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Solar Skyways

Ron Swenson, INIST, ecosystems@econet.org, Santa Cruz, CA 95061, USA

Abstract

In the autumn of 2007 a group of 200 people gathered in Uppsala, Sweden to view a prototype and explore collaboration in developing a new transportation alternative, the *podcar*, a small cabin on a fixed guideway operating directly above urban streets. Earlier described as PRT (Personal Rapid Transit) and more recently as ATN (Automated Transportation Network), this driverless on-demand mode of transportation offers mobility that is much faster and more convenient than a bus, plus much more efficient and safer than an automobile. It also lends itself uniquely to being powered by solar energy (photovoltaics) directly within the system's pathway.

At that conference and subsequently, proponents have demonstrated that it is possible to power this unique urban transportation system 100% with solar energy, that is, selling to and buying from the existing electricity grid to achieve "net zero" energy demand. Since 2011 the solar design has been refined through the Solar Skyways Challenge, an ongoing multidisciplinary initiative which to date has been embraced by students at three universities – in the Netherlands, Sweden and Silicon Valley USA.

The Challenge continues into its third year with students at San Jose State University and elsewhere forming multidisciplinary teams to design and build computer controlled scale models and full-scale system components, and ultimately a full scale test track to demonstrate the technical, environmental and economic viability of ***Solar Skyways***.

Keywords: Transportation; Podcars; Solar Skyways; Solarevolution; Capstone Project; Uppsala; SMSSV

1. Origins

During his two month tenure as a visiting scholar at San Jose State University in 1966, Bucky Fuller called attention to the finite nature of fossil fuels, saying that our decendents would pay us handsomely just to stay home and save the oil for a rainy day, if they could travel back in time. As a young instructor teaching an engineering course focused on the impact of technology on society, I resolved then and there to find ways to do more with less, and came to recognize that figuring out how to use solar energy for transportation is one of the more interesting challenges that humanity faces.

Thinking over the years about this challenge, I began the quest to integrate solar with electric vehicles in 1981 when I built and tested a solar powered electric tricycle. Of course it wasn't a practical vehicle, but I began then looking for a practical and economical way to power transportation with solar.

Fig. 1. (a) “The tricycle pictured here.. will travel 20 miles at a top speed of 15 miles per hour… The panel… converts sunlight directly to 35 watts of electricity...” [1] 1981 (b) Tonatiuh team at finish line, Sunrayce ‘95

Then, as many solar energy colleagues from Mexico will recall, in 1992 Beatriz Padilla and I organized a team of students and sponsors to build Tonatiuh, Mexico's first solar race car, which competed in SunRayce '95 in the USA and the World Solar Challenge in Australia in 1996.[2] To this day, when people ask me if we won the race, I say, "Yes we did. We made it to the starting line!" Many other teams weren't so fortunate to participate in what Australian organizer Hans Tholstrup called "Brain Sport." The origins of the modern hybrid electric vehicle can be traced directly to the experience gained by participants in that incredibly demanding test environment. When we competed in Australia in 1996, there were 18 Japanese entries, including the winning Honda Dream II and many other top performers. Back home shortly after the race, many members of those teams went on to create the Honda Insight and the Toyota Prius, not to mention many other EVs. (A team from General Motors in the USA won the first World Solar Challenge race in 1987, beating all other competitors by 2 days. By 1996, the best USA team arrived at the finish line in 24th place! It has been no surprise that the Japanese have held the lead in electric vehicles for over a decade.)

2. Commercially Viable Solar Transportation

After several prototype vehicles and false starts, in 2006 while debating biofuels vs. photovoltaics with a political policy group, I discovered a potential solution:

- Free up the streets for humans again and put the transportation system overhead. (Streets used to be the shared common space between our homes; now humans have no place on the ground in the machine-dominated madness of modern city traffic. Stepping out of a building and onto the sidewalk, you are taking your life in your hands. The notion that a stripe of paint protects bicyclists or a concrete curb protects pedestrians from 2 tonne monsters running at 50 km/hr is pure folly.)

- Use automation to run independent small lightweight electric vehicles on fixed guideways, mastering safety and improving headway between vehicles to achieve high capacity. Mimic roller coaster rides, except...
- Adjust the size of the vehicle to the module of a trip (logically like the 5 seats in a car, plus or minus) and establish a switching mechanism to take people non-stop from origin to destination (not to a central station with its congestion and time-consuming transfers), and ...
- Put solar arrays continuously along the top of the guideway!

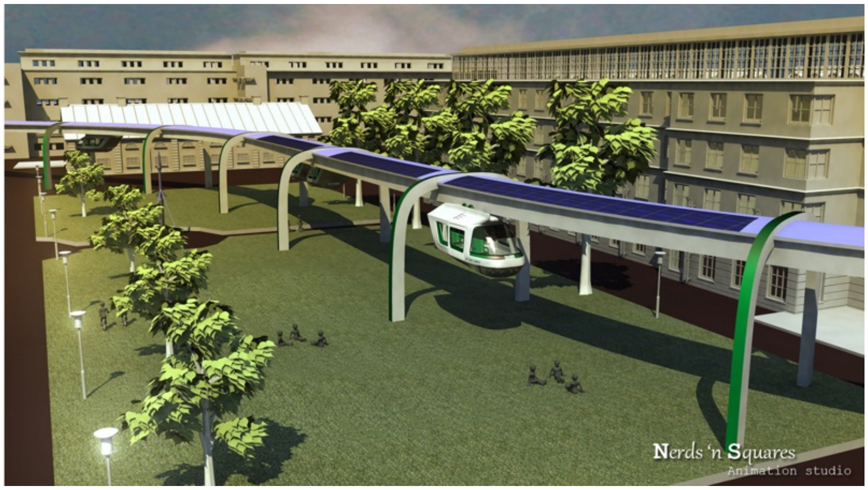

Fig. 2. Solar Skyways in Uppsala from Nerds ‘n Squares animation for INIST

The remaining question is how wide the array must be to provide 100% of the power required by the automated transportation network (net-zero, that is – exporting during the day and importing during the night, incrementally adding storage as that technology evolves).

It turns out that the width is not as large as might be expected. A solar array 2 meters wide can propel upwards of 10,000 vehicles per day along its pathway. [3]

3. Biofuels?

Why not biofuels or electric cars charged by solar?

Biofuels simply cannot scale. Visualize a field of biomass sufficiently wide alongside a highway to supply fuel for 10,000 vehicles per day. That field would be almost a kilometer wide. [4] Water and soil preservation requirements would also be staggering.

Hybrid and pure electric vehicles are improvements but they still don't really address the fundamental energy challenge. Switching from burning rock-oil (petroleum) to burning rocks (coal) for electricity is a step backward, not an advance. (The same applies to burning "natural" gas; what a waste!) Furthermore, finding places in the urban landscape for enough solar arrays to charge inherently inefficient electric vehicles is daunting. (EVs still weigh 2 tonnes to carry typically 1 or 2 passengers, in other words, inherently less than 10% efficient in carrying people vs. moving metal.)

4. Safety

One of my cousins died in a car accident at the age of 19 in a Corvair, the car that was "unsafe at any speed" and put Ralph Nader on the map.

"It is in the post-accident response that lawyers and physicians and other specialists labor. This is where the remuneration lies and this is where the talent and energies go. Working in the area of prevention of these casualties earns few fees. Consequently our society has an intricate organization to handle direct and indirect aftermaths of collisions. But the true mark of a humane society must be what it does about prevention of accident injuries, not the cleaning up of them afterward." [5]

With all the marvels of modern technology, we continue to tolerate a transportation system that kills more people directly in accidents than through all of our wars (fought over oil, also indirectly about cars since oil is the car's energy source).

5. Strategic Alliances

Knowing that Detroit companies bought up the trolley car routes from the 1930s to the 1950s to wipe out their competition [6], and that they repeated their folly by recalling and destroying their incredible EV1 fleet ten years ago [7,8] to prove that electric vehicles can't work, I realized that the automotive industry was not likely to be the place to start.

Fig. 3. (a) Pacific Electric Railway streetcars stacked at a junkyard in Los Angeles, 1956 (b) EV1s crushed by GM, 2003

Facing global depletion of hydrocarbon resources (in spite of the hype about shale oil and gas on Wall Street) and the protection of the petroleum industry, e.g., in Washington, DC, I realized that the petroleum industry wasn't likely to be a part of the solution either.

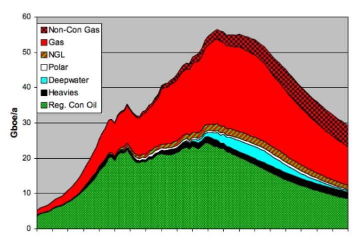

Fig. 4. Oil Depletion Curve

6. The Solar Skyways Challenge

So, building upon my experience in Mexico twenty years ago working with students at UNAM (Universidad Nacional Autónoma de México) and recognizing that if anyone were to be motivated, it would be the youth of today – those who will face the daunting inexorable challenges of an oil-depleted future, my associates and I launched the Solar Skyways Challenge.

6.1. Solar Skyways Challenge #2: The Nerds 'n Squares

In 2011 we enlisted the talent of three students from Delft University in the Netherlands to create an animation to demonstrate the process by which a solar transportation system might be constructed, and what it might be like to experience a ride on this system. The Nerds 'n Squares produced this animation with whimsical construction machinery based on real equipment used now or under development by startups in Silicon Valley. They replicated the existing buildings along the route in a 3D computer model of Uppsala, Sweden, and then they modeled the structure along the entire route, including station designs and the podcars themselves. The resulting elements were woven into a story line depicting one person's trip across the system. [8]

6.2. The Solar Skyways Challenge #2

In 2012 we reached out to professors and students in California, Sweden and elsewhere to participate in the "Solar Skyways Challenge" – a competition to design and build a solar powered ATN (Automated Transportation Network). Two groups responded enthusiastically.

6.3. Uppsala University

Speaking of challenges, one might imagine it to be especially difficult to power a transportation system by solar in a place like Sweden, where annual solar electricity production is half that of, e.g., the Mojave Desert in Southern California. However, the cost of fuel in Sweden is twice as high as in California, so the economic payback is the same -- less than 5 years without subsidies.

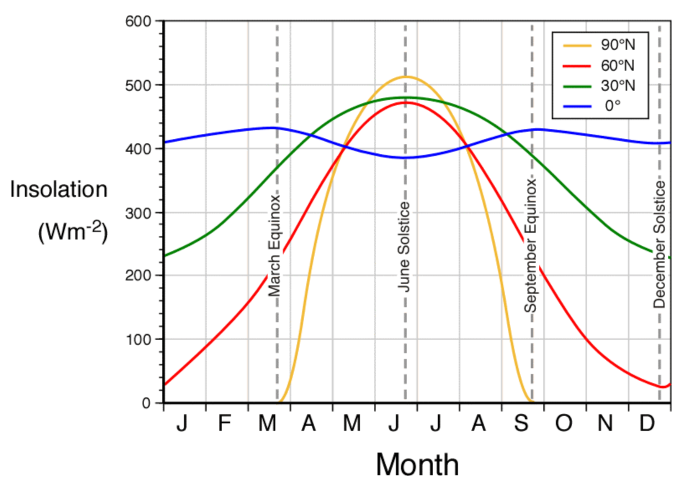

Fig. 5. Solar Radiation at the Equator, 30º North, 60º North and North Pole

Designing for a system at 60º North (the same latitude as Anchorage, Alaska), a group of students at Uppsala University took up the challenge and calculated that a solar system in Sweden that is 3.6 meters wide along 2 km of guideway would be sufficient to achieve 500 trips per hour, the anticipated system demand. This will become one of the longest solar systems in the world and its success will open markets for a technology which Sweden can readily export to the rest of the world, where the solar system's production can only be greater.

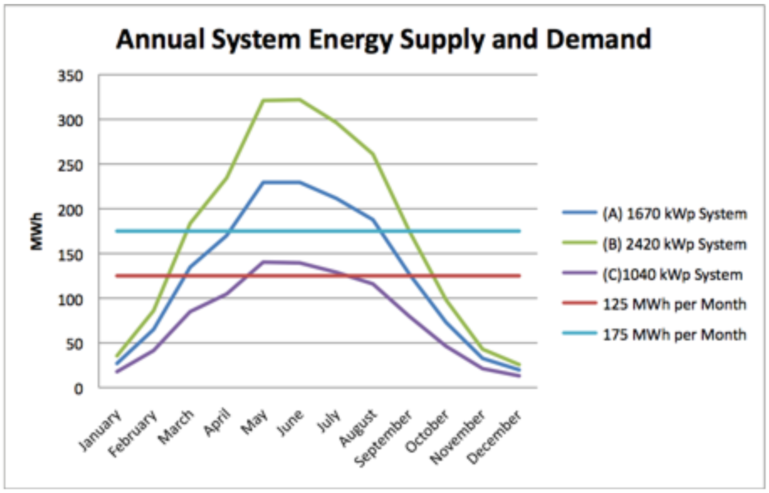

Fig. 6. Summary of Uppsala Solar System Analysis

6.4. San José State University

At San José State University in Silicon Valley, an interdisciplinary group of students focused on designing and testing the mechanics and electronics ("Mechatronics") for managing a solar ATN system by building a working 1:12 scale model. The model is nearing completion and results will be presented in October 2013 at the Podcar City 7 conference in Washington, DC. [[Burlingame et al 2013]] The team has also done environmental assessments, urban planning and business planning, with presentations to business leaders, city commissions and professional societies in Silicon Valley. [Furman 2013]

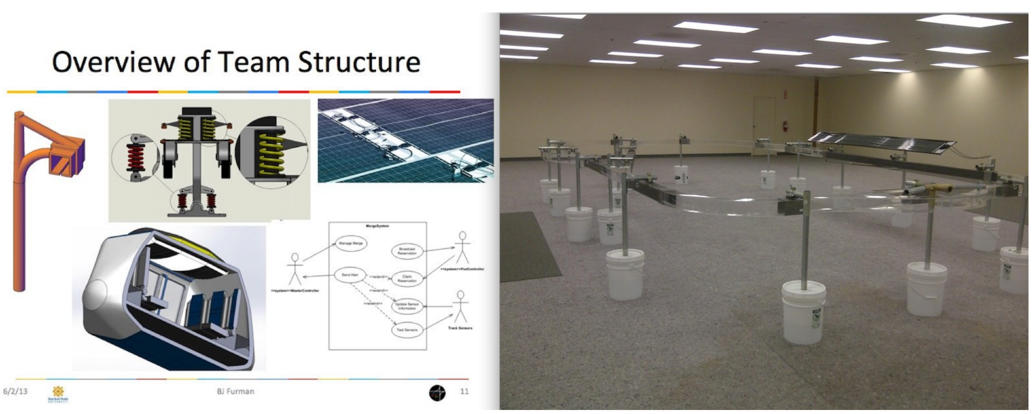

Fig. 7. (a) Overview from presentation at IEEE-VTS Santa Clara Valley; (b) Scale model track with sample solar array

6.5. Solar Skyways #3

Looking forward, the Solar Skyways Challenge #3 continues for the academic year of 2013-2014 in the northern hemisphere and as Challenge #3.5 in the southern hemisphere for the academic year of 2014. Student achievements will again be presented at Podcar City 8 in the autumn of 2014 in Europe.

7. Why Students?

Some of my friends in business and the engineering professions ask why would I reach out to students rather than engage with established businesses to achieve the solar transportation objective. Obviously, established businesses have customers to satisfy and employees who need work to do every day. And though many companies have R&D resources, they are not yet in the solar transportation business, by definition. So the potential of the technology remains elusive within the business community.

On the other hand, young people are open minded and imaginative, and society cushions them from risk because they don't have many obligations such as raising families. The students who have already participated in the Solar Skyways Challenge have in 9 short months accomplished more than most other groups simply because they brought fresh perspective and had the time to work out important details.With very limited funding, they have produced results which put the technology far beyond what has been achieved by established consultants working under major contracts. Is it worth it? The proof is in the pudding. Stay tuned!

8. Conclusion

The discovery of Fire defined humanity's humble origins. Fire was at the very core of human existence.

The discovery of Electricity defined modern civilization. Electricity is at the very core of modern civilization. Ironically, in the process, humanity's friend Fire has become the arch-enemy. The prescient Wizard of Electricity, Thomas Edison, laid down the gauntlet over 100 years ago, in 1910:

> "Sunshine is spread out thin and so is electricity. Perhaps they are the same, Sunshine is a form of energy, and the winds and the tides are manifestations of energy."
>
> "Do we use them? Oh, no! We burn up wood and coal, as renters burn up the front fence for fuel. We live like squatters, not as if we owned the property.
>
> "There must surely come a time when heat and power will be stored in unlimited quantities in every community, all gathered by natural forces. Electricity ought to be as cheap as oxygen...." [10. Edison 1910]

To keep enough oxygen in the atmosphere for Edison's comparison to matter, humanity must put out the Fire. Thankfully, burning wood in modern cities has been reduced to a summer ritual (the charcoal barbeque). But the squatters are still burning hydrocarbon minerals to make Electricity ... and to get around. Though progress is being made to produce Electricity with solar and wind, infernal Fire-belching machines are still running around loose on the streets. City dwellers have abandoned Fire in the kitchen, so now it is time to banish Fire from the streets. Given what humanity knows today, allowing machines on wheels to dominate the urban landscape is just plain insane.

Can we take the Solarevolution to the streets? With innovative young people taking the lead, it can happen.

Acknowledgements

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[3] Swenson, Ron. Do the math. On internet at http://www.solarevolution.com/dothemath/ (August 2013)

With these assumptions: 65 km/hr operating speed, 8 kw load, 2 sec interval, 25% empty, 5 hours at peak operation, 5 hours of peak sun equivalent, 167 watt/m^2, 1 person/podcar, 2 meters wide, the result is 10000 vehicles/day.

[4] MacKay, David. *Without the Hot Air*. Self-published at http://www.withouthotair.com/ 2009 (August 2013),.

Page 29: 12 km/liter vehicle efficiency, 10 kwh/liter fuel conversion; Page 43: 0.5 w/m^2 biomass produced. Calculation:

(10 kwh/liter*1000 watt-hr/kwh*10000 vehicles/km/day)÷(12 km/liter*0.5 watt/m^2*24 hr/day*1000 m/km) = 700 meters wide.

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