Evaluation of Solar-Assisted, Electric and Gas Golf Carts

Bathurst Glen, Richmond Hill, Ontario

Prepared by: Toronto and Region Conservation **Final Report 2010**

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Bathurst Glen Golf Course
Richmond Hill, Ontario

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THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The Sustainable Technologies Evaluation Program (STEP) is a multi-agency program, led by the Toronto and Region Conservation Authority (TRCA). The program was developed to provide the information, data and analytical tools needed to support broader implementation of sustainable technologies and practices within a Canadian context. The main program objectives are to:

- monitor and evaluate clean water, air and energy technologies;
- assess barriers and opportunities for implementing technologies ;
- develop supporting tools, guidelines and policies, and
- promote broader use of effective technologies through research, education and advocacy.

Technologies evaluated under STEP are not limited to physical structures; they may also include preventative measures, alternative urban site designs, and other innovative practices that help create more sustainable and liveable communities.

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

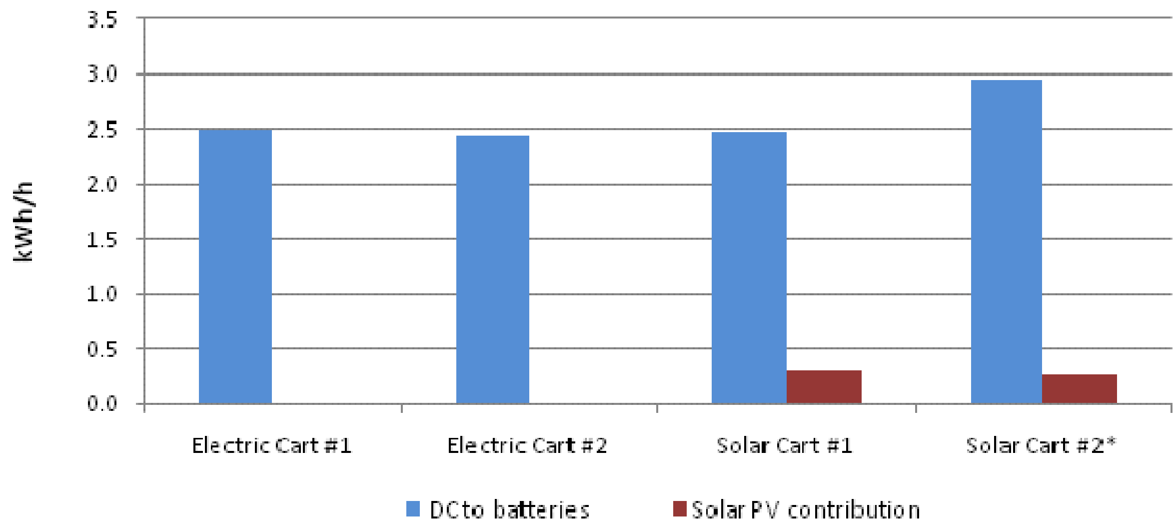
Municipalities are making efforts to reduce air pollution from small gasoline engines such as those found in lawn-mowers and gas-powered golf carts. These engines contribute to smog and greenhouse gas (GHG) emissions and often cost more to operate than their electric equivalents. This study examines the potential benefits of switching from gasoline to electric or solar electric golf carts through a side-by-side field evaluation of two solar-assisted electric golf carts, two standard electric golf carts and two gas-powered golf carts. The carts are assessed with respect to energy use and associated CO_2 emissions, dependability, and overall capital and operating costs. Golfer preference is also evaluated by means of a feedback survey.

The evaluation took place at Toronto and Region Conservation's Bathurst Glen golf course in Richmond Hill. Over the past few years, Bathurst Glen staff members have implemented several programs to improve golf course sustainability. This study of solar golf carts fits in well with these efforts, as well as the overall goal of becoming known as a "green" and environmentally responsible golf course.

Data was collected over a 3-month period from July 15 to October 15, 2009. The solar-assisted and standard electric carts were compared by measuring electricity at three points: (i) AC (alternating current) electricity drawn from the grid, (ii) DC (direct current) electricity flowing into and out of the batteries, and (iii) DC electricity produced by the solar panels. The amount of fuel consumed by the gas-powered carts was logged manually and oil changes were recorded in each cart's maintenance record. Various standard conversion factors were applied to compare the energy use, emissions and cost of the electric versus gas carts.

Figure 1 shows DC electricity consumption of the four electric carts. Electricity production from the solar photovoltaic (PV) panels is also shown. Based on the hourly-adjusted data, a solar-assisted cart might obtain a savings of 12 percent over a conventional electric cart. While this amount is significantly less than the manufacturer claims of between 30 and 50 percent, it is close to what may be expected from solar yield calculations based on the panel output. A slightly higher output may have been expected had a larger or more efficient panel been used.

Potential savings in consumption from the solar-assisted carts were difficult to detect in the comparison of actual AC power drawn from the grid. While the lowest AC consumption was indeed recorded by a solar-assisted cart, the difference was masked by overall variation among the carts, even when the data were normalized for differences in use. In fact, one of the solar-assisted carts used 30 percent more AC electricity than the average of the other standard electric carts. This was likely the result of a mechanical problem, and unrelated to the presence of the solar panels. Nevertheless, it does suggest that other factors relating to cart condition (e.g. tire pressure, new bearings) or driver behaviours are at least if not more important than the solar panels in determining overall energy consumption. Installing the solar panel in area with full sun exposure and connecting directly to the grid would maximize generation potential by eliminating losses caused by shading and battery charging.



*Solar Cart #2 includes data from July and August only, prior to failure of the PV panel

Figure 1: Contribution of solar panels to reducing electricity consumption, expressed in kilowatt hours per hour in motion.

Some manufacturers claim that solar panels can extend the discharge period of electric carts, prolonging their “in-service” time and even reducing the need for stand-by carts during the busiest part of the season. This claim was not borne out in this study. While solar panels may increase “in-service” time, this extra time was not necessary as all carts were plugged in daily, and had sufficient energy to last the full day. The solar panels may, however, extend the *lifetime* of batteries by reducing daily discharge levels, but this benefit was not tested in this study.

The most significant positive findings of this study relate to the performance of electric carts versus gas carts, rather than solar-assisted versus electric carts. The electric carts have 85 percent lower fuel costs and produce one-quarter of the emissions of the gas carts. They are also about three times more fuel efficient and are preferred by golfers for their quietness, smooth operation, and lack of exhaust fumes (Figure 2).

There are at least 179 golf courses within a 100 km radius of Toronto, of which roughly 80 percent are estimated to use electric carts. The remaining 20 percent use gas. Replacing this 20 percent, or 1432 gas carts, with electric carts, would reduce emissions by approximately 3.8 tCO2e per day or 608 tCO2e in an annual golf season. This is roughly equivalent to taking 155 mid-sized gasoline cars off the road. Further reductions in GHG emissions could be achieved by plugging the chargers into timers that shift charging entirely to off-peak hours when power generation is less reliant on fossil fuels.

If a carbon market is developed in Canada, golf courses could sell carbon credits by switching from gas to electric or solar-assisted electric carts. Assuming carbon costs of roughly $30/tCO2e, each golf course using electric vehicles rather than gas could expect an annual savings of $518.

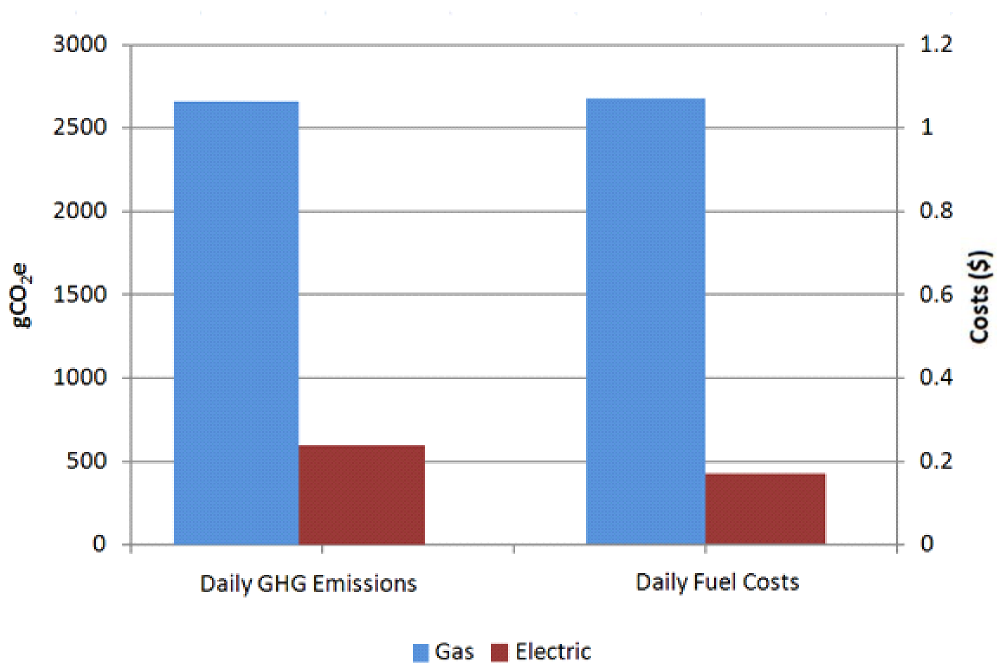


Figure 2: Daily GHG emissions and fuel costs for gas and electric golf carts

Overall, the electric golf carts offer several important financial and environmental benefits over gas carts. The addition of solar panels to electric carts can marginally improve performance and positive feedback from surveys suggests that these carts would also offer a marketing advantage to course operators. Hhowever, the large variation in AC consumption among the two solar-assisted and two standard electric carts tested in this study suggest that similar energy savings may be achieved at a lower cost by simply maintaining the carts in good condition.

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1.0 BACKGROUND AND OBJECTIVES

Municipalities are making efforts to reduce air pollution from small engines such as those found in lawn-mowers, dirt bikes, and gas-powered golf carts. These engines contribute to smog and greenhouse gas (GHG) emissions and are often more costly to operative than their electric equivalents. Some municipalities are already working with operators of "green" corporate fleets that rely on electric and hybrid vehicles to reduce emissions (TAF, 2010). There is a perception that gas carts, which can be refuelled in minutes rather than the hours it takes to charge an electric cart's battery bank, are more reliable. They can be run longer, which means less down-time. However, considerations such as the rising cost of fuel, pollution impacts, and improved real-world performance of electric vehicles have prompted a re-examination of the tradeoffs between gas and electric carts.

Electricity in Ontario is generated largely from non-carbon-based fuels (hydroelectric and nuclear), and the electricity supply mix is gradually becoming greener as Ontario's coal-fired power plants are phased out and new wind, solar, and biogas generation comes online. Electric motors are considerably more efficient than internal combustion gas engines (ICEs). Electric motors convert 80 to 90 percent of their input energy to kinetic energy (Engineering Toolbox, 2005), while ICEs convert only 16 to 37 percent (Lovins, 2004). Therefore, electric golf carts offer an undeniable opportunity to golf course operators to green their fleets. When some of the electricity for the carts is generated from the sun, there is potential for improvements in both cost and performance.

Solar-assisted golf carts recharge their batteries through a combination of grid-electricity and solar energy from panels mounted on the roof. They were developed to save energy and money by reducing the cost of charging batteries, increasing the distance that the cart can travel on a single charge, and extending the discharge period of the golf cart batteries. Depending on the golf course, the longer travel times may reduce the number of stand-by electric carts required, which can translate into additional cost savings.

This study examines the potential benefits of switching from gasoline to electric or solar-assisted electric golf carts through a side-by-side field evaluation of two solar-assisted electric golf carts, two standard electric golf carts and two gas-powered golf carts. The carts are assessed with respect to energy use and associated CO_2 emissions, dependability, and overall capital and operating costs. Golfer preference and the marketing potential of solar assisted carts are evaluated by means of a feedback survey.

In addition to comparing the overall performance of the different carts, the study also considers specific claims made by manufacturers about the environmental benefits of solar-assisted golf carts over conventional electric carts. These purported benefits include saving money by drawing less electricity from the grid, extending the daily "in-service" time of the carts, reducing the need for stand-by carts, and reducing charging costs.

2.0 STUDY SITE

The evaluation was conducted at Toronto and Region Conservation's Bathurst Glen golf course in Richmond Hill (Figure 2.1). Bathurst Glen is an 18-hole golf course measuring approximately 4,100 metres from the back tees. A full round can be played in about 3 to 4 hours. Over the past few years, Bathurst Glen staff members have implemented several programs to improve golf course sustainability by completing the Audubon Co-operative Sanctuary System for golf courses. This has resulted in lower use of chemical fertilizers and pesticides, improved wildlife and habitat management, lower water use, and energy savings. The use and study of solar-assisted golf carts fits in well with their overall goal of becoming known as a "green" and environmentally responsible golf course.

Figure 2.1: Bathurst Glen golf course, 12481 Bathurst Street, Richmond Hill, Ontario.

3.0 METHODS

The evaluation involved a side-by-side comparison of two solar-assisted golf carts, two standard electric golf carts and two gas golf carts. All carts were of similar size. Installation and testing of monitoring equipment occurred in May and June 2009. Field monitoring was carried out in July of the same year. The monitoring and evaluation methods for each of the major components of the study are discussed below.

3.1 Energy Use

This component of the evaluation assesses how much electricity or gas is used by the golf carts per hour of use. Table 3.1 shows the parameters logged for each cart type. Figure 3.1 presents examples of the equipment used and Figure 3.2 illustrates the monitoring set-up for the solar-assisted and conventional electric carts. It should be noted that, the electric carts operate entirely on DC (direct current) electricity. AC (alternating current) electricity is converted to DC electricity prior to entering the batteries. The photovoltaic panels (PV) supply DC energy directly to the motor when the cart is in motion and to the batteries when the cart is stationary.

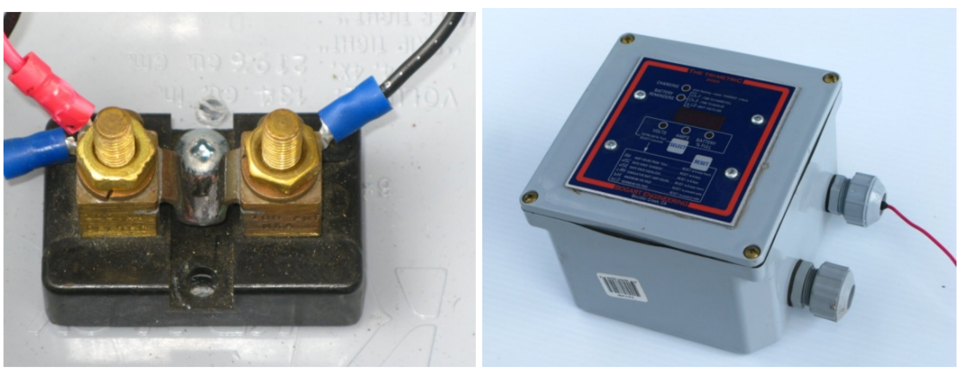

Figure 3.1: Amp meter shunt used to measure electrical current to and from the batteries (left). Battery meter logs data collected by an amp meter shunt (right)
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The DC electrical energy in Amp hours (Ah) that the solar-assisted and standard electric cart batteries received and discharged was recorded by an amp meter, and then multiplied by system voltage to obtain DC watt hours. The AC kilowatt hour (kWh) input to battery chargers designated for each of the golf carts in the trial was measured with a watt meter. Colour-coded plugs on each charger ensured that golf carts were always plugged into the same charger. DC electricity from the solar panel was measured with an amp hour meter. To assess reductions in GHG, it was necessary to know what time of day the carts were plugged in each day. This was logged manually by golf course staff.

For the gas carts, a standard form was used by Bathurst Glen staff to monitor gas volumes each time the gas carts were refilled. Energy use data were standardized based on hours travelled.

Table 3.1: Energy- and usage-related quantities logged during the study

Logged Quantity	*Gas Carts*	Conventional Electric Carts	Solar-Assisted Electric Carts
Watts		X	X
Volts		X	X
Amps		X	X
Gas	X		
Watt hours		X	X
Hours on course	X	X	X
Hours in motion		X	X

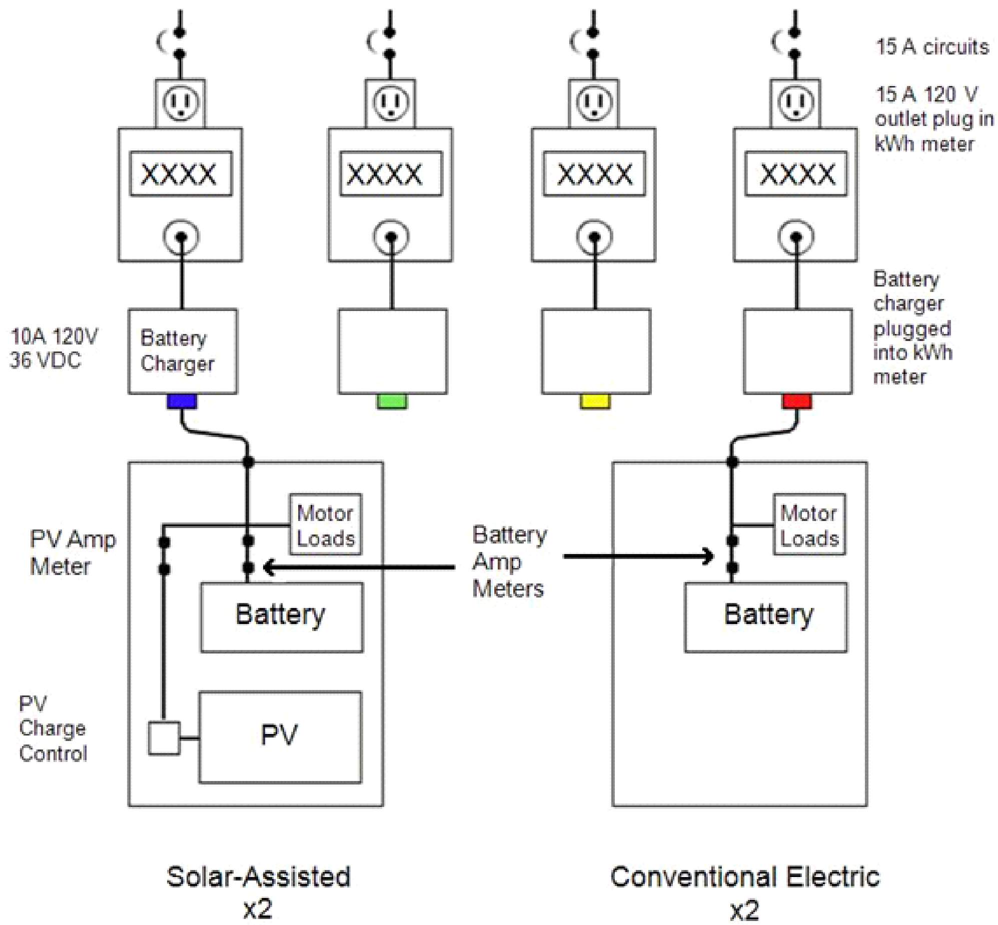


Figure 3.2: Monitoring set-up for evaluation of solar-assisted carts vs. conventional electric carts.

3.2 Emissions

Emissions factors obtained from Environment Canada, Natural Resources Canada, and the U.S. Environmental Protection Agency were used to estimate GHG emissions associated with energy use and source. The source of energy in Ontario during times when the carts were plugged in was also considered in estimating costs and GHG emissions.

3.3 Extended Discharge Period and Longer "In-Service" Time

In order to determine whether the solar-assisted carts extended the discharge period of the batteries, and provided longer 'in service' time than standard electric carts, the two cart types were fitted with hour meters to measure how long they were in use and normalize energy consumption among the carts. A log was kept of the daily usage of each cart. The amount of DC electricity drawn from the batteries was also monitored using an amp meter to assess whether the direct solar contribution to the motor would reduce the amount of electricity drawn from the batteries during daytime use.

3.4 Efficiency of Grid-Charging

The type of battery charger used may have an important effect on energy efficiency. Charger efficiency is indirectly evaluated using AC KWh and DC Ah readings to assess the efficiency of converting grid-electricity to electricity used by the carts. Cart efficiency is measured by comparing AC kWh to DC kWh to see how much more electricity was drawn from the grid than was actually used by the cart.

3.5 Maintenance Considerations

Maintenance requirements of solar golf carts over and above what would be expected for standard electric cars were documented, and any differences in cost were estimated. Maintenance costs of the electric versus gas carts were also compared.

3.6 Golfer Preference and Marketing Potential

Golfer preferences for each type of cart were assessed by means of a short survey. The carts were sent out on a first come first serve basis and the surveys were given out to the users as they went out. Golfers were asked to share their experience of using the vehicle as well as general thoughts. Specific questions included: Which cart did you drive? Did it matter which type of fuel the golf cart used? Would you prefer to drive a solar golf cart? Responses are used to determine which of the carts golfers preferred and why, and to comment on marketing potential for solar golf carts.

3.7 Comparison of Electric Golf Carts to Gas-Powered Carts

The amount of fuel consumed by the gas-powered carts was logged manually. Oil changes were recorded in each cart's maintenance record. "In-service" times recorded by the hour meter were compared. Costs of operating the carts were compared using historical gas and electricity prices, and maintenance records. GHG and smog emissions were compared using Environment Canada emissions factors for gasoline and electricity consumption. Standard energy conversions were used to compare overall energy consumption. Cart mileages were calculated by summing hole lengths plus an estimated “green to tee” distance based on distances between tees.

4.0 STUDY FINDINGS

Cart usage is an important variable in assessing performance. Table 4.1 shows usage for each of the carts included in this study. Three of the four electric carts had roughly equal use. Electric Cart #2 had the most hours of use, about 20 percent more than the average of the other carts. Solar Cart #1 used 14 percent more use than Electric Cart #1 and Solar Cart #2, which were driven about the same amount. Daily usage data were used to standardize the cart consumption per hour of use.

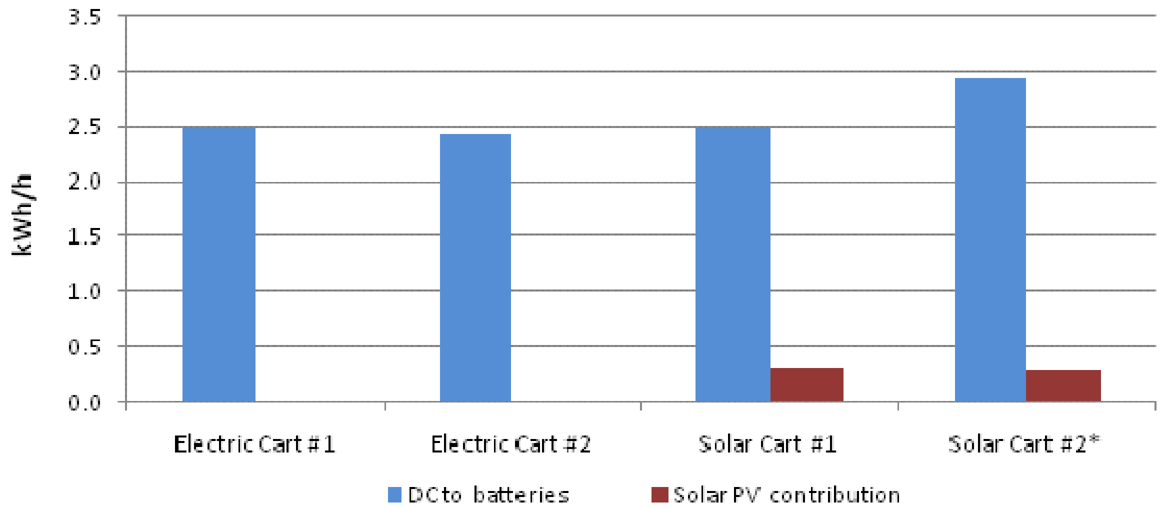
Table 4.1: Measures of time in use show Electric Cart #2 saw the most hours on the course

Cart Type	Average Daily Hours "on course"	Average Daily Hours "in motion"	Average Daily Holes Played
Gas #1	7.5	0.7	25
Gas #2	7.2	0.7	27
Electric #1	10.2	1.0	30
Electric #2	12.6	1.2	28
Solar #1	12.4	1.0	31
Solar #2	10.2	1.0	29

4.1 Energy Use

Electric and solar-assisted electric carts have a clear advantage over gas carts when energy consumption is compared. Gas carts were found to have a daily fuel consumption of 1.13 L, which contains about 10 kWh of energy (ORNL, 2010). The daily energy consumption of the electric carts was 3.3 kWh. This demonstrates the overall energy inefficiency of gas versus electric motors. The gas motor consumes about 3 times more energy than the electric motor to accomplish the same work.

Figure 4.1 shows DC electricity consumption of the four electric carts over the 3-month study period. The data is normalized to account for differences in cart usage. The contribution of solar electricity to the overall cart consumption is shown in red. A RETScreen model of the PV system was found to agree with the empirical data (see Appendix A). Based on the hourly-adjusted data, a solar-assisted cart might obtain a savings of 12 percent over a conventional electric cart. However, the variation in electricity consumption between all carts is about as large as the solar production, which implies that the lower consumption of Solar Car #1 might just as plausibly be attributed to any number of mechanical differences (e.g. new bearings, higher tire pressure, etc.) This suggests that a well-maintained electric cart, free of mechanical issues such as a sticky emergency break or under-inflated tires, may offer a better energy and financial payback than Solar Cart #2, based on performance data collected in this study.

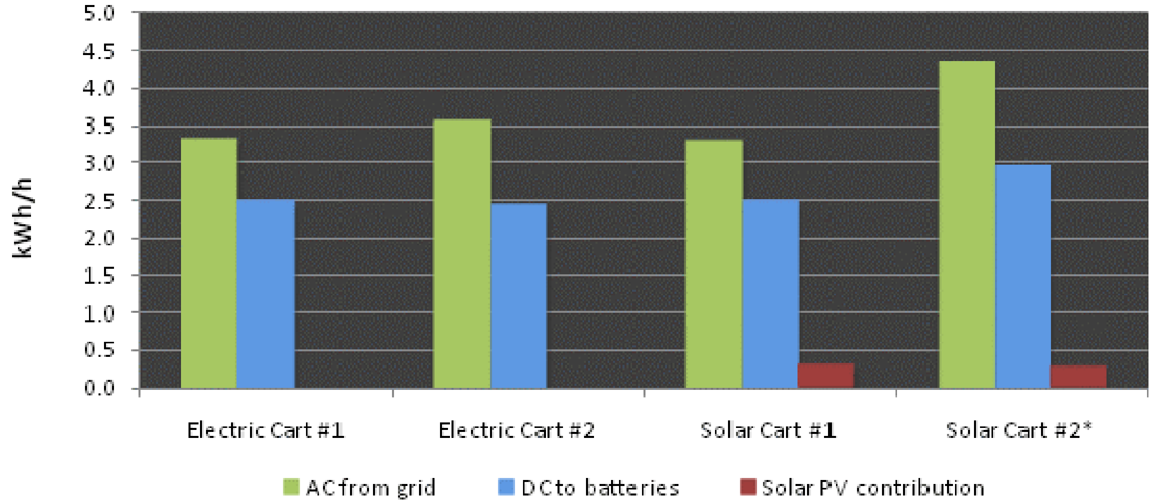


*Solar Cart #2 includes data from July and August only, prior to failure of the PV panel

Figure 4.1: Contribution of solar panels to reducing DC electricity consumption, expressed in kWh per hour in motion.

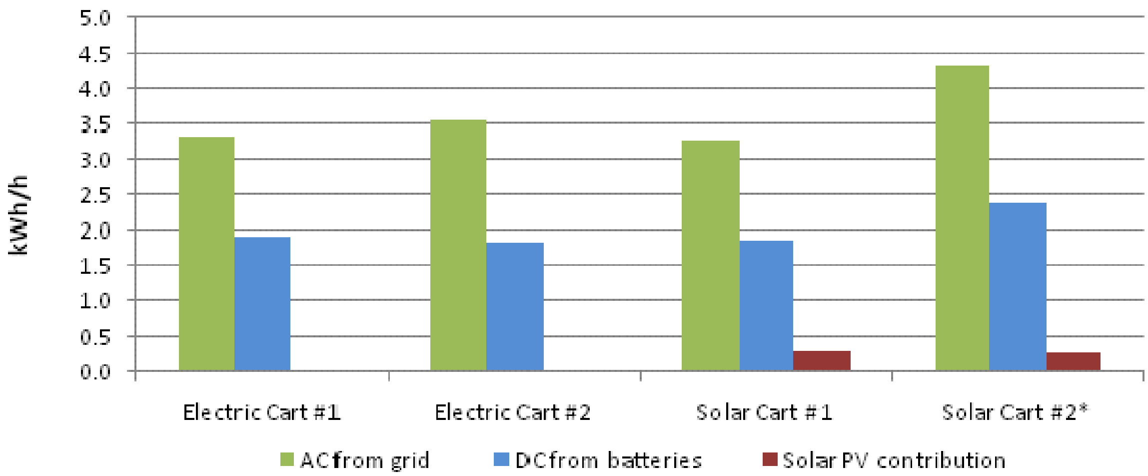
Some manufacturers claim that solar-assisted carts can reduce charging costs by 30 to 50 percent (SunCatcher, 2007). While this is conceivable based on idealized calculations of solar yield versus consumption (see Appendix A), the data from this study does not support this claim. Figures 4.2 and 4.3 show the normalized AC and DC consumption of the carts over the three month study period. The solar panels produced an amount of electricity equivalent to between 7 and 10 percent of AC consumption after efficiency losses (see subsection below on charger efficiency). However, any potential savings in electricity drawn from the grid due to the contribution of solar energy are masked by the much larger variations in AC consumption among the carts (Figure 4.2), even when differences in use are taken into account. In fact, Solar Cart #2 used 30 percent more electricity than the average of the other electric carts even though it had similar use (see Table 4.1 above). This cart also drew about 14% more electricity from the batteries (Figure 4.3). These performance results were likely the result of a mechanical problem, and unrelated to the presence solar.[1] Nevertheless, it does reinforce the point made earlier that other factors relating to cart condition or driver behaviours are at least, if not more important than solar in determining overall energy consumption.

[1] One of the golfers who used Solar Cart #2 reported on his/her survey that the tires were underinflated.



*Solar Cart #2 includes data from July and August only, prior to failure of the PV panel

Figure 4.2: AC and DC electricity drawn from the grid at night from July to October, 2009. The difference between AC and DC consumption represents charger inefficiencies involved in converting AC to DC. PV production is shown for reference.



*Solar Cart #2 includes data from July and August only, prior to failure of the PV panel

Figure 4.3: DC electricity drawn from batteries during the day, with PV production and AC consumption (drawn from the grid at night) from July to October, 2009. The difference between AC and DC consumption represents total inefficiency of the grid-to-battery charging process.[2]

4.2 Emissions

The emissions produced by solar-assisted and standard electric carts occur indirectly when the batteries are being recharged during the evening. Electricity during this time is being generated from a number of sources, some of which produce GHG emissions and contribute to smog, such as coal or natural gas. In

[2] These include the combined inefficiencies of (i) the charger converting AC to DC shown in Figure 4.2 and (ii) electro-chemical conversion as electricity is first stored in, and then removed from, the batteries.

Ontario, night time electricity is generated mostly from nuclear and hydroelectric power (Kennedy et al, 2009). As discussed in the previous section, the contribution from the solar panels was masked by several other factors affecting performance. Therefore it was not possible to conclude that the solar assisted carts were less polluting than the standard electric carts.

The gas carts produced much higher emissions than either the standard electric or solar-assisted electric carts. Electricity in Ontario currently has an emissions factor of 170 gCO_2e/kWh[3] with transmission losses of 6 percent (Environment Canada, 2010). Hence, the GHG emissions associated with operating an electric golf cart charged during off-peak hours is no more than 595 gCO_2e per day. By comparison, the gas carts use about 1.13 L gasoline per day. A litre of gasoline is equivalent to 2.3 to 2.4 kg of CO2 (USEPA, 2010a, NRCan, 2010); hence daily emissions for the gas carts are approximately 2,656 gCO_2e. Therefore the emissions from the gas carts are about 4.5 times higher than those of the electric carts (Figure 4.4).

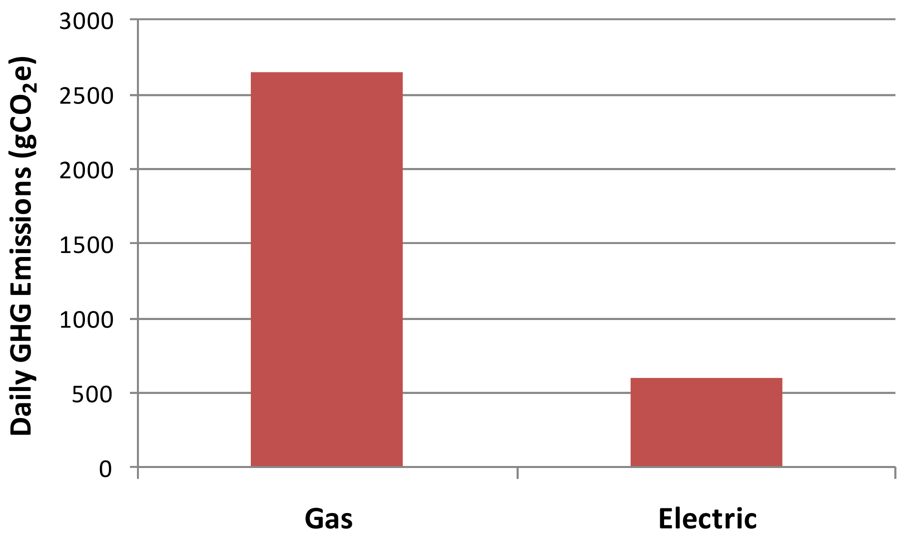


Figure 4.4: Daily green house gas emissions (gCO_2e) for gas and electric golf carts.

There are at least 179 golf courses within a 100 km radius of Toronto (Score Golf, 2010). Assuming an average of 18 holes per course, corresponding to 40 carts, there is an estimated total of 7,160 carts operating in the greater Toronto area (GTA). According to Bathurst Glen staff, roughly 80 percent of these courses use primarily electric carts, and the remaining 20 percent of courses use primarily gas carts. Most of these gas carts are operated by public courses, including those owned by the City of Toronto (R.McCutcheon, pers. comm., 2009). Switching all courses to electric carts would result in an

[3] Carbon dioxide equivalent (CO_2e) is a measure used to compare the emissions from various greenhouse gases based upon their global warming potential (OECD, 2005). CO_2e is the concentration of CO_2 that would cause the same amount of global warming as a given type and concentration of greenhouse gas. Examples of such greenhouse gases are methane, perfluorocarbons and nitrous oxide.

emissions reduction of approximately 3.8 tCO_2e per day,[4] or 608 tCO_2e annually (based on a 160 day golfing season), which is roughly equivalent to taking 155 mid-sized gasoline cars off the road.[5]

There are two additional considerations that, while difficult to quantify, indicate that electric carts offer better prospects for reducing emissions than the above calculations suggest. In addition to carbon dioxide, gasoline engines produce methane (CH_4), nitrous oxide (N_2O) and sulphur oxides (NOx). On average CH_4, N_2O and SOx emissions represent roughly 5 to 6 percent of emissions. (USEPAb, 2010). These numbers apply to automobile engines, but unlike cars, golf carts do not have catalytic converters. Hence, gas powered carts would emit more smog-related pollutants than indicated above.

A second consideration relates to the emissions factor for electricity, which doesn't account for the lower carbon content of off-peak (base load) electricity generation. Base load electricity supply in Ontario is currently comprised primarily of nuclear and hydroelectric, and coal generation (OPA, 2010a). Coal generation is expected to be eliminated from the supply mix by 2015 (OPA, 2010b). Carts were usually plugged in around 7 or 8 PM, and finished charging by midnight. Plugging in the carts after off-peak begins (e.g. at 9 PM, by use of a timer) would reduce charging costs and emissions. If these lower emissions during off peak hours are taken into account, electric carts would produce even fewer emissions than the above calculations suggest.

4.3 Discharge Period and "In-Service" Time

Some manufacturers of solar-assisted golf carts claim that the addition of solar panels can extend the discharge period of electric carts, prolonging their "in-service" time and even reducing the need for stand-by carts during the busiest part of the season. In this study, it was found that prolonging the discharge period is not necessary, since all electric carts (solar and conventional) are fully capable of performing day-long service.

Electric golf carts store about 7 kWh in their batteries.[6] The carts were on the course between 12 and 15 hours per day, used an average of 2.5 kWh per day, and a maximum of 4.0 kWh over the study period (see Appendix B for a table of longest daily usage for each cart). Thus there was ample charge available in the batteries and there were few if any days on which an electric cart needed to be exchanged for a new cart because of inadequate battery charge.

If the solar panels were helping to extend the discharge period and overall life of the battery, it may be expected that the solar-assisted carts would draw less DC electricity from the batteries because the energy coming from the solar panel helps to drive the motor when the cart is in motion. However, as shown in Figure 4.3 above, the solar panels appear to be offering little benefit in this regard. The conventional electric carts and solar-assisted carts drew about the same amount of electricity from their batteries, and Solar Cart #2 drew about 14% more.

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[4] 2655.5 gCO2e * 1432 gas carts (20% of the 7,160 estimated carts in GTA)
[5] NRCan, 2010, based on an annual average of 3,920 kg per car.
[6] A standard 220 Ah golf cart battery is 90 percent efficient at the 10-hour rate (see Appendix C for battery efficiency chart). Therefore 8Ah@10 hr rate * 36 V = 7,128 Wh

Other possible benefits related to prolonging battery life include extending the lifetime of batteries by reducing daily discharge levels, extending range and “in-service” times for carts on longer courses, or on courses which do not plug their carts in on a daily basis. These benefits were not tested in this study.

4.4 Charger Efficiency

The measured efficiency of the battery chargers was somewhat less than manufacturer specifications, but fell within an acceptable range. The DC consumption was about 27 percent lower than AC consumption, indicating a charger efficiency of 73 percent. The PowerWise II charger used in the study comes standard with EZ-GO electric carts and has a rated efficiency of 85 percent. This is comparable to other “best-in-class” chargers. See Appendix C for further discussion of battery charger efficiency.

4.5 Fuel Efficiency

Relating the higher energy and environmental performance of electric carts to fuel efficiency can be effective for marketing electric carts. Fuel efficiency is generally well understood by the public and can be used to communicate the benefits of electric carts by relating it to a familiar concept.

The distance a cart drives during an 18-hole round at Bathurst Glen is about 5,500 yards or 5 km. The gas carts consumed about 1.1 to 1.2 L per day over an average of 26 holes, or a distance equivalent of 7.2 km. The electric carts consumed about 3.3 kWh (the equivalent of 0.41 L) per day (ORNL, 2010), over an average of 29.5 holes, or a distance equivalent of 8.2 km. These numbers suggest that the gas carts obtained a mileage of 16 L/100 km (14 miles per US gallon), while the electric carts use the equivalent of 5 L/100km (47 miles per US gallon). If the distance driven was greater than 5 km over 18 holes, both carts would have obtained better mileage, but the electric would still have been roughly three times more fuel efficient.

Inefficiencies inherent to small gas engines result in much lower fuel efficiency for gas golf carts, even compared to gasoline cars. The 16 litres per 100 km obtained by the gas carts in this study is comparable to a Hummer H3 SUV, whereas the 5 L/100km obtained by the electric cart is similar to a Toyota Prius hybrid.

4.6 Fuel Cost

The daily fuels costs of an electric cart are approximately 16.5 cents per day, based on an off peak rate of $0.05 per kWh. The cost of gas is volatile, having ranged in recent years from $0.63/L to $1.37/L (Figure 4.5). With this level of volatility, it is difficult to predict the lifetime fuels cost of a fleet of gas carts. However, it is expected that over the next ten years the price of gas will increase. Using 6-year historical prices as a lower threshold, at an average of $0.95/L, the cost of fuel for a gas cart is about $1.07 per day. The fuel costs for the gas carts are therefore about 6.5 times greater than for the electric carts.

Other factors such as engine maintenance and battery replacement will affect the costs of operating the carts.[7]

The development of a carbon market, which is currently being planned in Canada, would allow individuals and companies to reap a financial benefit from measures taken to reduce carbon emissions. Estimates of the price of carbon emissions under anticipated carbon pricing schemes range from $15-$100 per tonne. Assuming a price of $30/tCO2e, each golf course using electric vehicles rather than gas could be expected to save $518.40 annually.[8]

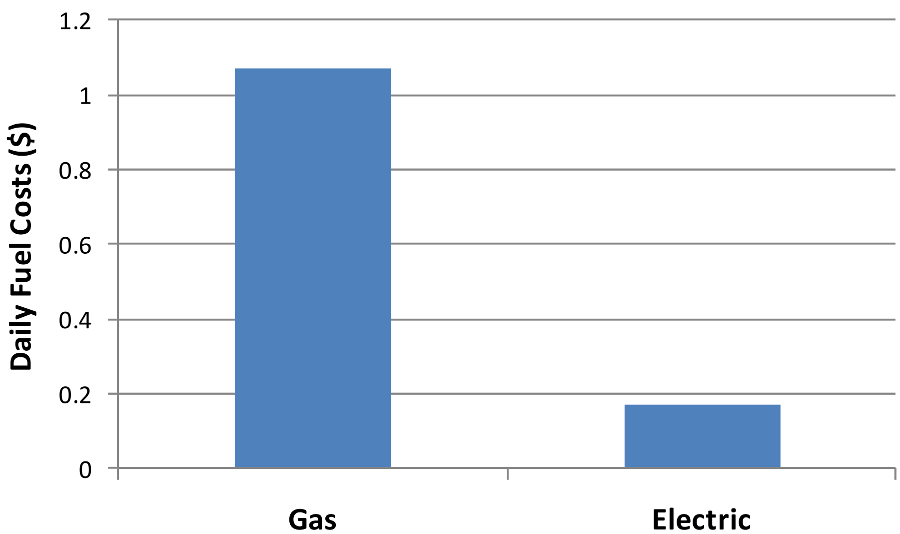

Figure 4.5: Daily fuel costs for gas and electric golf carts.

4.7 Maintenance Considerations

In addition to differences in energy consumption among cart types, there are also important differences in maintenance requirements. Once properly installed, solar panels are relatively maintenance-free, as are their “balance of system” components (charge controller, wiring). Panels should be occasionally wiped down to remove accumulated dust and debris. Apart from this, the maintenance of a solar-assisted golf cart is essentially the same as a conventional electric cart.

The battery bank is by far the most expensive component of an electric golf cart. Properly taken care of, electric golf cart batteries will last approximately 4 to 6 years before needing to be replaced. The cost of replacement is roughly $800-$900, or $140 per battery. However, golf courses typically replace their carts every three to five years, or the carts are leased. Thus, the cost of battery replacement would appear in resale value, or lease pricing, rather than as a direct cost to course operators.

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[7] See Appendices for discussion of electric vs. gas motor durability, recent improvements to electric motor design, and costs of battery replacement.
[8] 40 carts * 0.0027 tCO2e/day * 160 days* $30. The Province of British Columbia has implemented a self-imposed carbon tax of 2.34 cents per litre of gas, rising to 3.51 cents in 2012. International carbon pricing agreements are expected to be much higher (Lehmann, 2009)

Batteries require some maintenance, such as topping up their water levels 3 to 4 times per season and ensuring that the connections are clean, but these are relatively minor compared to the regular oil changes, spark plug replacements, and other maintenance requirements of gas engines. Appendix D provides a complete comparison of electric and gas maintenance requirements.

Overall, electric carts certainly require less periodic maintenance, and depending on how the costs of battery replacement are borne by golf course operators, may be less expensive than gas carts.

4.8 Golfer Preference for Solar-Assisted and Electric Golf Carts

Golfers offered positive, even enthusiastic, feedback on the solar-assisted carts as being “a great idea” and “eco-friendly.” These positive impressions suggest that solar-assisted golf carts can contribute to the positive image of a golf course as being proactive on environmental issues.

The user surveys showed an overwhelming preference for electric and solar-assisted carts over gas carts. Golfers were enthusiastic about the quietness, smooth operation, easy handling of the electric carts. Another frequent response was “no smell”, referring to the absence of exhaust fumes, although half of the golfers who took the survey said the fuel type did not matter.

The preference for electric carts over gas is supported by lower usage of the gas carts. The gas carts were in use an average of 7.4 hours versus 11.4 hours for the electric carts (solar-assisted and conventional). Half of the surveyed golfers drove a solar-assisted cart, more than 40 percent drove electric, and fewer than 10 percent drove a gas cart. Eighty five percent of surveyed golfers said they preferred the solar cart, however it may be that golfers who were more positive towards the solar-assisted carts were also more likely to fill out the survey.

5.0 CONCLUSIONS

This side-by-side comparison of golf carts has shown that electric carts can offer several important advantages over gas carts. The electric carts had 85 percent lower fuel costs and produced one-quarter of the emissions of the gas carts. They were also about three times more fuel efficient and were preferred by golfers for their quietness, smooth operation, and lack of exhaust fumes.

If all golf courses using gas carts within 100 km radius of Toronto were to switch to electric carts, it is estimated that GHG emissions would be reduced by 3.8 tCO_2e per day, or 608 tCO_2e annually, which is roughly equivalent to taking 155 mid-sized gasoline cars off the road.

Adding solar panels to the electric carts were found to provide a quantity of electricity equivalent to 12 percent of DC consumption. While this amount is significantly less than the manufacturer claims of between 30 and 50 percent, it is close to what may be expected from solar yield calculations based on the panel output. A slightly higher output may have been expected had a larger or more efficient panel been used.

Actual AC savings from the solar-assisted carts was between 7 and 10 percent due to efficiency losses in the charging process. However these savings in consumption were barely detectable in actual AC power drawn from the grid due to differences in the mechanical or electrical condition of the carts. This suggests that maintaining the cart in good condition may save as much energy and money as would the purchase of solar panels.

The claim that solar panels can extend the discharge period of electric carts, prolonging their “in-service” time and reducing the need for stand-by carts during the busiest part of the season was not shown to be an important benefit in this study. While solar panels may increase “in-service” time, this extra time was not necessary as all carts were plugged in daily, and had sufficient energy to last the full day. The solar panels may, however, extend the *lifetime* of batteries by reducing daily discharge levels, but this benefit was not tested in this study.

Golfers offered positive feedback on the solar-assisted carts as being “a great idea” and “eco-friendly”, suggesting that these carts can help to contribute to the “green” image of the golf course. They also showed a strong preference for the quiet and smooth ride associated with electric or solar-assisted electric carts. Overall, the electric golf carts appear to be a far better investment financially and environmentally. The addition of solar panels to electric carts can marginally improve performance and offer a marketing advantage to golf course operators. However, installing the solar panel in an area with full sun exposure and connecting directly to the grid would maximize generation potential by eliminating losses caused by shading and battery charging.

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APPENDIX A

Calculation of Solar Yield

Calculation of Solar Yield

Each solar-assisted golf cart used in this study had three 32-watt solar panels installed on its roof, giving a total of 96 watts per cart. The expected watt hours per day over 96 watts x 5 hours is 480 Wh, or 0.48 kWh. Thus, the expected watt hours over the three month study period (93 days) is 45 kWh. The carts consumed about 200 DC kWh over a three-month period. Thus, based on this calculation, the panels might be expected to generate a quantity of electricity equivalent to 23 percent of cart consumption, not quite the 30 percent claimed by manufacturers.

A more accurate estimate of solar yield was obtained using Natural Resource Canada's RETScreen simulator (Figure D1). RETScreen's prediction agrees almost perfectly with the observed yield data, estimating that the panels would provide 22.5 kWh over the period from July 15-October 15. The observed yield of Solar Cart #1 was 24.4 kWh.

Figure A1: RETScreen Energy Model – Solar Golf Cart Project

Power project

Base case power system

Grid type	Off-grid	
Technology	Reciprocating engine	
Fuel type	Natural gas - m³	
Fuel rate	\$/m³	
Capacity	kW	
Heat rate	kJ/kWh	
Annual O&M cost	\$	
Electricity rate - base case	\$/kWh	0.000
Total electricity cost	\$	0

Load characteristics

(•) Method 1
( ) Method 2

	Unit	Base case
Electricity - daily - DC	kWh	50.000
Electricity - daily - AC	kWh	
Intermittent resource-load correlation		

Percent of month used

Month	
January	0 %
February	0 %
March	0 %
April	0 %
May	0 %
June	0 %
July	50 %
August	100 %
September	100 %
October	50 %
November	0 %
December	0 %

		Base case
Electricity - annual - DC	MWh	4.600
Electricity - annual - AC	MWh	0.000
Peak load - annual	kW	

Proposed case power system

Inverter		
Capacity	kW	
Battery		
Days of autonomy	d	5.0
Voltage	V	36.0
Efficiency	%	85 %
Maximum depth of discharge	%	50 %
Charge controller efficiency	%	95 %
Temperature control method		Ambient
Average battery temperature derating	%	2.5 %
Capacity	Ah	100
Battery	kWh	4
Technology		Photovoltaic
Resource assessment		
Solar tracking mode		Fixed
Slope	°	0.0
Azimuth	°	0.0
Annual solar radiation - horizontal	MWh/m²	1.31
Annual solar radiation - tilted	MWh/m²	1.31
Photovoltaic		
Type		a-Si
Power capacity	kW	0.10
Manufacturer		Uni-Solar
Model		a-Si - US-32W
Efficiency	%	6.1 %
Nominal operating cell temperature	°C	45
Temperature coefficient	% / °C	0.11 %
Solar collector area	m²	1.6
Control method		Clamped
Miscellaneous losses	%	3.0 %
Summary		
Capacity factor	%	3.4 %
Electricity delivered to load	MWh	0.02

APPENDIX B

Longest daily usage

Table B1: Longest daily usage

	Longest period of time signed out (daily total)	Longest daily usage (manually-recorded hour meter)	Longest daily usage (hours in motion)
Gas #1	11	19	n/a
Gas #2	20	14	n/a
Electric #1	11.9	23	1.7
Electric #2	15.7	20	2.0
Solar #1	12.3	20	2.2
Solar #2	12.1	21	1.8

APPENDIX C

Discussion of Battery Charging

Discussion of Battery Charging

Optimizing system efficiency has to take the real working pattern of the vehicle into consideration. Stationary batteries are often incorrectly or inadequately charged (Van Mierlo, 2006). This leads to a shortened battery life and may also cause a premature and sometimes catastrophic battery failure (Byrne, 2010). Improper charging can shorten battery lifetime from 5 years to a single season.[9]

Efficient charging ensures batteries receive optimum charging, but with minimal wear and tear, regulating the voltage and current delivered to the batteries in three automatic stages.

Three-Stage Charging

Bulk: Replaces 70-80 percent of the battery's state-of-charge at the fastest possible rate.
Absorption: Replenishes the remaining 20-30 percent of charge, bringing the battery to a full charge at a slow, safe rate.
Float: Voltage is reduced and held constant in order to prevent damage and maintain batteries at a full charge.

The time share between these three working conditions has an important impact on the resulting efficiency. With a discharged battery, because of the potential difference between the charger and the battery, the recharge current is initially high and tapers off as the battery voltage and state of charge (SOC) increases. This results in the battery being partially recharged quickly but it requires prolonged charging in order to obtain a fully charged state. Once a battery is restored to full charge, it must be continuously supplied with energy in order to maintain it in that fully charged condition.

The Charger

In order to adequately charge a battery without damaging the battery, a charger must have tight voltage regulation, low ripple voltage and low electromagnetic interference (EMI) and radio frequency interference (RFI) noise characteristics.

The battery charger used in this study is the Powerwise™ II portable fully automatic line compensating, 21 amp DC output at 36 volts; input 120 volts, 9.5 amps, 60 cycle AC, Underwriters Laboratories (U.L.) Listed, C.S.A. The PowerWise II retails on the E-Z-GO Official Online Store for $434 and has a rated efficiency of 85 percent. A similar charger, the Xantrex TrueCharge 2, retails between $250 and $300 and has a rated efficiency of greater than 80 percent. Efficiency of 80-85 percent appears to be the industry standard for electric golf cart battery chargers.

A timer is available for $125 for the Powerwise™ II from GroovyCarts.com. However, a simple outdoor outlet timer may be more cost effective and adequate for most electric cart charging environments.

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[9] Personal communication, Ontario Battery Services (2010).

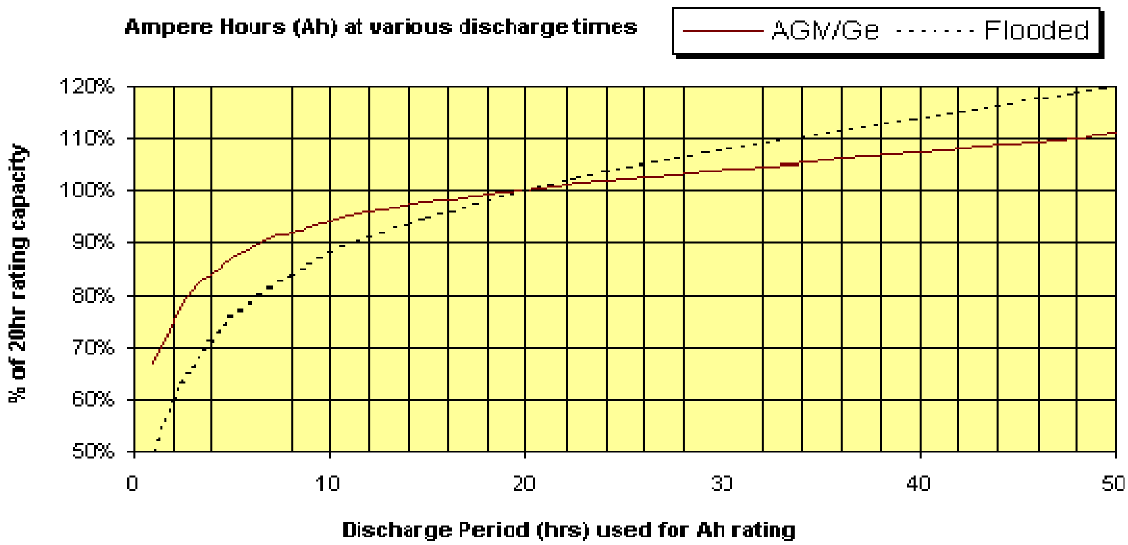

Figure C1: Battery efficiency at different draw-down rates.
Source: http://www.windpowerunlimited.com/batteries/Amp_Hours.htm

Conclusion

Golf cart battery charging involves many considerations but it essentially boils down to ensuring that the battery receives enough current to adequately charge the battery and keep it charged without letting the battery get too hot. A timer can be used to delay charging by an hour or two, thus charging during off-peak hours, thereby reducing carbon and pollutant emissions and taking advantage of "Time of Use" electricity rates.

At the 2009 International Battery Conference (BATTCON®), a panel of experts was asked what they considered to be the three most important things to monitor on a battery. They unanimously agreed on two: battery temperature and current. (Byrne, 2010)

APPENDIX D

Periodic Service Schedule:
Gas vs. Electric

Table D1: Periodic Service Schedule: Gas vs. Electric

GAS	ELECTRIC
MONTHLY - after 20 hours of use CHOKE CABLE Check for smooth movement and adjustment Check attachment, adjust as required DIRECTION SELECTOR Check attachment, adjust as required ENGINE Check for unusual noise, vibration, acceleration, oil leaks COOLING FAN **QUARTERLY - after 50 hours of use** ENGINE ELECTRICAL SYSTEM Check coil/spark plug wires for cracks/loose connections FUEL SYSTEM Check for leaks at tank, cap, system lines, filters, pump, carburetor Check system lines for cracks/deterioration THROTTLE/GOVERNOR LINKAGE Check operation and governed speed HARDWARE AND FASTENERS Check for loose or missing hardware and components Tighten or replace missing hardware **SEMI-ANNUAL - after 125 hours of use** BATTERY Clean battery & terminals DIRECTION SELECTOR Check for wear and smooth movement (lubricate shaft with light oil if required) AIR FILTER ELEMENT Check filter element, clean/replace as required OIL FILTER Clean in solvent (at oil change), replace 'O' rings if required ENGINE OIL Replace with SAE 10W-30 or 10W-40 that meets or exceeds SF, SG, CC oil, DO NOT OVERFILL DRIVE BELT Check for cracks, fraying and excessive wear **ANNUAL – after 250-300 HOURS** FUEL FILTER - Replace SPARK PLUGS - Replace, gap new plugs (Ref. Fig. 39 on page 23) MUFFLER/EXHAUST Check mounting hardware; check for leaks at head and muffler gaskets VALVES Check cold (intake/exhaust) per Technician's Repair and Service Manual **After 500 HOURS** TIMING BELT Check tension and for signs of wear/damage, replace if worn or damaged CARBURETOR - Clean CYLINDER HEAD AND PISTONS - Remove carbon from cylinder head and pistons Check valve seats for carbon buildup and clean as required	**MONTHLY - after 20 hours of use** BATTERIES Clean batteries & terminals. Check charge condition and all connections WIRING Check all wiring for loose connections and broken/missing insulation CHARGER / RECEPTACLE Clean connections, keep receptacles free of dirt and foreign matter ACCELERATOR Check for smooth movement PDS SYSTEM Check for PDS Controller braking force **QUARTERLY – after 50 hours of use** POWERWISE™ CHARGER PLUG - Clean auxiliary contact **GOLF CART SPECIFICATIONS** GAS: 9 HP, 2 cylinders, 95 cc ELECTRIC: 2.5 HP, 1.9 kW, 36v