Toward Net Zero:
Strategic Integration of Electric Mowers into Landscape Maintenance Operations

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Executive Summary

The effects of climate change are driving humanity to further consider their global carbon footprints, which have a considerable impact on the progression of climate change and atmospheric warming.

Drivers of climate change must be mitigated and actively reduced to ensure a habitable planet and environment for current and future generations. Maryland is no exception in the list of states that will be affected by excessive carbon emissions. At the current rate of carbon emissions, the Intergovernmental Panel on Climate Change predicts a rise in global sea levels of 52cm to 98cm by the year 2100, which will threaten the survival of coastal development in Maryland and around the world.

It stands to reason that state mitigation efforts would focus on the higher and easily targetable sources of carbon emissions from mobile origins such as vehicle fleets and mobile equipment used in municipal operations.

Within this framework, the Division of Maintenance and Development in the Prince George's County Department of Parks and Recreation, as part of its efforts to achieve net zero emissions, is beginning to transition its fossil fuel-based equipment to a nearly all electric fleet. Currently, the main challenge in moving forward is identifying the electric equipment that can best reach the carbon reduction goal by 2040.

This project's main objectives are to:

- supply electric mower options that can replace fossil fuel mowers in current use
- realize the carbon savings from an electrical alternative
- run a breakeven points analysis of mower options
- provide a decision-making framework to guide electric mower purchases over a 5-year transition period.

This report used a number of methods, including calculating pounds of carbon dioxide produced/hour, fuel cost/hour of operation, and total anticipated cost/hour of operation. These calculations were combined with a qualitative analysis reflecting the client's needs.

In examining four categories of mowers, we found some possessed better run times, cost results, or less emissions per hour. Based on these combined factors, we recommend four mowers to best meet the Division's needs:

- Mean Green WBX-33HD for large self-propelled mowers
- Husqvarna W520i for small self-propelled mowers
- Mean Green Evo-74 for zero turn mowers
- Toro Greensmaster® eTriFlex™ - 59" model 3370 for gang reel mowers.

Introduction

Carbon dioxide (CO_2) emissions along with methane (CH_4) and nitrous oxide (N_2O) emissions are major drivers of climate change. These greenhouse gases trap heat and increase the planet's temperature. Engine-based fossil fuel combustion is a significant source of CO_2 and N_2O, as well as generating carbon monoxide, volatile organic compounds, sulfur dioxide, airborne particulate matter, and other oxides of nitrogen.

Air pollution, specifically particulate matter emissions, arising from imperfect engine combustion of fossil fuels is a public health concern; adverse respiratory health effects are associated with sustained exposures to these pollutants (Ristovski et al., 2012). Accordingly, fossil fuel-based engine exhaust affects not only the planet but also people and communities in proximity to the emissions.

Currently, the lawn equipment market offers many gasoline-powered equipment options with gasoline lawn mowers representing 76% of the lawn mower market share in 2016. Electric (corded) and battery-powered (cordless) mowers are, respectively, 16% and 8% of the market (Saidani, M., & Kim, H., 2021). Previous research, including that of another capstone team working with the Division, revealed that in 2019, 23.2 metric tonnes of carbon dioxide emissions came from the Division's inventory of mowers (Grove et al. 2020).

Despite the dominant market share of fossil fuel-based mowers, interest in electric powered equipment has increased along with concerns about climate change and worker safety. In addition to the effects of fossil fuel engines on carbon emissions and air quality, the noise produced by these engines can negatively affect wildlife communities.

Other drawbacks of fossil fuel powered equipment include hearing loss and reduced limb motor neural control. Shaky hands and the sensorineural stages of the hand-arm vibration syndrome are major concerns among individuals who regularly use gas powered equipment, especially in commercial settings. Hand-held, fossil fuel-based equipment has been found to cause intermittent numbness, tingling, and reduced hand manipulative dexterity due to the intensive vibrations transmitted to the hands (Brammer et al. 1987). Hearing damage from noise are usually generated when noise levels exceed permanently 85 dB (Tint et al., 2012). Most lawn maintenance workers spend from 8 to 10 hours a day exposed to A-weighted sound levels greater than 85 dB. A-weighted sound levels at the operator's ear ranged from 82 to 102 dB (Lepley et al., 1994). Without appropriate ear protection, individuals risk hearing damage.

Replacing fossil fuel equipment with an electric alternative reduces, but does not eliminate, the carbon emissions associated with the equipment operation. The electricity required to charge the battery involves a carbon cost that should be considered in any comparison of fossil fuel and electric equipment carbon footprint. A detailed accounting of the carbon cost, and a comparison of both types of equipment, would involve determining the carbon cost of producing materials to make the mower, the emissions involved in manufacturing the mower, the cost to operate and maintain the mower, and the carbon costs to dispose of the mower. For a fossil fuel mower, carbon emissions are the greatest in the operation and maintenance phase, whereas an electric mower, is highest in its manufacturing and use of batteries (Saidani, M., & Kim, H., 2021).

The carbon footprint of electricity depends on the source(s) used to generate it. Maryland gets its electricity from a mixture of sources including coal, natural gas, nuclear energy, and petroleum. Renewable energy such as solar, wind, biomass, and hydropower make up 11% of the state's energy production and provide approximately 49% of energy production that would be considered carbon neutral (*Maryland at a Glance*). In Maryland, electricity generated and delivered to point of use produced 0.841 lb. CO_2 eq/kWh in 2018 (Environmental Protection Agency, 2021). This value considers the production of CO_2, CH_4, and N_2O in the generation, transmission, and delivery of electricity with 99% of contribution coming from the production of CO_2.

Net zero emissions, or carbon neutrality, is when "all GHG emissions released by humans are counterbalanced by removing GHGs from the atmosphere" (Levin et al., 2019). The County's Department of Parks and Recreation has a goal to be carbon neutral, net zero emissions, by 2040 (*Our Sustainability Efforts,* M-NCPPC). Lawn equipment powered by gasoline, diesel, and propane are a significant source of GHG emissions. Accordingly, switching to electric equipment will make it easier for the Department to reach its net zero emissions goal.

The Division of Maintenance and Development is currently making the transition to electric lawn equipment and has one fully electric crew already. To facilitate this transition, the Division is seeking information on possible electric alternatives that can be used in place of the existing fossil fuel mowers in their inventory. More specifically, the Division is seeking information on the carbon savings and financial implications that would be realized when converting to an all-electric mower fleet.

Comparison of equipment purchases from a financial perspective often focuses on determining the point in time at which the purchase cost and expenses needed to operate the equipment are the same for the two considered pieces of equipment—the "break-even point." Combining break-even with the practice characteristics of a potential purchase is a sound basis on which to make equipment purchases.

Goals and Objectives

To assess the financial implications and the likely carbon emission decreases from a transition to an electric mower fleet, the following objectives were established:

- provide electric mowers options that can replace the types of fossil fuel mowers currently used by Division of Maintenance and Development
- determine the carbon savings that would be realized in replacing a fossil fuel mower with an electrical alternative
- conduct a breakeven point analysis of mower options
- provide a decision-making framework to guide electric mower purchases over a 5-year transition period.

Methodology and Research Approach

The Division's mower inventory was identified from a 2020 report (Grove et al., 2020) and for each mower, included the model number, fuel use rate, annual hours of operation, and the per hour fuel usage rate. The Division's fossil fuel-based mowers purchased over the previous five years fell into three categories: large front-mount, self-propelled rotary mowers; zero turn mowers; and a fairway reel mower. The latter is a single item mower in the inventory but has an important role in maintaining low cut sports fields playing surfaces. A fourth category, small deck (<30") self-propelled rotary mower, was added based on a discussion with the Division's mowing crew. Selections in each category were based on the availability of information and on the Division's previous experience with a manufacturer's products, such as Mean Green.

The carbon emissions of the fossil fuel mowers were determined based on their fuel usage rate and a CO_2 combustion coefficient for the fuel type. For diesel fuel, we used a combustion efficiency of 22.46 pounds CO_2 per gallon (*Environment*, Energy Information Administration). For gasoline fuel, we noted that most regular grades contain 10% ethanol, and used a combustion coefficient of 17.6 pounds CO_2 per gallon.

The fuel usage rate for each fossil fuel mower was obtained from previous project work with the county that stated all technical specs for CO_2 production. Current retail gas station prices in Prince George's County (diesel: $3.61, gasoline: $3.37) were used to calculate the mower's hourly operational fuel cost.

For the comparison of fossil fuel and electric mowers, we assumed that the energy needed to charge the electric mower batteries was obtained from the regional grid. In 2018, electricity generated and delivered to point of use in Maryland produced 0.841lb. CO_2 eq/kWh (Environmental Protection Agency, 2020). Energy use per hour of operation for electric mowers was determined by using the manufacturer's run time and battery specifications. We also assumed that 70% of the battery charge capacity was drained during the mower's stated run time based on the representative working range for a lithium battery (Lithium Battery Failures). The battery's charging efficiency and charger were assumed at 85%, representing the midpoint of the likely range provided by a member of Toro's research and development team.

For the two electric reel mowers, the run time estimate was obtained from the literature (*Review of Electric Golf Course Machinery*) and video (Eclipse 360 ELiTE Introduction, 2021) that gave the number of the greens mowers could cover before recharging. The number of greens was divided at a mowing rate of 18 greens per 4 hours (Zakany, 2019). The calculated run times for two electric reel mowers are conservative estimates (*Review of Electric Golf Course Machinery*) with the number of greens that could be mowed ranging from 20 to 56 average sized greens. The price per kWh for electricity was $0.1261

The cost per hour of operation of each mower was determined by assuming that each had a usable life of 10 years, and that their maintenance costs was not a significant contributor to the overall operation cost during its 10 service years. The operation cost was calculated as:

$$\frac{operational\ cost}{hr} = \frac{purchase\ price\ (\$)}{10\ yr * hr\ operation/yr} + (\frac{gal\ fuel}{hr} * \frac{\$}{gal\ fuel})$$

or in the case of the electric mowers as:

$$\frac{operational\ cost}{hr} = \frac{purchase\ price\ (\$)}{10\ yr * hr\ operation/yr} + (\frac{kWh}{hr} * \frac{\$}{kWh})$$

The break-even point for to compare fossil fuel and electric equipment was calculated as:

$$fossil\ fuel\ equipment\ price + fossil\ fuel\ cost\ per\ hour * hours = electric\ equipment\ price + electricity\ cost\ per\ hour * hours$$

where hours represents hours of mower operation.

There are several assumptions inherent in this equation. It assumes that the equipment was bought at the current price. The purchase price of the mowers was found on company websites or quotes from sellers. When the Division decides to buy the equipment, the price may have changed.

It also assumes that prices for electricity and fossil fuels will stay the same. The fossil fuel cost per hour of operation and electricity cost per hour of operation are from the tables for each equipment in the Results section. New policies and changes in energy sources may change prices. There are other costs that could impact the comparison, such as maintenance, outfitting the trailer that powers the electric mowers, and more.

To create the decision matrix, numerical values were assigned to evaluation metrics on the basis of metric's perceived importance in purchasing an electric mower. These values, ranging from 1 to 5, weight the overall score of a purchase decision. The electric mowers are listed in columns and the rows specify considerations such as carbon emissions per hour of operation and cost per hour of operation. The final column shows the mower's weighted score. Higher values indicate a higher rank.

Results

Large Self-Propelled Mowers

The Toro 30288 Commercial Walk Behind Mower was selected as the representative fossil fuel mower in this category. It operates with a floating deck, a 48" cutting width, and a 15HP engine (Toro, Proline). It has a run time of 2.89 hours while producing 30.48 pounds of CO_2 emissions per hour of operation and a total anticipated cost of $48.77 per hour of operation.

An adequate electric alternative derived from current research is the Mean Green WBX-33HD. It has a 33" cutting width and a lithium-ion battery with a 15HP equivalency. It has a run time of 7 hours off a full charge (Mean Green Mowers). The mower has been found to produce .712 pounds of CO_2 per hour and the total anticipated cost is $95.56 per hour of operation.

Although it has a smaller cutting width, the WBX's horsepower rivals the Toro 30288's at an equal value of 15HP. The WBX is also a reasonable replacement given its significantly longer run time of 7 hours compared to 2.89 hours. The WBX also produces less carbon emissions per hour of operation. However, the WBX has a higher cost per hour of operation of $95.56 compared to $48.77 for the Toro 30288.

Table 1.

Price, hourly carbon emission, and cost of operation for ;arge, front deck, self-propelled mowers

Large Self-Propelled Mowers		
Type	**Current Fossil Fuel**	**Electric Option #1**
Manufacturer and model	Toro 30288	Mean Green WBX-33HD
Price	$4,721	Approx. $10,500
Engine/battery	15 HP* Kawasaki® FS (fuel capacity: 5 gallons)	Lithium-Ion battery (7.2 kWh)
Power source/watts	gasoline	7.2 kWh
Cutting width	48"	33"
Projected run time	2.89 hours	7 hours

Power consumption per hour	1.732 gallons	0.847 kw
CO_2 eq production per hour of operation	30.48 lbs	0.712 lb
Fuel cost per hour of operation	$ 5.85	$ 0.106
Yearly hours of operation	11 hours	11 hours
Total anticipated cost per hour of operation	$48.77	$95.56

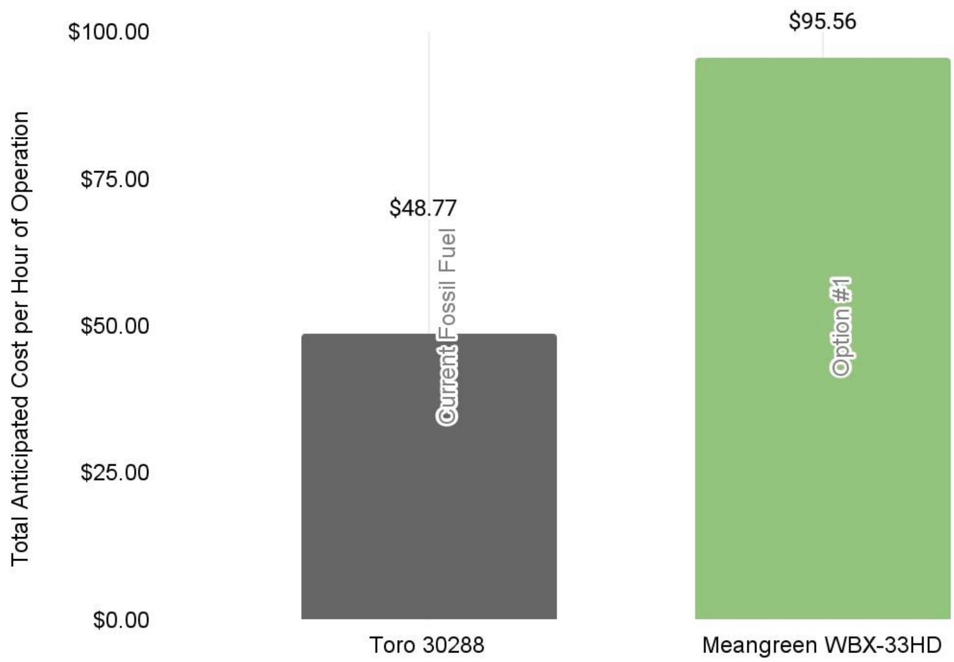

Figure 1. Total anticipated cost per hour of operation of large self-propelled mowers

Small, Self-Propelled Mowers

The Toro Timemaster Series 21199 is the current small, self-propelled fossil fuel mower. It has a steel deck of 30", is approximately 144 pounds, and its average run time is up to one hour. (Toro). Its CO_2 production per hour of operation is 5.28 lbs. and its cost per hour of operation is $11.01.

Two fully electric, small, self-propelled mowers have been identified for this comparison. The Husqvarna W520i and the Snapper 82V Max. The Husqvarna's 40-volt batteries are interchangeable; it can run on either a BLi100 with 2.6 amp hours, BLi22 with 4 amp hours, or a BLi30 with 7.7 amp hours. (Husqvarna: Battery, 2021). Its deck is aluminum, with a width of 20 inches (Husqvarna, 2021). By comparison, the Snapper 82V Max has a more durable steel deck of 21" and uses a lithium-ion 2.0 battery that can run for up to 90 minutes with two fully charged batteries (Briggs & Stratton, 2021).

The Snapper produces less CO_2 per hour and costs less to operate than the Husqvarna. However, it also requires swapping out the batteries every 45 minutes. The Husqvarna has a longer run time of 2.5 hours, exceeding the Snapper by an hour.

Table 2.

Price, hourly carbon emission, and cost of operation for small, front deck, self-propelled mowers

Small Self-Propelled Mowers			
Type	Current Fossil Fuel	Electric Option #1	Electric Option #2
Manufacturer and model	Toro Timemaster Series 21199	Husqvarna W520i	Snapper 82 V Max
Price	$1,099.99	$1,199.99	$699
Engine/battery	Engine: gross torque Briggs & Stratton 223cc OHV engine. Fuel capacity: 1.2 quarts (up to one hour run time) 0.3 gal	Lithium ion BLi950X battery	82V 90 min w/two 2.0 batteries (45 min each)

Power source/watts		40 volts, 1.5 kw	brushless 1200 Watts* 0.328 kw
Cutting width	30”	20”	21”
Projected run time	1 hr	2 hr 30 min	1 hr 30 min
Power consumption per hour	0.3 gal	0.49 kw	0.66 kw
CO_2 eq production per hour of operation	5.28 lb	0.41 lb	0.56 lb
Fuel cost per hour of operation	$ 1.012	$ 0.06	$ 0.08
Yearly hours of operation	11 hours	11 hours	11 hours
Total anticipated cost per hour of operation	$ 11.011	$ 10.969	$ 6.434

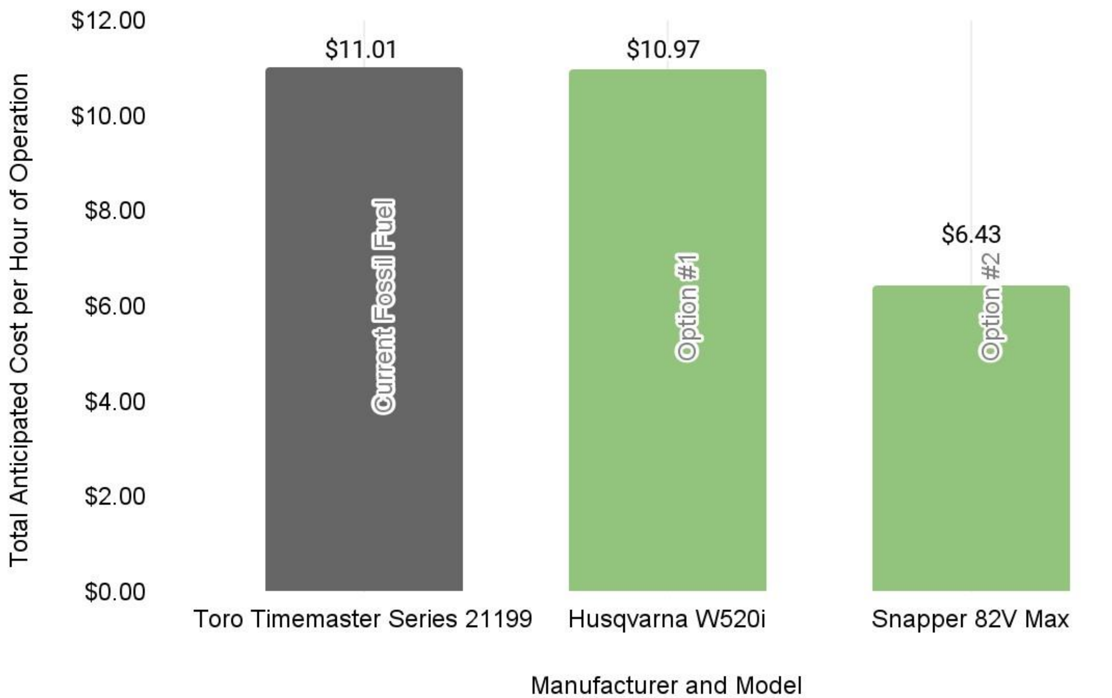

Figure 2. Total anticipated cost per hour of operation of small, self-propelled mowers

Zero Turn Mowers

The current fossil fuel powered zero turn mower is the Exmark Lazer Z E-series. It has a deck size of 72” with a runtime of 14.46 hours while producing 14.61 lbs. of CO_2/hr of operation. It’s estimated to cost $5.07/hr to run.

Two electric zero turn mowers were selected for comparison, the Mean Green evo-74 and the Gravely Pro turn EV-997007. The Mean Green mower offers battery options: a 14.5 kWh, 22 kWh or 35 kWh lithium-ion battery. It has a 74” deck width and the equivalent of 37HP with a listed run time of up to 8 hours. The current all-electric crew reported that they easily get two days of mowing from their current model. This is a plug-in mower, and it doesn’t carry spare batteries. However, the battery duration is more than enough for a full day of mowing, and it can be re-charged in the evening.

The second electric mower is the Gravely Pro turn EV-997007. Its deck width is 60” and is powered by 16kWh lithium-ion batteries. This mower is different than the Mean Green because it has FusionCore QuikSwap batteries (4) that can be replaced on the go (AriensCo.). This gives the crew the capability to carry extra batteries to ensure the job is completed. Gravely also offers a portable battery charger. This battery flexibility comes at the price, with only 5 hours of battery life when all 4 batteries are in the mower. Even though this is 3 hours shorter than the Mean Green, 5 hours may still cover a full day of mowing. Overall, the Gravely produced .3lbs less of CO_2/hr and is $1.21 cheaper to run per hour.

Table 3.

Price, hourly carbon emission, and cost of operation for zero turn mowers

Zero Turn Mowers			
Type	**Current Fossil Fuel**	**Electric Option #1**	**Electric Option #2**
Manufacturer and model	Lazer Z S-Series	Mean Green Evo-74	Pro Turn EV-997007
Price	$13,599	$38,000	Approx. $31,000
Engine/battery	Fuel capacity: 12 gallons	Lithium-ion	Lithium-ion
Power source/watts	gasoline	22 kWh	16 kWh Li-ion

Deck width	72"	74"	60"
Projected run time	14.46 hr	8 hr	5 hr
Power consumption per hour	0.83 gal	2.26kWh	1.90 kWh
CO_2eq production per hour of operation	14.61 lb	1.9 lb	1.6 lb
Fuel cost per hour of operation	$2.80	$0.23	$0.19
Yearly hours of operation	742 hours	742 hours	742 hours
Total anticipated cost per hour of operation	$5.07	$6.56	$5.35

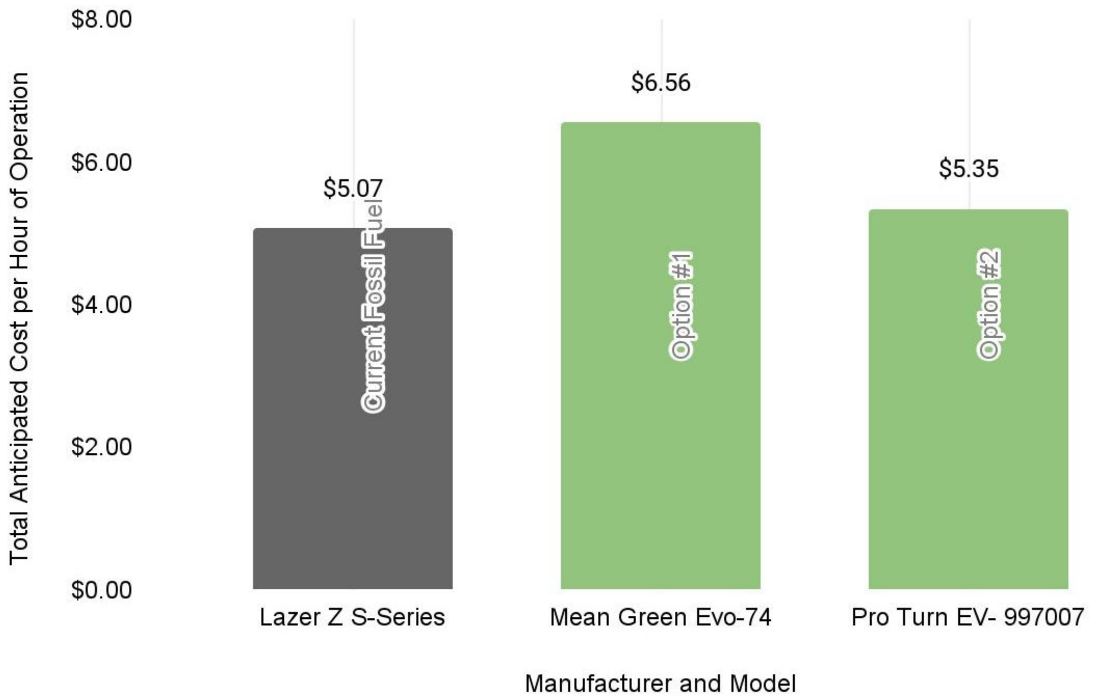

Figure 3. Total anticipated cost per hour of operation for zero turn mowers

Gang Reel Mowers

The Division currently has one gang reel mower, the Toro Reelmaster® 3100D. It has a 21.5HP (16 kW) Kubota® diesel engine, and a cutting width of 72" to 85". It runs on diesel for 6.82 hours and emits 24.69lbs of CO_2/hr of operation (Grove et al., 2020).

There are two electrical options, the Toro Greensmaster® eTriFlex™ Series Model 3370 and the Jacobsen Eclipse 360 Elite. The Toro runs on 8 Lithium-Ion Samsung® SDI batteries and also can also run on gasoline (Greensmaster® eTriflex™ Series). It has a runtime of 4.88 hours (Greensmaster® eTriflex™ Series) and uses 1.82kWh.

By comparison, the second electric option, the Jacobsen uses 2.26kWh. This zero emission mower uses a lithium-ion battery and has a cutting width of 63", which is slightly less than the current gasoline mower.

The Toro Greensmaster is the preferred option. Its CO_2 eq production per hour of operation, fuel cost per hour operation, and total anticipated cost per hour of operation f is lower than the Jacobsen. A review of the Toro says that this "lithium-ion battery greensmower could mow up to 20 average sized greens on a single charge" (Review of Electric Golf Course Machinery). Furthermore, Ian Beech (course manager at the Newcastle-Under-Lyme Golf Club) stated that "... we've been getting up to 56 greens done! Even with accessories such as the grooming brushes on the cutting units we're still getting 38-40 greens done!" (Review of Electric Golf Course Machinery).

We used the more conservative 20 greens estimate to calculate run time, but the Toro has the potential to do more greens.

Table 4.

Price, hourly carbon emissions and cost of operations for gang reel mowers

Gang Reel Mower			
Type	**Current Fossil Fuel**	**Electric Option #1**	**Electric Option #2**
Manufacturer and model	Toro Reelmaster 3100D	Toro Greensmaster® eTriFlex™ Series - 59" model 3370	Jacobsen Eclipse 360 Elite
Price	$53,413.36	$75,652	$59,999

Engine/battery	21.5 hp (16 kW) Kubota® diesel engine 7.5 gal	8 Lithium-Ion Samsung® SDI batteries/ Kawasaki 14.5 HP (10.8 kW) 48V 5400W brushless generator	Lithium Ion, 250 Ah lithium pack Amp hours and volts
Power source/watts	Diesel	10.8 kWh	12.2kWh
Cutting width	72"-85"	59”	63"
Projected run time	6.82 hours	4.88 hours	4.44 hours
Power consumption per hour	1.10 gal	1.82kWh	2.26kWh
CO_2 eq production per hour of operation	24.69 lbs	1.53 lbs	1.9 lbs
Fuel cost per hour of operation	$ 3.97	$0.19	$0.24
Yearly hours of operation	52 hours	52 hours	52 hours
Total anticipated cost per hour of operation	$106.69	$294.55	$324.32

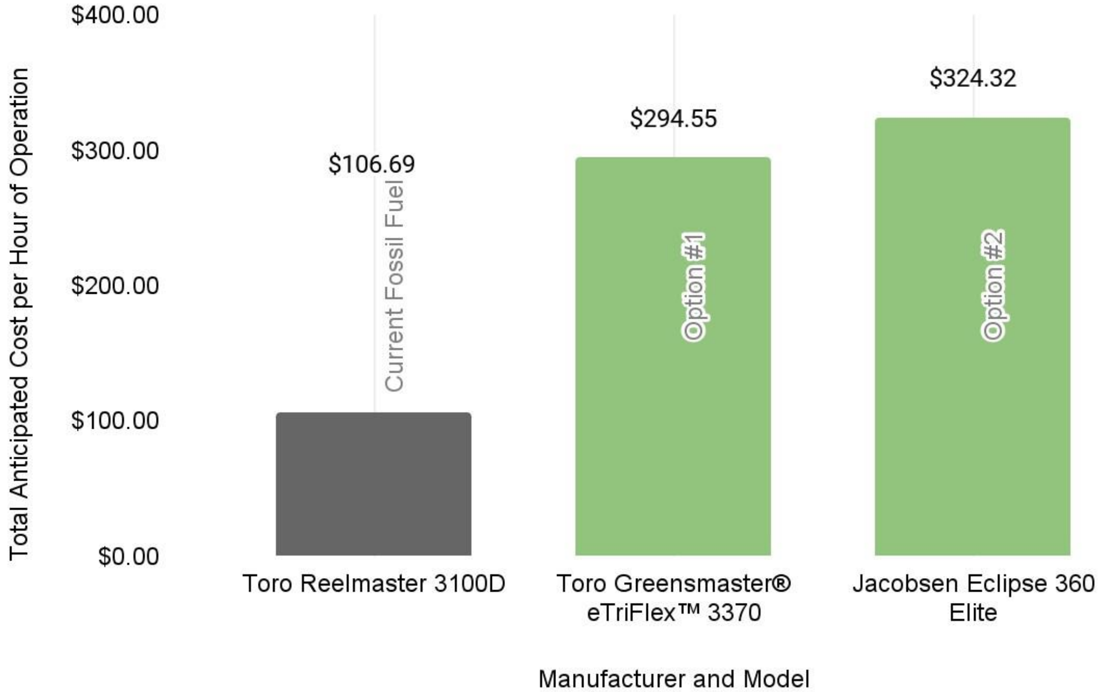

Figure 4. Total anticipated cost per hour of operation of gang reel mowers

Return on Investment

All the electric equipment has a higher initial cost than their fossil fuel counterparts, but a lower fuel cost per hour of operation. The fossil fuel cost per hour of operation ranges from $1.01 to $5.85, while the electric fuel cost per hour of operation is between $0.06 to $0.23. After initial purchase, all the electric mowers are cheaper when only fuel cost is considered.

After 10 years of operation, the electric recommendation for a small self-propelled mower will save Prince George's County $104.72. The large self-propelled mower, the zero turn mower, and the gang reel mower, will save $631.84, $19,069.40, and $1,965.60 respectively. Table 5 shows the fossil fuel cost for the current equipment and for the electric option for 10 years after purchase.

Table 5.
Estimated fuel costs for mowers 10 years after purchase

Estimated Fuel Costs 10 Years After Purchase			
Type of Equipment	**Current Fossil Fuel Equipment**	**Electric Option #1**	**Savings with Electric Option #1**
Small, self-propelled	$111.32	$6.60	$104.72
Large, self-propelled	$643.50	$11.66	$631.84
Zero turn	$20,776.00	$1,706.60	$19,069.40
Gang reel	$2,064.40	$98.80	$1,965.60

The break-even point is when the electric equipment pays off its purchase price, and operation savings. After that point, it will be less costly to use the electric equipment because the cost per hour of operation for the equipment is less than the fossil fuel cost per hour of operation.

Table 6.
Break-even point for each type of mower

Estimated Break-Even Point for Option #1			
Type of Equipment	**Hours to Break Even**	**Hours Used for 10 Years**	**Years to Break Even**
Small, self-propelled	105.04	110	9.55
Large, self-propelled	1,206.47	110	109.68
Zero turn	9,606.70	7,420	12.95
Gang reel	5,883.33	520	113.14

At the break-even point, the electric equipment will save money compared to fossil fuel, because, for all electric mowers, the cost per hour of operation is lower than fossil fuel. The average electricity cost per hour of operation for all the recommendations is about $0.15. The average fossil cost per hour of operation is $1.72. The fossil fuel cost per hour is significantly more than the electric cost per hour.

The assumption that the mowers have an operational lifespan of 10 years means some equipment will not reach the break-even point. Only the small, self-propelled mower passes the break-even point; the zero-turn mower is close to reaching it. These mowers would be the most similar in operation cost to their fossil fuel equivalents.

There are other real-life factors that are not accounted for in reaching the break-even point. The County's electric maintenance crew stated that even electric equipment costs more, they don't need to pay maintenance for oil, changing blades, and cleaning, which would cause the lower the hours to the break-even point. In a life cycle analysis of fossil fuel mowers, oil change and lubrication cost $75 for every 100 hours of use. The electric mowers don't incur this cost; they don't need oil changes and need only minimal lubrication (Life-cycle Cost Analysis for Gas/Diesel).

This analysis assumes the mowers have an 8-year lifespan, 2 less than this report's assumption. In that time the "repair costs could be at least $2,400 to $4,000" for the fossil fuel mower and $800 for the electric mower (Life-cycle Cost Analysis for Gas/Diesel ...). Another comparison of fossil fuel and electric self-propelled Snapper mowers found that "repair visits, filter changes, and part replacements" for fossil fuel mowers cost $450 for 15 years or "$30 per year on average." The electric mower maintenance is less at $200 for its lifespan "or about $13 per year" (*Are Electric Mowers Cheaper than Gas?*).

In general, it is more expensive to maintain a fossil fuel mower and these additional costs could decrease the hours to the break-even point.

The crew also mentioned the need to outfit trailers for the electric equipment, about $9,995 for the trailer (M-NCPPC Department of Finance). The cable to attach to the trailer that the crew currently has was $1,500, but according to Husqvarna they "can do the same thing with an extension cord … so this could be done, for less money". There will be a slight learning curve and more initial costs for electric equipment, which could increase the hours to the break-even point.

Table 7.
Decision Matrix Example

Evaluation Criteria	Fossil Fuel Mower	Electric Mower 1	Electric Mower 2
CO_2eq production per hour of operation	1	4	4

Total anticipated cost per hour of operation	1	2	3
Fuel cost per hour of operation	2	4	4
Price	4	3	2
Projected run time	4	5	1
Power consumption per hour	2	4	4
Weighted total	16	22	18

Discussion

Maryland's standards for its energy production are recorded in the Renewable Energy Portfolio Standard (RPS) Program, which was introduced in 2004, with a goal that 20% of the state's energy production should come from renewables. The updated program goal is 50% by 2030, "with a minimum of 14.5% from solar power and a goal of 100% renewable energy by 2040." (Maryland at a Glance).

If Maryland meets its RPS goal in 2040, then the Division of Maintenance and Development will have also met its goal of being carbon neutral by 2040. In pursuing these state goals, the decision to switch to electric mowers is supported by what the EPA concludes about switching to electric mowers. In 2019 they found that "...even under extreme maintenance scenarios (worst case scenario), the electric mowing solutions are still a greener alternative than the gasoline systems over the 10-year lifecycle described in the functional unit of the LCA" (Kim, 2021). The same study also found that the switch from electric to gas would lead to a reduction in CO_2 emissions of 49.9% in push mowers and 32.3% in riding mowers (Kim, 2012) over a 10-year life cycle.

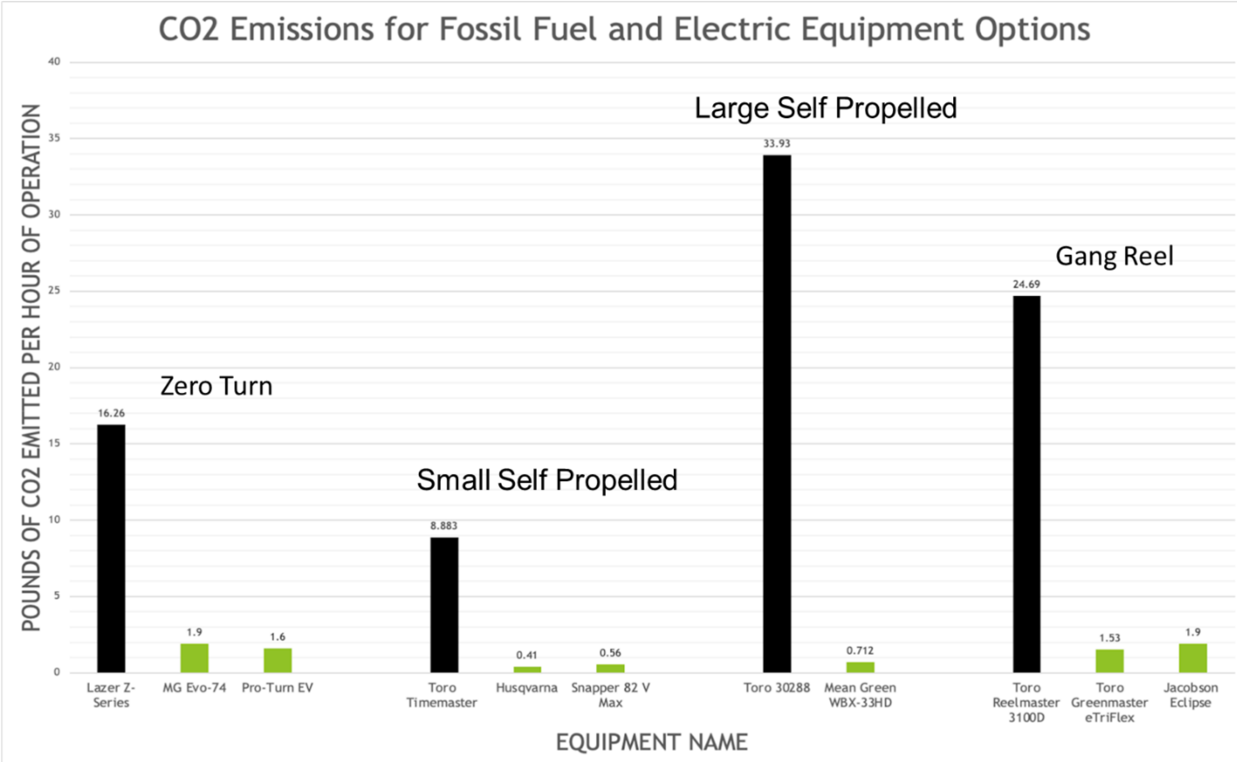

Figure 5. CO_2 emissions for fossil fuel and electric mower options

Carbon Emissions

The research of an earlier capstone team found that the Toro walk-behind mower produced 168 kg of CO_2 over a use time of 11 hours. This was based on an emission coefficient and the number of gallons used. As for the other types of mowers, the zero-turn mower produced 5,470 kg of CO_2 over a use time of 742 hours and the gang reel mower produced 582 kg of CO_2 over a use time of 52 hours.

Lithium-Ion Batteries

The lifespan of lithium-ion batteries varies with factors such as storage, temperature, and deep cycling, but regardless, their life expectancy can be a long; most manufacturers expect around 5 years, or at least 2,000 charging cycles. With proper care, they can last for almost 3,000 charging cycles. (Lerma, 2019).

Proper battery cycling, which includes avoiding full discharges and more frequent charging, is one way to prolong battery life. Storing fully charged batteries at high temperatures has been proven to be more detrimental than improper cycling over time. Improper storage won't cause the battery to die suddenly, but the run time and capacity will slowly decrease (Battery University, 2021). Instead, it's better for battery lifespan to avoid fully discharging and recharging after every use. It may be useful to establish a protocol advising workers to switch out batteries before the first one runs out of charge to ensure that the batteries will never fully run down.

Table 8.
Average charge time for electric mowers

Type of Mower	Average Run Time
Mean Green WBX 33HD	2.5 hours - overnight (GardenLand, 2021)
Husqvarna w520i	175-850 minutes (FR Jones and Son)
Snapper 82 V	30-75 minutes (Briggs & Stratton, 2021)
Mean Green Evo 74	6-12 hours (Focus on Landscapers, 2021)
Gravely Pro Turn EV- 997007	Overnight (Gravely, 2021)
Toro Greensmaster® eTriFlex™ Series - 59" model 3370	Overnight (Cutler, 2020)
Jacobsen Eclipse 360 elite	4-6 hours (Jacobsen, 2021)

Equipment Limitations

Electric mowers have some limitations, which make them not exact swaps for the current fossil fuel equipment. Member of the electric crew who have used both explained that in certain conditions the electric equipment will not be powerful enough.

For example, “you get a week of rain and everything that you’re supposed to mow that week, you’re doing the following week... so if it was already two weeks out, it’s three weeks or a month. So, you can imagine what stuff looks like you know, if you haven’t mowed the grass in a month or anything like that.” In these cases, the crew always takes the propane mower when grass hasn’t been cut for a long time. They also explained that for “sites we’re doing it every seven days … [the electric mowers] work fine.”

The electric mowers have a lot of potential but in some cases, they aren’t as powerful as fossil fuel mowers.

Conclusion and Recommendations

Based on these findings, we recommend that the Division of Maintenance and Development choose electric mowers from the two possible options in each category: large self-propelled, small self-propelled, zero-turn, and gang reel mowers.

Electric mowers will help the Division reach their goal of 50% CO_2 emissions by 2030. By transitioning to electric mowers, the Division can shift their equipment fleet to one with less carbon footprint while performing the same duties of fossil fuel-based equivalents.

Electric technology is progressing steadily, but so far, without breakthrough innovations. The Division can feel safe in purchasing current model electric mowers because current electric technology is sufficient to meet the Division's needs while also accounting for future improvements in battery life.

Opportunity, timeline, and cost are all considered in the decision matrix. For all mowers, except the large, self-propelled, there are at least two viable options for fully electric mowers. For the large, self-propelled mower, the only current option is the Mean Green WBX-33HD.

For the small self-propelled mower, the Husqvarna W520i seems to be the more appropriate choice, given its longer run time and smaller CO_2 emissions. For the zero turn mowers, the Mean Green Evo-74 appears to be the better option, with a longer run time and more battery options, including the ability to swap out batteries during usage. For gang reel mowers, the benefits of the Toro Greensmaster® eTriFlex™ Series – 59" model 3370 seem to outweigh those of the Jacobsen model. The Toro has a longer run time, generates less CO_2 emissions and uses less power.

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