Greening the Fairway

Final Report 2011

Lafayette College Technology Clinic
Easton, PA

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EXECUTIVE SUMMARY

The 2010-2011 Tech Clinic project is an extension of the previous year's, during which the group developed a solar-powered low speed vehicle (golf cart). This year's team aimed to (1) reduce the power requirements of this vehicle, (2) maximize the vehicle's power potential, and (3) show that it can be an efficient alternative in settings ranging from golf courses to college campuses. We created a business plan to model the benefits of investing in sustainable low-speed vehicles (LSVs) and illustrate existing business potential.

The team has partnered with the Slate Belt Council of Governments and Air Products and Chemicals Inc, the former of which is interested in the project's potential to bring business and entrepreneurial activity to the Slate Belt region. Air Products sees potential for this project to be expanded into the field of hydrogen fuel and as the starting point for the development of educational programs in the Lehigh Valley. Over the past year, Technology Clinic completed research and preliminary designs for the use of a hydrogen fuel cell, but unfortunately could not complete a hydrogen prototype due to time and monetary constraints. The Technology Clinic instead successfully expanded the solar design of the previously developed solar LSV, doubling the solar energy capabilities of the preceding model.

The Technology Clinic believes solar low speed vehicles have application potential in a variety of settings. We collected empirical data of golf course LSV use, and also Lafayette College's delivery and maintenance services use of LSVs. We then calculated the energy savings and reduced carbon emissions from switching to solar powered LSVs and determined the solar potential in the various settings. Depending on the area of use, up to 39.57% kWH of savings is attained from utilizing a LSV outfitted with eight 15 W solar panels.

The Technology Clinic also analyzed the solar capabilities of solar charging stations, which provide another option to power LSV's by solar energy. Using the solar charging station at Metzgar Sustainability Center, the Technology Clinic created a model enumerating the number of 200 W panels needed to power an LSV fleet. We estimate utilizing a solar powered LSV powered from a charging station saves up to an estimated 13,200 kWH per year and avoids 18,876 pounds of carbon dioxide emissions.

The Technology Clinic designed a business plan, centered on retrofitting LSVs with solar panels. The solar design implemented this semester cost an approximated $93.75, at retail price. With current solar retrofitting kits selling at $2,000, we suggest prices ranging from $500 to $1500 to maximize competitiveness and profitability. Our model shows retrofitting LSV's with solar panels provides a beneficial investment. The model illustrates a payback period of twelve years with a 34% return on investment for carts used for light utility work, and a 33% return on investment with a twelve year payback for carts used in settings with heavier use requirements. With these benefits, the Technology Clinic believes that solar technology will provide concrete economic benefits and is a viable business opportunity.

The Technology Clinic's work has shown Solar LSVs have significant potential to reduce carbon emissions and create business and entrepreneurship in the Slate Belt. The project also successfully promoted community engagement and created potential for economic growth within the Slate Belt. The Technology Clinic believes the developed model is the best economic option to create business opportunities and reduce carbon emissions. In the future, the team looks to hydrogen for alternative energy applications and is confident that hydrogen fuel cells will be an adequate option to power LSV's when cost and availability become more feasible.

Claire Brown

Majoring in Biology with a minor in Economics, Claire Brown ’12 wants to continue her studies and earn a graduate degree in nutrition and public health, specializing in community nutrition aid. On campus, Claire enjoys devoting time to the Landis Community Outreach Center, through which she coordinates an after school program for local children at the Easton Area Community Center. She is also involved as the treasurer of the Alterative School Break Club, which works to engage students in service projects throughout the year. Outside of academia, she enjoys competing in equestrian competitions and spending time with her sisters and the rest of her family.

Ting Chiu

As a major in English and minor in Psychology, Ting Chiu ’11 has spent the past two years invested in the Economic Empowerment and Global Learning Project (EEGLP) team at Lafayette College where she collaborated with community members in New Orleans and Easton, PA on economic development projects. Her involvement in activities on campus also include EXCEL work conducting a case study on rural water access, an internship at the Lafayette College Experimental Printmaking Institute (EPI), and Executive Board position on the Lafayette Activities Forum (LAF). Ting is currently working on an honors thesis in the department of English.

Brent Hoagland

Brent Hoagland is a member of the class of 2012 at Lafayette College. He is a Biology and Economics double major. He has been on the Executive Board of Landis Community Outreach Center’s Pre-orientation Service Program and works as a volunteer in many community programs. Currently, he is a member of the Economic Empowerment and Global Learning Project (EEGLP) team focus on development efforts in rural Honduras. Last summer he held an internship on Wall Street at a long/short equity hedge fund.

Chris Kelly

Chris Kelly ’13 is a sophomore Geology/International Affairs double major from Boyertown, Pennsylvania. Chris is currently the treasurer for the German Club, secretary of LEAP (Lafayette Environmental Awareness and Protection), and Resident Advisor for the TREEHouse. He ran track and cross country throughout high school and enjoys staying active playing ultimate Frisbee, jogging, and hiking when he has time. Chris hopes to combine his interests to engage in environmental diplomacy via a job, fellowship, or graduate school post-graduation

Elliott Mitchell-Colgan

Elliott Mitchell- Colgan ’12 studies electrical engineering and aims to develop more efficient technologies and make advancements towards a more renewable society. His academic honors include research and analysis of the design of sustainable energy systems, with reports on economic, environmental and social impacts. Elliott comes from Fairbanks , Alaska, prior to moving to Las Vegas where he attended a small liberal arts high school. His interests include the study of Spanish, German and Japanese as well as psychology. He also enjoys playing soccer and creating and appreciating artwork. Elliott hopes the Technology Clinic’s efforts will produce valuable findings that can be used to increase economic wealth and decrease negative impact our society has on the environment.

Zainab Nandawula

Zainab Nandawula, '11 is from Mukono, Uganda. She is majoring in Chemical Engineering with a minor in Economics. While at Lafayette,she has worked as an Excel scholar researching the conversion of cellulosic and other food wastes to fuel ethanol. She has been a chemistry tutor, a Writing Associate and an Intercultural Assistant with the Office of Intercultural Development.She has also served on the board of Minority Scientists and Engineers and the Lafayette chapter of Tau Beta Phi.

Alexandra Smith

Alexandra Smith ’11, is a senior chemical engineer major with a minor in art from Scotch Plains New Jersey. She attended a private high school that had a focus on sustainability, but her interest in green technology came to the for front when she took a class on green engineering and technology in Scandinavia, focusing on Norway and Sweden. In addition to her studies she’s a member of CHANCE Floor, Creating Harmony And Necessary Cultural Equality, a special interest living group and president of The Residing Association of Dedicated Stitchers

Dan Bauer

Dan Bauer is the founder of the Technology Clinic and Professor Emeritus of Anthropology. As an undergraduate he studied engineering and journalism. He has lived in Peru, Ethiopia and Mexico. Photography and automobile restoration are enduring interests.

W. A. (Bill) Hornfeck

Professor Hornfeck has taught Electrical and Computer Engineering at Lafayette College for over twenty years. He served as department head for fourteen of those years. Prior to his present position, he taught at Mississippi State University, Gannon (PA) University, University of Alabama in Huntsville, and Auburn University. He has worked at NASA’s Johnson Space Center and Computer Sciences Corporation, and been a consultant to the U.S. Department of Energy, NASA, U.S. Department of Defense, and General Electric, among others. Professor Hornfeck has combined his research interests in energy studies with international engineering education. He earned his MS and PhD degrees from Auburn University and the BS degree from Penn State University, all in Electrical Engineering.

ACKNOWLEDGMENTS

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Jeff Euclide, Entech Engineering
Judy Bauer
Brad Orey, Lafayette Reprographics
Bruce Ferretti, Lafayette Reprographics
Bob Chunko, Lafayette Plant Operations
Lafayette Electrical Engineering Department
Lafayette Sustainability Committee
Air Products & Chemicals Inc

- Brian Bonner
- Dave Taschler
- Dave Farese

Victor Rodite, Slate Belt Council of Governments
Lafayette Reprographics

- Gene Snyder
- Brad Orey

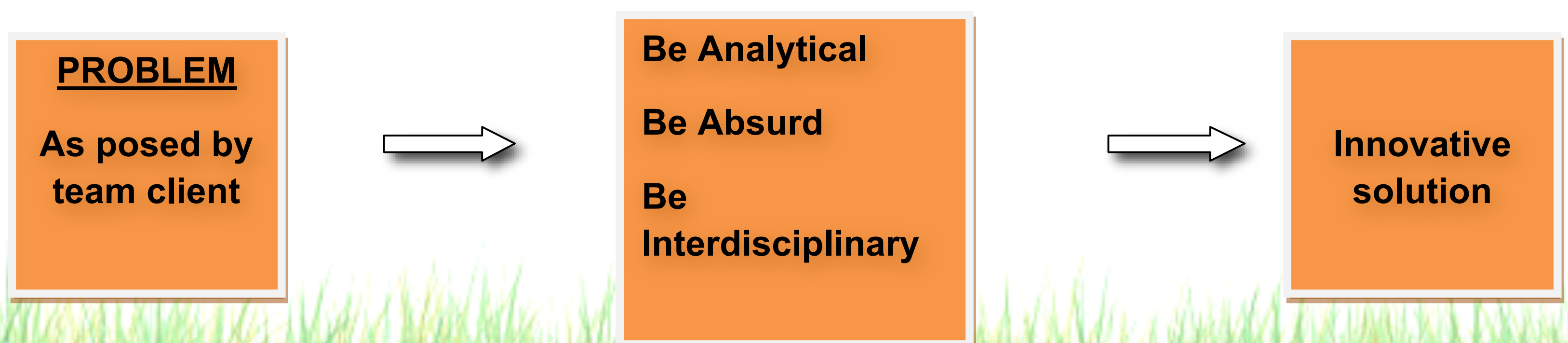
TECHNOLOGY CLINIC: A <u>“SYNECTIC”</u> APPROACH

At the heart of Technology Clinic, which was founded in 1986, is dedication to interdisciplinary learning, “town-gown” collaboration, and promotion of creative solutions to real-world problems. Small groups of students, each of whom hail from disciplines as diverse as Engineering and the Fine Arts, work under the mentorship of two faculty advisors to solve real world problems. Each yearlong Technology Clinic project focuses on a question or problem specified by a team client (which has in the past been both public and private organizations). One example of a notable Tech Clinic achievement is the water borne “Trash Skimmer” that rounds up debris contaminating bodies of water. This was designed and developed by the (1987) Technology Clinic team time and is now manufactured and used internationally.

We base our thinking on a problem solving technique known as ***Synectics*,** a methodology that encourages creative and sometimes counterintuitive solutions to problems and challenges. The approach is based on the belief that a group is greater than any of its individual members and encourages the building of ideas from that of others. ***Synectics*** makes use of metaphors among other educational strategies to encourage connection-making and allows risk taking in thinking. Success comes when highly involved, mutually supportive members of a group come together in a climate that supports teamwork, problem solving, and decision-making. The varying perspectives of students from diverse backgrounds are valued as the building blocks of novel solutions to difficult problems.

“The process of creative thinking comes from understanding and struggling with making the absurd possible, the unheard of acceptable, the unfathomable concrete.”

- J. Martin Hays



Current Project

The work of the current Tech Clinic Team is an extension of the 2009-2010 Tech Clinic project, which resulted in the production of a solar-powered golf cart. This year's team aims to reduce the power requirements of this vehicle by looking towards improvement of battery life and performance, as well as other ways of producing energy in an environmentally friendly fashion. In particular, our goal is to prototype a golf cart that can provide the equivalent of thirty-six holes of golf daily.

The development of a green low speed vehicle is of particular interest to this group for several reasons. In particular, low speed vehicles using renewable energy sources provide an opportunity to substantially reduce greenhouse gases that would otherwise be emitted by large vehicles travelling small distances. Moreover, their low cost and energy requirements make them suitable foundations for subsequent development of green energy technology in other transportation systems. In addition, low speed vehicles powered by renewable energy are an advantageous investment and provide many industry opportunities.

Client

The current project is a partnership with **Air Products and Chemicals Inc** and the **Slate Belt Council of Governments.** Air Products sees an opportunity to expand the solar golf cart project by incorporating the use of hydrogen fuel. It also has an interest in supporting worthwhile educational programs that the project might inspire or create in the Lehigh Valley area. In a complimentary role, the Slate Belt Council of Governments views the project as one with potential to create business and entrepreneurial applications in the Slate Belt.

Mission Statement

Research and development of an environmentally sound and economically feasible low speed vehicle that can provide industrial opportunities in the Slate Belt Region.

ALTERNATIVE ENERGY

As a first step to achieving our goal the Technology Clinic considered four different options of powering the golf cart and assessed each option for both ecological and economic viability. The fall semester of our project was spent on investigating mainly wind, biofuel, hydrogen and solar as options of alternative energy. We determined that Biofuel and wind were not feasible, and therefore narrowed down our study to Hydrogen and Solar energy.

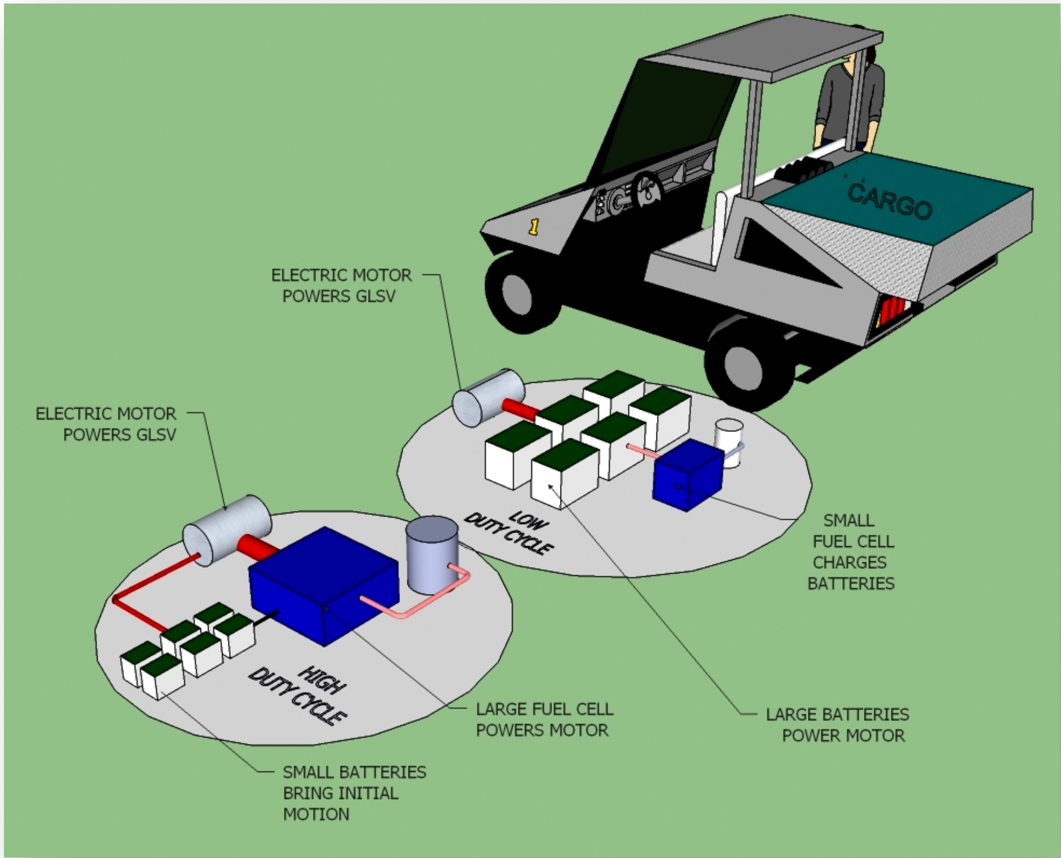
Wind	Biofuel
• Method: Wind→ kinetic energy → mechanical energy → electricity • Device: Wind generator, wind charger • Conclusion: - Pros= low long-term cost, - Cons= high initial capital investments, large area needed to house the windmill, windmill can be disruptive to natural landscape	• Fuels: Biodiesel, Bioethanol, Solid biomass • Method: Gasification of solid biomass Bioethanol: hydrolysis and fermentation of sugars Biodiesel: transesterification of oils & fats • Conclusion: - Pros= neat concept, reduced emissions, greater energy balance, mainly use waste - Cons= current production methods are not environmentally friendly, difficulty accessing raw materials that can properly be used to process fuel
Hydrogen	**Solar**
• Method: Electrochemical cell converts fuel→ chemical energy → electric energy by stripping the hydrogen from natural gas • Device: Hydrogen fuel cell powered by hydrogen fuel • Conclusion: - Pros= already being applied to the vehicle industry, production of hydrogen car models, buses and boats are in production as well - Cons= high cost	• Method: photovoltaic cells convert sunlight → energy • Device: Solar panels • Conclusion: - Pros=Very effective, well known, consumer friendly, practical for any industry - Cons= not a new idea

Hydrogen v. Solar

In the end, the Technology Clinic concluded that while hydrogen powered low speed vehicles would be a viable option in the future, the current cost and limited production of fuel cells made the idea uneconomical and unfeasible for this semester's project. Our decision was aided by the use of a software program known as Wisedecider (Appendix 1.3) Instead, the Technology Clinic designed a model that would be applicable to hydrogen powered golf carts given more time and resources. The following are the kinds of factors we considered when weighing the options between improving our golf cart with hydrogen or solar.

Factors	Hydrogen	Solar
Cost	Currently high due to limited availability (Estimated $15,000)	Widely available and cost within our resources (Estimated $300)
Originality	Never previously done	Previously done, with room for expansion
Availability	Best suited model for this project is currently utilized only in telecommunications systems	Easily ordered from reliable, known company
Feasibility	Difficult given the short timeframe	Applicable in one semesters timeframe
Market Potential	New concept, not known by the majority of consumers.	Better marketability since solar energy is a well known alternative energy source

The Technology Clinic did, however, create a model for potential powering of low-speed vehicles with Hydrogen fuel cells. The ‘high duty cycle’ model is analogous to the Chevrolet Equinox, where the Hydrogen fuel cell powers the engine and also includes a small battery set to bring initial motion to the vehicle. The ‘low duty cycle’ model is similar to the Chevrolet Volt where the fuel cell powers a large battery set which in turn powers the motor.



Retrofitting the Current Golf Cart

The Technology Clinic decided to expand the potential of the golf cart model previously designed. We concluded that doubling the cart's panels from four 15 W panels to eight 15 W panels would both max out the potential for on-board solar, and provide enough energy to accommodate low speed vehicle use in a variety of settings.

Battery options

We next looked at different battery options to determine the most efficient and environmentally friendly option to power the low speed vehicle with (Appendix 1.3). We determined that, given cost and availability, lead-acid batteries remained the best option for this project. We replaced the old lead-acid batteries in the cart with new ones in order to collect more reliable data on the performance quality of the batteries. We predict in the future, Lithium ion batteries will provide a better option.

Battery Type	Brief Description
Lead acid batteries	○ Cheapest, most available, and easiest to use and maintain ○ most widely used battery ○ Heavier per unit power compared to other options ○ Lead makes this option environmentally hazardous
Nickel Metal Hydride batteries	○ Found in the Toyota Prius ○ More expensive than Lead-Acid ○ Better weight to power ratio and a better environmental profile ○ Harder to regulate charging process
Lithium Ion Batteries	○ Used in hand-held electronics and the Chevy Volt ○ Much newer and less well understood in terms of safety and performance ○ Povides much more power ○ Lightweight ○ Expensive ○ Harder to regulate charging process

Overall Improvements to the cart	
Batteries	**- Up to 53.2V (fully charged)**
Solar panels	**- 8 panels** **- 120 Watt rating** **- 48 volts**

Given consumer's increasing environmental consciousness and the healthy current atmosphere, the low-speed vehicle market is a smart investment. In looking at solar panel investments and respective duty cycles, we determine that there are two possibilities to power a cart with solar energy. Solar panels in stationary charging panels will provide sufficient power for a fleet of golf carts, and are applicable to settings with heavy use requirements. Additionally, solar panels attached on-board the golf cart provide enough solar energy to power golf carts used less intensely over the course of a day.

In the context of this project, the "duty cycle" is defined as the ratio of moving work (vehicle is operating) to stand-still (time when solar panels are collecting solar energy). On-board solar panels only make sense if the application exhibits a fairly low duty cycle so that it has plenty of rest to collect energy. An on-board system of solar panels would be worn down quickly if put under too rigorous an operational schedule. In this case, a stationary system of solar panels would provide a better option since energy can be collected all year long. This application is well suited for a golf course as the solar panels will continue to collect energy even when the golf course is non-operational in the winter months.

Determining Use Requirements of LSVs on Golf Courses

In order to determine whether on-board solar panels or stationary charging systems would be the best option for a golf course, we first collected some key information from fifteen local golf courses. The key findings from this survey are as follows:

- Most golf courses are a North Eastern rolling hills, which means they are 50 % flat and the hills are not steep.
- The average length of cart paths is about 4 miles
- Golf courses typically have 75 golf carts.
- Most of the golf courses in the Lehigh valley are publicly owned
- Many golf courses lease their carts at a cost of approximately $53,000 per year for 75 carts

We tested the current golf cart in order to determine the solar energy capabilities of on-board panels. The conducted trials allowed us to determine if a golf cart powered by on-board solar panels would provide enough energy to meet the use requirements in different duty cycles. We tested the cart over a route that simulated a golf course. See appendix 1.3.

<u>We tested the golf cart under three conditions.</u>

(1) Without solar panels (powered by battery only) – To determine the energy consumption of an electric golf cart

(2) With the original solar array plus battery set – To determine the energy output of the cart with four 15 W solar panels

(3) With the expanded, doubled set of solar panels plus the on-board batteries. – To determine the energy output of the cart with eight 15 W solar panels.

Testing Summary

	No Solar Panels	4 15 W Solar Panels	8 15 W Solar Panels
Energy Consumption (kWH)	**2.4**	**1.27**	**2.75**
Total Mileage (miles)	**4.04**	**4.04**	**4.33**

The empirical data collected throughout the tests runs allowed the Techology Clinic to calculate the solar energy potential of golf carts utilizing on-board solar panels. We assume seven hours of sunlight per day and 212 sunny days per year. See appendix 1.4 for testing details.

Solar Potential of On-Board Solar Panels	
Solar Hours/day	7
Sunny days/yr	212
Energy Consumption with 4 panel (kWH)	2.4
Energy Savings (kWH/yr)	115.42
Energy Consumption with 8 panel (kWH)	1.27
Energy Savings (kWH/yr)	488.07

Determining the Use Requirements of LSVs on a College Campus

After determining the solar energy potential of on board solar panels, we then collected data of golf cart use in lower use settings, where on-board solar panels will provide a reliable option to power golf carts. We collected data on golf cart use in two settings at Lafayette College.

(1) Reprographics and Bulk Mail Services

a. Golf carts utilized to operate delivery services

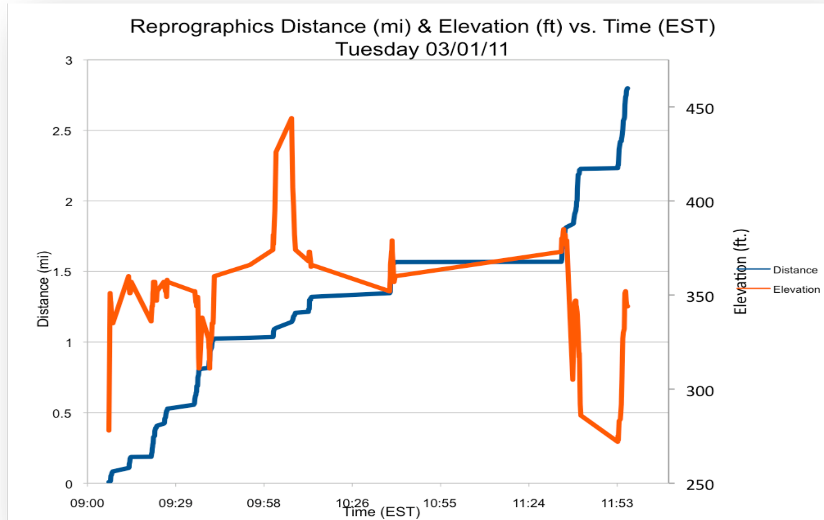
b. Use is concentrated in one part of the day, and only short distances are travelled.

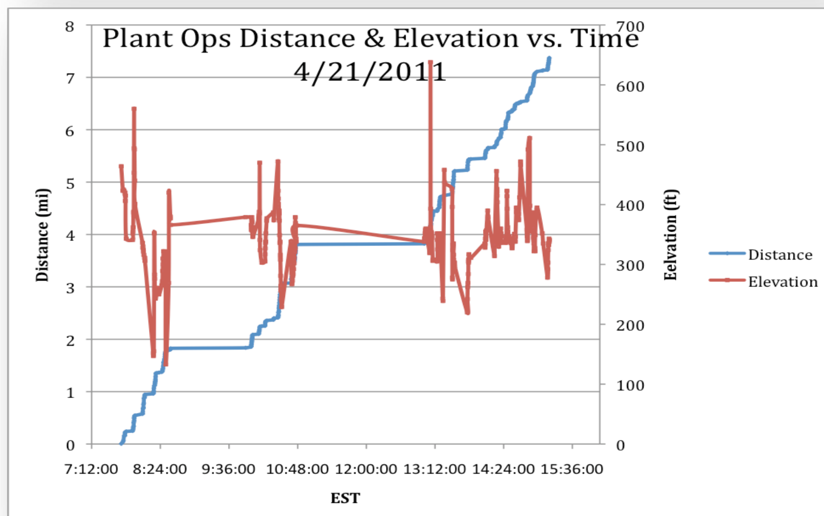
c. On-board solar panels would provide enough energy to power carts

(2) Plant Operations

a. Use small utility low-speed vehicles utilized for grounds keeping and gardening purposes.

b. Plant Operations vehicles undergo heavier use, sometimes handling heavy loads or travelling steeper terrain. While on-board solar panels may provide enough solar energy, stationary panels may also be a viable option in certain utility settings.





Figures at right detail operation of golf cart use on Lafayette College Campus, see appendix 1.5 for details.

On-board solar energy production applications

After determining the solar potential of the golf cart utilizing on board panels, and also the use requirements in three different settings, we calculated the percent of kilowatt hours saved if a solar golf cart were utilized instead of a standard electric cart. Calculations for both the solar models are shown.

Application	4 panels (% kWH Saved)	8 panels (% kWH)
Golf Course	8.74	36.98
Mail Delivery	23.45	99.17
Landscaping	9.36	39.57

We also compared this to the energy consumption over one year's time of a golf cart with no solar panels in the three use settings.

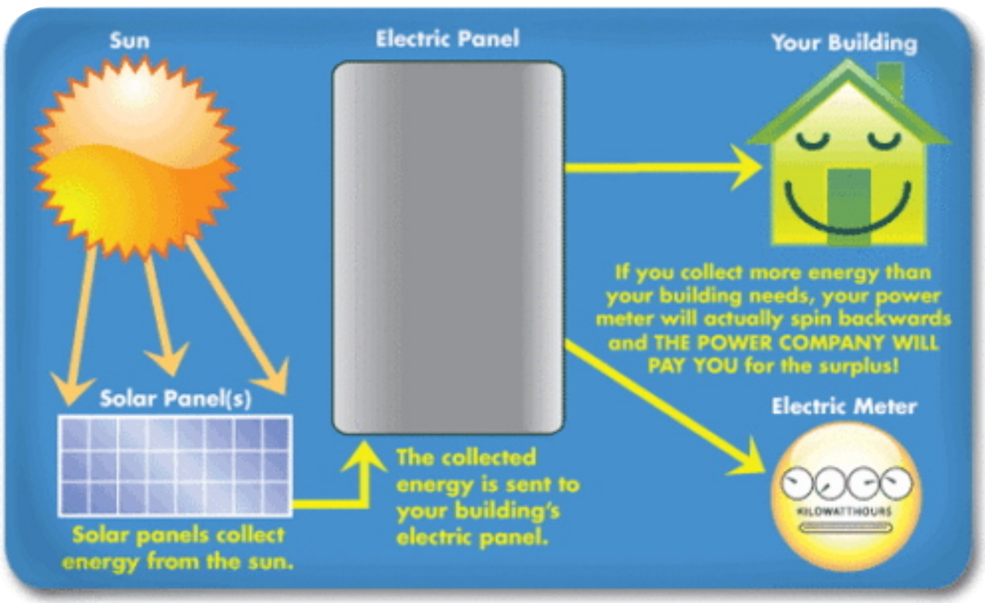
Application	Miles/day	Days/ Yr	Energy (kWh/cart/yr)
Golf Game	8.08	240	**1320.00**
Mail Delivery	2.410	300	**492.14**
Landscaping	6.04	300	**1233.42**

Solar Charging Stations

After determining the needs of a golf course and calculating the energy potential of on-board solar panels, we also looked into solar charging stations, another option to provide solar energy for low speed vehicles. With stationary panels, sunlight would be collected and sent to the electrical panel.

Electrical Costs: Average Golf Course

With stationary panels, instead of the cart directly collecting solar energy, a solar station collects energy on the grid. Golf carts collect solar energy by connecting to the grid at night. By putting solar energy on the grid, golf courses would be saving the cost of electric previously used to power the golf carts. Our research of golf course electric costs revealed on average, courses pay 14 cents per kilowatt. With a solar charging station, the electrical costs would be reduced and the golf course would also be entitled to net metering benefits (See appendix 1.6 for details).



Determining Stationary Panel Requirements

We used Lafayette College's solar PV station located at the Metzgar Sustainability Center in Forks Township, Pennsylvania as a case study of stationary panels. There are a total of 16, 200W solar panels at Metzgar fields, and the Technology Clinic gathered data regarding the energy production of this solar array to demonstrate how a stationary solar panel can meet the needs of a golf course (see appendix 1.7 for details). Using the data collected from the Metzger center, we calculated the solar charging station size requirements needed to offset 100% of the annual electricity costs of a golf cart fleet. We calculated the number of required panels for low use and high use settings in order to determine the best option (on-board or stationary) for each application. As illustrated in the graph below, 20, 200W solar panels provides enough energy to power about 10 LSVs without the need to plug in to a source of electricity.

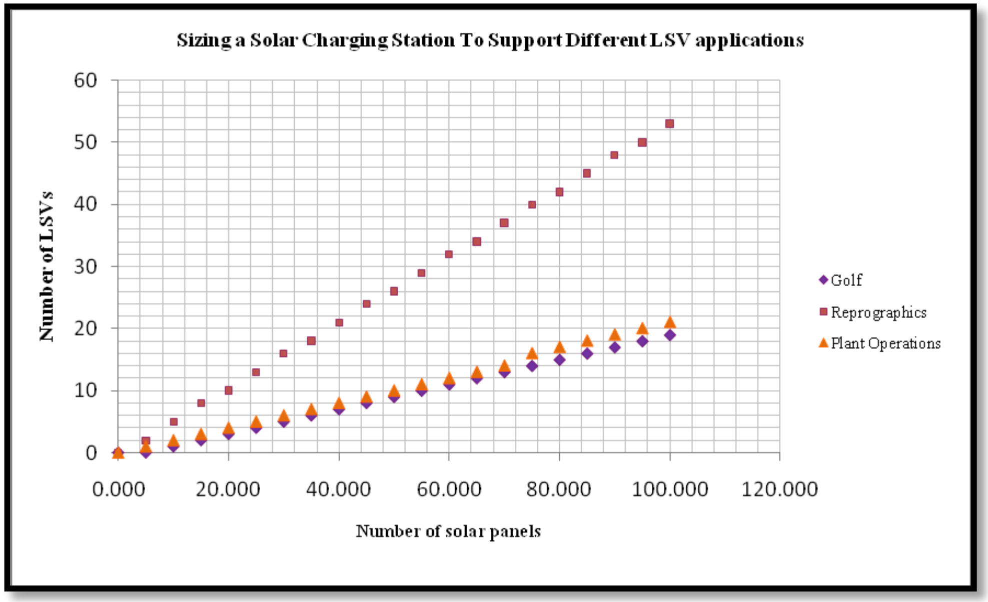


Figure at right: number of low speed vehicles that can be supported by different solar PV panels

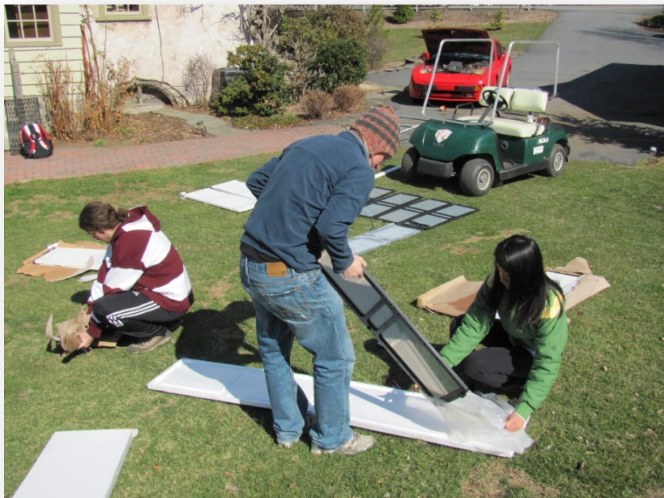
After calculating the energy savings in each application, we determined the amount of environmental savings that would be gained by adopting stationary charging panels to operate low speed vehicles.

Environmental Savings

Energy (kWH/yr)	CO_2 Avoided (lbs)	Gas Displaced (U.S. gal)	Trees Replaced (Rain Forest)
115.42	165.05	8.25	4
488.07	697.94	34.9	14
13200	18876	943.8	378

Creating a Product: An Economic Business Model

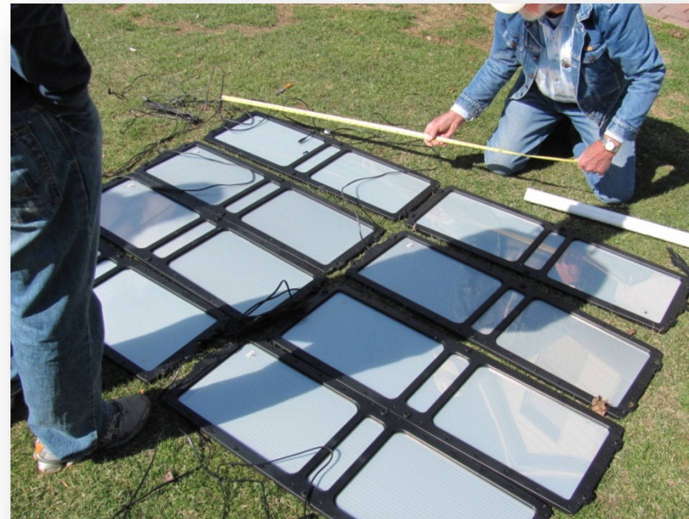
As we spelled out in our Mission Statement, the Technology Clinic underwent this project for two main reasons: to (1) create an environmentally sustainable LSV and (2) analyze the potential economic viability of the product as an investment opportunity for the Slate Belt Region. By retrofitting our existing golf cart and doubling its on-board energy production capacity, we have successfully accomplished the first part of our mission and created a prototype for an LSV that we believe is marketable to various industries. In this section of the report, we present our business model and discuss the economic feasibility and profitability of this product. The benefits to be had in terms of reduced carbon footprint outweigh the direct economic benefits, but non-quantifiable compensation that a consumer gets from purchasing the product (i.e. energy independence and increased self-esteem for a good deed) must be factored into the market price of current green technologies.



Current solar retrofitting kits sell at $2,000. Tech Clinic retrofitted our own golf cart with four additional 15 watt solar panels as well as materials (tubes, screws, glue and wood). The cost per panel plus materials was an economical $93.75, and all purchases were made at retail value. We think a retrofitting company would be able to purchase at whole sale prices and be able to lower costs even further. The $93.75 cost we calculated does not, however, cover cost of labor that would presumably be needed to professionally retrofit a golf cart. The cost of a professional installation will therefore likely be higher than the raw cost of materials. An additional amount might also be needed for the purchase of a charge controller to regulate the charging of the battery in a golf cart.

Solar Retrofitting Kits	**Tech Clinic Retrofitting** (solar panels and installation materials)
$2000	$93.75

The market for green technologies tends to be priced at a level that exceeds the economic benefits or returns of the product; consumers are willing to pay a premium for the newest and greatest technology; it is for this reason that solar retrofitting kits can be sold at a price much higher than the value of its raw materials. We suspect that the appeal of solar power will be sustainable beyond the “early to adopt stage” and will continue to be marketable even when consumers no longer are “trendsetters” for using solar-powered gear. As the chart below illustrates, Tech Clinic has combined the explicit and implicit benefits of using solar energy to suggest possible selling prices of “Light Utility” and “High Utility” golf carts. A “Light Utility” vehicle equipped with 8, 15 W panels, for instance, would only cost $750 to retrofit but could sell at a price of $1,500, double the cost of equipping.



Energy (kWH/yr)		**Cost**	**Benefit**	**Suggested Price**
Light Utility	**115 (4 panels)**	**$375**	**$238**	**$500**
Light Utility	**488 (8 panels)**	**$750**	**$948**	**$1500**
Heavy Utility	**488 (8 panels)**	**$750**	**$945**	**$1500**

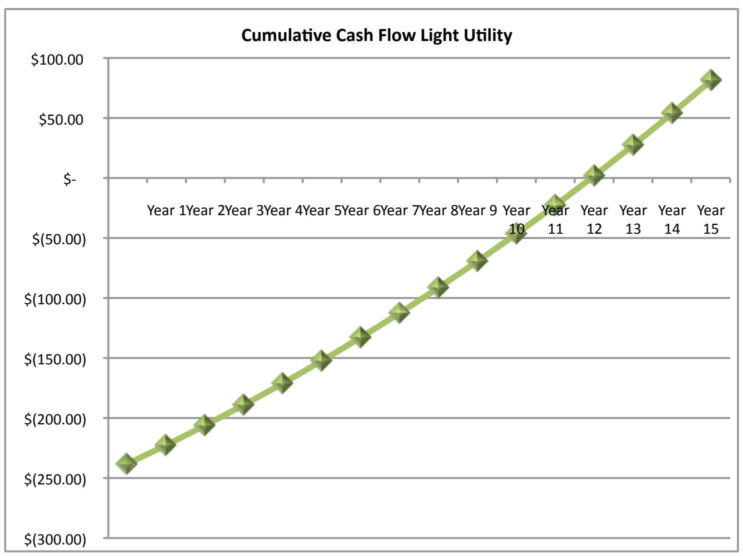
<u>Determining the economic value to the consumer:</u>

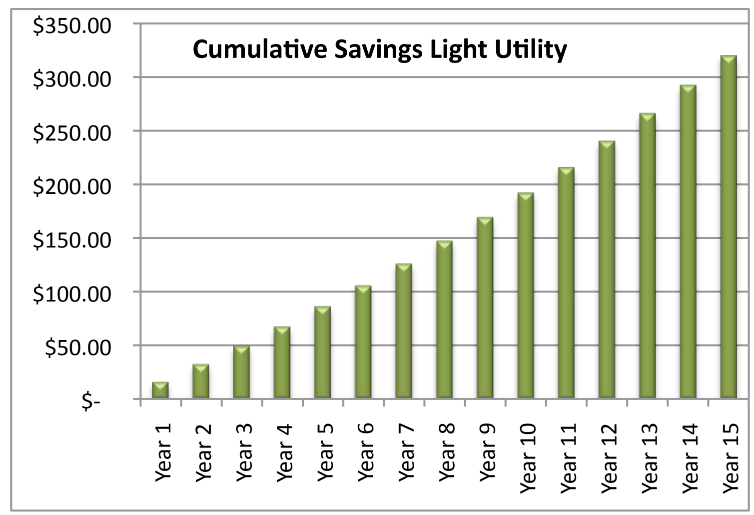
The data collected from the empirical test runs were used to calculate the energy consumption of each type of low speed vehicle as well as the energy produced from four panels or eight panels. The cash flows were mapped out for the original outflows with no solar panels and solar outflows with the number of appropriate solar panels. Electricity costs increase at a 2% rate per year. The cash flows were then discounted using a 4% rate. Determined by the capital structure of a golf course, rate to borrow, tax rate, risk free rate, beta and risk premium. The cost per cart was then calculated by holding the net present value at zero.

Payback: year 12

ROI for Light Utility = 34%

ROI for Heavy Utility = 33%





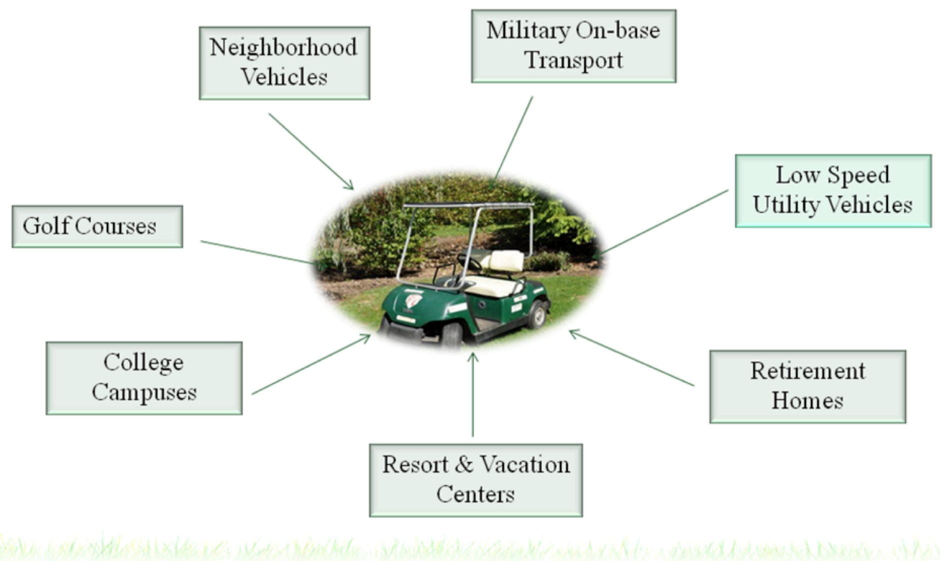
Applying the Business Model to a Golf Course

The duty cycle of a golf cart was too high to install solar panels at this time and meet the requirements of 36 holes a day. Our previous report noted that a stationary charging station would be an acceptable alternative. Our model represents a for-profit golf course that could fit 50 200watt solar panels on the property. The solar installer charges $5 per DC peak watt. This was determined by surveying companies and averaging prices. A federal tax credit of 30% can be applied to the total costs of installation. By mapping out the cash flows and the savings in energy costs, the return on investment is 26%, internal rate of return of 2%, payback period is in year 17 and a compound return of 4%. The course would be able to run 9 carts by solar energy alone and would save 13200 kWh per year. This investment is sound for the golf course and is profitable for an installer.

Potential Markets for Green Golf Carts

In addition to golf courses and Lafayette College, there are many industries and types of venues to which a green golf cart can be marketed. Many Resorts and Vacation Centers, for instance, already use golf carts (for transportation, grounds maintenance, etc.) so the added benefits of a *green* golf cart could be an attractive investment.

Business &Market Opportunities



There is, however, future market research to be done in order to better understand the selling potential of a green golf cart. The Tech Clinic feels the following are particularly important questions that can be addressed by a Slate Belt business or a future Tech Clinic group.

- Do people really care about green products?
- Can the prestige of using green energy boost demand of green products?
- Who is willing to pay to go green?
- What premium is too high to pay?

Tech Clinic's Role in Society

As part of our closing remarks, the Tech Clinic team would like to comment on the role that we see ourselves as playing in our immediate as well as extended community. Over the course of retrofitting a solar-powered golf cart, assessing the ecological sustainability of the product, and developing a business model that examines the potential the golf cart has to bring entrepreneurial opportunities to the Slate Belt Region, we hope the Tech Clinic team has accomplished the following:

- Inspiring social entrepreneurship among students
- Promoting community engagement and involvement
- Playing an educational role in society

We sought to accomplish these three things by introducing the younger generation and inspire in them the spirit of entrepreneurship when we presented "synectics" and our current project to the students of Pen Argyl High School. We furthermore presented to math, science, and technology teachers at Bangor High School in the hopes that the concepts behind Technology Clinic projects will be integrated into high school curricula so that students can begin thinking about creative problem-solving with real-world implications at an early age.

Summary of Findings and Concluding Remarks

The Technology Clinic provides a unique opportunity for creative thinking and problem solving. At the beginning of the year, the group came together and began researching the various applications of green energy in the hopes of improving upon a product developed by a previous Technology Clinic. We ultimately settled on investigating solar energy as had been on the original cart, but we improved the energy-generating capacity by doubling the solar array of our golf cart from 4 to 8, 15 W panels. With this new and improved golf cart, the Tech Clinic team has drawn the following from our work over the past year:

1. Practical designs of hydrogen fuel cells in LSVs are possible in the future

2. Solar LSVs show significant potential to
    - Reduce carbon emissions
    - Create business and entrepreneurship in the Slate Belt

3. Tech Clinic continues to play a great role in
    - Nurturing a problem-solving mindset in students
    - Promoting community engagement

The use of hydrogen fuel to power a golf cart was an entirely new concept for which we did not feel we had appropriate time to conceptualize a prototype. The production and distribution of hydrogen are currently in the infant stages and acquisition of a hydrogen fuel cell would furthermore be costly. Solar, on the other hand, was well-known by both members of the Technology Clinic and also the potential consumers we hoped to attract through the project. We ultimately decided to focus solely on the research and prototype development of a hydrogen golf cart, while tangibly expanding the energy capacity of our current solar model by doubling the solar panel array. In accomplishing this, the Technology Clinic proved hydrogen fuel cells are a viable option to power golf carts. We also designed a prototype as to what this would look like. Given this information, future Technology Clinics with more time will be able to focus on the development of a hydrogen powered cart, using our design as an idea springboard. Until that time, when hydrogen fuel cells become more widely available and more economically feasible, solar powered golf carts are a very beneficial option to increase sustainability. We feel that through out work together, we have successfully accomplished our mission. We first went about researching the most environmentally sound low speed vehicle. In considering the second important aspect, economic feasibility, we decided currently solar power would be the best option. Then, we expanded the solar design, creating a LSV with enormous potential for consumer investment. From here, we designed a business plan to model the gains from investing in a solar powered low speed vehicle. We feel this model will be able to be applied to businesses in the Slate Belt Region, looking to adopt solar energy a business investment.

Given our time constraints, the Tech Clinic was not able to explore every avenue of research and study that we feel are important to our project. We therefore propose the following list of “Future Work on Green LSVs” that Tech Clinic teams succeeding us can consider pursuing if they seek to build on our work this past year:

1. Design and build a hydrogen LSV
2. Expand empirical tests on the solar carts
3. Research the use of more efficient PVs
4. Investigate other technology concepts e.g. the importance of charge regulators

Appendix

1.1 Making the Decision between the use of a hydrogen fuel cell or solar energy to power the low speed vehicle

The decision making program “Wise Decider” was used to aid our various decision-making processes throughout the project. This flexible and customizable program allowed us to input the various factors that we feel were crucial to arriving at a decision regarding whether to use hydrogen or solar to retrofit our existing golf cart. Examples of factors and questions the Tech Clinic team find to be important include “Do we have the proper resources?,” “Can we finish on time?,” and the “marketability” of the golf cart product we ultimately design. The shade of gray indicates the level of negativity of any given variable, with the darkest indicating the most negative. The answer “No” to the question “Can we finish on time?” is the darkest shade of gray because it represents a severe obstacle to using hydrogen energy for our project.

An example of an output window from the program is shown below:

Decide

Name for Decision | Alternatives | Values | Outcomes | Explore Table | Decide

	can we finish on time?	do we know potential users	do we have resources?	marketable	SB jobs potential	newness
on-board solar utility	Yes	can be used on campus	we have the funds we have the expertise	case can be made	cart modifications	similar product exists
fixed solar	Yes	can be used at Metzgar	can collect numbers from Metzgar and do the math	case can be made	panel installations	has not been used for golf
on-board solar golf	Yes	Duty cycle?Are there 18 hole users?	we have the funds we have the expertise	somewhat	cart modifications	similar product exists
hydrogen charged LSV	No	no	we might be able to get funds and less complex	less expensive, what price?	seems possible	never done on non-fork lift LSVs
hydrogen powered LSV	No	no	do not have the funds, need more time, and will need some exp help	very expensive, 3kw unit $15k	?	never done on non-fork lift LSVs

1.2 Research of low speed vehicle applications

As a part of the necessary research for our project, the Technology Clinic gathered information about Low speed Vehicles (LSVs). We found that LSVs are being increasingly used in commercial and industrial operations where the need for a convenient and quiet vehicle is required. Due to performance and cost constraints, the economical and ecological viability of any cart would depend upon the “duty cycle” of the applications.

Given their high demand, commercial golf courses offer a market niche that the environmentally friendly golf cart could occupy. As courses become more environmentally conscious in their operation, using a solar powered low-speed vehicle could become very attractive. In this application, solar -energy will be collected in stationary panels and used as needed because the operational demand is so high.

Other than on a golf course, regular or modified golf carts and other forms of low-speed vehicles are also being used today with more frequency in other contexts such as

(1) Recreational settings such as retirement and other residential communities

(2) Models with a flat bed are useful to landscapers and gardeners (vehicle may in this case have a higher duty requirement since it is being used to transport heavy object or materials)

On-Board Solar Panels to Power Golf Carts

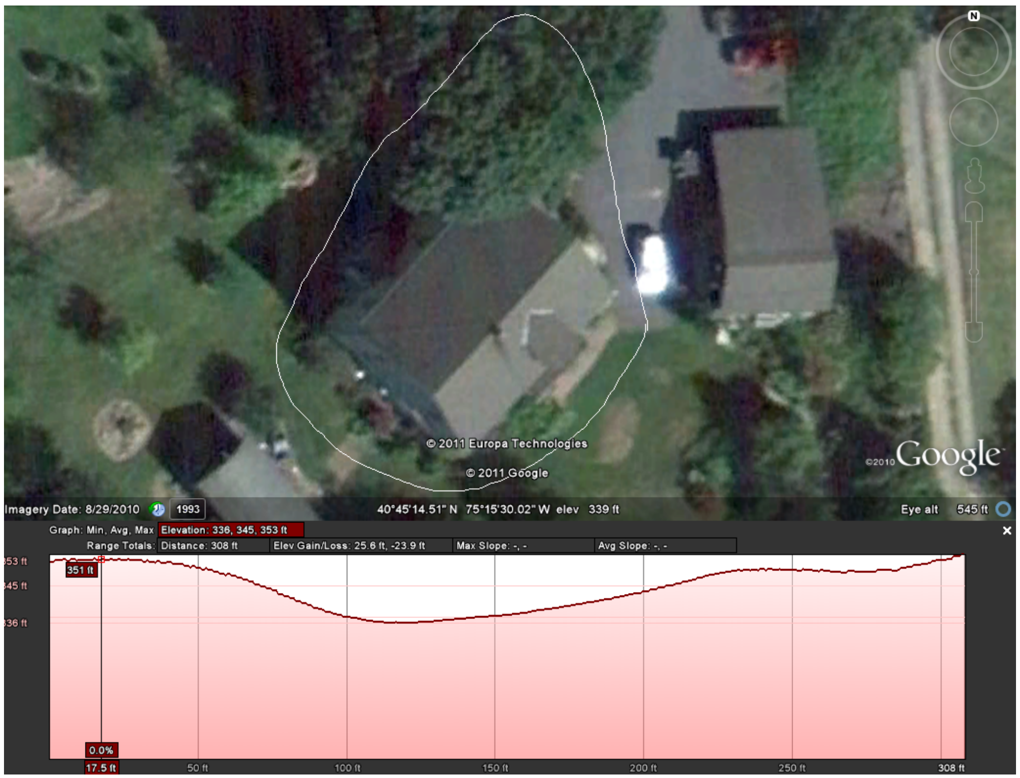
On-roof solar panels provide a power option for low speed vehicles with lighter use requirements. In recreational settings, such as retirement communities or college campuses, average use may be under an hour per day. Given adequate sunlight, enough energy would be gathered during times of rest to power the vehicle when needed. Low speed vehicles in utility settings also can be powered by on-board solar panels, but in a setting such as this, the cart undergoes additional strain from carrying a utility load, and so utilizing the maximum surface area of the roof would be beneficial. By collecting data on the use of golf carts in these various settings and then testing the needs against the ability of our golf cart, we are able to generate a model and conclude that replacing gas or electrical carts with solar vehicles will be beneficial economically and environmentally.

Stationary Solar Charging

With solar charging stations, the energy collected during the winter months can be put back on the grid and then put into use during the summer months when the golf course uses the most energy to charge the golf carts or a potential solar-powered clubhouse. A golf course is an ideal location for the application of stationary solar panels because most golf courses will have a shed to store the golf carts and solar panels can be easily mounted onto the roof of the shed; the angle for optimal capturing of sunlight of course will be a factor determining the exact placement of the panels. An investment in solar panels means that a golf course can drastically decrease its energy requirements and potentially meet zero emissions standards.

1.3 Course description for testing golf cart capabilities

We estimated that two laps around our faculty advisor's property would be the approximate distance from hole to hole, and therefore used 72-lap travel distance as a proxy for the amount of usage typical of a golf cart. This distance is roughly 4.0 miles, an average length for a golf course path. The terrain of the said property matches the "North Eastern rolling hills" landscape that we found in the survey to be typical of golf courses, which makes our tests particularly good proxies for the energy usage that we aim to study.



1.4 Summary of golf cart testing

March 25, 2011

We tested the golf cart on this circuit with no panels connected as a control condition. This run served as a trial that all other solar panel data could be based off of to see what sorts of gains the panels offer compared to their absence. With a new battery attached to the cart, this test allowed us to determine the exact energy discharge of the battery over the 4-mile use cycle. The initial charge was measured to be 51.6 V. 5.4 V was discharged throughout the run and the voltage post-run was 46.2 V. **After running the course, it required 2.75 kWh for the battery to be recharged completely.** We, furthermore, placed 71 lbs worth of logs onto the cart to account for the added weight of two sets of golf clubs. The trial lasted roughly 90 minutes, approximately 4.0 miles were covered, and the outdoor temperature was 40°F.

March 28, 2011

We next tested the golf cart with the solar design implemented by the previous Tech Clinic, which utilized four sixteen kW solar panels. This run allowed us to test the solar potential of on-board panels, by measuring the battery discharge and recovery. The initial charge battery charge was measured to be 53.2 V. 4.7 V was discharged throughout the run, the post-run voltage being 48.5 V. **The golf cart battery required 2.4 kWh before becoming completely recharged**. We again added 71 lbs of logs, approximating the weight of two golf club sets. The trial lasted 90 minutes and the outdoor temperature was 41°F and 4.04 miles were covered.

April 15, 2011

The final test involved the current golf cart design, which utilizes eight sixteen kW solar panels. This test allowed us to gather how much additional solar energy would be gained from expanding the solar collection area. The initial battery charge was measured to be 53.2 V and 3.6 V was discharged over the 4.33 mile course. The voltage post-run was 49.6 V. **After the test run, it required 1.27 kWh to fully recharge the battery.** The weight of the simulated golf club bags was 71 lbs. The course took roughly 90 minutes, outside was partly cloudy with a temperature of 67°F.

Conclusion of the Three Tests

Over the three test runs, the kWh required to recharge the batteries to full potential decreased. The decreasing recharge requirement reflects the addition of the solar panels and solar energy potential. It should be noted that for each run including panels, four hours elapsed before measuring kWhs. This time period was meant to simulate normal golf cart use, where operating and resting time are intermixed.

1.5 Summary of campus use of golf carts

Testing Campus Use - Reprographics

Reprographics' average operating time was 2 hours and 13 minutes daily. Out of this time, between 16 and 27 minutes were spent moving between campus delivery locations. Average distance covered was 2.41 miles with an average moving speed between six and nine mph. The approximated duty cycle, or ratio of time spent moving, to time stationary ranges **between 1:29 and 1:44 (.034-.023)**. On average, a 100-foot ascent and descent is recorded with mild terrain elevations and drops recorded daily.

Testing Campus Use – Plant Operations

The average use of Plant Operations carts was collected over a three day period. Daily averages ranged widely, from 0.96 to 7.38 miles per day. The average distance was 4.35 miles. The amount of time the cart was working also varied greatly over the days during which data was collected. Due to the importance of this number in calculating the moving vs. collecting ratio, we decided to calculate an average total moving time, instead of approximating ratios for each day. Taking the average of the two heaviest days in use yields a ratio of **1:14 (.072)** for moving vs. collecting (duty cycle). **The use of on-campus utility vehicles is significantly greater than campus delivery vehicles,** which is reflected in the higher duty cycle. The terrain covered by the Plant Operations cart was similar, with elevation ranging from 133 feet to 633.

1.6 *Benefits to Stationary Solar Charging Systems – Net Metering*

Every time a solar-powered system is connected to the grid, it includes a net metering agreement subject to Pennsylvania law. This law protects individuals and businesses that have a solar pv system such that power companies are required to credit solar producers at the same rate as if the power were bought from the utility company. In other words, those who produce energy off the grid are monetarily reimbursed for the amount that they would have spent had they taken that particular amount of energy off the grid instead of producing it through zero-carbon emission means.

This monthly credit has a maximum of the amount of power that the consumer uses per month. The consumer will not be reimbursed for energy amount that is greater than that which is used for the past month's billing period. If the solar array produces more power than the customer has used in that billing cycle, that credit is saved for use on future bills for up to a year. If the solar power is generated during the day and the customer uses power at night, the cost deduction will still occur.

An additional benefit to solar energy is that the customer will not be charged for the extra electrical energy consumed if the solar array produces less power than the consumer uses. The customer is billed at the regular rate for any amount of energy needed beyond what the consumer's solar panels produce.

Despite the benefits of net metering, the customer does not get paid the same amount as utility companies charge, as their rates include service and distribution fees.

1.7 *Metzgar Sustainability Center Solar Array*

Station Identification		PV Physical Specifications	
City, State	Allentown, PA	Number of panels	16
Latitude	40.65° N	Weight (lb/panel)	39
Longitude	75.43° W	Hailstone Impact Resistance	1" @ 50 mph
Elevation (m)	117	Dimensions/panel	58.5 in by 38.6 in
PV System Specifications		Typical Performance Characteristics	
Peak Power (Wp) Watts	200	Peak Power (Wp) Watts	200
Total Peak DC Rating (KW)	3.2	Max. Power Voltage (Vmp) Volts	26.3
DC to AC Derate Factor	0.85	Max. Power Current (Imp) Amps	7.6
AC Wattage (KW)	2.7	Open Circuit Voltage (Voc) Volts	32.9
Array Type	Fixed Tilt	Short Circuit Current (Isc) Amps	8.1
Array Tilt	35°	Short Circuit Temp. Coefficient (mA/°C)	5.6
Array Azimuth	180°	Open Circuit Voltage Coefficient (V/°C)	0.12
		Max. Power Temp. Coefficient (%/°C)	0.5
Energy Specifications		Max. Series Fuse (Amps)	15
Mean Annual Solar Radiation (kWh/m2/day)	4.46	Normal Operating Cell deg. C	45
Annual AC Power Production (KWH)	4219.00		
Annual Power Production per panel (KWH)	263.69		

1.8 *Tech Clinic Business Model*