PERSONAL TRANSPORTATION, ONE HUNDRED PERCENT SOLAR POWERED

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ABSTRACT

Is it possible to power a high capacity personalized ground transportation system with solar energy?

Renewable energy alternatives have been offered as principal means for combating the challenges of global warming and declining fossil fuel reserves. In particular, renewables combined with energy storage are seen by many as natural alternatives to fossil fuels (coal and natural gas) for electricity generation.

The same enthusiasm has not held sway for transportation, where oil dominates and renewables have not been demonstrated (except for woefully inadequate biofuels). Wind energy has been envisioned as suitable for charging EV batteries at night and solar by day but substitution of renewables generation in place of fuels has been seen as limiting because of intermittency and because the necessary batteries have low energy density compared to fuels (the only alternative deemed dense enough to propel cars long distances). With looming oil shortages, do solutions exist?

In response to this challenge, a solar-powered PRT system ("podcar") is being designed in Uppsala, Sweden. A fleet of podcars is to be suspended under a beamway covered with a PV system averaging 2 meters wide along its full extended length, based on patented designs and a 400 kW PV overhead canopy recently built in California. Preliminary calculations demonstrate that the grid-connected system will produce sufficient electricity to power about 7,000 trips per day on average on a 3.8 km route, powering fewer trips in the winter but with sufficient surplus in the summer to counter-balance the entire deficit of the winter months. Payback for the solar energy component is anticipated to be less than 5 years, without subsidies.

1. INTRODUCTION

Oil prices are skyrocketing. Fuel shortages are becoming reality in many countries around the world and threats of shortages are looming on the horizon in the USA. Consequently, the motivation to find alternatives is building rapidly and proposed energy and transportation solutions are emerging from all quarters. In turn, policy makers are obliged to confront choices for expenditure of public funds with limited technical understanding and economic signals distorted by the interests of incumbent stakeholders.

Mobility is by definition a social phenomenon leading to infrastructure requirements that call for broad consensus. Can we minimize changes in the established infrastructure by adapting automobiles to biofuels or electricity stored in batteries? Can we or must we abandon the automobile in favor of public transit with the concomitant costly retooling of transportation infrastructure? Are we left with only a few unpalatable options? By what criteria do we evaluate the alternatives which stand before us?

2. ORDER OF MAGNITUDE IMPROVEMENTS: 10X

What must be the scale and what can be the rate of transformation of mobility from oil to ingenuity?

If oil declines at 4% per year and solar PV installations experience very high growth at 50% per year, it would take 10-15 years for solar to begin to make a dent against anticipated decline in oil "production." (Fig. 1) One way to speed that process is to find applications which deliver high leverage against the status quo. By what criteria do we assess energy alternatives? Can we find solutions which deliver an order of magnitude ("10X") improvement?

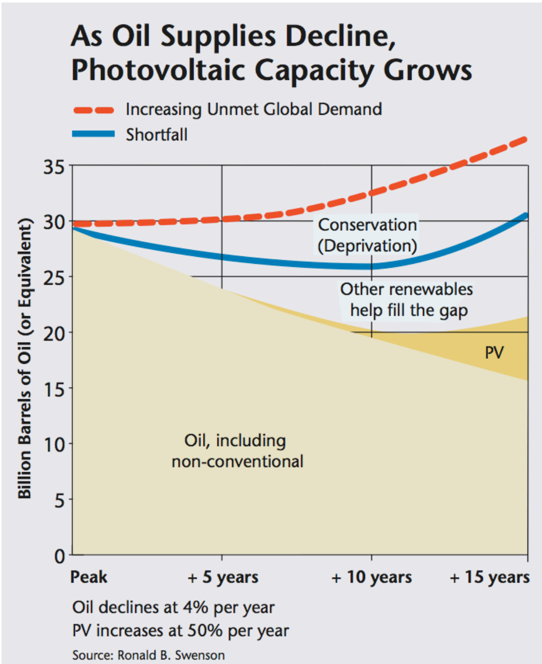

Fig. 1: As Oil Supplies Decline, PV Grows

2. <u>SOLAR TRANSPORTATION</u>

It is proposed that solar energy (PV) is a potential primary energy source for mobility infrastructure. Furthermore, the very premise of a personalized transportation system built with PV placed directly within the transportation corridor may become a driving force to liberate transportation from many of the shortcomings of the automobile and urban railroads which have plagued society for over half a century. Can 10X improvement be achieved?

2.1 <u>The Concept</u>

A suspended electric-powered personal rapid transit ("PRT" or "podcar") system has been proposed and is being developed under contract to the City of Uppsala in Sweden, with the participation of several local stakeholders. The system will operate under a PV system that averages 2 meters wide along its full extended length. (Fig. 2)

PRT offers a unique combination that embraces the advantages of personal vehicles, combined with the advantages of public transit. Podcar "guideways are arranged in a network topology, with all stations located on sidings, and with frequent merge/diverge points. This approach allows for nonstop, point-to-point travel, bypassing all intermediate stations."(3) Originally envisioned and implemented in Morgantown, WV to address the first oil crisis of 1973, podcar technology has advanced dramatically in the past several years.

Based on the integration of patented and engineered podcar technology, plus a recently constructed 400 kW PV solar canopy in California (Fig. 3) and several working small-scale PRT systems operating in the UK and the UAE, the design becomes largely the integration of existing elements.

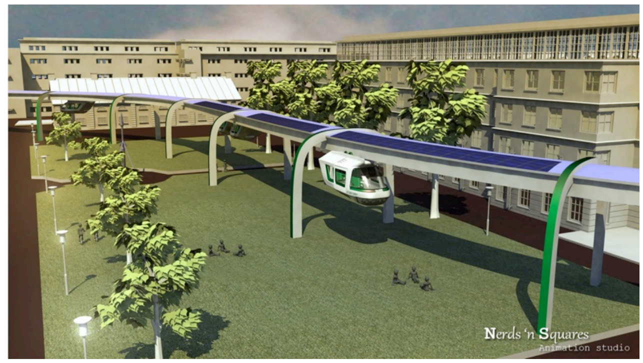

Fig. 2: Podcar and Solar Beamway in Uppsala

Fig. 3: Solar 400 kW Canopy in Santa Cruz, CA

2.2 <u>Generation, Load and Payback Calculations</u>

Preliminary calculations demonstrate that the PV system will produce sufficient electricity to power nearly 7,000 trips per day (annual average) for the 3.8 km route, while powering fewer trips in the winter and more trips in the summer to produce sufficient surplus energy to counter-balance the entire deficiency of the winter months.

Generation:
3,800 m long * 2 m wide * 143 w/m^2 = 1,087 kW
1,087 kW * 900 kWh/kW/year ÷ 365 = 2,680 kWh/day.

Load: 6,700 trips/day * 0.4 kWh/trip = 2,680 kWh/day.

Simple economic payback for the solar energy system component is anticipated to be less than 5 years, without subsidies:

Solar capital cost: 1,087 kW * 4.00 $/W = $4.3 million

Gasoline, operating cost for equivalent travel:
2 km/trip * 6,700 trips/day * $2/liter ÷ 10 kM/liter =
= $2,680/day

Payback time:
$4.3 million ÷ $2,680/day ÷ 365 days/year = 4.4 years

Payback in the USA would be about the same. Even though the cost of fuel would be about half as high, the solar production would be about twice as much as in Sweden.

3. FAILINGS OF EXISTING TRANSPORTATION

How do solar powered podcars address the failings of the existing transportation system? How do they overcome the limitations posed by the commonly espoused alternatives (biofuels, EVs and robotic cars)? Can solar transportation liberate us from the limitations of such alternatives?

3.1 Private automobiles

What are the limitations of the private automobile?

Energy. The most obvious limitations of the incumbent vehicle fleet are the escalating price of energy and (ultimately more importantly) the declining availability of fossil fuels. Even though there have been some small domestic increases in production recently, the USA nonetheless faces competition for oil from China and India ("Chindia") in the global marketplace. Already the impact is being felt in the marketplace.

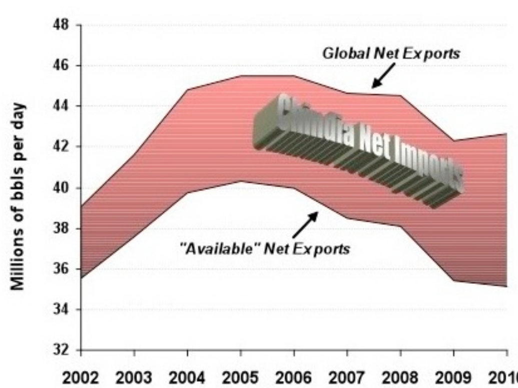

Fig. 4: Available Net Exports = Global Net Exports less China & India Net Imports

The alternatives to oil that are being advocated by substantial stakeholder constituencies are partial solutions which give rise to the same failings and disadvantages as the fossil-fueled automobile. A flex-fuel or electric car does not resolve these long-standing challenges:

Congestion. Automobiles have a large carbon footprint. They also have a physical footprint, collectively capturing up to half or more of the urban landscape (Fig. 5), space which could be liberated for the enjoyment of people – pedestrians and bicycle riders – if the transportation system were positioned far enough above the ground.

Fig. 5: Parking Space for cars in the Urban Landscape

Safety Hazards. Every year over a million people die worldwide and countless are seriously injured in traffic accidents.(7) Even robotic vehicles cannot avoid a child running into the street or swerving on a bicycle. Can we design a system that is forgiving of texting teens, drunken drivers and unforseen road hazards?

Insecurity. It can be no surprise that the largest oil importer has the largest military budget. Need more be said?

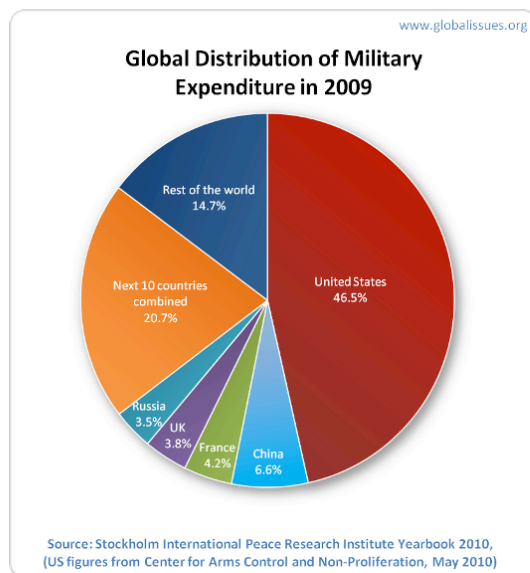

Fig. 6: Global Distribution of Military Expenditure

Noise. Flex-fuel vehicles are as noisy as conventional cars, and though modern EVs may be quieter than fuel burning cars, they can still add to the never ending chorus of blaring horns and screeching tires.

Invasion of the human landscape. Humans have adapted to an urban landscape impacted by dangerous fast heavy machines weighing up to 2 tonnes or more, traveling at high speed. Yet people greatly appreciate the tranquility and vitality of market streets freed of vehicle traffic (e.g., Strøget in Copenhagen) but they have come to accept such urban havens as the exception rather than the rule.

3. 2 Public Transit

Most mass transit systems move people in groups over scheduled routes. This has inherent inefficiencies:

Delays. Time is lost while waiting for the next bus to arrive, while taking indirect routes to destinations and while stopping en route to pick up or drop off others passengers with their own distinct destinations.

Confusion. Public transit is often accompanied by confusing, inconsistent and inaccessible schedules.

Excessive Mass. To support a large number of people, each public transit vehicle must be structurally massive.

Energy. Slowing and accelerating such large mass is a factor which undermines public transportation's energy advantage, while slowing other traffic in turn.

Disruptive construction. While under construction, mass transit can be extremely disruptive to existing street activity and business operations.

Cost Prohibitive Construction. A BART extension under construction in Silicon Valley is projected to cost $230 million/mile in its suburban segment and over $600 million per mile along the prime urban corridor, where the rail is to be positiioned underground by tunneling along major streets and by using the cut and cover method at stations.(4) Is there a less expensive alternative?

4. LIMITATIONS POSED BY NEW ALTERNATIVES

4.1 What about EVs?

The solutions being proposed with significant stakeholder constituencies are fraught with the same failings and disadvantages as the fossil-fueled automobile. A flex-fuel or electric car does not resolve these long-standing challenges:

Economics. Even if electric vehicles were to cost the same as internal combustion vehicles, the US consumers no longer have the kind of money necessary to convert the entire fleet in a timely fashion. (Fig. 7)

In 2009 there were 234 million light duty vehicles in the USA.(6) At an average price of $30,000, it would cost $7 Trillion to replace that fleet with electric vehicles. In the face of enormous consumer debt brought about largely by America’s addiction to imported oil, the expectation that consumers might finance this replacement appears to be untenable.

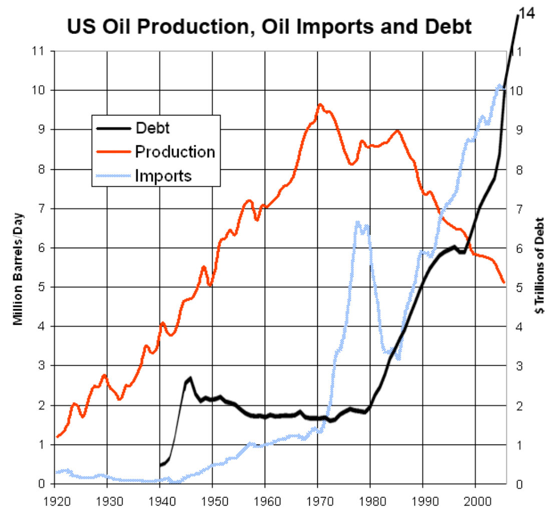

Fig. 7: US Oil Production, Imports and Debt

Much concern has been expressed about the availability of lithium for batteries. Consumer credit may become a scarce commodity long before serious lithium shortages occur.

4.3 What about biofuels?

Much attention has been given to finding replacement fuels for internal combustion engines. The term “drop-in fuels” has been coined by the US military, suggesting that there need be no design changes to facilitate the transition.

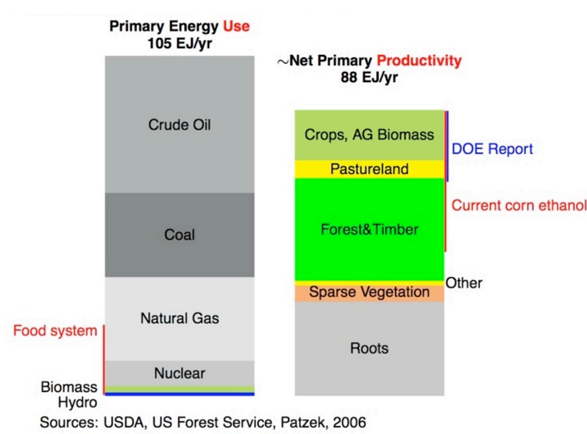

Fig. 8: Net Production of Biomass in US

However, if all productive biomass were to be exploited, including the roots of all growing plants, there simply would not be enough fuel to meet America's primary energy diet.(Fig. 8)

Then too, how do the various renewable alternatives compare in terms of total Watts per unit area?(Fig. 9)

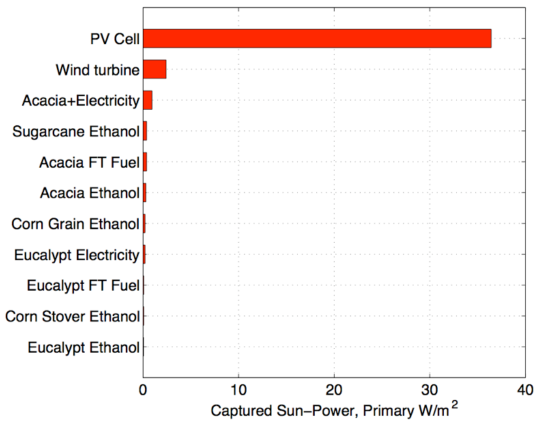

Fig. 9: Sun-Power from PV, Wind, Biomass

If there is a way to apply PV directly to transportation, clearly it offers more than10X improvement over any of the biomass alternatives. Can it be done?

4.2 <u>What about wind energy?</u>

Wind energy has been envisioned as suitable for charging EV batteries at night and solar by day but substitution of renewables generation in place of fuels has been seen as limiting because of intermittency and because batteries have low energy density compared to fuels, the only alternative deemed dense enough to propel cars long distances. While wind energy produces more energy per unit of land area than biofuels, there are limitations to a system designed in such a way as to be dependent on battery technology and its inherent inefficiencies. Can a solar podcar system overcome this limitation?

5. <u>ADVOCACY IN THE MARKET</u>

Podcar systems are under development in numerous cities around the world – in Europe, the Middle East, North America and Asia. Many of these systems are designed to solve congestion problems, without primary consideration of energy performance. In addition to Uppsala, Sweden, one city in particular has envisioned the use of renewable energy as a key feature of a podcar system, San José, California. In a recent RFP for an "Automated Transit Network," the City staff identified the use of renewable energy as a primary consideration, "the ATN Consultant team shall fully evaluate how the ATN system could be constructed to maximize its energy efficiency and potentially be powered in whole or part by renewable energy."(15)

6. <u>A TERAWATT OF PV</u>

The USA has 4.3 million km (2.7 m miles) of paved roads.(8) A podcar network 4 meters wide and 1 million miles (1.6 m km) long, about 37% of the paved road in the USA, would produce a terawatt of electricity. Based on an average solar capacity factor of about 20%, this network would produce around 1,800 TeraWatt-hours per year or half of the 3,700 TWh of electricity generated in the USA. Without disrupting desert land or building long electric transmission lines, an extensive solar powered podcar network would not only provide mobility but also have sufficient surplus generation capacity to provide a significant fraction of total electricity to the electric grid.

7. <u>CONCLUSIONS</u>

Bearing in mind the challenge of finding alternatives to fossil fuels while there are sufficient natural resources and social stability to create such alternatives, not only for electricity production but also for transportation, and confronting the limitations of the transportation alternatives which have recently found favor, it is clear that fresh alternatives must still be considered. For all of these reasons, solar powered podcar networks represent a potential which merits rapid development and testing. Furthermore, a transportation system above the streets can liberate people from the tragic consequences of traffic accidents and free up major portions of cities for open space and human activity. The coming oil crisis is an opportunity to transform mobility as we recreate our cities for humans.

8. <u>REFERENCES</u>

8.1 <u>Websites</u>

(1) http://www.solarskyways.com/
(2) http://www.solarskyways.com/DoTheMath
(3) http://en.wikipedia.org/wiki/Personal_rapid_transit
(4) http://ivn.us/2012/03/14/construction-starting-in-april-on-san-jose-bart-extension/

8.2 <u>Transportation Statistics</u>

(5) Research and Innovative Technology Administration, National Transportation Statistics, Table 1-35: U.S. Vehicle-Miles

http://www.bts.gov/publications/national_transportation_statistics/html/table_01_35.html

2.013 + 0.617 = 2.630 trillion light duty vehicle-miles, 89% of 2.953 trillion total vehicle-miles

(6) Research and Innovative Technology Administration, National Transportation Statistics, Table 1-11: Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances

http://www.bts.gov/publications/national_transportation_statistics/html/table_01_11.html

There are 194 + 40 million = 234 million light duty vehicles, 92% of the 254 million total vehicles including motorcycles, trucks and buses (2009).

Therefore the average light duty vehicle travels 2.63 T ÷ 234 M = 11,000 miles per year.

8.3 Safety

(7) Research and Innovative Technology Administration, National Transportation Statistics, Table 2-18: Motor Vehicle Fatalities, Vehicle-Miles, and Associated Rates by Highway Functional System

http://www.bts.gov/publications/national_transportation_statistics/html/table_02_18.html

19,125 rural +14,298 urban =33,423 fatalities (2009)

8.4 Electricity Consumption

(8) CIA Factbook

https://www.cia.gov/library/publications/the-world-factbook/geos/us.html

USA electricity consumption 3.741 trillion kWh (2009)
Roads 4,374,784 km (2.7 m miles) paved including 75,238 km (47,000 miles) of expressways, 2,131,420 km unpaved, 6,506,204 km total (2008)

8.4 Other References

(9) Swenson,Ron. Solar Skyways: Mobility in a World Beyond Oil. Podcar City Conference, Stockholm, 2011

(10) Swenson, Ron and Robert Baertsch. Solar Powered Personal Rapid Transit (PRT): Electric Vehicles without Batteries or Congestion, ASES, San Diego, CA, 2008

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(12) Swenson, Ron. Solar Power Potential with PRT. ATRA, Santa Cruz, California. 2006.

(13) Swenson, Ron and Francis de Winter. The Production Peaks in Petroleum and Natural Gas: Information, Misinformation, Awareness, and Implications. Solar World Congress, ISES, Orlando, 2005.

(14) Swenson, Ron and Francis de Winter. A Wake Up Call. Solar Today, March/April 2006.

(15) REQUEST FOR PROPOSAL for San José Automated Transit Network, FFRDC Development Services, RFP # 08-09-DOTAD-009, August 31, 2009

The City of San José's Request for Proposal in 2009 incorporated these renewable energy objectives:

San José ATN: Renewable Energy

"Ensure that the ATN system is built in the most energy-efficient manner possible and all practical means of capturing and utilizing renewable energy to power the ATN system are fully pursued. (pg 5)

"Experience with renewable energy systems & energy-efficiency strategies (pg 6)

"… the ATN Consultant team shall fully evaluate how the ATN system could be constructed to maximize its energy efficiency and potentially be powered in whole or part by renewable energy.

"… quantifying preliminary energy requirements of ATN systems, identifying potential for renewable energy generation, and calculating carbon emissions reductions achievable through renewable energy ... (pg 24)

"… evaluate cost/benefits of using renewable energy to offset all or a portion of the energy requirements of the ATN system, estimate carbon emissions reductions achievable through use of renewable energy ... Identify other green building practices, including energy efficiency measures, that could be cost-effectively integrated into the design. (pg 27)

"Provide analysis of cost/savings and recommend specifications to execute energy-efficiency and renewable energy strategies determined feasible…." (pg 28)