USHERING IN AN ERA OF SOLAR-POWERED MOBILITY

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Abstract: Modern mobility, for both humans and commodities, relies almost exclusively on fuels derived from petroleum. At the same time the world is experiencing soaring demand for mobility, environmental and resource constraints have become increasingly acute. This article discusses the role that electric drive, initially in the form of hybrid electric vehicles, can play in addressing the mobility challenge. This article discusses the opportunity that electric drive vehicles create to use solar and wind power for transportation. The potential of the emerging vehicle integrated PV concept is discussed, along with the importance of connecting cars to the electric grid.

Keywords: electric vehicles, solar energy, renewable energy systems, electric power systems

1. MOBILITY IN THE 21ST CENTURY

Human progress is tied to advances in mobility. Societies adept at harnessing technology to reduce the travel times to distant lands successfully gained access to new resources, allowing wealth creation opportunities beyond which local resources allowed. The process accelerated dramatically as fossil fuels were employed to provide even greater opportunities to move people and commodities across great distances.

Today, mobility is a commodity for which demand is linked closely to income. Specifically, increases in demand for highway travel and air travel in a country tracks closely growth in national income. Figure 1 provides data on per capita vehicle miles travelled (VMT) and per capital air travel from 1960 to 2004 in the US. During this timeframe per capita income grew from $13,800 to $38,856 while per capita VMT more than doubled and per capita domestic air travel quadrupled. Based on the experiences in the US, per capita VMT took approximately 30 years to double, while per capita domestic miles flown doubled in just ten years.

![Graph showing mobility trends in the US](image)

Fig. 1. Mobility trends in the US: Per capita vehicles miles travelled and per capita domestic air travel, 1960 to 2004 (Sources: US Bureau of Economic Statistics and the US Bureau of Transportation Statistics)
As incomes in the developing world rise, demand for mobility likewise increases in these regions. Myer and Kent (2003) in their book *New consumers: The influence of affluence on the environment* highlight the rapid increase in demand for personal automobiles occurring in the developing world and in countries as a new consumer class emerges. They argue that over 1 billion of these new consumers will soon have an aggregate spending capacity, in purchasing power parity terms, to match that of the US. Recent data suggests that China is rapidly expanding its automobile manufacturing capabilities; annual passenger production grew from 100,000 vehicles in 1991 to 2.3 million in 2004—a 28 fold increase (Worldwatch Institute, 2006).

We have reached an apex in global mobility. The sheer volume and pace of movement, of both humans and commodities, on this planet is incomprehensible. The 3.7 trillion passenger-kilometers of air travel in 2005 equals over four and a half million round trips from the Earth to the Moon (ICAO, 2005).

What made this level of mobility possible, and how much longer can it be sustained? This critical question is addressed in the next section of the article.

1.1 Petroleum and transportation: resource constraints, the environment, & supply risks

Petroleum-derived fuels, such as gasoline for vehicles and jet fuel for modern aircraft, provide over 97% of primary energy for transportation. Of the 80 million barrels used globally each day in 2003, approximately one half are consumed for transportation. The US Department of Energy’s Energy Information Administrations (EIA) predicts that global oil consumption will reach 118 million barrels per day by 2030 (EIA, 2006). In sum, transportation is entirely dependent on a single source of energy—petroleum—and its consumption for transportation purposes is predicted to rise by 47% in twenty-five years. Most of this increase will come from rising demand for transportation in non-OECD countries (EIA, 2006).

The state of modern transportation systems is extremely precarious. Relying exclusively on petroleum as a source of energy for transportation creates significant risks, the most important of which is resource limits. Volumes have been written about the so called peak oil phenomenon, which suggests that global oil production peaks and subsequently enters a prolonged period of decline. While oil does not “run out” many predict that prices rise dramatically in the face of rising demand and declining production (Simmons, 2005). While the timing of peak oil is the subject of debate, it’s generally accepted that it will occur within the first half of this century.

The use of petroleum for transportation is a factor linked to global climate change. The combustion of fuels for transportation causes carbon dioxide emissions, the primary pollutant contributing to global warming, into the atmosphere. Approximately 25% of global emissions of carbon dioxide come from the transport sector. In addition, transport related emissions are one of the fastest growing categories, which is likely to increase the share of total carbon emissions coming from the transport sector.

A number of recent scientific studies suggest that global climate change is occurring more rapidly than scientists predicted and is already having negative impact on ecosystems across the globe. Governments and non-governmental organizations worldwide are calling for dramatic reductions in carbon dioxide emissions to minimize further warming of the Earth and the associated consequences of rising sea levels, more severe weather patterns, and negative ecosystem impacts. Clearly, efforts are needed to reduce the transport-related emissions of carbon; this can only be accomplished by either reducing the amount of travel, increasing the efficiency of the vehicle fleet, shifting toward alternative fuels, or some combination there of.

Supply risks are an additional concern linked to the transport sector’s exclusive reliance on oil as a primary energy source. Roughly one-third of global oil production comes from the politically volatile Middle East (EIA, 2006). Furthermore, this region is home to the largest known oil reserves, thus the region will become increasingly important as a global supplier. The region is currently ensnared in several armed conflicts, including the conflict between the US and Iraq. Terrorist attacks on key ports and escalating regional violence could cause significant supply shocks.

2. TOWARD SUSTAINABLE MOBILITY

The scope of the mobility challenge is daunting. The issue must be addressed on multiple fronts, from smart planning to reduce the need for travel by automobiles to the development of new vehicle technologies.

The remainder of this article focuses specifically on options to reduce the light vehicle fleet’s dependence on petroleum-derived fuel sources. This is achieved through either improving fuel economy and/or using alternative fuels. Progress has been made in these areas, but virtually all vehicles commercially available today run primarily on either gasoline or diesel fuel.

In the US, the primary mechanism for regulating vehicle fuel economy is the Corporate Average Fuel Economy (CAFE) standard, established at the
national level. These standards remain unchanged since 1985 at 27.5 miles per gallon (mpg). Europe is further along in addressing the mobility challenge with more developed mass transit systems and a much more efficient light vehicle fleet than that found in the US.

The search for viable alternative fuels has focused on biofuels, with interest in biofuels surging in recent years. Brazil is often held up as a successful example of large-scale biofuel development, meeting 20% of its transport fuel requirements with ethanol derived from sugar cane. The development of flex-fuel vehicles in the US is gaining momentum, which provides a vehicle owner a choice of energy options to meet their transportation needs. For example, some automobile manufacturers are building vehicles that operate on biofuel blends like E85—a blend of 85% ethanol and 15% gasoline.

Biofuels offer the potential to reduce our dependence on gasoline for the light vehicle fleet, but the potential is limited. There is much debate about the energy balance of biofuels and the appropriateness of using arable land to produce energy crops as opposed to food. It is unlikely that biofuels will emerge as a replacement for gasoline as a transport fuel, although they could serve to displace a small portion of gasoline and diesel fuel for the light vehicle fleet.

Much effort is being directed at producing fuel cells for mobile applications, fuelled with onboard compressed hydrogen. Fuel cell vehicles running on compressed hydrogen are viewed by some as the ultimate means to achieve sustainable mobility. In recent years, however, some have questioned the over emphasis on research and development in to fuel cell vehicles and their potential to reduce carbon emissions in the short-term. It is becoming increasingly clear that hydrogen-powered fuel cells vehicles face a number of technical and economic challenges that will likely take decades to address (Morris, 2003).

In a 2004 report prepared by the US-based Center for Energy and Climate Solutions for the National Commission on Energy Policy concluded, “We believe that the most plausible vehicle of the future is a plug-in hybrid running on a combination of low-carbon electricity and a low-carbon biomass-derived fuel.” (Center for Energy and Climate Solutions, 2004)

2.1 The hybrid electric vehicle revolution

Hybrid electric vehicles (HEV), using both an internal combustion engine and electric motor, achieve dramatic improvements in fuel economy. Commercially available HEVs boast fuel economy ratings of over 50 mpg. For example, the most popular hybrid, the Toyota Prius, achieves a fuel economy rating of 60 mpg highway and 51 mpg city.

Consumers now have several HEV options to choose from, and their popularity among the car-buying public is increasing. Virtually every major automobile manufacturer is manufacturing, or plans to in the near future, HEVs. In 2005, HEVs reached 1.2% of new cars sold in the US, more than doubling the number sold in the prior year. Toyota is the leading manufacturer of HEVs, globally selling over 50% of all hybrids purchased in the US in 2005.

The evolution of HEVs to allow charging from the electric grid, so called plug-in hybrids (PHEV), is assumed by many to be desirable—some may argue inevitable. Ultimately, the economics of displacing gasoline with electricity should drive consumer demand for PHEVs. The cost of electricity to drive a vehicle the same distance as one gallon of gasoline is equal to approximately $1—or even less if off-peak electricity prices are assumed (Denholm and Short, 2006). Furthermore, as discussed later in this article, PHEVs could potentially generate revenue for the vehicle owner by providing grid support services. Combined, these value propositions could serve to usher in an era of advanced vehicles with dramatic reductions in gasoline use and tailpipe emissions.

A growing, national movement to bring PHEVs to the market has emerged in the US, bolstered by the undeniable economic and national security benefits that result from displacing gasoline with electricity. One highly-visible, grass-roots campaign, called Plug-In Partners, seeks to demonstrate to the major automobile manufacturers that a national market exists for flexible-fuel PHEVs; dozens of businesses, utilities, municipal governments, and environmental groups have joined the Plug-In Partners campaign.

While there are no commercially available PHEVs on the market, a number of prototypes have been built and tested. The most established PHEV program is housed at the University of California Davis, where Professor Andrew Frank works with students designing and building prototype PHEVs. A second development project involves collaboration between the Electric Power Research Institute and DaimlerChrysler. They produced, and are in the process of testing, several prototype plug-in hybrid vans using the Sprinter platform. Two start-up firms plan to offer conversion kits for current generation hybrid electric vehicles to allow grid charging of the on-board battery pack. These conversions kits offer the potential to almost double an HEV’s fuel efficiency rating to 100+ miles per gallon by increasing the size of the battery storage system and installing the hardware and controls to allow charging from the electric grid.

3. HYBRIDS AND RENEWABLES: EXPLORING THE POTENTIAL
As the vehicle fleet moves toward electric drive, initially in the form of HEVs, the opportunity for renewables, beyond biofuels, to serve as an energy source for the transport sector emerges. This opportunity is greatly enhanced when vehicles connect to the grid to charge an onboard battery pack. The remainder of this article explores this opportunity from the emerging vehicle integrated concept (VIPV) to the role that wind can play in powering grid-connected cars.

Hybrids electric vehicles with the capability to recharge from the electric grid dramatically reduce the needed liquid fuels for transportation. Studies have found that most vehicles could meet the vast majority of their daily commute with a PHEV designed with a 40 mile all electric range. Thus, PHEVs can exploit wind and solar as a fuel source and at the same time dramatically reduce liquid fuel requirements. It becomes more realistic for biofuels to meet the lower liquid fuel requirements needed as the vehicle fleet relies to a greater degree on electricity.

3.1 The Solar Hybrid Electric Vehicle

In 2003, the author presented the vehicle integrated photovoltaic (VIPV) concept to an American audience at the annual meeting of the American Solar Energy Society. The paper titled, Vehicle integrated PV: A clean and secure fuel for hybrid electric vehicles argued that HEVs create an opportunity for PV to serve as an energy source for the transport sector.

Until recently, PV has not been considered a viable energy source for vehicles. Some experiments were conducted using PV for electric vehicle (EV) charging, but efforts to commercialize have stalled due to the perceived lack of market acceptance for these types of vehicles. Other efforts to deploy PV for transportation have taken place at a variety of university research centers, where teams of students and faculty build vehicles powered solely from solar. These vehicles are designed and built to compete in solar car races such as the World Solar Challenge, which began in Australia in 1987. These vehicles were never intended for commercial production, the futuristic look and design of these experimental vehicles would not likely appeal to mass markets.

Since the 2003 conference, the author learned of a variety of projects to advance the VIPV concept. Researchers at the University of Queensland in Australia are developing a commuter hybrid vehicle with PV integrated in to the body panels. An engineer in Canada installed a 270 watt solar array on the roof of his Toyota Prius, increasing the mileage by approximately 10%. Even the major auto manufacturers are eyeing the VIPV opportunity, with both Ford, and its close corporate partner Mazda, displayed hybrid vehicles with modest amounts of VIPV at recent auto shows. The author produced a second article on the topic highlighting recent VIPV activities, which appeared in the May/June 2006 edition of Solar Today.

In October of this year, the French specialty vehicle manufacturer Venturi Automobiles announced plans to offer the first commercially available solar hybrid sports car called the Astrolab. The company also produces an urban electric commuter vehicle called the Eclectic. The 3-seater vehicle has solar PV integrated on to the roof of the vehicle. Venturi claims that this is the first energy-autonomous vehicle available to the public.

![Image 1](https://example.com/image1.jpg)

**Pic. 1.** PV integrated Toyota Prius, Lapp Renewables LTD, 2005

![Image 2](https://example.com/image2.jpg)

**Pic. 2.** Venturi Automobiles’ Astrolab, the first commercially available PV integrated hybrid
Recently, Taiwan’s PV cell manufacturer E-Ton Solar announced a joint venture with several partners, including Yulon Nissan Motor Co., Ltd. to develop PV products for the car market. The joint venture began with the manufacturing of PV modules for car sunroofs.

3.2 Design Considerations for Solar Hybrids

Given current HEV designs, VIPV could serve to enhance the overall efficiency of the vehicle, but only provide a small portion of the vehicle’s energy requirements. In this context, VIPV is similar to regenerative breaking, which, through converting the kinetic energy lost in breaking to electrical energy, serves to enhance the overall efficiency of an HEV. A number of design and engineering considerations could serve to increase PV’s role in fuelling a new generation of solar hybrid vehicles.

The key parameters dictating VIPV’s ability to displace gasoline for transportation are the quantity of PV in watts integrated on to the body panels and the efficiency of the vehicle drivetrain. The amount of PV that can be integrated on to a vehicle is a function of the available space and the efficiency of the PV technology deployed. Venturi Automobile’s Astrolab mentioned above contains 3.6 m² of PV integrated on to the vehicle. Measurements of the available surface area of a number of conventional vehicles suggest available surface areas of between 3.5 m² to 5.5 m² (Letendre et al., 2006). Figure 2 indicates potential PV in watts for three different scenarios of available surface by PV conversion efficiencies.

As Figure 2 illustrates, the sunlight to conversion efficiency of the PV technology deployed in VIPV applications is an important parameter. While flat plate silicon PV has high conversion efficiencies, thin film PV may be better suited for VIPV applications. Again referring back to Venturi Automobile’s Astrolab, the vehicle uses high efficiency monocrystalline PV cells to achieve 600 watts of PV on the available 3.6 m² of surface area. Copper indium gallium diselenide (CIGS) solar cells, which are not yet fully commercial, offer both advantages of flexibility like other thin film PV technologies, but with much higher conversion efficiencies. One US company, DayStar Technologies, is nearing commercial-scale production of a CIGS PV product on flexible steel. Generally, the US is leading in the development of the next generation PV technology, which should be predominantly flexible thin films.

It should be noted that the onboard PV capacity may not necessarily be constrained by the available surface area on the vehicle’s body panels, but flexible PV could be used to design retractable solar shades that could be deployed when the vehicle is parked to provide additional PV capacity for daytime charging.

The efficiency of the vehicle drivetrain determines the number of solar miles obtained from any given VIPV system. Current hybrids, like the Toyota Prius have all electric efficiencies in the 156 watt-hours per kilometer range. Figure 3 illustrates solar miles for a 500 watt VIPV system in a region with an average of 4 sun hours per day for total annual PV generation of 710 kWh.

Advances in the use of lightweight materials for vehicles will serve to increase the potential solar miles delivered from a VIPV system. However, even today’s commercially available hybrid can benefit from VIPV. Initial VIPV applications will provide
incremental improvements in vehicle efficiency, but the future potential is much greater. The Leonardo Project, sponsored by the European Commission, aims to train a new generation of engineers in sustainable transportation focused initially on designing and building a solar hybrid. This project, and other like it, will serve to advance knowledge on these concepts and ultimately achieve advanced designs that dramatically improve existing technologies and approaches.

Battery storage devices are a critical enabling technology for the solar hybrid revolution. While many advances have been made in battery technology, reductions in price and improvements in performance are needed to produce commercially viable solar hybrid vehicles.

A promising new battery technology was unveiled at the September 2006 California Air Resources Board Zero Emission Vehicles Symposium. Nevada-based Altairnano announced a new lithium ion battery system called NanoSafe™, which replaces graphite as the electrode materials with nano-titanate materials (www.altairnano.com). The company claims that this new materials solve the thermal runaway problem with conventional lithium ion batteries, and offer significant improvements in cycle life and delivers optimum energy/power balance in the high power region, which is critical for hybrid and electric vehicle applications.

3.3 Plug-In Hybrids Facilitates the Use of Wind for the Transport Sector

While both conventional HEVs and PHEVs can adopt a VIPV strategy allowing for the use of solar for transportation, only plug-in hybrids facilitate the use of wind power for transportation purposes.

Wind power is the fasting growing new source of power generation world-wide. In the US alone the American Wind Energy Association estimates that over 3,000 MW of new wind will go on line in 2006. Globally, estimates of installed wind power capacity reached 60,000 MW in 2005 (Worldwatch Institute, 2006). Wind power is a clean and renewable source of power generation that will continue to expand in the coming years.

The intermittent nature of wind power creates challenges for developers seeking to integrate wind into electric grids and wholesale markets. At low wind power penetration rates intermittency is less of an issue; however, as wind plays an increasingly important role in the global supply mix, intermittency will need to be addressed. The variability of output from wind farms creates challenges given the existing electric industry structure, which is characterized by scheduled flows of power from sources to sinks. The cost and environmental characteristics, however, are sufficiently compelling that regulations have been devised to facilitate wind power integration in to the electric supply mix.

The variability of wind power can be understood in discrete categories based on increasingly longer time intervals that characterize the market strategy that is needed to manage the variability as more and more wind appears on the electric network. These categories are:

- Minute to hour variability, addressed through regulation markets, intra-hour adjustments, or spinning reserves.
- Hour to day, addressed through operating reserves (spinning and non-spinning reserves)
- 1-4 days, dispersion of wind resources with transmission, operating reserves, load management, and dedicated storage (Kempton and Tomic, 2005a)

Recent analyses suggest that the emergence of PHEVs and other electric vehicles could serve to address the intermittency challenge associated with wind and other intermittent resources like solar (Letendre et al., 2002; Kempton and Tomic, 2005a, and Denholm and Short, 2006). In one of these studies Kempton and Tomic (2005a) calculate that that electric vehicles with onboard battery storage and bi-directional power flows could stabilize large-scale (one-half of US electricity) wind power with 3% of the fleet dedicated to regulation for wind, plus 8–38% of the fleet providing operating reserves or storage for wind.

At a minimum, the nature of PHEV charging complements the intermittent nature of wind power. Given the high periods of non-use of vehicles, PHEVs represent a new source of load, unlike critical loads like computers and other information technologies, which do not require a constant flow of power for re-charge. The charging of PHEVs can be modulated as the power production from a wind farm varies. This serves to address the first tear of intermittency (variability) described earlier. I envision new power contracts between PHEV owners and developers of wind farms. The complementary nature of wind power and PHEVs creates an opportunity to further enhance the environmental character of PHEVs through wind power charging.

To address the second and third tiers of wind power variability described earlier, PHEVs would require reverse flow capabilities. This concept has become widely known as the vehicle to grid (V2G) concept, which is covered extensively in the next section of this article. Millions of PHEVs connected to the electric grid would represent a very large aggregate energy storage resource. Figure 4 indicates the amount of storage that would be connected to the grid for PHEVs with various electric only ranges
transmission users. final and distribution end to power; the MW available 10,000 across that massive interconnected resource. vehicle, kW per one 10 vehicles [hydro and wind], alternating in vehicles drive a power represent could [coal, (chemical energy mechanical oil], gas, (Kempton) over which is isolation other thousands of generating each over which is isolation other thousands of generating convert stored power system relies on (ISO) Independent the is 5 System dispatch to demand. stored vehicles in Figure (V2G) to grid illustrates schematically the vehicle to grid concept. Advances and cost reductions in wireless communications would allow a central operator to dispatch stored energy in vehicles upon demand. In Figure 5 the Independent System Operator (ISO) is delivering a dispatch signal to those vehicles connected to the grid and prepared to deliver power at a moments notice.

Fig. 5. Schematic of vehicle to grid concept (Kempton and Tomic, 2005a)

Even at small fractions of the vehicle fleet, electric drive vehicles could represent a very large power resource. At 10 kW per vehicle, one million vehicles represent 10,000 MW of available V2G power; the
current global vehicle fleet is estimated to be over 600 million vehicles (Worldwatch Institute, 2006).

4.1 V2G Research Finding

The author knows of just one V2G demonstration project (Brooks, 2002). The demonstration project was conducted by a California-based electric vehicle development company AC Propulsion, in conjunction with the California Independent System Operator (ISO). AC Propulsion produces the only V2G capable electric vehicle drivetrain. For the demonstration project a Volkswagen Beetle was converted to a pure electric vehicle outfitted with AC Propulsion’s bi-directional charger and a communication link with the California ISO. They successfully demonstrated the remote dispatch of power from a parked electric vehicle in response to a signal from the ISO.

Most of the research to date on V2G involves modelling and economic analyses. One comprehensive study, for which the author was involved, was funded by the California Air Resources Board. Although no technical barriers were discovered in the research, a number of key issues were identified that bear on the economic value of V2G power services.

Research on this topic suggests that V2G capable cars are best suited to provide grid services that require a rapid response, but our used for a short duration. The limited onboard energy storage of an electric drive vehicle is not suited for providing base-load power. The most promising markets for V2G power fall under the heading of ancillary services—services purchased by grid operators to maintain system reliability. The two most valuable ancillary services in the US are for regulation (frequency response) and spinning reserves. Economic analyses demonstrate that a single vehicle can generate hundreds of dollar annually providing these services (Letendre and Kempton, 2002).

A second important issue for V2G capable cars, which determines the potential revenue from providing grid services, is the power output that can be sustained by a vehicle providing ancillary services. Kempton and Tomic (2005b) identify three key factors that limit the amount of power a grid-connected car can deliver back to the grid. These include the on board vehicle electronics, capacity of the plug circuit, and energy storage capacity and state of charge when the vehicle is plugged in to provide grid services.

A PHEV’s vehicle’s power electronics should not create a binding limit on the amount of power that can be exported to the grid. PHEVs require high power components for acceleration and to optimize vehicle performance. The electric drivetrain designed and manufactured by AC Propulsion mentioned earlier provides 80 amps in either direction, allowing 19.2 kW of power output. Thus, the critical factors dictating the reverse power potential come down to the capacity of the plug circuit and the size and state of charge of the PHEV’s battery pack.

Given the evidence on the V2G potential today, the next logical step would be a large-scale demonstration project. A fleet of say 100 electric drive vehicles equipped with a bi-directional charger could serve to resolve some issues that would give the private sector more confidence in pursuing the V2G business opportunity. In the end, the revenue that V2G could generate would help to overcome the price premium for the first-generation plug-in hybrids or pure electric vehicles, thus ushering in a new era of clean, flexible fuel vehicles.

As experience is gained and the price of electric drive vehicles declines, their use in providing peak power and storage for intermittent renewables is more likely. Furthermore, an increasingly fleet of V2G capable vehicles could eventually enhance the overall reliability of the grid and support a more environmentally sound electric supply mix.

5. CONCLUSION

As we enter the early stages of the 21st Century, society has reached an apex in mobility. The global economy is poised precariously on continues flows of people and goods, made possible by an abundant and cheap source of energy—oil! Recent events suggest that this critical resource is no longer abundant and cheap. In 2006, petroleum reached record prices on international exchanges of over $70 per barrel. Some of the world’s most renowned petroleum geologists are warning that we are quickly approaching the point at which we have extracted approximately one half of the existing oil reserves buried deep in the Earth crust—the so called peak oil event.

These, and other critical geopolitical events, suggest that society must rapidly pursue the development of alternative means of transportation to maintain even a portion of the mobility we have come to rely upon in this modern era. It’s becoming increasingly clear that electric drive will play a central role in the future vehicle fleet. Already, today hybrid electric vehicles (HEVs) have gained commercial success. Many groups are actively pursuing the logical evolution of HEVs to allow charging from the electric grid. Others are focused on hydrogen as the primary energy carry for transportation, fuelling a future fleet of fuel cell vehicles. Regardless of the technology that dominates the future, vehicle will rely increasingly on electric drive and contain significantly more onboard battery storage than today’s fleet of internal combustion engines.
This new era of electric drive vehicles allows for renewables, beyond biofuels, to serve as an energy source for the light vehicle fleet. Vehicle integrated PV and grid-connected cars charging from wind power become real possibilities as hybrid electric vehicles emerge as viable alternatives to internal combustion vehicles. There is tremendous momentum in this direction as research organizations, governments, and private industry seek to solve our imminent mobility crisis. A French specialty automobile company plans to offer the first commercial solar hybrid to consumers. E-Ton Solar, a major PV manufacturer, has entered a joint venture to develop products specifically for the car market.

Finally, the V2G concept is the ultimate vision whereby the transport and electric power sector converge and reap tremendous efficiencies while improving reliability, reducing pollution, and delivering greater energy security to those nations with the foresight to seize this opportunity.

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