# Designing the Car of the Future


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## Abstract

*The world is facing pressing challenges including population growth, water and food shortages, global warming, and resource depletion. To address these challenges, we must fundamentally rethink the problem of personal transportation. On alternative is to develop highly efficient shared transportation systems as a replacement for private car ownership. In this system, drivers would choose vehicles from a shared pool, and pay per use. The cost structure would encourage drivers to select the most efficient vehicle for each trip. In most cases, this might be a single-seat, short-range urban vehicle.*

*The basic requirements of a personal transportation system are to transport people and their cargo from one place to another conveniently, comfortably, safely, efficiently and inexpensively. We can further refine the requirements for a single-seat urban vehicle in terms of seating capacity, performance, range and required payload. This paper outlines the target specifications of such a vehicle.*

*According to prevailing business-as-usual thinking, vehicles of this type are seen as impractical and little effort is being made to design them. Western's Sunstang solar car team has decided to design and build a practical battery electric single-seat 3-wheel vehicle. It has a planned weight of about 250 kg, with a top speed of 135 km/h and a range of 200 km. Surprisingly, there are no established design competitions for vehicles of this type. This paper suggests that this might be a good direction for other solar car teams, and proposes a new competition to promote this idea.*


## 1 Mobilizing to Save Civilization

The world is facing pressing challenges including population growth, water and food shortages, global warming, and resource depletion. A consensus is emerging about at least some of the important changes and trends required to address the challenges. These include: stabilization of populations, stabilization of food and water supply, redesigning cities, large improvements in energy efficiency, and shifting to renewable sources of energy.

The problem is an urgent one, and many experts argue that "business as usual" will not be enough. Lester Brown of the Earth Policy Institute argues that in order to avoid the worst effects of climate change, greenhouse gas emissions must be reduced by 80% by 2020 [1]. George Monbiot proposes a plan to cut emissions by 90% by 2030 [2]. Many others agree with the issues, and the necessary response, e.g. [3, 4]. Even if global warming turns out to be an exaggerated threat [5], it is clear that our current consumption of fossil fuels must be drastically reduced because demand is increasing while supply is decreasing [6].

The plans proposed by Brown, Monbiot and others are achievable with current technology, and do not require reductions in standard of living. It is still a matter of debate whether market forces alone will be enough to achieve the necessary changes, or if a response similar to the U.S. mobilization following the attack on Pearl Harbor will be required. It is possible that both views are compatible: if the price of energy skyrockets, a warlike mobilization will be required to literally save civilization.

## 2 The Car of Today

The private car has emerged as a prominent symbol of 20th-century society. It has come to be associated with freedom, mobility, affluence, status and personal image. It has dictated the design of cities, neighborhoods and transportation infrastructure. This in turn has made car ownership a necessity.

Vehicle buyers reasonably choose vehicles with the capacity, performance and range to meet all of their anticipated requirements. The result is vehicles that are oversized and overpowered for most trips. Furthermore, the fixed costs of car ownership outweigh the operating costs, so there no incentives to reduce use. As a result, people drive vehicles with much more capacity than needed, and drive them more frequently than necessary, since the cost is the same whether they drive or not.

The feasibility of private cars as a viable form of transportation rests largely on the historic and continuing availability of cheap fuel. Since the cost of fuel is a relatively small portion of the overall cost of owning a car, there are few incentives to improve efficiency. The higher initial cost of alternative vehicles like plug-in hybrid vehicles (PHEVs), fuel cell electric vehicles (FCEVs) and battery electric vehicles (BEVs) is not sufficiently offset by reduced operating costs. Furthermore, BEVs are generally discounted as a viable alternative due to their limited range compared to conventional vehicles.

Many industry and academic studies assume that future cars must have similar capacity and performance as today's cars. Few question the need for a 2000 kg vehicle with a 300 HP engine to transport a 70 kg driver and 10 kg of groceries. According to this thinking, a green vehicle is a 2000 kg vehicle with a hybrid-electric drive train. Smaller cars with smaller engines are not considered an acceptable option.

## 3 The Car of Tomorrow

Radically different vehicles have been proposed and demonstrated by car manufacturers and enthusiasts for many years, but for the most part these are mere curiosities. Riley surveys many of these in his excellent book *Alternative Cars in the 21st Century* [7], and makes a strong case for ultralight vehicles with alternative powertrains.

Many studies have demonstrated that battery electric powertrains are the most efficient ones available if the electricity to charge them comes from renewable resources. Depending on the assumptions, BEVs are about twice as efficient as FCEVs in terms of distance travelled per kW-h of electrical energy generated. Ahman [8] estimates the primary energy efficiency based on electricity from renewable sources (wind, solar, or hydro) to be 57% for BEV versus 26% for FCEV. Other papers agree that BEVs are substantially more efficient than FCEV if the primary energy is electricity from renewable sources [9, 10]. These studies rightly state that the lifecycle energy efficiency and carbon emission of BEVs depends on the source of the primary electricity. If electricity is generated from coal power, BEVs have no clear cut efficiency or environmental advantage over alternatives.

In addition to maximizing energy efficiency of the powertrain, it is also important minimize the power required to propel the vehicle. The power required is a function of vehicle mass and inertia, aerodynamic drag, rolling resistance, and driveline losses. Amory Lovins and his colleagues have argued since the early 1990s that fuel efficiency of vehicles can be improved many fold by aggressively reducing weight and improving aerodynamics, and have developed the 'hypercar' concept to demonstrate what is possible [11].

## 4 Personal Transportation in the Future

To address the global challenges, we must fundamentally rethink the problem of personal transportation. We can reasonably predict that in the future, the cost of energy will be much higher than today, and will reflect the true environmental costs. Energy supply will shift toward renewable resources as they become cost competitive with fossil fuels. Society will be forced to adapt to higher energy prices by using much less energy. One likely change is redesigning of cities to reduce the frequency and distance of personal travel. New modes of personal transportation will evolve to meet these changing needs. The current paradigm of private vehicle ownership is likely unsustainable and inappropriate for future personal transportation needs.

## 5 Design Requirements for Personal Transportation

Most thinking about future vehicles uses current vehicles as a benchmark. It is widely assumed that private vehicle ownership will expand as developing countries follow the path of the developed countries. Future vehicles must have the same power, performance, size, and capacity as current vehicles, while being more efficient.

Let us reject these assumptions, and consider the real requirements for personal transportation from first principles. The basic requirements are listed below:

1. Get one or more people and their cargo from one location to another.
2. Do this as efficiently and conveniently as possible.
    a. Minimum elapsed time.
    b. Minimum waiting, delays, and steps.
3. Provide reasonable comfort.
    a. Protection from rain.
    b. Protection from heat or cold.
4. Be as safe as possible.
5. Minimize cost (and hence energy use).

When we consider the basic requirements this way, it becomes clear that the transportation systems that have evolved over the past century are suboptimal in a world of scarce energy, and that better design solutions can be found.

Let us now propose the following system as part of the larger transportation infrastructure of the future:

- Privately-owned vehicles will be replaced by vehicle sharing systems.
- People will chose vehicles from a pool, and pay for use like a utility.
- Different vehicles will be available for different purposes:
    - Short single-person trips
    - Long single-person trips
    - Short or long multi-person trips
    - Short or long cargo trips
- A pool of vehicles is within walking distance of every location. Existing parking lots and driveways could be used for this purpose.
- Payment will be based on vehicle type and usage, and users will choose the most efficient vehicle for each trip.
- Vehicle sharing will be integrated with other modes, including rail, subway, bus, etc.
- The transportation network will be integrated with the power grid [12], and will be controlled, scheduled, managed and billed using advanced IT systems.

If we consider this scenario, the challenge is to design a range of vehicles that provide exactly the capacity needed for each purpose, but no more. Three points stand out:

- The majority of trips involve a single person and a short distance.
- There are currently no vehicles available that satisfy the basic requirements for short trips with a single occupant.
- The auto industry is not seriously developing vehicles of this type.

# 6 Problem Definition

Based on the discussion so far, we can formulate the following problem definition:

*Design a single seat, short range vehicle that provides comfort, weather protection, and safety, and uses as little energy as possible.*

If we consider the need for a single platform that can be reconfigured, rather than different vehicles, the problem definition can be extended as:

*Design a modular vehicle that is safe and uses as little energy as possible. It should be easily reconfigurable to provide the following capabilities as needed:*

- *Passenger capacity 1, 2, 3 or 4*
- *Cargo capacity*
- *Range: short, medium, unlimited*

- *Performance: urban, highway*

## 7 Target Specifications

It should be possible to build a prototype single-seat BEV with a curb weight similar to a typical Formula SAE race car or solar car, not including batteries. For most BEVs, the batteries constitute a significant fraction of the total curb weight. In general, about 25% of the total vehicle weight is batteries.

We will assume a vehicle weight without batteries as 200 kg, and with batteries as 250 kg.

A typical mid-size BEV has a curb weight of about 1500 kg, and requires about 25 kW-h of battery capacity. If we assume an energy density of 250 W-h/kg for the best available Li-ion battery packs, and allow 50 kg for batteries, the capacity will be about 12 kW-h. This is a reasonable first approximation.

A significant drawback of BEVs is the high cost of batteries. A recent report from Deutche Bank [13] estimates that the cost of Li-ion batteries will fall to about $325/kW-h by 2020, and that costs are dropping faster than expected. If we use this figure, a 12 kW-h battery pack will cost about $4000.

The new Nissan Leaf is a full-size BEV with an 80 kW motor. For our vehicle, we will estimate the power requirement to be about 10 - 20 kW. A motor of this power is sufficient to power the Sunstang solar car at highway speeds.

## 8 Sunstang: From Solar to Battery

Over the last two decades, solar car competitions including SunRayce and World Solar Challenge have attracted many university design teams. The overriding theme of these competitions is environmental sustainability. However, it is clear that solar-powered cars will never be a practical transportation alternative. Furthermore, after many years of competition, the design of solar cars has become highly optimized, and the team with the biggest budget and most expensive (and most efficient) solar cells usually wins.

Solar cars are essentially battery electric cars charged by on-board solar panels. Due to the very limited energy available, solar cars are by necessity highly efficient. If we remove the solar panels, we are left with highly efficient, ultralight BEVs.

Based on this reasoning, Western's Sunstang solar car team has decided to withdraw from solar car competition and focus on designing and building an ultra efficient BEV. To save costs and development time, they are reusing parts and technology from the Sunstang solar car, including motors and batteries. The target vehicle specifications are listed in Table 1:

Table 1. Sunstang electric vehicle specifications.

| | |
|---|---|
| Vehicle type | 3 wheel single passenger BEV |
| Structure | Steel chassis with composite body |
| Curb weight | 250 kg |
| Motor | In-hub CSIRO motor<br>10.5 kW |
| Top speed | 135 km/h |
| Range | 200 km |
| Estimated prototype cost | $125,000 |

A prototype vehicle has been designed as shown in Figure 1 and Figure 2, and construction is nearing completion.

Figure 1. Sunstang electric vehicle concept.

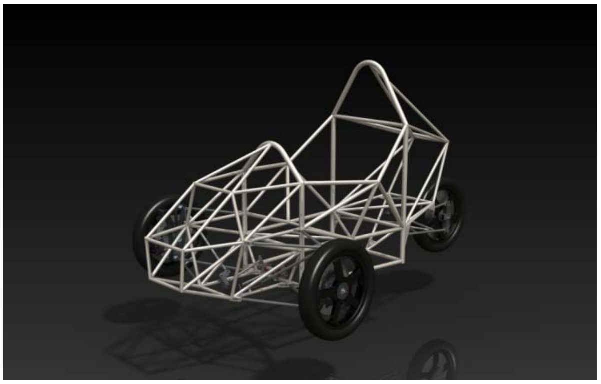

Figure 2. Sunstang BEV chassis design.

## 9 Student Design Competitions

Many students choose a design project because they can compete with teams from other schools. Surprisingly, there is no university competition for lightweight electric vehicles.

The Shell Eco-Marathon [14] is a competition to design eco-friendly vehicles. Interestingly, battery electric vehicles are explicitly prohibited from this competition. Another recently announced competition is the Zero Emissions Race [15], founded by private solar car pioneer Louis Palmer. Almost all of the entries are commercially available or prototype vehicles from commercial organization. The lone university entry is a battery-powered 1972 Volkswagen Beetle from University of British Columbia.

The World Solar Challenge (WSC) [16] is the premier international competition for solar-powered cars. WSC also hosts the Eco-Challenge, a demonstration event for environmentally-friendly production and experimental vehicles. In the 2009 competition, only two of the 17 vehicles entered were BEVs. WSC organizers have contacted the Sunstang team, and have expressed an interest in introducing a new competition category specifically for experimental electric vehicles.

Canadian engineering schools are well represented at international solar car competitions, and are well positioned to design the car of the future. There is also great opportunity for collaboration between schools to share knowledge and design ideas.

## 10 A New Competition?

None of the existing competitions are suited to promoting the design of a vehicle of the type described in this paper. If the focus is on a short-range vehicle, then competitions that emphasize long-distance travel are inappropriate. An urban vehicle should be tested in urban conditions, with urban speeds and stop-and-go driving.

In many respects, this competition would be structured like the existing SAE Supermileage competition, with objective scoring criteria. The criteria would correspond to the design requirements regarding maximum speed, acceleration and range. Comfort, convenience and overall practicality would be assessed, and safety would be emphasized.

We can consider the optimal design to be the one that satisfies the requirements while minimizing energy use and cost. A useful measure for the energy efficiency of a personal transportation system is energy in kW-h per person kilometer, kW-h/p-km, based on lifecycle energy cost. The objective scoring criterion could be the energy in kW-h required to recharge the batteries at the end of a prescribed endurance event.

## 11 Conclusions

It is clear that the nature of vehicles in the personal transportation system of the future will be radically different, driven by the need to conserve energy and adopt sustainable practices. This paper defines the essential design requirements for personal transportation, and proposes alternative system for personal mobility based on vehicle sharing. This leads to the requirement for a single-seat vehicle for short urban trips. This type of vehicle is ideal for student design teams, but no suitable competition exists. Western's Sunstang solar car team has decided to change focus to develop such a vehicle, and this could be the future direction for existing solar car teams and competitions.

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