Solar-Powered Personal Rapid Transit (PRT): Electric Vehicles without batteries or congestion

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ABSTRACT

Powering transportation with solar energy will require extremely efficient vehicles. Battery-powered vehicles pose difficult technical challenges that have not yet been proven in the marketplace. Personal Rapid Transit (PRT) provides a solution to transportation that 1) does not require batteries or liquid fuel and 2) solves the congestion problem with overhead guideways.

We present a transportation solution that is based on a computerized driverless vehicle that runs on a solar-powered guideway suspended over existing highways.

The potential market generated by this system is substantial. We estimate that 540,000 miles of guideway in the US would serve most urban centers and all major highways in rural areas. The goal is to provide a PRT station within 1/4 to 1/2 mile of every passenger. This would require 92.4 million kW of PV in order to provide 100% of the electricity to drive PRT. Nighttime use could be offset by daytime excess power provided to the grid or from wind and geothermal. The cost of PRT is significantly less than battery-powered electric vehicles and could be implemented in the timeframe required to manufacture 200m electric vehicles. Contracts for PRT PV would range in size from \$20m for a small 10 miles loop to \$20B for a large 1000 mile network assuming \$3m per mile for the PV system.

Today Sweden, South Korea and the United Kingdom have invested in PRT, with a sharply rising investment rate. Combined with solar, we see this field of technology as an unprecedented possibility in the transportation field for true sustainable travel.

Several vendors have ¼-mile prototypes in progress and the first commercial implementation at Heathrow airport (without solar) is scheduled for Spring 2009. We expect larger implementations in 2010 as several cities are considering the technology. The solar community would benefit from early adoption in order to drive design decisions that incorporate PV.

Our paper will detail the assumptions behind our estimates as well as the challenges facing adoption.

Index Terms – transportation, solar, guideway, electric vehicle, Personal Rapid Transit, PRT, transit-oriented development, traffic reduction, congestion

1. INTRODUCTION

Personal Rapid Transit (PRT) is an electric-powered transportation system that borrows from the architecture of the automobile. With the twin problems of climate change and peak oil looming, it is imperative to speed the transition to electric-powered ground transportation. Plug-in hybrids and electric-powered mass transit might achieve this goal, but each has problems that have slowed implementation. Battery technology presents a significant hurdle for mass production of plug-in hybrids. Mass transit is limited by human factors and high cost. PRT offers promise of electrified transport without the delays and fixed schedule of mass transit, while freeing the passenger from traffic congestion and down-time behind the wheel. Given historical growth in Vehicle Miles Traveled ("VMT") at 2% per year, we are facing a need to constantly widen highways. Figure 1 shows the vision of our cities and highways in 30 years at current growth rates. PRT was first developed in the 1970s, but never achieved widespread adoption due to cheap oil and the lack of computer power to build large networks. With advances in maglev, advanced computer networking software, PV manufacturing, plus growing awareness of climate change and peak oil, the time is ripe for a new look at PRT.

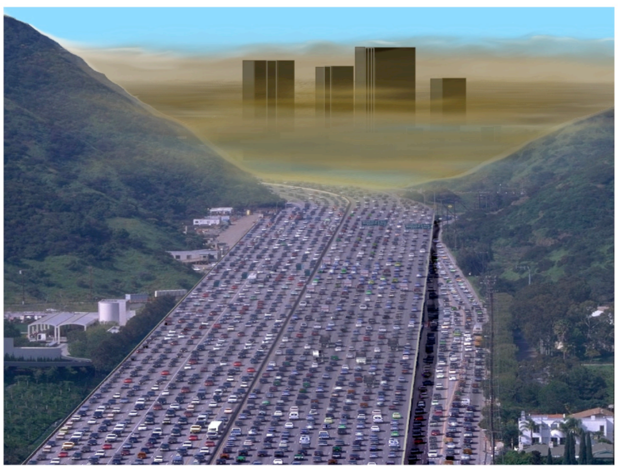


Fig. 1: Projection for US highways after 30 years of 2% growth in traffic.

2. STATUS OF CURRENT PRT SYSTEMS

2.1 Government reports

Aggressive GHG emission targets have been set by many governmental organizations. California has some of the most stringent mandates in the US that have been passed into law by the state legislature (AB32) and an executive order by Governor Schwarzenegger (S-03-05). The California Air Resources Board has been tasked with the challenge of creating a plan to implement these goals. Transportation, shown as the thickest band in Figure 2, is one of the biggest contributors and most difficult to solve, due to the energy storage problems.

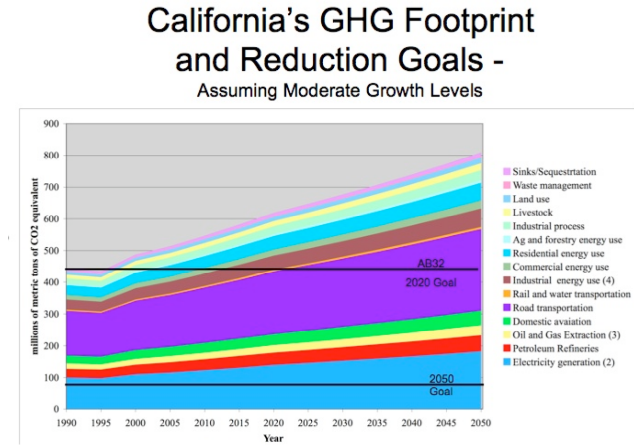


Fig. 2: GHG emissions in California projected out to 2050. Ground transportation shown as thickest bar. Source: CIEE

After decades with only a single PRT system in operation in the US (Figure 3), governments are starting to take an interest in PRT. The California Air Resources Board formed the ETAAC committee to identify technologies to address CO2 emission reduction goals. Their final report stated that PRT has one of the highest potentials for GHG reductions and called for an evaluation at the state level (1). The state of New Jersey commissioned a PRT study which predicted a rise in this type of transportation system (2). The Swedish Transport Institute SIKA also has a study (3,4) that combines PRT with freight and called General Transport System (GTS). The European commission has a report that shows the benefits of PRT but points out the lack of awareness of the technology (5).

2.2 Second Generation PRT Systems

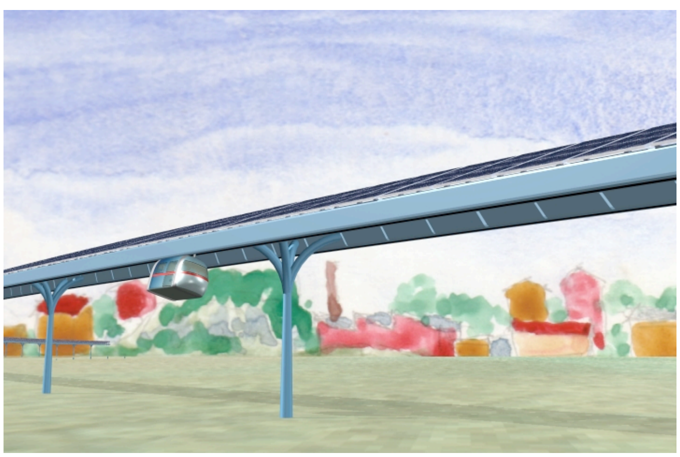
Several companies (POSCO and ULTra) have started building demostration/pilot systems that are improvements on the first generation systems of the 1970s. These systems run at 25-37 mph, carry 4-6 passengers, and have a weight similar to an automobile. POSCO has a demonstration system in Uppsala, Sweden, and ULTra is currently building a pilot project at Heathrow Airport (6-8).

Fig. 3: First generation system in Morgantown, WV has carried 16m passengers since the 70s with no fatalities or major injuries.

2.3 Third Generation PRT Systems

Higher speed systems are also under development that use maglev instead of wheels to lower maintenance costs and energy requirements. Unimodal is developing a system (9) that holds two passengers, and is considerably lighter to reduce infrastructure costs.

Fig. 4: Solar PV shown attached to PRT Guideway.



3. ENERGY REQUIREMENTS FOR SOLAR PRT

First, we will estimate energy needs per mile of guideway infrastructure. Second, we (roughly) estimate the size of the US network and area of PV needed to provide at least half of the light-duty transportation needs in urban and dense suburban areas as well as intercity traffic. Obviously, wind and geothermal will play a large role, but we think the fixed guideway and distributed nature of the system will match well with distributed PV, shown in Figure 4.

3.1 Energy requirements per mile of guideway

The stated continuous power requirements for a single PRT vehicle range from 2-3kW during normal operation (6-9). Since PRT is non-stop and power from regenerative braking does not need to be stored in a battery, the average power requirements are very close to the power needed for normal operating speed. Estimates range from 50-75 watt-hours per mile. Compared with Plug-in hybrid or electric vehicles, which range from 200-500 watt hours per mile (10,11), PRT makes renewable-powered transportation a viable goal in a much shorter time frame.

TABLE 1. ESTIMATED ENERGY REQUIREMENTS FOR ONE MILE OF PRT GUIDEWAY

Traffic volume	**Vehicle spacing (seconds)**	**Hours per day**	**Kilowatts per mile**	**kWh per mile**
Rush hour	0.5	4	480	1,920
Midday	4	6	60	360
Off peak	10	6	24	144
Night	120	8	2	16
			Total kwh per day per mile	2,440

Using traffic count data collected by US DOT for every major US highway, we can estimate an average traffic pattern that would be required to power a one-mile section of guideway, shown in table 1. If we assume 4 hours of solar insolation per day, this leads to an estimated 600 kW of PV per mile -- about 8 ft wide if placed on the guideway. At $5 per watt, solar would add $3m to the per mile cost of $10-30m for PRT. By building the guideway along transmission lines, PRT could strengthen the stability of the grid by feeding excess power onto the grid without building additional high voltage transmission lines.

3.2 PV requirements for US PRT Network

The current US highway network is composed of 3.9m miles of highways and local roads. Most of the rural roads and low volume residential streets would not be candidates for a PRT guideway. Assuming that we install PRT along existing high volume roads and partial coverage on lower volume streets, we estimate about 550,000 miles of solar-powered guideway would need to be constructed (See Table 2). At $13m per mile, the cost spread over 20 years would be $357B annually. Compared with our annual expenditure of $977B on fuel and car replacement, PRT could be funded by simply redirecting 35% of our existing expenditure on oil, cars and light trucks. Replacement of a portion of the existing annual oil expenditures totaling $657B (assuming $90 per barrel and 20m barrels per day), and annual US sales of 16m cars and light trucks totaling $320B, could provide adequate funding for massive PRT deployment.

TABLE 2. MILES OF EXISTING US ROADS AND ESTIMATED FINANCIALLY VIABLE PRT ROUTES

	MILES OF US ROADS		**MILES OF PRT**
URBAN			
Interstate	13,491	200%	26,982
Other Freeways and Expressways	9,175	100%	9,175
Other Principal Arterial (115-130ft)	53,447	100%	53,447
Minor Arterial (80-106 ft)	89,911	100%	89,911
Collector (60-90 ft)	88,604	25%	22,151
Local Road (little thru traffic)	598,514	10%	59,851
URBAN SUBTOTAL	853,142		248,026
RURAL			
Interstate	33,067	200%	66,134
Other Principal Arterial	98,952	100%	98,952
Minor Arterial (80-106 ft)	137,751	50%	68,876
Major Collector (60-90 ft)	433,754	10%	43,375
Minor Collector (limited thru traffic)	272,360	0	0
Local Road (no thru trafffic)	2,102,977	0	0
RURAL SUBTOTAL	3,078,870		277,337
TOTAL	3,932,012		538,854

3.3 Installation issues for solar PRT

Ideally, solar panels could be mounted on the guideway to provide an integrated solution and avoid distribution losses. The extra weight and wind loads make this difficult, PV could be located on nearby buildings or open areas. By combining such projects with PRT implementations, the solar industry could be rapidly expanded while at the same time minimizing losses associated with long distance transmission of power.

4. CO2 REDUCTION POTENTIAL

Assuming traffic patterns from table 2, we calculate 72,000 cars per day on a bi-directional section of guideway. Using 400 grams of CO2 per mile for a typical car from the GREET model, each mile of guideway installed would reduce CO2 by 10,000 metric tons per year. California currently emits about 120m metric tons per year from all road transportation. This would require 12,000 miles of bi-directional guideway to offset all CO2 emissions from road transportation. If this can be built for $15m per mile, the annual cost spread over 20 years ($9B) would be far less than the amount California spends on fuel for in a single year (~35B).

5. DISCUSSION

Although the estimates in this paper are extremely rough, they provide a compelling argument for in-depth evaluation of PRT. The alternatives for moving our transportation system away from oil are remarkably limited. The hidden costs in crumbling bridges, health care, battery research, biofuel production, military protection of oil supplies, oil exploration and oil imports are increasing. The ecosystem services that support human life are popping like rivets on an airplane wing. The US needs a bold new vision for reclaiming leadership on the economic and environmental front. The annual expenditure of $500B-700B that is currently sent out of the country to buy oil and foreign cars could be reinvested in PRT and solar PV in order to reinvigorate our sagging economy. Partnerships between the solar industry, the nascent PRT industry, green architects, developers and government are imperative. Figure 5 presents a vision for integrating PRT into cities, providing a realistic roadmap for transit-oriented development, traffic reduction, greenhouse gas reduction and urban infill.

Fig. 5 – PRT can create walkable areas in dense urban settings

6. ACKNOWLEDGEMENTS

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7. REFERENCES

(1) Lloyd, A, Epstein, B, et al. Recommendations of the Economic and Technology Advancement Advisory Committee (ETAAC) Final Report: Technologies to consider for reducing Greenhouse Gas Emissions in California. A Report to the California Air Resources Board Adopted by the committee Feb 11, 2008, presented to ARB on Feb 28, 2008 http://www.arb.ca.gov/cc/etaac/etaac.htm http://www.arb.ca.gov/cc/etaac/ETAACFinalReport2-11-08.pdf

(2) Carnegie, Jon A. and Hoffman, Paul S., Viability of Personal Rapid Transit In New Jersey, New Jersey Department of Transportation, Trenton, NJ: http://faculty.washington.edu/jbs/itrans/big/PRTfinalreport.pdf

(3) "A general transport system: A case study of the value of alternative transport systems" Swedish Institute for Transport and Communications Analysis, SIKA Jan 2006 http://www.sika-institute.se/Doclib/2006/sr_2006_1_eng_total.pdf

(4) Tegnér, G, Hunhammar, M, Andréasson, I, Nowacki, J, Dahlström, K, "PRT in Sweden: From Feasibility Studies to Public Awareness", 11th International Conference on Automated People Movers, Vienna, 22-25 April 2007 http://advancedtransit.org/pub/2007/tegner20070422.pdf

(5) Leiss, U, Helmreich, W, Jauernig, G, "Third Annual Thematic Research Summary - Other modes" European Commission Directorate-General for Energy and Transport Deliverable D2.E-2.5 Issue 1.0 August 2006

(6) ULTra PRT system http://www.ultraprt.com/heathrow.htm

(7) Vectus PRT system http://www.vectusprt.com/eng/prt/prt_4_vectusprt.asp

(8) Taxi2000 vendor study
http://faculty.washington.edu/jbs/itrans/big/SWEfeasibilitystudy.pdf

(9) Skytran PRT system http://www.skytran.net

(10) Rousseau, A, Shidore, N, Carlson, R, Nelson, P, "Research on PHEV Battery Requirements and Evaluation of Early Prototypes", Advanced Automotive Battery Conference, Argonne National Lab, May, 2007

(11) U.S. Department of Energy, Idaho National Laboratory Website, EnergyCS PHEV America Test Data, http://avt.inl.gov/pdf/phev/prius.pdf