Silicon Is About to Change the World—Again!

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In 1999, this PROCEEDINGS invited me to speculate about the future of transportation [1]. That paper described a leisurely adoption of SkyTran (Fig. 1) over the next half-century. However, today's energy and global warming concerns suggest a faster deployment pace should be considered by the federal government.

I. INTRODUCTION

Electronics has changed the world, but only half-way. Our communications and information technology (IT) are twenty-first century, but our transportation and energy technology (ET) are not. We use Twitter while waiting for the bus, track packages or monitor the electrical grid online, but the physical realities of surface transportation and power electronics have not changed all that much in a hundred years.

This is about to change. What tiny signal transistors did for IT, big power transistors will do for ET. Thanks to high-power transistors, most mechanical prime movers will ultimately be replaced with more reliable and more efficient electrical prime movers.

Just as the automobile replaced the horse in one generation and the Internet quickly replaced snail-mail letters, newspapers, faxes, and libraries in one generation, power electronics will replace mechanical transmissions in your generation. The tools are available now. The key components are the high-power transistor—the *muscle*—and real-time controls—the *brains*: reliable, nimble controls that respond instantly to a dynamically changing environment.

This paper describes several examples of benefits derived from replacing mechanics with power electronics, including SkyTran—a silicon-based transportation system. However, the new power electronics has much wider application than SkyTran alone. Mating diverse distributed power sources to the electric grid is challenging, but SkyTran's power electronics partner, One-Cycle Control, Inc., a spinoff of California Institute of Technology (Caltech) and the University of California, Irvine, has shown how agile power control can help.[1] Interestingly, One-Cycle Control accomplishes this with *no* digital signal processing or microprocessor software. (It is hard to beat a zero lines-of-code program for software development time and the resulting low bug count.)

II. EXCITING APPLICATIONS FOR HIGH-POWER TRANSISTORS

High-power transistors (e.g., insulated gate bipolar transistors) and agile power-conversion technology have profound cascading implications in many important areas besides our high-speed silicon-based SkyTran personal/mass transportation system. The generated power that comes from solar, wind, run-of-river microhydropower, geothermal, bio mass, etc., is not produced in any form residential or commercial industry customers can use. It must be conditioned to the proper phase, voltage, and frequency. Advanced power conversion can significantly reduce the need for giant expensive centralized utility complexes to convert power by enabling cost-effective local

[1]One-Cycle Control was founded by married Caltech Ph.D.s, Greg and Keyue Smedley, who incidentally has more than 100 IEEE papers to her credit.

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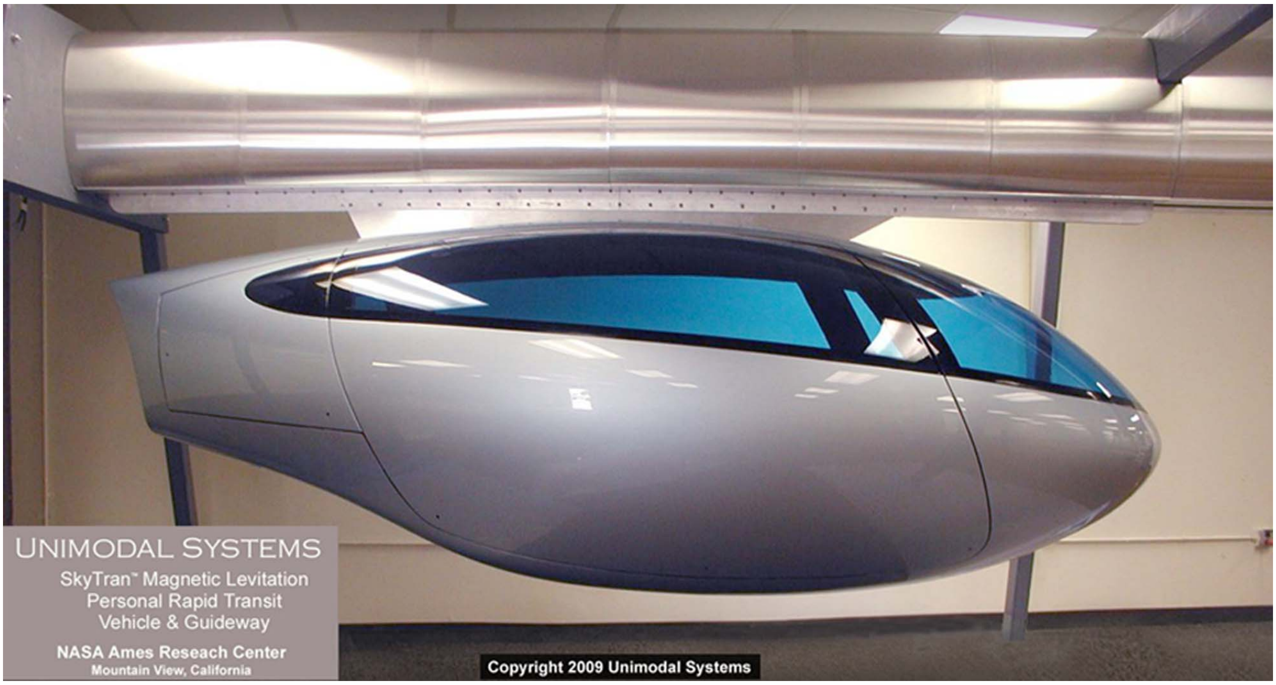

Fig. 1. *NASA Ames Research Center full-size SkyTran prototype. UniModal Systems, LLC, in collaboration with NASA Ames Research Center and One-Cycle Control, Inc., now has a full-size SkyTran powered prototype operating on a short passive Maglev guideway at NASA Ames in Mountain View, CA. UniModal also currently has a multiyear federal Department of Transportation grant to help advance our planet-saving technology. Increased government investment can drive adoption through system-level demonstrations.*

conversion at the source. Even small environmentally minded municipalities and green-power entrepreneurs can now economically make their own multisource, fully renewable, fully conditioned, clean electricity.

A. Prime Movers Such as Trucks, Locomotives, and Ships

These all use narrow power-band engines. Everyone is familiar with hearing tractor-trailer drivers revving their engines and shifting to the next higher gear, repeatedly. Power transistors and nimble electronic controls can eliminate gearboxes, improve efficiency, and provide a wider operating range.

B. Wind Turbines and Microhydro

Wind turbines using "silicon gearboxes" in place of mechanical gear boxes will provide power over a wider dynamic range with better efficiency and lower maintenance costs. Large wind turbines will no longer waste the potential hundreds of kilowatts generated by slow winds. Fractional-megawatt run-of-river hydroelectric generators could power hundreds of thousands of locations worldwide that lack access to electric grids [5].

C. Grid 2.0

Transients, unbalanced reactive loads like motors, and conventional active power supplies result in a polluted, inefficient grid. In many cases, the required reactive current increases the amount of current that must flow through the grid by ~20%. The capacity loss and distribution loss can be recovered by locating reactive power delivery at the user, even in the home.

The IT revolution of the past half-century moved us from expensive centralized mainframe computers to distributed cheap microprocessors. "Grid 2.0" lets us migrate from massive fixed power plants and inflexible infrastructure to a variety of distributed and diverse power sources. The new ET revolution promises to make commuting and freight delivery quick and easy, save energy, and drastically cut greenhouse gas emissions.

D. SkyTran—Silicon Based Transportation

Our country (and indeed the world) is very concerned about the environment, reducing transportation costs, eliminating fossil fuel consumption, and simply using much less energy in all aspects of life. SkyTran's transportation and Grid 2.0 capability can enable these goals while enhancing the quality of life for all. SkyTran employs personal-sized vehicles that are streamlined and fully computer controlled. Like a taxi, you ride as a passenger (not a driver) on 1-ft-wide "guideways" built above the ground, so that you are safely separated from ground traffic. Like a freeway, there will be a nonstop high-speed section of guideway with "exits" and "entrances" that lead to and from offline SkyTran stations. These offline stations are essential for nonstop high-speed travel.

At each offline station, there also will always be a supply of empty SkyTran vehicles. That means you board immediately with no waiting and no schedule hassles, saving you more of your valuable time. The SkyTran system uses passive magnetic levitation to create a way for vehicles to move without contacting the guideway—eliminating significant maintenance costs—no tires and no gears. Maglev allows much higher speeds than wheeled vehicles while providing the ultimate in a quiet, smooth ride.

The Internet allows more throughput and better connectivity than the circuit switching method of the classic telephone network. SkyTran does the exact same thing for transportation—individually switched SkyTran vehicles rather than single-destination trains. It may be counterintuitive for transportation, but carrying small packets of people, nonstop, point-to-point provides more throughput and connectivity than large vehicles like trains and buses that make frequent stops. The resulting huge hourly passenger (and goods) capacity means rush-hour congestion will become a thing of the past. It is interesting to note that if power electronics was applied to eliminate the reactive grid losses in the United States, the savings would be enough to power a nationwide SkyTran system.

At the same time, the SkyTran guideways can symbiotically become the Grid 2.0 conduit to provide transportation and distribute power to and within communities with no reactive losses. These developments are concurrent.

SkyTran replaces the automobile's thousands of moving parts with essentially just one: the vehicle itself. Its light two-person vehicles are suspended from overhead guideways containing passive magnetic levitation and linear-motor power electronics. Even traditional mechanical switching of vehicles is superseded by noncontact, electromagnetic, computer-controlled switching.

Eliminating nearly all the mechanical parts of an automobile allowed me to design a vehicle that is very light—about 200 lb (91 kg)—so guideways and supports need a trivial amount of materials and construction time compared with highways designed for 80 000 lb (36 tonne) tractor-trailer trucks. All these omitted parts further led to SkyTran vehicles whose small size, combined with an optimum streamlined shape, dramatically reduced aerodynamic drag. The results of this radical debulking of the mechanical car are revolutionary: 200-mpg (1.2 L/100 km) fuel economy at 100 mph (160 km/h); ultralight guideways supported by standard utility poles that carry as many passengers as a freeway; and extraordinary safety and convenience. Since SkyTran is an order of magnitude more energy-efficient than automobiles and uses grid electricity instead of liquid fuel, its electricity demand could be met entirely by renewable sources such as solar, wind, biomass, and run-of-river hydropower.

Planned 150 MPH SkyTran speeds for intercity travel has another huge benefit. Currently, 60% of all domestic airport flights are for trips under 500 mi. Because of faster door-to-door trip times and lower costs that 60% could be replaced by non-stop 150-MPH SkyTran. This would save an immense amount of fossil fuel energy and resulting CO_2 emissions. This would radically improve the inefficient hub-and-spoke airport architecture at the same time. SkyTran will drastically cut the oil consumption and carbon emissions associated with moving humans and light cargo anywhere. Its guideway-powered vehicles use neither heavy batteries nor liquid fuel; they can use any power source that feeds the electric grid.

Replacing half of the United States' annual 3 trillion miles of gasoline-powered automobile travel [2] with SkyTran requires an additional 200 TW-h of electricity. This in turn increases total U.S. electrical demand by 6% while simultaneously eliminating 70% of all U.S. foreign oil imports [3], [4].

Automobiles currently consume 360 million gallons of gasoline a day (1.4 billion liters) at a consumer cost of $363 billion per year ($2.77 per gallon; $0.73 per liter) [5]. Replacing half of the vehicle miles traveled in the next 15 years with SkyTran would save approximately $2.7 trillion. Diesel fuel consumption adds another 140 million gallons of fuel per day (530 million liters) that largely carries freight. The same SkyTran infrastructure could reduce trucking by 50% by carrying pallet-sized cargo directly to local stores, saving an additional $1 trillion in diesel fuel. Not only are huge amounts of money saved but this also means that 1.4 trillion gallons (5.2 trillion liters) of fossil fuels would not be burned and thus would not contribute to carbon emissions.

Because of the low power consumption at high speeds, power for the SkyTran transportation system can be entirely supplied by an assortment of existing forms of renewable energy [6]. For the past 50 years in the United States, the percentage of people using mass transportation systems of all forms has continued to dwindle, while automobile popularity and resulting road congestion has soared. Sky Tran's car-like point-to-point utility, 100 mph nonstop, low energy, low user-cost technology is the only solution out there that can promise to eliminate traffic congestion in all cities and dramatically reduce vehicle-related deaths. Ponder that last statement and what it means for everyone's quality of life.

E. Low-Cost Access to Space

Launching satellites to orbit takes an enormous amount of energy. The combination of passive Maglev and instantly variable high-power technology can also enable a new generation of very low-cost orbital launch systems. A green, all electric, fully reusable, first-stage boost will result in huge cost reductions to orbit non-manned payloads.

For decades, aerospace engineers have discussed ideas on how to launch payloads into orbit cheaper by using a first-stage dolly that runs on a rail system up a mountain. This is because almost half of a rocket's propellant is used to get the payload up to 50 000-ft (15 000 m) altitude and a speed of Mach 1.8 (1200 mph) [7]. The nimble power-conversion technology being discussed in this paper is an important enabler for such launch concepts. Concurrently, hypersonic air-breathing vehicles are being tested and are close to fruition [8].

What if we build a Maglev launch ramp for several miles up the slope of a Hawaiian volcano? Agile high-power electronics and nimble controls could smoothly accelerate payloads to supersonic speeds, where supersonic combustion ram jets (scramjets) take over to accelerate the payload to hypersonic speeds and out of 99% of the atmosphere (105 000 ft, 32 000 m). Then a small low-cost rocket third stage would carry the payloads to orbit and the hypersonic scramjet returns for reuse. The Maglev dollies, of course, could return their kinetic and potential energy with regenerative braking as they initially are decelerated after scramjet separation from the Maglev dolly and also while coasting back down the mountain for the next launch an hour later.

The capability to launch small payloads into orbit at very low costs would transform the design criteria for satellites. Since you are no longer spending many millions of dollars per launch, you can relax the superreliability requirements and associated costs for these satellites. This will enable much faster technological progress in communication satellites and low-cost zero-G robotic manufacturing. One prime candidate: space-based photovoltaic power plants promise unlimited supplies of clean solar electricity 24 h a day.

I believe this technology will lead the way to low-cost access to space. Given the enormous potential of silicon-based infrastructure to solve so many of our present problems, we need to act now. The time is right for government and industry to join forces in promoting and advancing these important technologies.[2] ■

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[2]To learn more, visit www.SkyTran.net; www.SkyTran.org; www.UniModal.com; and www.OneCycleControl.com.

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