FY for the medium case scenario, and **-$90,329**/FY for PF, and **-$17.26**/tonPF/FY for the high case scenario. A graphical display of the results with a breakdown by source can be seen in figures 16 and 17.

For each possible tonnage of palm tree waste, changes in impacts from business as usual to alternative one, would result in a 32% decrease in tons of CO, a 28% decrease in tons of NOx, a 21% decrease in tons of HC, a 25% decrease in tons of PM, a 99% decrease in tons of CO2 equivalent, and a costs savings of 94%, ranging from $352,000 to $1.4M, per City of Phoenix fiscal year.

Emissions savings are largely realized from a reduction in private hauling diesel miles traveled, which account for some 64% of BAU, and are halved to compose 32% of private hauling in alternative one per year. The tradeoff will be an increase of 20% emissions from B20 biodiesel vehicles per year to load and process palm tree waste in alternative one, but the overall net will still be less.

Greenhouse Gas savings are largely realized from a reduction in organics digested in the landfill, which account for some 97% of CO2 equivalent emissions in BAU, and are nullified to compose 0% of CO2 equivalent emissions in alternative one per year. Additionally, there will be an 80% reduction in private hauling CO2 equivalent emissions per year in alternative one. The tradeoff will be an increase of 46% CO2 equivalent emissions from B20 biodiesel vehicles per year to load and process palm tree waste in alternative one, but the overall net will still be less.

Costs savings are largely realized from a reduction in the operation of the SR85 landfill, which account for 18% of total costs in BAU, and are nullified to compose 0% of costs in alternative one per year. In addition to removing this cost, a revenue generation is added in alternative one, which composes 51% of total revenue. The tradeoff is an increased cost of 13% related to private hauling in alternative one, but the overall net will still be less.

6. Discussion

Analysis and comparison of this attributional life-cycle assessment emphasizes a policy focused on removing palm tree waste from the municipal solid waste stream. Of the three end of life solutions proposed, the business as usual process not only has the worst environmental impacts, but also costs the City of Phoenix the most money to operate. However, while alternative one of a City owned and operated mulching operation shows large reductions in emissions, GHGs, and costs, therefore making it a recommendable course of policy action, it must be understood that this option is dependent upon and only viable in a market where 17,000 to 70,000 tons of mulch could be sold and moved annually. Additionally, the benefits, longevity and usability of a palm based mulch are unknown, and so this policy recommendation becomes dominated by cautious investment into an already saturated and tested market.

The better policy recommendation would be alternative two, a third party solution. This option would further reduce emissions, GHGs, and costs to the City of Phoenix, and actually flip them into savings. Unfortunately, the major weakness of this alternative is that no such company or solution exists, and as such, it is unknown how long the City of Phoenix would have to maintain BAU operations. However, what the City of Phoenix could do is twofold: 1) invest in developing a third party solution, and 2) contract with them. The value in contracting with them is that if the City of Phoenix wanted to emphasize their sustainable interests, they could require that any contractor solution produce emissions and GHGs lower than those calculated for BAU.

Thus, the policy suggestions at this time would be to continue BAU, expand the study of palm tree waste, study palm tree mulch and the mulching market, and invest in startup solutions either monetarily or with knowledge.

While emissions and GHGs savings related to palm tree waste are unlikely to change for several years, a development in the area of cost was actually achieved. Per attributional life-cycle assessment's design, areas of improvement are brought to light. This life-cycle assessment, isolated from a waste operations perspective, inclusive and exclusive of palm fronds, that private hauling makes up a disproportionate amount of cost and emissions to the City of Phoenix. In the BAU model for all MSW, privately contracted hauling costs the City of Phoenix $8.8M annually, making it more expensive than operation of the NG transfer station or the SR85 landfill. As a percentage, it accounts for about 28% of costs and 64% of emissions. Therefore, from the City of Phoenix's perspective, there is a potential cost savings associated with switching from a private hauler to an in-house operation. After recoupment of the initial investments costs, and exclusion of driver salaries and maintenance, it is anticipated that such a maneuver could save the City of Phoenix's Public Works Department a minimum of $1M annually.

Works Cited

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Appendix

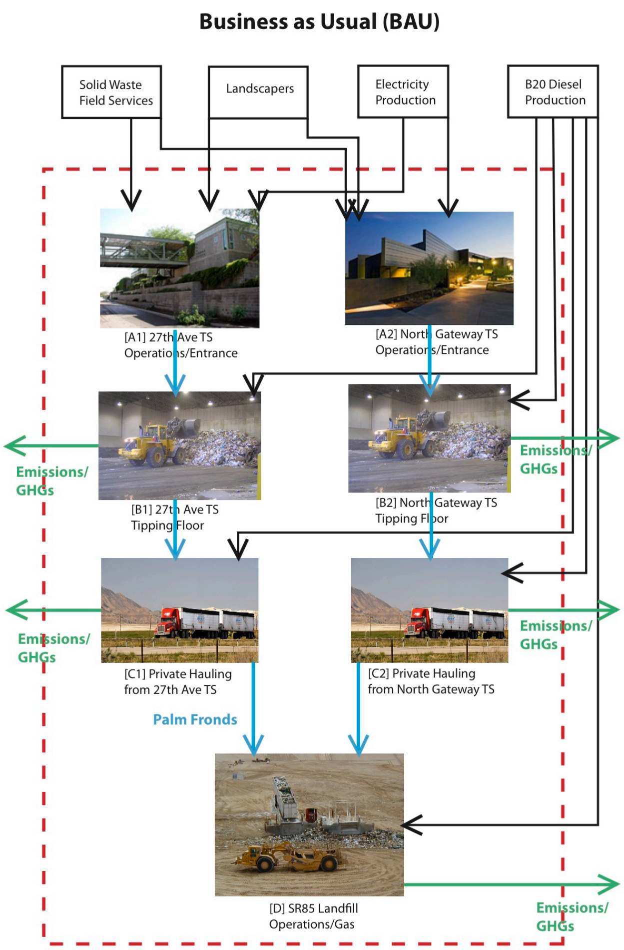


Figure 1

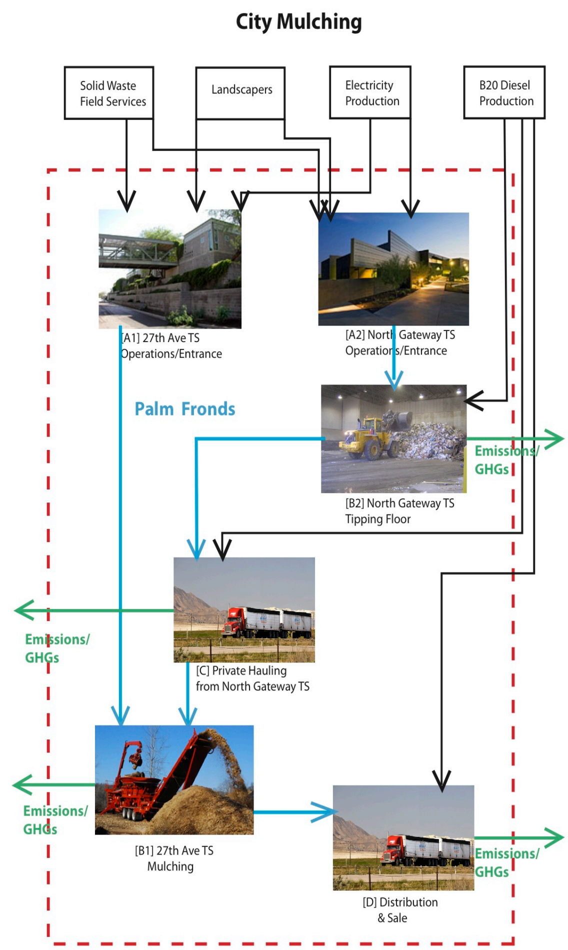


Figure 2

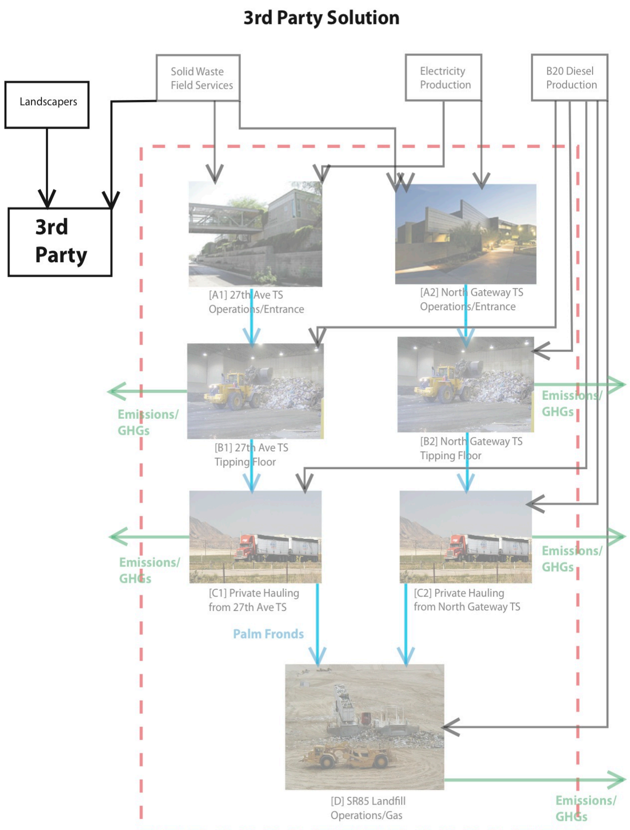

3rd Party Solution
Landscapers
Solid Waste Field Services
Electricity Production
B20 Diesel Production
3rd Party
[A1] 27th Ave TS Operations/Entrance
[A2] North Gateway TS Operations/Entrance
[B1] 27th Ave TS Tipping Floor
[B2] North Gateway TS Tipping Floor
Emissions/ GHGs
Emissions/ GHGs
[C1] Private Hauling from 27th Ave TS
[C2] Private Hauling from North Gateway TS
Emissions/ GHGs
Emissions/ GHGs
Palm Fronds
[D] SR85 Landfill Operations/Gas
Emissions/ GHGs

Figure 3

Data Collection: Figure 4

BUSINESS AS USUAL (BAU)						
Knowns and assumptions:						
Functional Unit: tons of palm fronds/fiscal year						
Fiscal Year:	*July-June*	312	*days @ TSs*	*5am-5pm*	*M-F*	*5:30am-3:30pm Sat*
		260	*days @ landfill*	*5am-5pm*	*M-F*	*No weekend*

[A1] 27th Ave TS Entrance/Operations (Solid Waste Only)						
Knowns and assumptions:						
Gate Rate (Residential/Self-haul)		*20*	*$USD*			
Gate Rate (Commercial)		*38.25*	*$USD*			
MSW		*536,998.11*	*Tons*			
Palm Fronds		*27,485*	*Tons*	0.7573	comes from landscaper	
	Data Collected	*Data Collected*	*Normalized per activity*	*Normalized per F.U.*		
Inflows:	**Tons/FY**	**USD$/FY**	**USD$/FY for PFs**	**USD$/Ton PF-FY**		
Electricity/Staff Labor	N/A	-10,031,949	**-$250,798.72**	**-$18.68**	*2.50%*	
			-$513,461.99	**-$18.68**	*5.12%*	
			-$1,003,194.89	**-$18.68**	*10%*	
Palm Fronds (2.5%)	13,424.95	N/A				
Palm Fronds (As Organic 5.12%)	27,485.00	N/A				
Palm Fronds (10%)	53,699.81	N/A				
Outflows:						
Palm Fronds (2.5%)	N/A	203,334.33	**203,334.33**	**15.15**	*2.50%*	
Palm Fronds (As Organic 5.12%)	N/A	416,287.81	**416,287.81**	**15.15**	*5.12%*	
Palm Fronds (10%)	N/A	813,337.34	**813,337.34**	**15.15**	*10%*	

[A2] NG TS Entrance/Operations (Solid Waste Only)						
Knowns and assumptions:						
Gate Rate (Residential/Self-haul)		*20*	*$USD*			
Gate Rate (Commercial)		*38.25*	*$USD*			
MSW		*324,713.91*	*Tons*			
Palm Fronds		*7,658*	*Tons*	0.7573	comes from landscaper	
	Data Collected	*Data Collected*	*Normalized per activity*	*Normalized per F.U.*		
Inflows:	**Tons/FY**	**USD$/FY**	**USD$/FY for PFs**	**USD$/TonPF-FY**		
Electricity/Staff Labor	N/A	-7,898,382.27	**-90,831.40**	**-24.32**	*1.15%*	
			-186,274.16	**-24.32**	*2.36%*	
			-364,115.42	**-24.32**	*4.61%*	
Palm Fronds (1.15%)	3,734.21	N/A				
Palm Fronds (As Organic 2.36%)	7,658.00	N/A				
Palm Fronds (4.61%)	14,969.31	N/A				
Outflows:						
Palm Fronds (1.15%)	N/A	56,558.34	**56,558.34**	**15.15**	*1.15%*	
Palm Fronds (As Organic 2.36%)	N/A	115,988.07	**115,988.07**	**15.15**	*2.36%*	
Palm Fronds (4.61%)	N/A	226,725.19	**226,725.19**	**15.15**	*4.61%*	

[B1] 27th Ave TS Tipping Floor

Knowns and assumptions:						
B20 CO2 Emissions	8.12 kg/gal	x conversion	pounds/gal			
	8.12	2.20462	17.9015			
Diesel CO	15.5	g/bhp-hr		B20 CO Emiss.	-0.11	
Diesel NOx	4.5	g/bhp-hr		B20 NOx Emiss.	0.02	
Diesel HC	1.3	g/bhp-hr		B20 HC Emiss.	-0.211	
Diesel PM	0.1	g/bhp-hr		B20 PM Emiss.	-0.101	
966H	262	hp				
966K	267	hp				
JS190	128	kw x	1.34102209	171.6508275	hp	
Emissions Equation	factor*hp*hrs*weeks*vehicles		:g			

Inflows:	B20 gal/FY	Fuel Cost (USD$/FY)	Operation (Hrs/Week)	Diesel kg/FY	B20 kg/FY	pounds/FY	Tons/FY
CAT 966H Loader B20	8,229.15	-29,815.54	70	N/A	N/A	N/A	N/A
CAT 966H Loader B20	3,773.60	-13,533.89	70	N/A	N/A	N/A	N/A
CAT 966K Loader B20	13,571.70	-48,788.22	70	N/A	N/A	N/A	N/A
CAT 966K Loader B20	13,514.00	-48,359.86	70	N/A	N/A	N/A	N/A
JCB JS190 Exc. B20	3,433.40	-12,294.04	70	N/A	N/A	N/A	N/A
JCB JS190 Exc. B20	4,289.30	-15,259.55	70	N/A	N/A	N/A	N/A
Outflows:							
GHGs							
CO2	N/A	N/A	N/A	N/A	380106.54	837990.4758	**418.995**
Emissions							
CO 966H	N/A	N/A	N/A	29564.08	26312.031	58008.03022	29.0040151
CO 966K	N/A	N/A	N/A	30128.28	26814.169	59115.0537	29.5575269
CO JS190	N/A	N/A	N/A	19369.07938	17238.481	38004.2992	19.0021496
						Total	**77.56369**
NOx 966H	N/A	N/A	N/A	8583.12	8754.7824	19300.96837	9.65048419
NOx 966K	N/A	N/A	N/A	8746.92	8571.9816	18897.96207	9.44898104
NOx JS190	N/A	N/A	N/A	5623.28111	5735.7467	12645.14196	6.32257098
						Total	**25.42204**
HC 966H	N/A	N/A	N/A	2479.568	1956.3792	4313.072606	2.1565363
HC 966K	N/A	N/A	N/A	2526.888	1993.7146	4395.383152	2.19769158
HC JS190	N/A	N/A	N/A	1624.503432	1281.7332	2825.734664	1.41286733
						Total	**5.767095**
PM 966H	N/A	N/A	N/A	190.736	171.47166	378.0298599	0.18901493
PM 966K	N/A	N/A	N/A	194.376	174.74402	385.2441702	0.19262209
PM JS190	N/A	N/A	N/A	124.9618024	112.34066	247.6684667	0.12383423
						Total	**0.505471**

[B1] NG TS Tipping Floor							
Knowns and assumptions:							
B20 CO2 Emissions	8.12 kg/gal	x conversion	pounds/gal				
	8.12	2.20462	17.9015				
Diesel CO	15.5	g/bhp-hr		B20 CO Emiss	-0.11		
Diesel NOx	4.5	g/bhp-hr		B20 NOx Emis	0.02		
Diesel HC	1.3	g/bhp-hr		B20 HC Emiss	-0.211		
Diesel PM	0.1	g/bhp-hr		B20 PM Emiss	-0.101		
966H	262	hp					
966K	267	hp					
JS190	128	kw x	1.34102209	171.650828	hp		
Emissions Equation	factor*hp*hrs*weeks*vehicl	:g					
Inflows:	**B20 gal/FY**	**Fuel Cost (USD$/FY)**	**Operation (Hrs/Week)**	**Diesel kg/FY**	**B20 kg/FY**	**pounds/FY**	**Tons/FY**
CAT 966H Loader B20	4976.03143	-18028.966	70	N/A	N/A	N/A	N/A
CAT 966H Loader B20	2281.83375	-8183.7203	70	N/A	N/A	N/A	N/A
CAT 966K Loader B20	8206.58339	-29501.433	70	N/A	N/A	N/A	N/A
CAT 966K Loader B20	8171.69316	-29242.411	70	N/A	N/A	N/A	N/A
JCB JS190 Exc. B20	2076.12041	-7434.0034	70	N/A	N/A	N/A	N/A
JCB JS190 Exc. B20	2593.66904	-9227.1985	70	N/A	N/A	N/A	N/A
Outflows:							
GHGs							
CO2	N/A	N/A	N/A	N/A	229844.161	506719.035	**253.3595**
EMISSIONS VALUES BELOW LIKELY NOT THE SAME BUT COPIED DUE TO NO DATA							
Emissions							
CO 966H	N/A	N/A	N/A	29564.08	26312.0312	58008.0302	29.0040151
CO 966K	N/A	N/A	N/A	30128.28	26814.1692	59115.0537	29.5575269
CO JS190	N/A	N/A	N/A	19369.0794	17238.4806	38004.2992	19.0021496
						Total	**77.56369**
NOx 966H	N/A	N/A	N/A	8583.12	8754.7824	19300.9684	9.65048419
NOx 966K	N/A	N/A	N/A	8746.92	8571.9816	18897.9621	9.44898104
NOx JS190	N/A	N/A	N/A	5623.28111	5735.74673	12645.142	6.32257098
						Total	**25.42204**
HC 966H	N/A	N/A	N/A	2479.568	1956.37915	4313.07261	2.1565363
HC 966K	N/A	N/A	N/A	2526.888	1993.71463	4395.38315	2.19769158
HC JS190	N/A	N/A	N/A	1624.50343	1281.73321	2825.73466	1.41286733
						Total	**5.767095**
PM 966H	N/A	N/A	N/A	190.736	171.471664	378.02986	0.18901493
PM 966K	N/A	N/A	N/A	194.376	174.744024	385.24417	0.19262209
PM JS190	N/A	N/A	N/A	124.961802	112.34066	247.668467	0.12383423
						Total	**0.505471**

[C1] 27th Ave TS to SR85 Private Hauling							
Knowns and assumptions:							
Dist. 27th Ave - SR85	51.2	miles 1 way	102.4	miles 1 rnd trip	2	hr rnd trip	
Dist. NGTS - SR85	67.9	miles 1 way	135.8	miles 1 rnd trip	2	hr rnd trip	
City Cost	Capacity (tons)	Capacity (gal Fuel)	Trips/Day	City Cost (USD$/Ton)	MPG		
MBI Semi-Trailers	25	100	4	-10.26	6.5		
Diesel CO2	22.2	pounds/gal					
Semi-trialer hp	250						
Inflows:	**# of trips/FY**	**Miles traveled/FY**	**Diesel gal/FY**	**COP cost/FY**	**kg/FY**	**pounds/FY**	**Tons/FY**
MBI Semi-Trailers	21479.9244	2199544.259	338391.424	-5509600.609	N/A	N/A	536,998.11
Outflows:							
GHGs							
CO2						7512289.622	**3756.145**
Emissions							
CO					166469.41	367001.7997	**183.5009**
NOx					48329.83	106548.9096	**53.27445**
HC					13961.951	30780.7961	**15.3904**
PM					1073.9962	2367.753547	**1.183877**

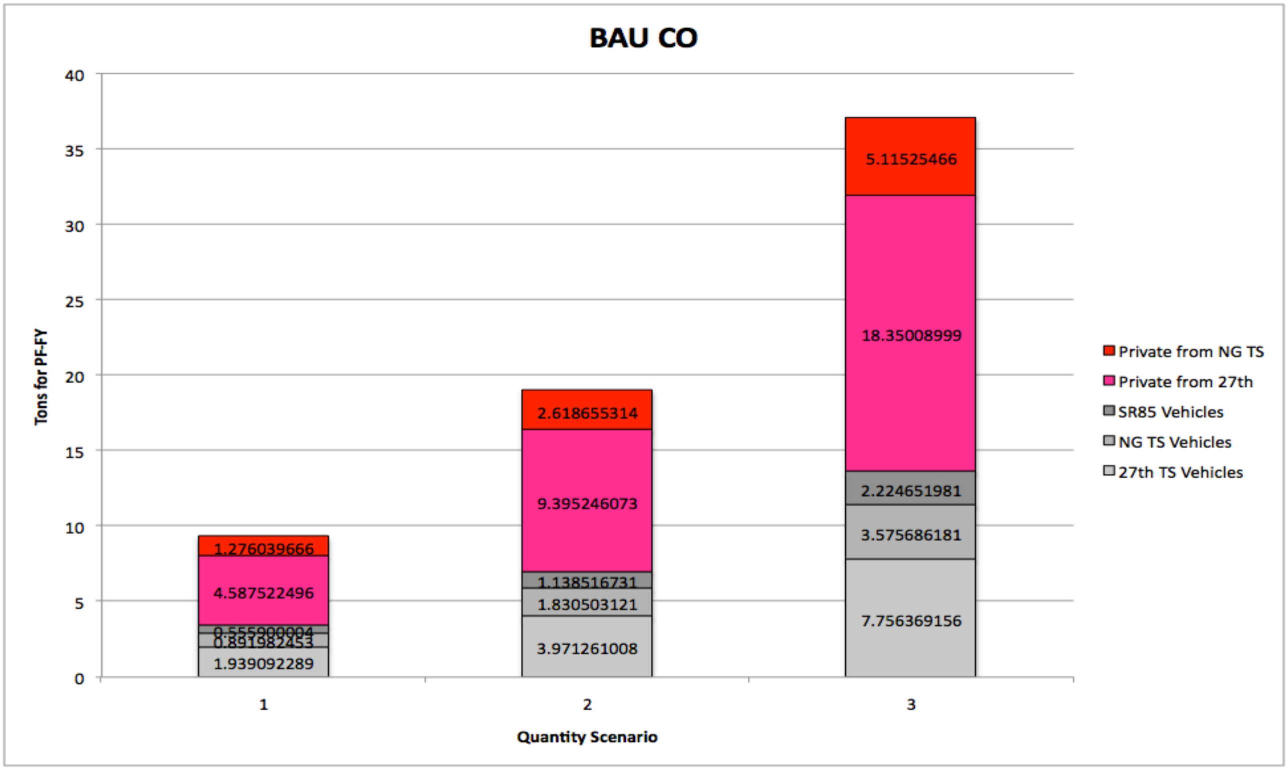
[C2] NG TS to SR85 Private Hauling							
Knowns and assumptions:							
Dist. 27th Ave - SR85	51.2	miles 1 way	102.4	miles 1 rnd tri	2	hr rnd trip	
Dist. NGTS - SR85	67.9	miles 1 way	135.8	miles 1 rnd tri	2	hr rnd trip	
City Cost	Capacity (tons)	Capacity (gal Fuel)	Trips/Day	City Cost (USD$/Ton)	MPG		
MBI Semi-Trailers	25	100	4	-10.26	6.5		
Diesel CO2	22.2	pounds/gal					
Semi-trialer hp	250						
Inflows:	**# of trips/FY**	**Miles traveled/FY**	**Diesel gal/FY**	**COP cost/FY**	**kg/FY**	**pounds/FY**	**Tons/FY**
MBI Semi-Trailers	12988.5564	1763845.96	271360.917	-3331564.7	N/A	N/A	**324,713.91**
		3963390.22					
Outflows:							
GHGs							
CO2						6024212.35	**3012.106**
Emissions							
CO					100661.312	221919.942	**110.96**
NOx					29224.2519	64428.3702	**32.21419**
HC					8442.56166	18612.6403	**9.30632**
PM					649.42782	1431.74156	**0.715871**

[D] SR85 Operations						
Knowns and assumptions:						
B20 CO2 Emissions	8.12 kg/gal	x conversion	pounds/gal			
	8.12	2.20462	17.9015			
Diesel CO	15.5	g/bhp-hr		B20 CO Emiss.	-0.11	
Diesel NOx	4.5	g/bhp-hr		B20 NOx Emiss.	0.02	
Diesel HC	1.3	g/bhp-hr		B20 HC Emiss.	-0.211	
Diesel PM	0.1	g/bhp-hr		B20 PM Emiss.	-0.101	
966H	262	hp				
966K	267	hp				
JS190	128	kw x	1.34102209	171.6508275	hp	
Emissions Equation	factor*hp*hrs*weeks*vehicles		:g			
Landfill Emissions	0.306572	tons of co2	per ton of MSW			

Inflows:	**Tons/FY**	**USD$/FY**	**B20 gal/FY**	**Fuel Cost (USD$/FY)**	**Operation (Hrs/week)**	**Diesel kg/FY**	**B20 kg/FY**
Electricity/Staff/Labor	N/A	-5,732,022.30	N/A	N/A	N/A	N/A	N/A
MSW	893,766.37	N/A	N/A	N/A	N/A	N/A	N/A
Palm Fronds (Low)	17159.16	N/A	N/A	N/A	N/A	N/A	N/A
Palm Fronds (As Org)	35143.00	N/A	N/A	N/A	N/A	N/A	N/A
Palm Fronds (High)	68669.12	N/A	N/A	N/A	N/A	N/A	N/A
CAT 966K Loader B20	N/A	N/A	11632.8857	-41,818.47	60	N/A	N/A
JCB JS190 Exc. B20	N/A	N/A	3676.54286	-13,079.61	60	N/A	N/A
JCB JS190 Exc. B20	N/A	N/A	3676.54286	-13,079.61	60	N/A	N/A
Outflows:							
GHGs Vehicles							
CO2	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GHGs Landfill (CO2 Eq.)		N/A	N/A	N/A	N/A	N/A	N/A
Emissions							
CO 966K						12912.12	11491.7868
CO JS190						16602.06804	14775.8406
NOx 966K						3748.68	3823.6536
NOx JS190						4819.955237	4916.35434
HC 966K						1082.952	854.449128
HC JS190						1392.431513	1098.62846
PM 966K						83.304	74.890296
PM JS190						107.1101164	96.2919946

	USD$/FY for PFs	**USD$/TonPF-FY**			**Tons for PF-FY (CO2 Eq.)**	**Tons/Ton-PF-FY (CO2 Eq.)**
Total	**-374,512.86**	**-40.35**		**Total**	**5405.713**	**0.32459354**
	-767,235.83	**-40.36**			**11071.37**	**0.32460306**
	-1,498,903.50	**-40.35**			**21633.14**	**0.32459354**
	Not offset by SWS fee				GHGs	

Figure 5



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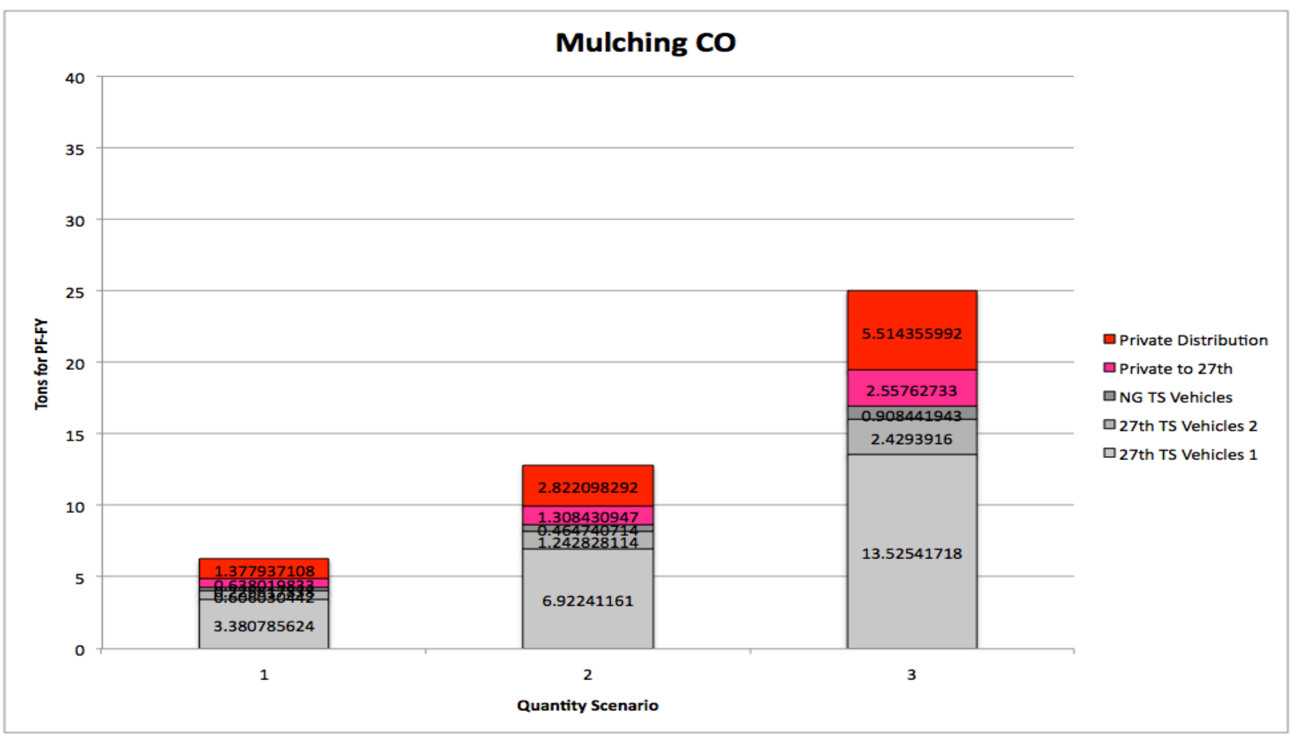

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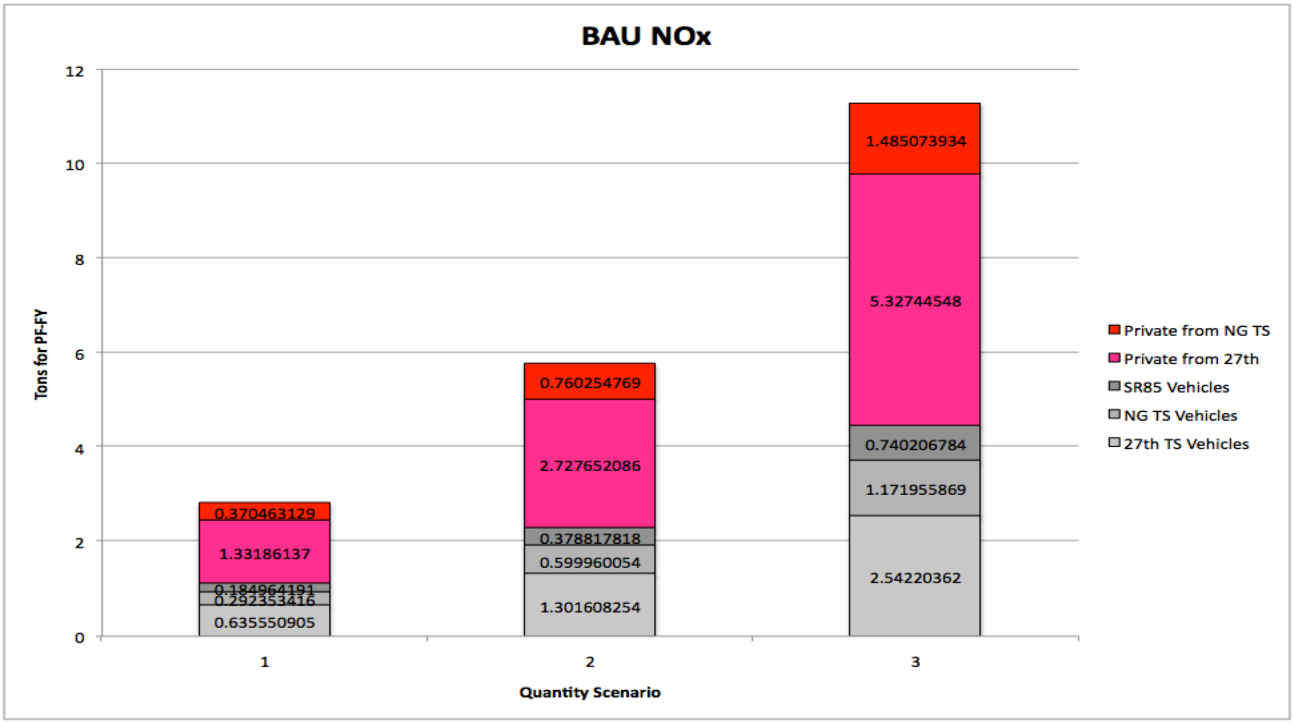

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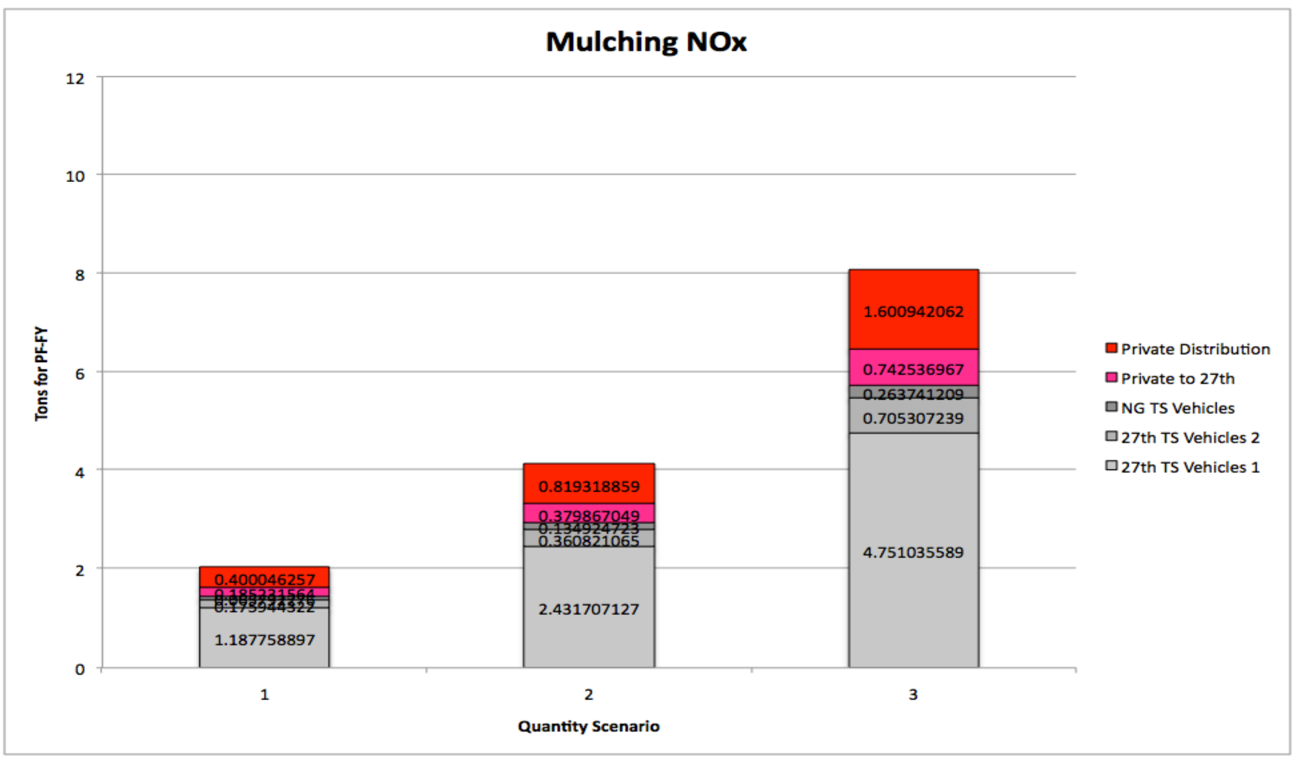

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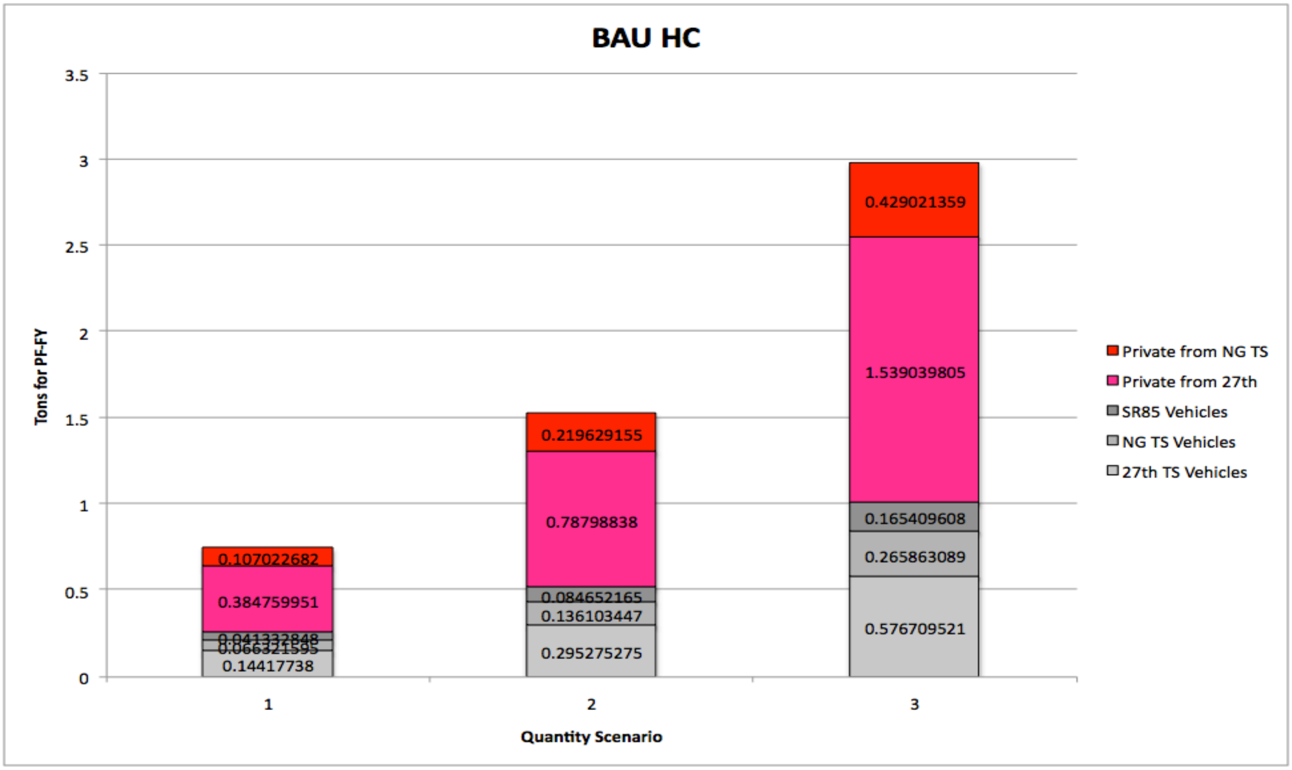

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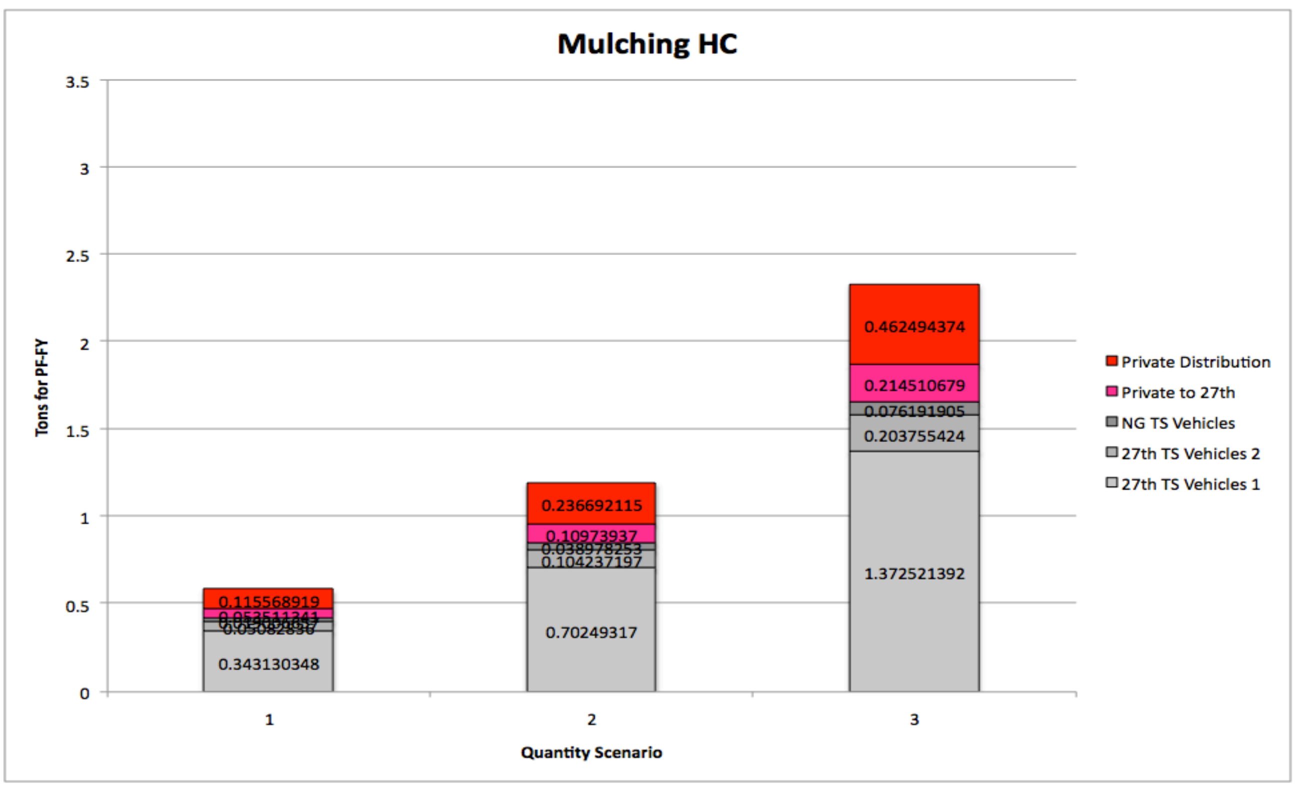

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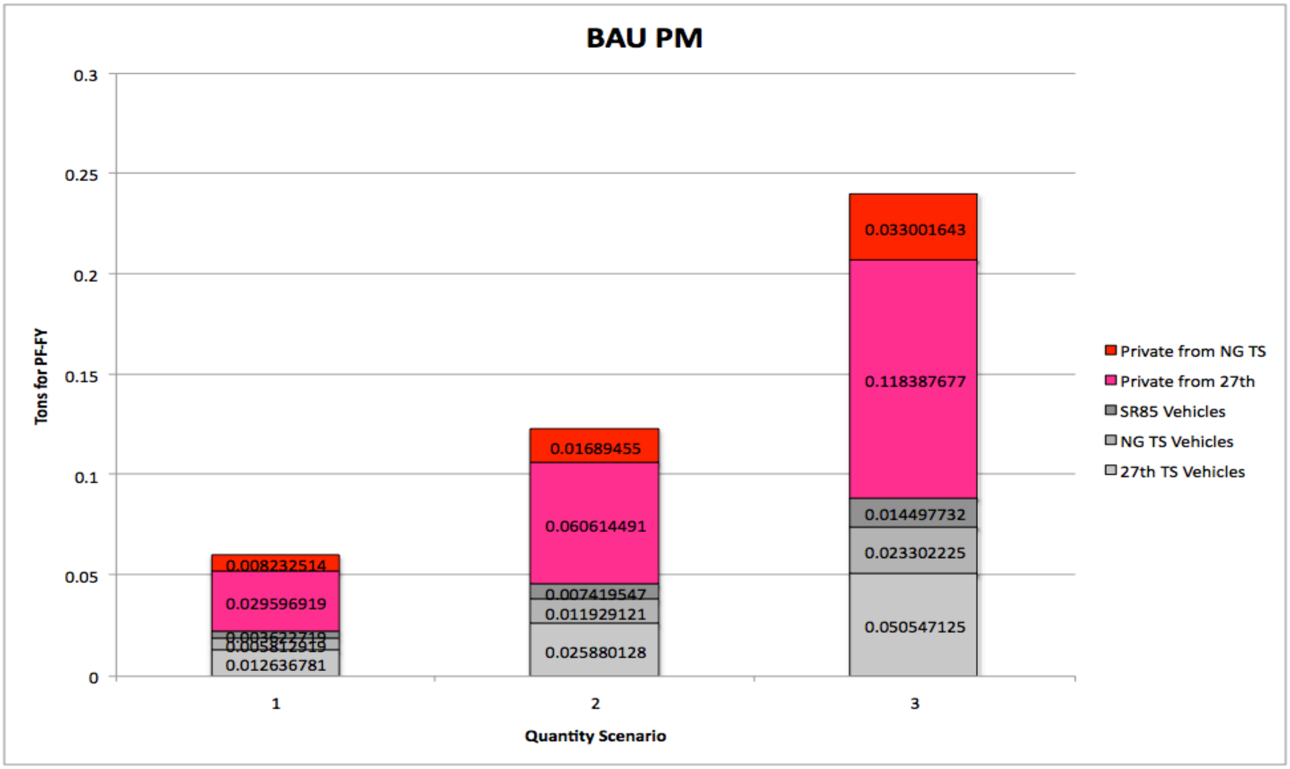

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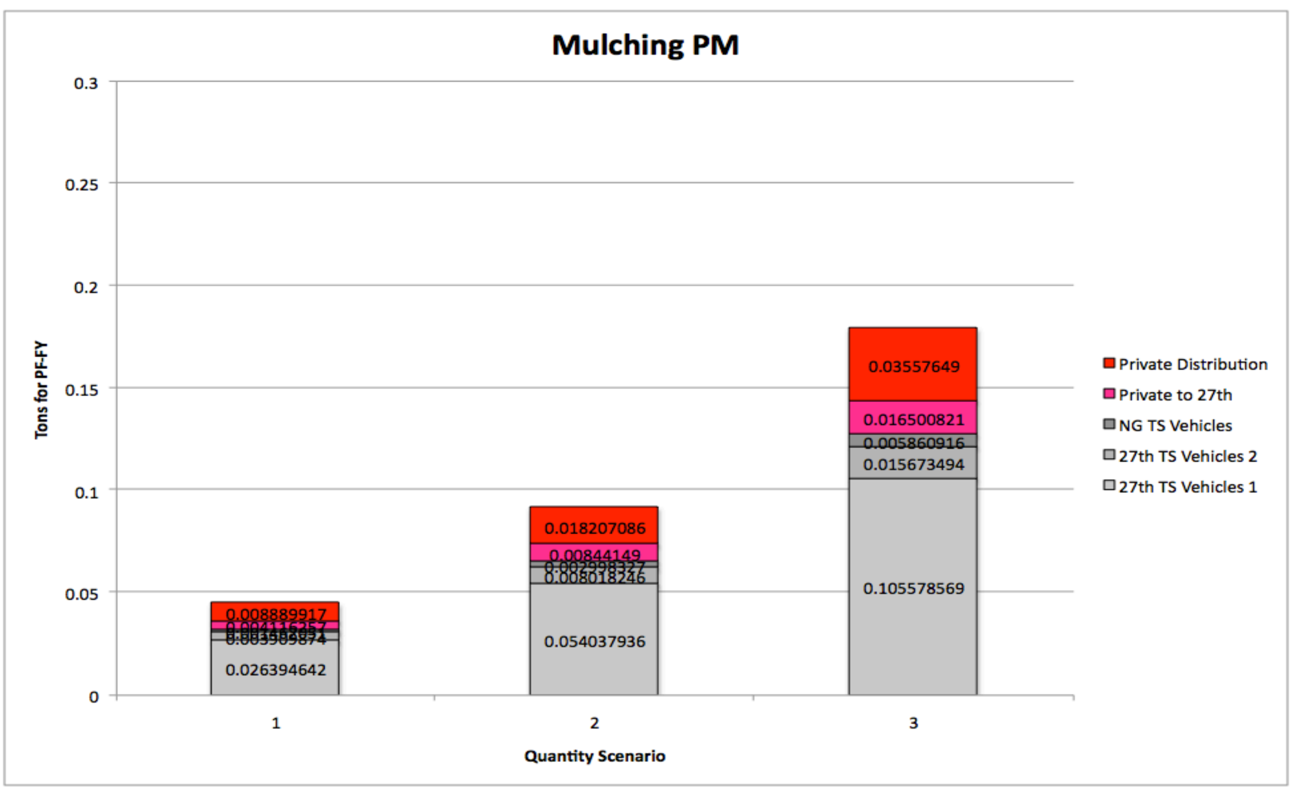

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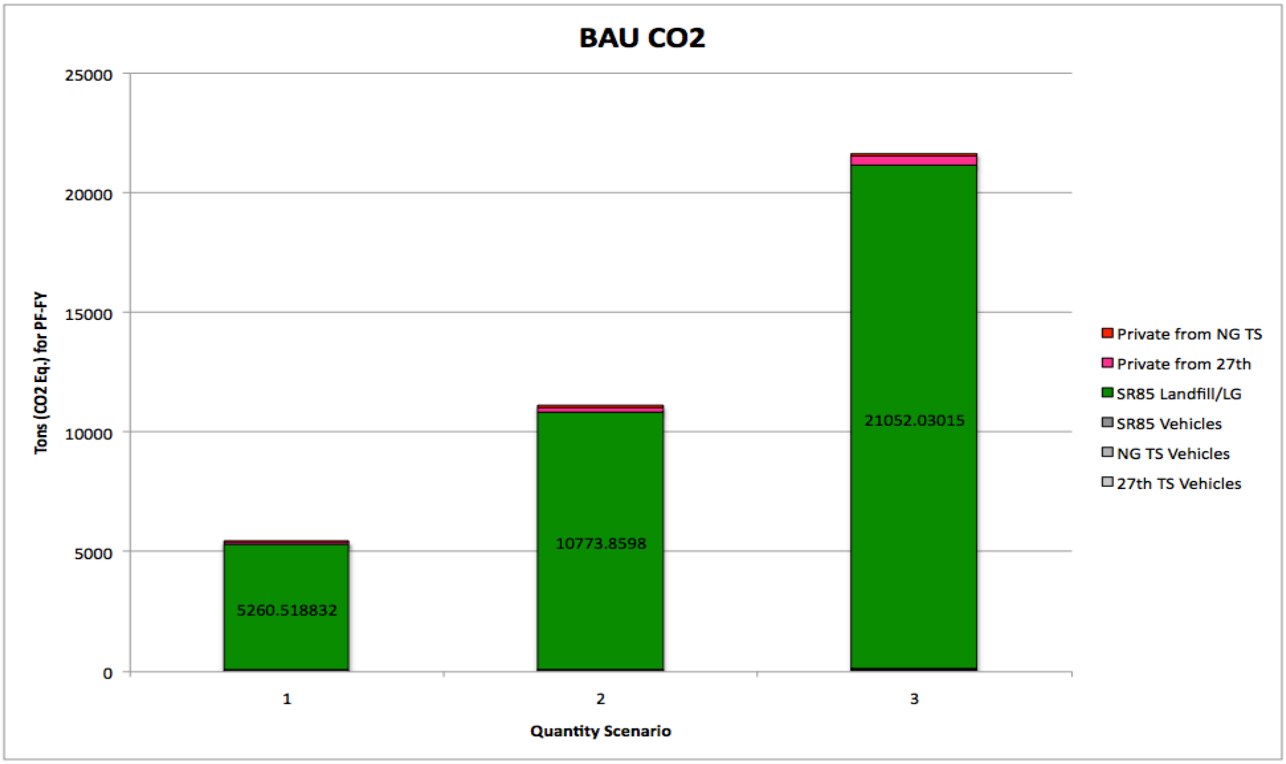

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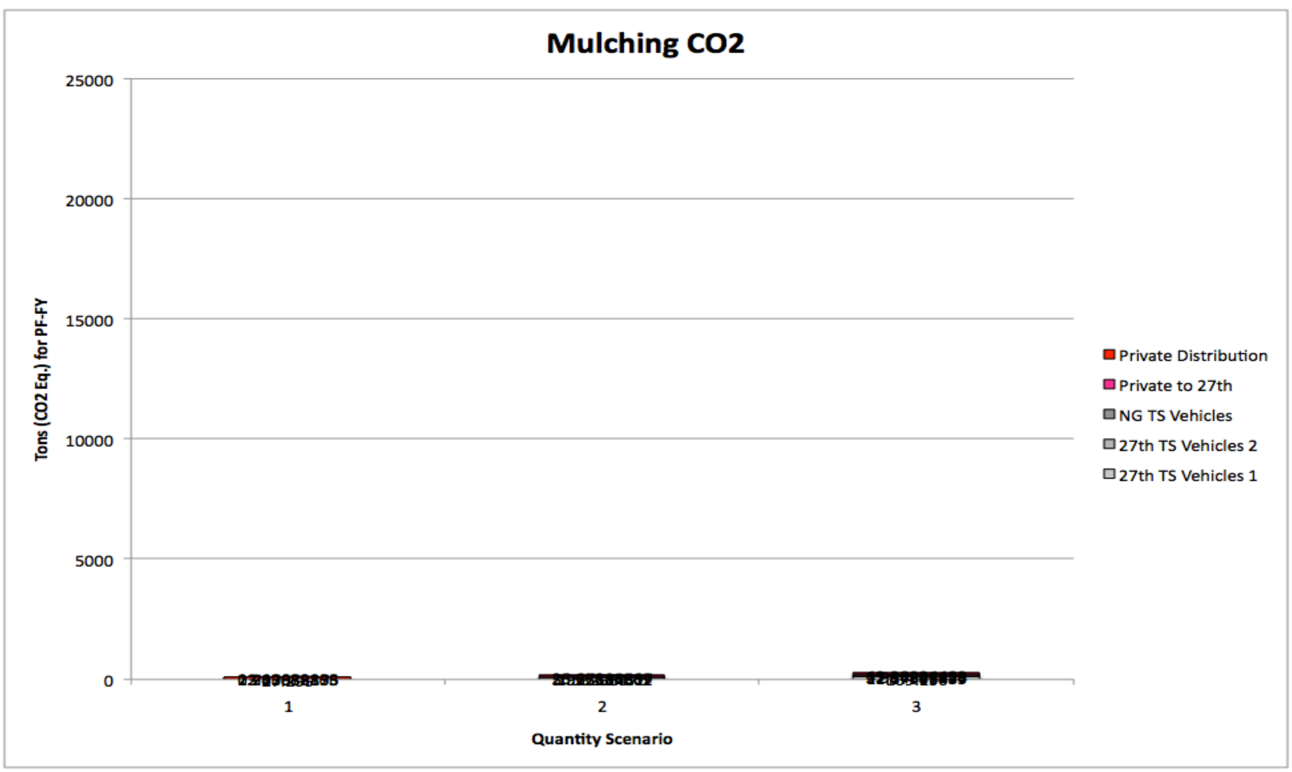

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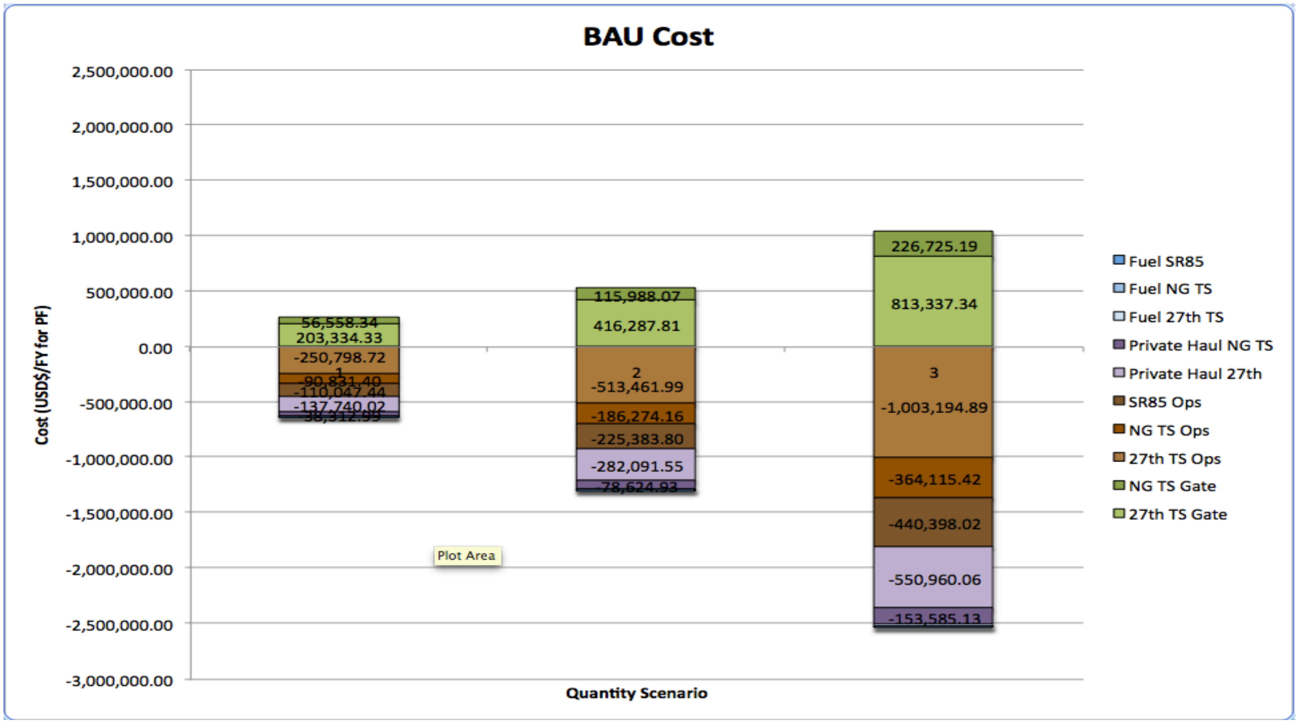

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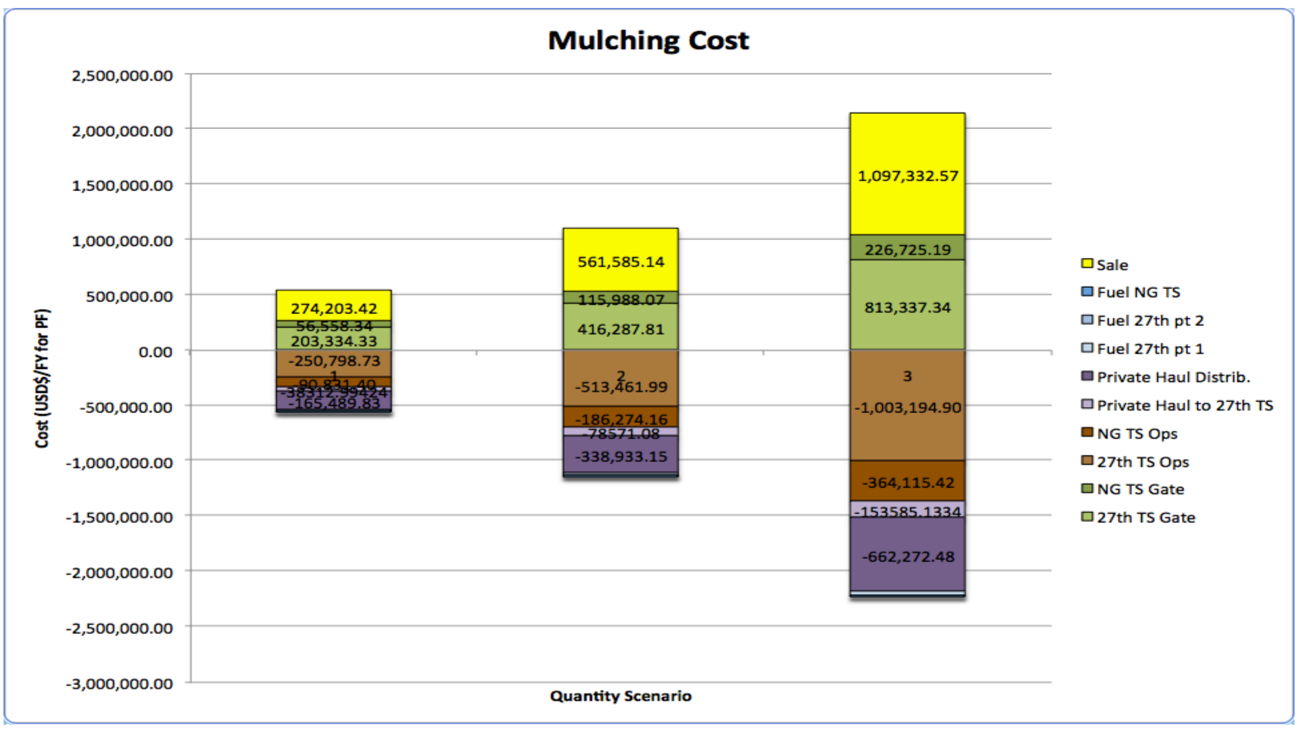

Figure 17