Abstract:
This study analyzes the reasons a promising technology fails and brings forth the ramifications of such a failure. The analysis is done on solar car technology; specifically, the path of the MIT Solar Electric Vehicle Team, the conversion of its founder to electric vehicle manufacturing, and the absence of solar cars from the market today. The results show that such a failure is caused by the saturation of the technology before the existence of a product that meets the needs of the targeted market. On the other hand, such an endeavor can lead to major contributions in related areas due to the carryover of engineering expertise and technological components into related fields.
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1 Introduction

When a promising technology fails to breakthrough into the commercial market place, examining the technology itself as well as the social circumstances surrounding it can help explain why. An analysis of this sort involves looking at the technology from two different perspectives. One point of view looks to the technology for weaknesses in satisfying the proposed market. The other viewpoint looks at the social events that led to the wrong market being proposed.

Understanding the reasons for failure only provides half the story surrounding a failed technology. The other half comprises its future. What happens to a failed technology? This paper performs a case study analysis of Solar Car technology to understand how solar car technology failed the commuter vehicle market. In particular, the paper analyzes the technology as it relates to MIT SEVT, a student run organization, and the company that spun off from it, Solectria. It then tries to define the contributions of the solar car rush to other fields.

James Worden unofficially started the MIT SEVT in 1986. The team comprised a total of seven people and went on to design, build, and race solar cars in the United States, Europe, and Australia. Around 1989, the team members were preparing to graduate, when two core team members, James Worden and Anita Rajan, joined forces to create a startup company. The team was also at a vital point in its development and succeeded in establishing itself as an official MIT club in 1991. Doing so was a declaration of its continuity, and the team still races solar cars today. The company, on the other hand, was named Solectria and now sells electric, not solar, cars and components.

Despite their significant role in the solar car technology at MIT, Worden and Anita left the field to develop more commercially viable vehicles. What events led Worden and Rajan to shift their focus from solar cars to electric vehicles? And in light of these events, why is there still a club at MIT that continues to develop solar car technology?

To show the development of solar car technology and the contribution it made, despite not achieving market acceptance, this paper is organized into four sections. The first section contains the general context and history for solar car technology. Also included here is a basic explanation of how a solar car works. The section after that, the promise, will focus on the early and mid 1980s to show how the belief in solar technology was growing and the faith people had. The next section, the failure, discusses at which point solar car enthusiasts realized that solar car technology would not achieve commercial viability. The last major section contains the aftermath, which analyzes where solar electric vehicles are today. It also looks at the spin off, Solectria from the MIT SEVT and tries to rationalize the technological decisions they made.

2 Background

A general knowledge of how a solar car works will provide the necessary context for much of the discussion at hand. This section gives an overview of the technology and limitations involved in building a solar car.

2.1 How Does a Solar Car Work?

A solar car works by converting sunlight into electrical energy through photovoltaic cells. This energy is passed either to the battery for storage, or to the motor to run the car [14]. This
decision is made by a small onboard computer. The motor controller is responsible for sending the electricity smoothly to the motor when the gas pedal is depressed, controlling the torque that goes to the motor such that the car maintains the desired speed. An interesting process used in low energy cars is regenerative braking [19]. It allows some of the kinetic energy stored in a vehicle’s translating mass to be stored in the battery when the car is slowing down. The motor can be flipped to operate as a generator, thereby providing braking torque to the wheels and recharging the batteries. The motor takes care of gear changes electronically, and turns the wheels.

2.2 Solar Cells

The first silicon solar cell was built at Bell Labs in 1954. By the late sixties, solar cells were widely used on U.S. space satellites. This solar cell technology was also applicable as concerns about the environment and the need to provide power to isolated regions grew. Solar cells, or photovoltaics, work using light, not the heat, of the sun. They are created by joining an n-type and a p-type semiconductor, creating an electron rich and an electron poor layer similar to a parallel plate capacitor [26]. When sunlight strikes the cell, photons are either reflected, absorbed, or passed through, with the absorbed photons contributing to the generation of electricity. These photons cause atoms of the semiconductor to free electrons, leaving behind positive charges. The flow of electrons thus created constitutes an electromotive force that drives

![Solar Cell Diagram](image.png)

Figure 1: Solar Cell Diagram

Cells can be grouped into space grade and terrestrial grade categories. Space grade cells are up to 29% efficient, and are used mainly in satellite production due to their high cost. Terrestrial grade cells, on the other hand are much cheaper, with three main types: amorphous, polycrystalline, and monocrystalline. Monocrystalline cells are the most efficient for their price, usually 14%, causing them to be the cells of choice for solar cars. Cells usually measure 10cm x 10cm, costs approximately $6.00, and produce approximately .5 volts and 3 amps of current each. Power can then be calculated by multiplying the voltage and the current, giving an estimated 1.5 volts per cell. Because cells are extremely fragile, many engineers put them

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1 US Department of Energy
through a process called encapsulation. Doing so strengthens solar cell durability, but decreases the efficiency. For cells 14% efficient, encapsulation would reduce the overall efficiency to 12.5%.

Joining a number of these cells together forms a solar array. Voltage can be increased with a series connection of the cells, and current increased with a parallel connection. A solar car array can have a number of different parallel or series configurations. The amount of power generated by the array is highly dependent on this configuration, and therefore a car module’s power rating is equal to the product of the peak total voltage and current. This is the number given in the specifications of a car. This measurement incorporates the design of the array, the efficiency of the cells, and the number of cells used.

2.3 Limitations

To put the limitations of a solar car in perspective, a simple calculation will suffice. Only 1000 W/m² of energy reaches the earth’s surface in an hour of “peak sun” [23]. This term can be thought of as the amount of sunlight that reaches a sunny area on cloudless, summer day around noon. An average solar array configuration spans 8m², meaning the total amount of energy hitting the solar car during peak sun is 8KWh/m² [8]. Of this energy, average solar cells are only able to convert 12.5% to electricity. As a result, the total amount of converted energy available to a car consists of 1 KW/h, approximately the same amount of energy used to run a hairdryer.

With cars running on 700-1500 Watts [27], efficiency is hypercritical. Therefore, advances in all aspects of engineering, from mechanical to electrical to materials and computer science are key. The three primary areas of energy loss consist of aerodynamic drag, braking, and rolling resistance. One third of the energy is lost comes from each of these areas. Each area equally contributes one third to the total amount of energy lost [8]. Aerodynamic drag increases exponentially with speed. To minimize aerodynamic drag, engineers make solar cells as sleek as possible. In the area of braking, engineers use the aforementioned process of regenerative braking to recycle energy. Rolling resistance is proportional to weight. As a result, solar cars are engineered to be very light. This energy limitation enters into every detail while building solar cars. Despite these constraints, there still existed a lot of hype around solar cars.

3 The Promise

The early 1980s were a hot time for solar cars. In the late 1970s, a bicycle enclosed in a sleek shell proved that with a paltry one horsepower, a vehicle could be propelled to over sixty miles per hour [15]. With electronic and photovoltaic research taking an upturn in efficiency, the time had come for solar power vehicles.

3.1 The Initial Faith

All new technologies start with an initial group of enthusiasts. Solar technology was no different and their core group of believers could be found in the racing circuits that started to spring up starting in the early 1980s. No sooner was this happening anywhere than in Europe where the first solar car race marked a beginning for development in solar car technology.
In 1982, a solar car race started in Switzerland called the Tour de Sol. The number of entrants, all solar powered vehicles, was up to 100 by 1984 [20], and the race continues today. In these races, technologists, the media, and the general public have been able to witness actual working solar cars. Solar car technology was still somewhat of a romantic notion at the time, and this practical display of functionality brought a sense of reality to this dream.

The solar car racing added excitement and interest in this area and led to further development. In fact, European companies were already prototyping for mass production [20]. The faith in this technology was not just from the initial enthusiasts, but had spread to the commercial market.

The hype around solar car technology was also growing because of the rapid technological advancements being made in the technology. Race to race, year to year, solar cars were improving quickly. The reason for this was simply that like most new technologies, the initial attempts were not done efficiently [12].

With solar cars, there was a large room for improvement in all parts of the car. Initially, these parts were being bought off the shelf, and were designed more for heavy, industrial applications as opposed to sleek, lightweight solar cars [7]. So for parts such as the motor and drive train, the frame/chassis, wheels, and especially the motor controllers, considerable optimization was possible. This room for improvement meant increases in maximum speed, distances traveled, and other measures of performance, all of which further added to the excitement around solar car technology.

### 3.2 Beginning of the MIT SEVT

It was soon after the start of the races in Europe that solar car fever started catching on in the United States. In 1984, a car built by two engineers in the US set a record by going twenty-five miles per hour [Northeast Sun, May/June 1989]. Also in 1984, a solar vehicle constructed for less than $5,000 was able to make it across the US, being the first solar car to do so [15]. At around the same time, an American high school student James Worden was already building solar cars.

#### 3.2.1 Worden Brings Solar Cars to MIT

When Worden was developing his interest in solar cars in the early 1980s, there were not any books on how to build them. References did exist, however, on electric cars from the development and experimentation that was done in the early 20th century. These were the only sources of literature Worden used to win the 1984 Massachusetts state science fair with his entry Solectria I (see Figure 2), his first roadworthy electric car [20].

The question that Worden sought to answer with Solectria II was “how can you design a vehicle that can travel at least 50 miles, be charged from solar panels, keep up with traffic, be visible enough on the road, have all the requirements to be legally registered on the road, and most of all, be inexpensive enough so

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1 Sherman, Joe. *Charging Ahead.*
that you could afford to build it?" [28]. Using all the resources and technology he could get his hands on, Worden built Solectria II with only $2000.

It was his first practical SEV - a small, two-seat car designed for city commuting and charged by the sun. Although the biggest challenge was "building a working vehicle" before Worden started and throughout the design and construction phases of the car, Worden was always searching for ways to make it "better." More specifically, Worden wanted to make his car faster, more reliable, and more practical than other solar cars at the time. He had a passion for solar cars because of the technological challenge, the push to help the environment, his desire to create and build, a love for cars and speed, the learning experience, and the possibility of shaping tomorrow's technology. All of these were factored into his initial decision to pursue solar electric vehicles.

Solectria III was the first car that Worden built while at MIT, and one he built almost single-handedly. Worden heard about the Swiss Tour de Sol through a friend literally four weeks before the event. Worden took his remaining parts to Switzerland, finished building the vehicle, and then raced the first American entry in the Swiss Tour De Sol. Although he didn't have a great finish, he started what was soon to be the MIT SEVT.

Although Worden was not all that successful in the race in Switzerland, it opened the door for the development of the solar electric vehicle team at MIT. Immediately coming back from racing in Switzerland, there was a tremendous amount of media coverage in the United States. Most importantly, however, it raised a keen interest at MIT among students and faculty.

3.2.2 The Team Grows

Getting people to join the team was not an easy task. Often, it was just a matter of luck in getting people’s attention. This is how Gill Pratt found his way onto the SEVT [16]:

I was sitting in my office in Building 20 when James drove by. He used to work there in the room Doc Edgerton had given him. He looked in the door and saw some crazy apparatus and then asked me if I knew anything about switching motor controllers. The truth is that I didn’t know anything about them at the time, but I was willing and interested in learning.

Pratt proceeded to do a quick examination of the car and proclaimed that he could create far better motor controllers than the simple series-parallel switch that was being used by the current car. With that Pratt found himself a critical spot on the team. Until then, James had never built a car with real motor controllers, and Pratt’s expertise in the area would come in very handy. Although his work would have positive environmental ramifications, his primary motivation for joining was learning and engineering.

Anita Rajan, who joined the SEVT in early 1988, described her involvement with the team as “destiny” [18]. Her story is a classic example of how any presence and attention that the team could garner on campus, greatly aided in its recruiting efforts:

I was standing on 77 Massachusetts Avenue having just read about the team when James just happened to drive by in his car, the Solectria 2. Everyone was in awe at how cool it looked. At first I didn’t think too much of it, but having just read about it what the MIT Solar Electric Vehicle Team had been doing all over the world, I decided that I wanted to be a part of something like that. And so I found out about the SEVT and before I knew it, I was working on Solectria 4 a month later.
The ability to attract the interest and curiosity of the general public was perhaps the greatest strength of the SEVT for its growth into a flourishing, completely student-run, organization. The idea of solar technology in automobiles carried a “certain extravagance” and “appeal to college r care that solar car technology was vastly limited by how much power the sun can actually provide. They were intrigued by its nature and felt that they could make it happen.

3.2.3 Expertise Develops

In many ways, Worden was the heterogeneous engineer that Donald MacKenzie describes in his book, “Inventing Accuracy,” as “engineering of the social as well as the physical world” [11, pg.28]. Worden needed to do this to succeed given the constraints involved in being a leader in the development of solar and electric vehicles. He would play the role of the marketer, the fundraiser, the manager, the engineer, and the creator.

One example of Worden’s social engineering skills came in providing benefits to team members as a form of recruitment. He found a way to offer UROP credit to students who took part in the SEVT. Furthermore, those students who took part in the team were practically guaranteed an A grade as a GPA booster. Such tactics, coupled with the appeal of solar car technology being a “cool, new technology” unlike an ordinary research project sparked interest in the MIT community.

Additional recruitment brought something else that money could not buy: additional expertise. The core of the team consisted of 5 members: Worden was the founder and leader, Gill Pratt was the electronics expert, Catherine Anderson and David Brancazio were mechanical engineering students who served as mechanics on the team, and Eric Vaaler, an older graduate student, was knowledgeable about lightweight composites and, just as important dealing with MIT professors. This mix of students from a variety of backgrounds allowed advancements in every area of the car as each student was able to focus on one aspect instead of having one person trying to do everything. Keeping in mind that the challenge in building a solar car was trying to make every part as efficient as possible, the diversity in talent and allowing members to focus on particular areas was key. The limiting factor was how much power they could get from the sun. Thus, the technology was essentially shaped by efficiency.

Eric Vaaler was able to elicit the help of Woody Flowers, a senior professor of the mechanical engineering department, who would prove to be a true mentor for the team and play a vital role in its development. Thus, the challenges of building a working vehicle were greatly aided in the areas of budget and work force as the SEVT grew.

3.2.4 Solar Excitement

As the racing community grew, it also aimed to educate. Teams made stops at schools along the race route to explain about the technology and its possible effects on the environment. At the same time, awareness about solar power was leading to a rise in the use of photovoltaic panels for electricity generation around the world, mainly in regions far from the electricity grid such as remote villages and Native Indian Reservations [21].

The team was growing: Worden had a team of elite enthusiasts who were interested in building solar cars. They, as well as other enthusiasts all over the world, were excited about the
future of this technology. They understood the ramifications to the environment if they succeeded, although it wasn’t the major driving force behind their interest in solar technology. The solar car community was approaching an unprecedented level of technological development towards the late 80s. This attitude could be seen especially in the races. For example, after the 1988 American Solar Cup, James Worden said, “We can’t believe it! This is the beginning of a solar explosion in the United States” [15]. Or as another racer, John Paul de Joria put it:

This is to show the world that solar energy is for real and here to stay. We can make a difference with the sun. We can knock out pollution. We can knock out the dependency on oil. This is the start of something big. Everyone here is a Wright brother.

3.3 Technological Development

The excitement and enthusiasm behind solar cars was well founded because a great deal of innovation was being made on each component of the solar car. Cars as a whole were performing better and better in this stringent energy environment. All parts of the solar car including the motor controller, the wheels, the motor, and the batteries saw substantial improvement. Newer models completely replaced older versions of the same component.

Races emphasized the challenge of building a car that could run off of minimal power due to the limitations of solar energy. However, contestants were ready to challenge this with ultra-efficiency [8]. The advent of lightweight plastic construction allowed the weight of some solar cars to be less than half the weight of a typical electric car’s battery supply. Using high-pressure bicycle or motorcycle tires, which decreased the friction between the road and the car, rolling resistance was reduced. Other design advantages came from aerodynamically shaping the car to make it perform with minimal power output. With recent electronic and photovoltaic research taking an upturn in efficiency, the time had come for Worden and others to embark on the feat of overcoming solar power limitations and building vehicles.

3.3.1 Guerilla Engineering

Perhaps the faith in the technology is best reflected by the measures the team took to develop it. The trajectory of the MIT SEVT was shaped by the social factors of being a student run organization as well as the engineering factors. Unlike a corporate atmosphere, one advantage the team carried was that the students were there by choice and obviously loved what they did or they would not have continued. This allowed them to remain student run and not have to deal with potential limitations faced by having an authoritative figure leading the team. “There was a real point of pride that we did what we did without faculty support,” Anderson said [22]. “James held things together. The rest of us got compassionate and put in hours, but he was really the catalyst. He already had the art of collecting the right people around him.”

Although development at a research institution like MIT had many benefits, there were also disadvantages that this posed on the students. Politics at MIT brought new constraints onto the team. Woody Flowers tried to get official status for the team, but was unable to because of the danger involved in working and racing automotive vehicles, something not looked at favorably by administrators. “It would have been tenure suicide,” Anderson explained [22]. In some sense, however, this was a blessing in disguise. Now the team could avoid the school’s
bureaucracy, move faster and with fewer restrictions, and perhaps most importantly put all its money into solar cars rather than giving 40 percent of it to MIT administration and overhead (which approved clubs were required to do) [3].

Without an official advisor, however, the team could not get lab space and other benefits that an officially recognized student organization could have access to. Team members had no sanctioned storage space. Instead, they used dorm rooms, closets, and empty spaces under tables. They had no official work space either and had to work on loading docks, in parking lots, and in off-limits MIT labs since tools were often in short supply. This forced the team to slip into a mode of operation dubbed “guerilla engineering” by team member Catherine Anderson [22].

It was almost an undercover form of the “heterogeneous” engineering idea that MacKenzie alludes to, mentioned earlier. One tactic of guerilla engineering that was absolutely essential was getting time in the locked labs at night [9]. The cryogenics lab, for instance, where professors taught the physics of extremely low temperatures, could be entered through a window in an adjoining women’s rest room. This lab had lathes that Anderson used to turn magnesium billets into wheels. In the architecture building, the team would sometimes work late nights laying up composite wings to held photovoltaic arrays, and the shells that made up the car body. Working with composites was very tricky because making a decent shell out of composites, which mix fabrics and resins in matrices with varying drying times, required a fair amount of orchestration and finesse. Resins had varying pot lives, fibers had to be laid up correctly for strength, and a volunteers had to be given direction. The fumes were also a problem, especially those from polyester resins. They traveled into vent ducts and into classrooms and offices. The professors complained. In order to quell those complaints, the team switched to epoxy resins, which were more toxic than the polyesters but emitted very little smell. Thus, the Solectria IV made a switch over to a graphite-epoxy body from a body that was formed from mylar over tubes.

The team also had to make frequent use of the MIT student shop, managed by 385-pound Joe Caligiri, or “Tiny.” Tiny’s shop was an official space for student projects. Few student projects were as big as a car, however, so the solar racing team took up a lot of space. After sometime of dominating the resources at the shop, the SEVT was soon banned from using the facility in any manner, especially since it lacked an official status. However, Tiny had taken a liking for the girls on the team (at the time it was Anita and Catherine) [18]. The team took advantage of this and sent to the girls to carry out jobs in the shop whenever there was a need to do so.

With Worden’s leadership and capabilities as a heterogeneous engineer, the team had the guidance to overcome the limitations of solar car technology. Using guerilla engineering, the were able make the most of their resources at MIT. As such, they were able to use their diverse abilities to make improvements to all parts of the car.

3.3.2 Motor Controllers

Motor controllers are frequently referred to as the "brains" of a solar car. This component performs the complex task of deciding how much current actually reaches the motor at a given time. This determination of current by the motor controller allows the car to accelerate, decelerate, or stay at a constant speed [6].

Motor controllers that existed on the market before development in the solar car industry were mainly used in the robotics fields. These motors, which could be bought off the shelf, were
used for applications such as forklifts. Since most applications of these types of motor controllers were for items that were immobile, weight was not an issue at all. The motor controller could be quite heavy and the application still worked sufficiently [15]. In the case of solar cars, however, weight played a large role in determining how efficient a car would be. Attempts were made to make the car, and as a result all its components, as light as possible while meeting the specific needs of each component. With these types of requirements, the off the shelf motor controllers were not satisfactory for solar cars.

The first motor controller used by a solar car built at MIT was simply a knife switch [18]. Worden used it in his very first race at MIT before any sort of solar car team was assembled. A knife switch is only able to switch between two voltages, the voltage of the battery and ground as seen in Figure 3. In effect, it was a standard DC motor controller. The idea behind it was that when the driver of the car decided to accelerate by pressing the gas pedal, the motor controller would turn the switch "on" between the battery and the motor allowing the full current generated by the battery to reach the motor. When the gas pedal was no longer pressed, the switch would be turned "off" and no current would be fed into the motor. The result was the solar car would "go from zero to light speed in a very small number of seconds" (Gill Pratt) when switch "on" and the slow down quickly when switched "off" [16]. It was very difficult to coast at a steady speed. The car ride, instead of being smooth, was similar to flooring the gas pedal and then slamming your brakes.

After recruiting Gill Pratt to the solar vehicle team, he became the resident expert in terms of motor controllers. He had no previous experience in the field and attributes that to a great deal of his success [16].

![ Knife Switch (Standard DC) Motor Controller](image)

**Figure 3**

It was an entirely self-taught thing on my part and the advantages that gave were that I didn’t think the problem was as hard as a lot of other people. I came from the bottom rather than taking a bunch of classes and saying 'Boy, this stuff is hard'. I was very naïve and that let me put a few things together and see what would happen.

With little experience, Pratt attempted many designs that would otherwise have seemed difficult. In fact, on many occasions his designs failed miserably. He used this position as a learning experience. The corporate world would not have provided such an opportunity to experiment, and in the process destroy thousands of dollars of equipment. Pratt recalls one instance when he designed a motor controller that failed in a way such that it turned the motor on full blast permanently. This caused the driver to end up driving into a snow bank. Reminiscing, Pratt calls this his worst mishap.

Although Pratt did make mistakes, it was this learning experience that enabled him to make significant improvements in motor controllers. The first major innovation he made was with the motor controller he called the chopper. This motor controller, also called the pulse width modulating motor controller, attempted to improve on the previous design used by the
team by smoothing out changes in current delivered to the motor when the pedal was pressed or let go of. This would give the solar car a better ride. It did this by alternating at a very fast frequency between ground and a battery voltage (see Figure 4) to create the illusion of an average voltage that the motor would see in terms of current delivered to it. This way, whenever acceleration was needed, the motor controller would simply step for a longer amount of time to the battery voltage in comparison to the amount of time spent at ground. It worked in a similar fashion when deceleration was called for. This motor controller worked quite well with the motor technology of the time, but as motors sought more power, an improvement could be made.

Pratt also developed the next major innovation in motor controllers. As motors required greater amounts of current to generate more power, the pulse width modulating motor controllers were no longer sufficient. A motor controller was needed that could deliver a large amount of current in a safe, robust manner. Thus came the BRLS motor controller. This motor controller aimed to control torque as opposed to previous motor controllers that controlled speed [16]. The reason for this is that acceleration (and deceleration) is much better if you can control torque. The design of this motor controller was extremely simple, consisting of two finite state machines. One finite state machine performed the chopping effect described in the pulse width modulating motor controller. The other finite state machine performed what is called commutation. Commutation is a six-step process that determines how much and in what direction current is delivered to the motor. The process is robust in that at each step, shoot through is eliminated which means that there is no chance the motor controller will short circuit itself.

3.3.3 Wheels

The first wheels used by solar car teams were wheels similar to those used by conventional gasoline cars [5]. They were thick, wide tires that were quite safe, capable of traveling at high speeds, and supported quick turns. They also performed well in a variety of weather conditions, from dry weather to wet conditions.

Wheels, however, are the least efficient part of a solar car due to rolling resistance. Rolling resistance refers to the energy lost by the solar car because of contact with the ground. About one third of the energy used by a solar car is lost due to this factor. Because of this limitation, contact with the ground should be minimized. The typical wide tire used initially was about six to eight inches across [4]. A smaller surface contacting the ground would drastically reduce the amount of energy lost.

The major innovation with respect to tires was the idea of moving away from wider conventional car tires to thinner bicycle tires [1]. This is depicted in Figure 5. With these thinner tires, which were roughly about one inch across, there was far less ground contact in terms of surface area touching the ground. As far as performance, these tires functioned quite
well. Giving them a high air pressure allowed these thinner tires to be relatively safe. They could still travel at high speeds, speeds in the range of eighty miles per hour. Turning, specifically sharp turns were also handled well with bicycle tires. In addition, the tires were able to perform well in all weather conditions.

### 3.3.4 Motors

The first motors used by solar car teams were brushed motors [16]. These motors were extremely efficient in terms of energy consumption. The motor works by having coils spin around stationary magnets to generate the mechanic motion to turn the drive train. The magnets are positioned on the outside with coils on the inside.

A brushed motor is not particularly efficient in terms of its power to weight ratio. Typically, these motors cannot put a lot of current through its windings. This occurs for two main reasons. The windings on the inside of the motor cannot dissipate heat very well because they are on the rotor, the part of the motor that turns. The other reason is that if you spin the motor at a very fast rate, “all the different parts kind of want to fly out” (Gill Pratt) due to the centrifugal forces associated with spinning [16].

A brushless motor corrects many of the flaws of a brushed motor [17]. It allows far greater power for the motor because it overcomes the current constraints of the brushed motor. Inverting the structure of a brushed motor, a brushless motor works by placing the magnets on the rotor parts that spin, keeping the coils stationary. The coils are now on the outside part of the motor. This means that windings can be cooled much more effectively. This is because they are static and there’s a solid heat path to the outside. The rotor shaft can also spin much faster because it is now “a solid chunk of stuff” [16]. The overall effect of this improvement is that the speed of the motor can be increased as well as the amount of current given to the motor. Since power is speed multiplied by force, and since increased current results in increased force, the overall effect is a dramatic increase in the amount of power the motor can deliver.

### 3.3.5 Batteries

The MIT solar car team was not able to innovate on every part of the solar car. For example, the learning curve associated with battery technology was just too steep for any member to become an expert. So instead of developing the technology, they bought off-the-shelf batteries from various battery manufacturers.

The batteries that most teams initially used were lead acid batteries [18]. These batteries performed adequately but were not by any measure state of the art. The solar car team, instead, used silver zinc batteries. These batteries were used by the U.S. Department of Defense in its torpedoes. They were far more efficient in terms of energy maintenance.
4 The Failure

The MIT SEVT made considerable progress in achieving higher performance with their solar cars, but their development would soon stagnate. This would ultimately lead to a test of their product and a turning point in their pursuit of solar car technology.

4.1 The Technology Saturation

Substantial improvements were being made in the early stages of solar car technology development largely due to the lack of solar car application specific components. When solar car enthusiasts first began working on solar specific components, simply catering them to the needs of a solar car constituted major advancements. As this progression occurred, however, there came a point where only incremental changes were occurring to the current model of each component. This means that fundamentally the components were staying the same. The same amount of engineering effort reflected less performance output. This effect is referred to as saturation of the technology behind each component. As a result, the overall efficiency and performance of solar cars was no longer increasing at the sharp rate it was previously.

Some examples detailing the status of solar car components today will illustrate this technology saturation. Motor controllers have not become much more efficient since the advent of the BRLS motor controller. The MIT solar car team first used the BRLS motor controller in 1989. Since then, it has been adopted across the board by virtually every solar car team that races [16]. It has, in fact, become the industry standard for motor controller technology. This has not changed in the last ten years.

James Worden used bicycle tires in his first car built at MIT. The team has continued to use bicycle tires since then because of the far greater efficiency they provide. Thinner tires are used across the board by all solar car teams to save as much energy as possible. In effect, for the last fifteen years, thin tires have been the norm when it comes to wheel technology [10].

Most teams today continue to use brushless motors because of the greater power availability associated with this motor. The MIT SEVT has continued to use this motor since Gill Pratt developed it in 1989. Silver zinc batteries are still some of the best on the market today. Although they are slightly more expensive than the industry standard, most teams continue to use them. Technology saturation in each of these major components meant that they had achieved a peak in performance. It was now the time to test their product.

4.2 The Transcontinental Journey

Towards the end of their college careers, James Worden and the other core members of the solar car team embarked on their first transcontinental journey (Figure 6). This was one of the first occasions outside of competitive racing where they were going to extensively test their vehicle's reliability and durability. It was meant to show how well the car would hold up in a practical setting. They were

Figure 6: Transcontinental Journey
planning to test their newest car, the Solectria V on a journey from Los Angeles, California to Washington, D.C. This car incorporated many of the technology advancements that had taken place since the team was initially formed.

The rationale behind this trip was to show that solar cars were an environmentally safe, alternative form of transportation [18]. If the team could show that it was possible to drive across the country in less than two weeks in a solar car, it was possible for anyone to use a solar car for a short commute to work. They also were striving to break the world records for distance traveled and time for a transcontinental journey.

Their journey was scheduled to run for ten days with stops in various cities along the way. The actual trip took longer than expected. Rather than taking ten days, the trip lasted a total of sixteen, leaving on July 19, 1989 and arriving at the Pentagon on August 4. Both weather and the actual length of the journey played a major role in the delay. The weather during the sixteen-day span ranged from harsh desert heat to heavy rainfall. The majority of the days were overcast and rainy, conditions not well suited for solar cars. This was also the first time that the club had ever attempted a race of this length.

Even though the race took longer than anticipated, it was a success on many counts. The problems encountered on the trip were minor and the car had to be stopped only for driver changes, flat tires, impaired vision due to weather, and for press conferences. There were no major technical problems. They also received a great deal of publicity in each of the cities where they stopped. This accomplished their goal of greater public awareness of alternative forms of transportation.

From a commercial point of view, however, the trip was a failure. There are several characteristics that a commercially viable car must have. It must be extremely reliable, comfortable, and be able to function on its own. Solectria V experienced many flat tires and often was incapable of maintaining highway speeds of fifty-five miles per hour [20]. This type of reliability would be sufficient in racing conditions since in the racing environment they are considered minor points of failure that could be repaired immediately. In a commercial setting, however, frequent flat tires and inability to go at high speeds is not tolerable. Solectria V was also a very cramped car. Figure 7 shows that it barely had enough room for the single driver that was on board. Commercial cars typical can hold at least 4 passengers. In addition, commercial cars typically have amenities such as air conditioning, radio, and power locks and windows. With the energy available to solar cars, these types of amenities were impossible. Self-sufficiency was also an issue for Solectria V in terms of commercial viability. During the trip, the car was chaperoned on the highway with another car in front and behind. This was done to protect the car because it was not always be capable of traveling at highway speeds. Because of these reasons, commercial viability was slim.

Despite the numerous advances made in solar cars in order to increase their efficiency, enthusiasts were beginning to realize that they could only take it so far. With motors that are up to 99% efficient, super lightweight composites, advances on wheels, improvements on batteries, and great aerodynamics, the cars were still not close to satisfying even bare commercial commuter needs. The efficiency factor had come a long way since people started designing for solar cars, but solar cars were still not viable for real world applications.
5 Failure Analysis

The model of sustaining and disruptive technologies that Clayton Christensen discusses in his book, The Innovator's Dilemma, can be used to analyze what went wrong with solar cars. The reasoning also helps explain why James Worden and most of his colleagues were convinced that they were failures in the commuter vehicle market [18]. Christensen describes sustaining technologies as technologies that improve the performance of their products in the ways that matter to their customers. Well-managed companies are excellent at developing these technologies: they listen to their customers, seek higher margins, and look at larger markets. Disruptive technologies, however, change the value proposition in the market. They almost always offer lower performance in terms of the attributes that mainstream customers care about. Figure 8 shows that with experience and sufficient investment, developers of disruptive technologies will always improve their products' performance such that they are able to take over the market [2, pg.64]. The innovators do this by offering sufficient performance in old attributes as well as offering new features.

5.1 Characteristics of a Disruptive Technology

In many ways, solar car technology looked similar to an early stage disruptive technology. Compared to gasoline cars, solar cars were simpler and lower performing. Solar cars get their energy from solar cells that convert solar energy into the electricity that drives the motor. This conversion is simpler than the complex chemical processes that a gasoline car requires to function. Furthermore, solar cars were slower, less reliable, and could not travel as far in a single trip. Being simple and lower performing are both characteristics of a disruptive technology.

Other common traits of solar cars with disruptive technologies include being developed in an insignificant market. Solar cars were initially developed and used by the racing circuit in Europe and America. Although this small community received considerable attention, the number of people actually using or involved in the development of solar cars was very small. In addition, mainstream commuters were uninterested in solar car technology as a practical application. It was viewed as more of a futuristic dream than a reality. In the minds of many commuters, the technology was just too far fetched.

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1 Christensen, Clayton. The Innovator’s Dilemma.
5.2 Falling Short

Given that solar car technology looked disruptive at first, we can further examine Christensen’s model to see why they failed in the commuter vehicle market. Figure 9 plots the sustaining technology, gasoline cars, and what looked like a disruptive technology, solar cars. This plot reveals what happened in the commuter vehicle market. Gasoline cars had been flourishing for sometime and the innovation had tapered off when solar cars appeared on the scene. As is expected of a disruptive technology, solar cars initially offered lower performance than cars in the commuter vehicle market. Then, as was discussed earlier, there was innovation and technological development, but this quickly saturated. The plot shows how the development fell far short of realizing a product that could penetrate the commuter vehicle market. Solar car technology was so inferior that consumers in the market did not even feel that it was plausible to see such a car in the near future. It is not as important that solar cars fell so far short of achieving the same performance as gasoline cars, but rather that their improvement did not reach a trajectory that would achieve market needs in the commuter vehicle market. Christensen points this out when he says, “What matters instead is whether the disruptive technology is improving from below along a trajectory that will ultimately intersect with what the market needs” [2, pg.58]. In short, the technology just could not overcome its power limitations to satisfy commuter needs.

5.3 Finding the Right Market

Christensen’s model shows how solar car technology was a failure. It can also be used to explain why. Perhaps the greatest problem was how the innovators of this technology were looking at the wrong market. Christensen states that “The companies that succeed in commercializing the [disruptive technologies] must find different customers for whom the new technology’s attributes are most valuable” [2, pg.264]. In other words, disruptive technologies essentially create their own market. They find a set of customers who value their technology’s strengths and can ignore their weaknesses.

Commuters, however, could not disregard the weaknesses of solar cars. They were not willing to drive in a car that could not accelerate very quickly, go as fast, or was unreliable. Furthermore, the commuter market as a whole did not value two of the major strengths of solar cars: they were pollution free and they did not need to be manually recharged. There may have been a very small component environmentally conscious enough to pay the premium for a solar car, but this was untrue for the majority of the market. Commuters were already used to the convenience of gasoline cars and the amenities they offered. Solar cars could not afford the weight and complexity of air conditioning, CD players, or power windows. Although solar cars
were cheaper to maintain, they also had a higher initial unit price that made them very unattractive to the mainstream commuter vehicle market. Examination of these factors leads to the conclusion that the innovators of solar car technology were simply looking at the wrong market to introduce the technology.

The framework that Christensen presents can also be used to speculate on the right market to introduce solar car technology. As Christensen states, the goal is to find a set of customers who strongly value the strengths of the technology and can disregard the weaknesses. One plausible market for solar vehicles is a terrestrial application of the rovers that NASA uses in space. Data collection in a hot, sun rich area where manual labor is difficult would be an ideal application. The vehicles would recharge autonomously, and the driver’s discomfort would not be an issue because there would not be a driver. In addition, these vehicles could be kept lightweight and simple without a need for too many amenities.

In his book, Christensen states “The attributes that make disruptive technologies unattractive in established markets often are the very ones that constitute their greatest value in emerging markets” [2, pg.113]. Simplicity is an example of one such attribute. Commuter vehicle users desire cosmetic features and complexity to add convenience, but a lightweight and unadorned product is preferred by users of land rovers. If the innovators could put their love for vehicles aside, another excellent application for solar car technology would be irrigation pumps; it would utilize many of the same components developed for a solar car. These are just two markets that are far better suited for solar technology penetration than the commuter vehicle market ever was.

It is easy to understand how these small niche markets were overlooked. However, it is important not to underestimate the importance of first penetrating a market that will embrace the technology. Market acceptance can catalyze the growth and development of a technology until its performance is high enough to penetrate the technology of the sustaining technology (in this case, commuter vehicles). Instead, the developers of solar car technology attempted to jump directly into the sustaining technology’s market; there was no opportunity for the technology to be embraced by a loyal set of customers who could foster its growth and development beyond just the racing circuits in Europe and America.

6 The Aftermath

Having understood the reasons analyzed for the failure of solar cars in the commuter vehicle market, one may ask: What happened to James Worden and his team? What happened to the technology? This section delves into the answers to these questions by analyzing the actions undertaken by the team at that time, and looking at where solar cars are today.

James Worden graduated soon after the transatlantic journey, and went on to pursue a Masters of Science degree at MIT. The degree program was soon dropped, though, in favor of a career in car technology. Worden left school and started a company in 1990 with teammate, and soon to become wife, Anita Rajan. Named after the solar cars he had worked on, Solectria Corporation was initially a custom manufacturer and reseller of solar car parts. Using their expertise in solar car equipment, they put together a catalogue of merchandise. Becoming middleman between suppliers and schools was a great way to get their name onto the market. The company also gave expert advice to solar car builders around the country [18]. In spite of these early efforts, the company could not grow viably in such a concentrated, narrow niche.
They had to make a broader move. Finally, enough money was put together from sales and investors to build the first Solectria vehicle for production.

The car was an *electric* vehicle.

### 6.1 The Faithful Jump Ship

Considering the SEVT had done very well in the races, the team had some of the most qualified engineers in solar vehicle technology. Most of the early team members helped out at Solectria in the early days, and those are people that had been pushing the envelope in this field for over four years. The fact that these experts decide to switch gears and go electric may come as an initial surprise. However, in light of the failure analysis presented earlier, it shows that Worden had understood the first implication of the transatlantic trip: the parts were optimal, but they could not be put together in a package a commuter would want to buy.

The migration of the experts in a new field is burdening proof that the initial faith had faded. Solar cars could go on the road, drive across the country, make it through days of bad weather, but they were too expensive, uncomfortable, and unreliable. When it came to commercial viability, the people that had started solar fever in the United States were not building or selling solar vehicles. Christensen states that the people originally working on a new technology in a startup environment are the ones most capable of making it flourish. He says, “entrant firms have an attacker’s advantage” [2, pg.62]. In the case of Solectria, the technology did not flourish; it faded.

Worden, though, was very intent on building commuter cars, and did not see that it was simply the wrong market for the technology. Even if considered for applications where short distances were key, it was far behind electric cars in its ability to meet demands for comfort, amenities, and weather-independent functionality. Solar commuters barely had space for one person; electric cars had enough power to use regular car bodies and fit up to four people. Worden and the people around him did not try to find a better market for their product, thereby driving solar cars into the ground as a commercially viable endeavor. Christensen sees the rise of a disruptive technology to be a direct result of aggressive, innovative marketing: “If …a company forces a disruptive technology to fit the needs of current, mainstream customers, … it is almost sure to fail” [2, pg. 259]. In light of this, perhaps if they had sought out specialized customers to whom they could sell an entire vehicle, they may have been able to push the field out of the rut it had fallen into.

### 6.2 Carry-over of Expertise

Realizing that the technology had saturated before a product was anywhere near ready to be put on the market, the people at Solectria had gone to the next best thing. They had to get out of solar cars, yet they chose a related technology in which their solar experience would give them an edge. Electric vehicles are the technological kin of the solar ones. The main parts are the same, except that electric vehicles charge their batteries from a power outlet as opposed to a solar array. This allows electric cars to store much more power, enabling them to come closer to meeting the market needs of commuters [25]. These cars can have steel bodies, car-type tires, and air-conditioning. They could run in any weather. Although they were limited by how far they could travel, they could run regardless of the weather, making them ideal for buses and inner city commuting. Electric cars are a “reinvention.” In the early 1910s, they were seriously competing
with gasoline and steam powered vehicles, until they got shelved because they could not run as fast or as long as their gasoline counterparts. These cars are now making a comeback with longer travel times (range) due to advances in battery technology, aerodynamics, and the microprocessor revolution. Below the surface, though, they had very similar electronics to the solar cars that Worden and his team had worked so hard at making efficient. That is where their expertise would carry over.

The engineers at Solectria had been designing super efficient parts for years. They knew exactly where all the power losses occurred, where they could cut them, and how little a car could run on. On the other hand, most companies working on electric vehicles were gasoline car giants (Toyota, Honda). In spite of their brand name advantage, their engineers were used to working in an environment where power was expendable. They were used to heavy parts, high-tech features, and speed. Yet they were now entering an area where efficiency would allow a car to either meet some customers’ needs, or fail all of them.

In light of this, the engineers at Solectria had a head start. Their bottom up approach and their work on the parts needed allowed them to buy bodies of gasoline cars and outfit them on their own. Another advantage they had was that they were able to experiment with a lot of the technology without risking their careers. Gill Pratt, who consulted with Solectria on a commercial version of the BRLS, explained it best in describing what it took him to get to the BRLS controller [16]:

I got to design a lot of motor controllers that failed, which at a big firm you don’t get to do. I burned up many thousands of dollars of parts and each time I learned this amazing lesson that there is always a reason something blows up.

Solectria also capitalized on its engineers’ history in composite work through its Pre-Form Engineering Group that provides research and development consulting for advanced composite design and processes. Composite cars are not yet sold by the company, though, because it cannot afford to invest in mass production of car bodies considering the size of its customer base. James Worden, however, never lost sight of the benefits of using composite material for the body of the car. The engineers at Solectria realized that these materials were lighter, stronger, and in most cases cheaper than other possible options such as aluminum or ultra light steel.

Solectria first sold electric vehicles that were conversions of conventional gasoline cars. They bought the steel bodies from suppliers like Ford, and fitted them with electric parts. This was done to act as a stepping-stone before moving to the more ambitious composite version of the vehicle.

[James], don't be such a dreamer…do conversions first as a stepping stone. We need to get conversions going first, work out all the electrical bugs, get a market going, get some cash flow coming in. Then we could worry about doing our own vehicle. [20,pg.70]

After gaining experience and establishing a name for themselves, Solectria made a prototype of a car, the Sunrise, made completely of a composite body. This car, shown in Figure 10, entered the 1995 Tour De Sol but is not yet on the market.

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1 Sherman, Joe. Charging Ahead.
Thus, moving into the electric vehicle industry was the perfect balance between integrating the parts they had created and buying the standard gasoline car carry-overs that they had no expertise in manufacturing (steel bodies, wheels, amenities).

6.3 A Winning Strategy

Today, Solectria is a successful company in Arlington, Massachusetts with over sixty employees. The company sells three electric vehicles (Figure 11): a 4-door sedan, a micro truck, and a pick-up van [24]. Components such as motors, motor controllers and gearboxes are also for sale. They are mainly by corporations or state authorities that choose to outfit their own electric vehicles such as the Miami Beach “ElectroWave” shuttle bus service. ElectroWave consists of seven twenty-two passenger electric buses that are powered by Solectria components and has shuttled over 1.5 million passengers since its conception in 1998. To this date, over 400 Solectria vehicles have been sold worldwide, and over 1000 others use Solectria components.

As opposed to Christensen’s suggestion of adapting the market to the technology, Solectria succeeded by adapting the technology to the market. They took what they had learned and capitalized on it in a field where understanding the weaknesses of solar cars gave them the upper hand.

6.4 Enthusiast Circle Prospers

While the transatlantic trip described in section 4.2 demonstrated the failure of solar cars as commuter vehicles, that same event strengthened their worthiness for racing. For the team, this resulted in a shift in the definition of success from trying to prove that these cars were viable to one of pure racing. They were able to use much of the technology the core team had developed. As a result, they could black box many hardcore electronics and instead concentrate on integration, composites, and aerodynamic design. For example, the Aztec (Figure 12), which was used in the two previously mentioned race’s, had renowned cutting-edge aerodynamics. Such advances could only be made because of the strong foundation the core team provided.

Cars could be more reliable, faster, and built out of off-the-shelf parts engineered for racing. The SEVT has now become more of a club for hobbyists. The learning curve for the

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1. http://www.solectria.com
building of a car is much lower because of the availability of reliable specialized parts. As a result, the types of innovation that occur now deal more with putting the different parts of a car together, working on composites, and experimenting with different aerodynamic shapes. Although the club still uses their cars to promote environmental concerns, racing new cars is the predominate goal of most members.

This sentiment that solar car building transitioned to a sport was also true in the general solar car community. Charles Habermann, of the University of Minnesota team, described solar racing as “a Rubik’s Cube on steroids”. There are so many different approaches to building a car, from the best suspension, the best shape, and the best array configuration that it was indeed a sport when they race. The satisfaction comes from designing, building, and then racing the product that resulted. Most schools aim to have a new car every couple of years that has a different twist in this “Rubik’s cube”, instead of just racing the same car every year.

The racing community, therefore, continued to grow and now comprises a number of high schools as well as one elementary school.

6.5 A Springboard Technology

When a large number of skilled individuals spend substantial effort and time working on a new endeavor, the endeavor may not flourish but there will be other contributions. Solar car technology never made it into the market, yet one can see the ramifications of the solar car rush in a number of commercially successful areas.

The technology at hand therefore can be compared to a springboard: rising to a stable, virtually stagnant position has enabled it to propel other technologies forward. The solar car rush brought substantial advances to the design of electric vehicles, the use of solar power, and the education of young students in the sciences. By designing cars that will run on as much power as a hair-dryer, the primary solar car designers had to work from the bottom up with efficiency as the number one priority. This led to better motors, better use of batteries, and better motor controller design as described in section 3.3. These have been adopted by some electrical vehicle manufacturers, and can be individually used in other, non-vehicle applications.

Another key area that has been charging ahead is the composite hull car. Composites were not only lighter, but they also made cars safer than their steel counterparts. Gill Pratt calls this the number one contribution of the technology due to the safety ramifications [16]:

If you design it the right way, the fibers in a thing like this will crush and absorb a tremendous amount of energy. It’s … like crushing a piece of paper. There are many parts of the paper that are absorbing the energy compared to a steel car which will bend very easily

Although the major car companies are not yet using composite hulls, smaller companies like Solectria have had been pushing for such a product. As mentioned in section 6.2, Solectria has a prototype composite car that it has been advertising and racing. Most of the engineers in the field are expecting many future cars to shift from steel to fiber [3, 16].

Solar cars also helped spread the word about the use of harnessing solar power. When the cars stopped in the towns during the races, they caused havoc: people young and old gathered around to see demonstrations by the teams; the press wrote article after article about the space-rocket shaped vehicles and their environmental implications. By spreading the word about solar energy in this exciting way, the cars contributed to the rise in the use of solar cells for other,
more practical uses. This was the most effective way of advertising solar power and preaching about the environment without boring your listeners. The person listening may not be convinced to buy a solar car, but he or she may go buy a solar panel for supplemental electricity at home. The racing also lead to a lot of young people getting interested in it and trying to find out how they can do similar projects at their own schools. Lastly, it created a sport that has an educational as well as a social benefit.

In light of the contributions of solar car technology, one can see that such endeavors do not simply disappear, instead they diffuse into other areas and give them the push they may need to prosper. They also show that enthusiasts can contribute greatly to serious engineering, as is the case in other fields as well. One such example is the MIT Rocket Team, which was founded in 1998 in hope of becoming the first student team to launch a rocket into space [13]. This latter team is already claiming that it will have an revolutionary impact on the rocket industry:

We are pioneering a number of new aerospace technologies (including a new type of rocket engine — patent pending) that could lead to dramatically reduced launch costs which have the potential to reshape the industry.

7 Conclusion

The path of solar car technology, specifically through the MIT team, has been examined to show reasons for failure of a promising technology, and the fact that such an effort does not simply disappear. Instead, if one looks carefully, one finds that its ramifications have pervaded into a number of fields.

Stepping back from the cars themselves and studying their history, trajectory, and demise have brought to light the indicators to their failure, the survival skills of those involved in designing them, and their impact on technology today. The initial belief that these cars were going to cause a real threat to the gasoline industry slowly yet surely disappeared. The engineers could only push the technology so far before the physical limitations of the cells and the sun's energy were too large to overcome. By the time the parts had become reliable, the whole was still not sufficient. There was no way to put the components together such that a customer would switch from gasoline to solar.

This study thus shows that such technologies fail because of exactly this situation: the innovations saturate before a viable product can be produced for the targeted market. The question is then put forth of whether there could have been a better market, and that is a possibility that remains, yet cannot be determined until someone attempts it.

The absence of a technology from the market place of today does not, though, render it obsolete or useless. As outlined in the Aftermath section above, the work done in the field can find a viable outlet. That outlet may be in a non-commercial application of the same technology, such as solar car racing. On the other hand, it may be in less obvious, yet commercially viable alternatives in which the parts valuable carry over, such as electric vehicles and composite hulls.

Although the solar car has been somewhat cast aside, people are reluctant to condemn it due to its romantic implications of running purely on the sun’s energy. Perhaps it will be reinvented as well one day, similar to its electric car counterpart. The latter had to wait nearly a century.
8 References


[16] Pratt, Gill. Board of Consultants, MIT SEVT. Interview Conducted by Rania Khalaf.


[21] Sienko, Tanya. SEVT Enthusiast. Interview conducted via e-mail by Paritosh Somani.

[22] Sienko, Tanya. SEVT Enthusiast. Transcripts from Interviews.


Appendix

Computers to date have played a small role in solar car development. In terms of the actual car, a small onboard computer called the maximum power point tracker (MPPT) delivers energy efficiently from the solar cells to the batteries or motor. This piece, however, is more of a hardware solution than a computer that actually runs software and does processing.

As solar cars have become more of a hobbyist endeavor, many teams find themselves trying to tweak as much efficiency as they possibly can out of a car. As a result, many teams today use computer-aided design (CAD) programs to help sketch out the initial plans before any actual building is done. Programs that do this are being sold today off-the-shelf; a hobbyist can simply enter his design and evaluate various design tradeoffs.

Another application in today’s market for computer application occurs during the actual racing events. Embedded computers on a solar car provide important metrics that team members in a chaperone vehicle can compile during a race. The members can then feed this information back to the driver, guiding him on his driving. Data about the terrain of the race route can also be gathered using a differential global positioning system. Analysis of the car and terrain data is done using user-constructed graphs and tables, and energy management algorithms. This information and processing power gives the user the tools to best operate a solar car. The University of Michigan team has proposed an integrated application that would utilize this type of information, all through the use of a customized software application. In the specification, user input would be validated against a specific query language. Successful implementation of such an application has yet to be completed.

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