"Energy Solutions from Glass Road Surfaces"

Joseph V. Ryan
Pennsylvania State University

Background:

The amount of solar energy striking the earth's atmosphere at any given moment is staggering: ~170 million GW[1]. Indeed, light from the sun powers nearly every renewable resource on the planet. The future of civilization depends on the collection of this energy, as fossil fuels diminish in quantity and energy needs increase.

Proposed Idea:

This is less of an innovative energy generation idea, and more a solution to an existing exciting but unproven concept. Scott Brusaw, an electrical engineer from Idaho, was a speaker at the recent International Workshop on New Functionality in Glass in Washington, DC. He proposes replacing the current asphalt road surfaces with a system of solar panel road surfaces - "solar roadways" - crisscrossing the nation[2]. In addition to providing electricity, Mr. Brusaw envisions the encapsulation of power, phone, and fiber optic cabling within the roadways to consolidate and add redundancy to the power grid. Using some of the assumptions from his website, as well as personally researched data, here are the enormous power generation possibilities of such a proposal:

The amount of solar energy that penetrates the atmosphere and reaches the surface is approximately 1kW per square meter when the sun is overhead. At current efficiency levels of ~15%, photovoltaic cells can therefore produce about 150W per square meter in direct sunlight. Since weather and latitude cause severe reductions to this amount, an estimation of ~25W per square meter (or ~2.5W/sf) will be used[3]. According to the U.S. Department of Transportation, there are 3,995,635 miles of roadway in the country[4]. Assuming solar panels covering each highway with an average width of 30 feet, this gives an "instantaneous" power generation capacity of over 1,500 GW of electricity, or nearly 200 times the maximum capacity of the Grand Coulee Dam (the largest single power generation facility in the country). Assuming only four hours of usable sunlight per day, this would produce 2.3 million GWh annually. The electricity consumption for the entire United States was 3.5 million GWh in the year 2000, according to the Department of Energy[5]. This single renewable energy effort could produce over two thirds of our power needs at the current levels of efficiency. In addition, laboratory scale solar cells have demonstrated nearly 30% efficiency, which would double the energy production if they could be economically incorporated into the solar roadways.

To further illustrate the scale of this idea, assuming road replacement is only done in the sunny southwestern United States, solar roadways in New Mexico, Utah, Arizona, Nevada, and southern California[6] would produce ~280 GWh of electricity annually. This is using the same conservative estimates, despite the fact that there will be much more available sunlight at a relatively high angle, and is roughly equal to the electrical demand of the entire state of California[7]. Mr. Brusaw rightly makes the point on his website that enormous quantities of additional power generation could be gained by extending the use of these solar generation surfaces to pave sidewalks, driveways, parking lots, and other impermeable surfaces.

All this depends, of course, on the development of a durable, transparent protective layer for the solar cells embedded in or deposited onto the roadway. A glass surface with a failure stress 50 times as great as is currently available would fit that bill nicely. Traditional hot-mix asphalt (HMA) has a tensile strength of only 2-3 MPa and vertical stress of ~25 MPa[8], while strengthened glass would have a fracture strength 100 to 2000 times higher. However, strengthened glass is not a desirable casement simply because of its mechanical and optical properties, but also due to the processability and formability inherent with glass melting.

I was introduced to the possibility of microwave processing glass while working in the lab with an artist from California who got his degree in the physical sciences. The most striking memory I have is when he used a $4 second-hand microwave to drip chalcogenide glass all over our laboratory floor within seconds of turning the unit on. This led me to believe that a glass roadway could be simply and cheaply created with a microwave paver. This unit would be similar in operation to current asphalt pavers, except would use microwave power to melt the glass in place. I was surprised to learn that microwave paving has already been the subject of several patents (albeit for asphalt and related materials) and is being proposed for use on the moon. Lawrence Taylor of the University of Tennesee discovered that "with 50 Watts of energy I took a 1cm block of lunar soil to 1700°C in 10 seconds". He proposes the use of a "Zamboni-like" machine to densify and vitrify the moon surface to create roads and limit the effect of suspended lunar dust[9]. While lunar soil (regolith) is an admittedly different (and non-transparent) material than traditional oxide glasses, this illustrates the workability of quickly melting a glassy powder by microwave heating. Transparent oxides are no different, requiring only that they be heated above a certain critical temperature before they will significantly absorb microwave radiation[10]. This initial heating can be done by mixing the base glass frit with a sacrificial absorber that will either burn off or remain in the glass structure. Silicon carbide is an excellent absorber at room temperature[10], and an oxycarbide glass with no residual carbon can be made to be optically transparent as well as extremely strong.

One technical issue that must be addressed is that of traction. Rubber on glass has a very high static friction coefficient (μ_s) of 1-2, meaning that it takes more force to start rubber sliding on glass than the normal force of gravity. Solid-solid friction is due to several factors: adhesion, surface structure interaction, plowing, deformation/fracture, and aggregate interference[11]. The extremely high μ_s of rubber on glass is primarily due to adhesion between the rubber and the surface of the glass[12]. In dry conditions, therefore, there would be few surfaces better for a roadway than glass. When a lubricant such as water is introduced, however, friction is due to the viscous flow of the liquid and has little to do with the contacting materials, creating the dangerous hydroplaning common on wet roadways. In current technology, asphalt is mixed with an aggregate that creates roughness, channeling the water and allowing the rubber of the tire to make intimate, adhering contact with protruding asperities. This same principle can be applied to microwave paved roads. Molten glass can easily be molded into shapes specifically designed to maximize the run-off of water and maximize tire-roadway contact in wet conditions. A roller just behind the microwave source could be used to texture the roadway surface in the desired pattern. The extremely high strength of this new glass or glass treatment will slow the wear of these asperities and increase the life of the roadway.

Additionally, when roadway wear dictates re-surfacing, the same microwave paver unit could be used again to re-melt the glass surface, burn off any tire debris, oil, or other carbonaceous contaminant, and roll a fresh roughness pattern into the surface. This treatment could indefinitely extend the useful life of the road, and is much quicker and cheaper than importing materials, ripping up road, and repaving. Not only does this increase the long-term value of the roadways, but it also will limit road or lane closures, improving traffic flow and increasing driver safety.

It might be expected that these shapes would cause scattering of light and decrease the effectiveness of the underlying solar cells. If the correct shape is chosen, however, the engineered roughness could actually help concentrate the incident illumination and make the solar cells more efficient. Fresnel lenses have been used for more than 150 years to focus light emitted from lighthouses and signal lamps. The sharp edges inherent in their design (Fig 1) allow light to be focused using a much thinner lens than would normally be required. To ensure that each lens is focused on a power generation cell, guiding telemetry on the solar collection layer would time the patterning roller to align the lens shapes with cells on the bottom layer. Not only would this concentrate the incident light, it would also allow light collection from a wider angle, increasing the number of hours each day available for power generation. Combining the principle of the Fresnel lens with channels to enhance water run-off would provide the roughness needed to make the road surfaces safe in wet conditions while increasing the power generation capability of the entire system.

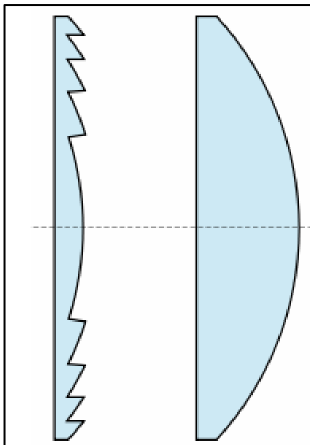

Fig 1 - Comparison of Fresnel (left) and traditional lenses (right) with the same focal length[13]

This technology is not only applicable to roadways that are used for solar generation, however. Traditional roads would be an excellent textured glass paving. Indeed, it would be much easier to design a glass susceptible to microwave melting if transparency were not an issue. Once the correct material is chosen and a microwave paver is built, a glass roadway would be economically competitive with current construction. According to the Connecticut Department of Transportation, asphalt currently sells for $375 per standard ton[14]. A major glass manufacturer quoted the production of glass frit for $0.10 to $0.20 per pound, with the cost decreasing with increasing demand[15]. This translates to $200-$400 per ton of frit, likely cheaper than asphalt. Further, diluting the manufactured glass frit with crushed recycled glass would allow the cost effective use of these materials and lessen the load on landfills.

Conclusions:

All available evidence points to an impending energy and environmental crisis for the United States and the world at large. Dramatic steps need to be taken to reduce carbon emissions and restructure our energy systems in order to alleviate climate change while ensuring the future supply of electricity. Outside-the-box concepts like that proposed by Scott Brusaw are likely the only solutions that can work quickly enough and at a large enough scale to make a lasting impact. The economy of scale will certainly work in favor of financing concepts like these, as costs will come down when mass-production is scaled up to meet the need. While the engineering hurdles are clearly numerous and substantial, this type of idea is necessary to retain our way of life in the future.

References:

1 - *McGraw-Hill Encyclopedia of Science and Technology*, 5th edition
2 - www.solarroadways.org
3 - Paul Horowitz, The Art of Electronics, Winfield Hill
4 - U.S. Department of Transportation, Bureau of Transportation Statistics; http://www.bts.gov/publications/national_transportation_statistics/html/table_01_01.html
5 - U.S. Energy Information Administration; http://www.eia.doe.gov/emeu/aer/eh/frame.html
6 - Road mileage data from personal e-mail correspondence with DOT employees of Nevada and New Mexico, extrapolated to the other states mentioned
7 - California Energy Commission - http://www.energy.ca.gov/electricity/STATEWIDE_CONSUMPTION.PDF
8 - B. Birgisson, et al., *Journal of Materials in Civil Engineering*, Mar/Apr 2004, pp. 116-121
9 - G.Gugliotta, *Discover*, March 2007, p.32
10 - M.N. Rahaman, Ceramic Processing and Sintering
11 - ASM Handbook v.18, Friction Lubrication, and Wear Technology
12 - http://insideracingtechnology.com/tirebkexerpt1.htm
13 - Image courtesy of Wikipedia article on Fresnel Lenses, used only to illustrate concept
14 - Connecticut Department of Transportation; http://www.conndot.ct.gov/asphalt/asphalt.aspx
15 - Personal conversation with an employee of the company that preferred not to be identified.