Evolution and Prospects of Solar-Assisted Hybrid Automobile Technology

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Abstract – Recent advancements in solar and hybrid energy systems have accelerated the development of mild hybrid vehicles incorporating solar technology. This article presents a systematic review of key research and demonstration projects over the last decade. Both a historical outline and a thematic synthesis are provided, including books and journal articles that address critical engineering challenges for these vehicles. The review specifically analyzes past, current, and projected applications of solar energy in automotive sectors, examining technical requirements and optimal vehicle architectures. Key parameters such as hybrid drive integration, battery selection, panel configuration, and control strategies are discussed, along with major design achievements noted globally. The central aim of this work is to evaluate the technical feasibility of using both solar and conventional combustion energy sources in future automotive applications. Integration strategies of internal combustion engines with photovoltaic modules are reviewed, and the ongoing evolution of the field is highlighted. Overall, the findings indicate strong global interest and rapid progress, while emphasizing the need for continued engineering optimization to fully realize the potential of combined solar-hybrid propulsion systems.

Keywords - Hybrid solar car, solar energy, IC engine, electrical car.

1. Introduction

This paper has brief study of how this hybrid solar car is efficient in our daily life because now day's pollution and fuel rate is very big problem many people having petrol cars. Use of solar energy is being used for vehicles, besides the control of vehicular pollution in the city, less consumption of fuel, Hybrid solar car are effective reducing global warming and environment problem in big frame. Over the last 10 year, a larger amount of solar car, hybrid solar car and electric operated car research has been carried out, which is originating from several independent developments that all resulted in the idea of hybrid solar car and electric operated car. These are three main developments as discussed.

1.1 Solar operated cars

A solar car is driven by solar energy obtained from solar panels on the surface (generally, the top, side and bonnet) of the car or using a solar jacket in electric bicycles. Photovoltaic cells convert the sun's energy directly into electrical energy. Solar cars combine technology typically used in the autorickshaw, bicycle, four wheeler and automotive industries. Solar cars are often fitted with gauges as seen in conventional cars. In order to keep the car running smoothly, the driver must keep an eye on these gauges to spot possible problems.
The term of "solar car" usually implies that solar energy is used to power all or part of a vehicle's propulsion. Solar car are not sold as practical day-to-day transportation devices at present day, but are primarily demonstration vehicles and engineering exercises and model of a car.

1.2 Hybrid solar energy and electric operated cars

A hybrid car is a vehicle that uses two or more distinct power sources to move the car. The term most commonly refers to hybrid electric vehicle (HEVs), which combine a solar energy and electric energy. But instead of using a solar panel for energy, electric cars get their energy from batteries. When the batteries run out, they must be recharged by plugging or solar panel the car into an electric power outlet like home. If you drive an electric car, you would recharge its batteries overnight while you slept. Hybrid cars have the best mileage rating of all cars. There are many hybrid cars available to buy today.

1.3 Hybrid solar energy and IC engine operated car

Hybrid solar car use a combination of internal combustion engine (ICE) and solar panel, electric motor powered by stored battery system. It is driven by specified petrol engine and solar energy obtained from solar panels on the surface (generally, the top or window) of the car vehicle. The stored battery system can be recharged by the solar energy and IC energy as well as regenerating braking system Photovoltaic cells converts the sun's energy directly into electrical energy. Hybrid Solar cars combine technology typically used in the auto three-wheeler, and four wheeler etc, alternative energy and automotive industries.

The paper is organized into five main parts, first part after a general description of history of hybrid car, second part the issues relative of hybrid solar car review wok at last 10 year, solar car mode, technologies parameter of hybrid a solar car, finally last part conclusion of hybrid solar car.

2. History of hybrid car

2.1. The History of Solar Car Hans Tholstrup and Larry Perkins pioneered solar car (*trigger)* racing when they completed a solar car from Perth to Sydney (Australia) in 1983. Several model of solar car, powered only by the sun, have been built and tested in since '70s [29]. These type of vehicles were not intended as day to day in transportation but are rather demonstration car , model of solar car and also to stimulate students ,research toward energy saving and a solar car application (Welling,1996; Ozawa et al,1998 Pundey and Howlett,2002; Gomez de Silva and Svenson,1993). Since the introduction of World Solar Challenge (WSC) in 1987, many universities and companies have taken part and are involved in research activities to develop technologies for solar vehicle. Within 20 years, the development of solar cars is so remarkable in terms of the vehicle weight, speed and the energy management. Most of the solar cars were using three wheels, front two wheels with effective steering and suspension systems, a rear wheel with built-in DC motor, an aerodynamic body shape which is capable of reaching a top speed of 120 km/h and able to complete the 3000 km distance from Darwin to Adelaide in 4 days. In the year 2007 World Solar Challenge, the team from Ashiya University, Japan with their solar car 'TIGA' as shown in figure 1 with an average speed of 93.57 km/h (WSC, 2007). [9]

And different event of solar car racing is hold by the world solar challenger shown figure in 2011 to 2001 year. All these figure of solar car as shown in below figure .1 to figure.6 with manufacturing by university or collage and recent year. Nuna is the name of a series of manned solar racing car that won the World solar challenge in Australia four times in a row, in 2001 (Nuna 1), 2003 (Nun 2), 2005 (Nuna 3) and 2007 (Nuna4). The Nuna are built by students who are part of the Solar Team at the Delft University of Technology in the Netherlands. [25]

And different type of prototype model a solar car was inspired by the Apollo, and National Kaohsiung University of Applied Sciences built to compete in races such as the Australian World Solar Challenge (WSC) in 2007 as shown in figure .7

Solar car is one of the most prestigious project in the field of solar automobile technology in the under guidance of Delhi Technical University INDIA both models is inspired by a Neta Ji Subhas Institute of technology and Delhi engineering collage Delhi.[21]

The detailed study of solar car as manufacturing by university or collage, total racing time to perform by a vehicle covered average speed and winner team of country. All these future is shown by the table .1 in the below

2.2 The History of electric car with solar energy operated
The history of electric vehicles can be generally divided in to three parts; the early years (1890-1929), including their golden age of dominance in the market from (1895-1905), the middle year (1930-1989); and current years (1990- present). In the early year, England and France were the first nations to experiment with electric vehicles, with the United States showing some interest in about 1895.the first electric vehicle may have been a converted Hillman sociable tricycle created by M. Raffard in France in1881. The first commercial application of EVs was a fleet of New York taxicabs in 1897. The association of electrical vehicle manufacturers was formed in 1906 to promote electrics car which is to travel much longer distances than formally on a single charge of a battery. [26] The association of electrical vehicle manufacturers was formed in 1906 to promote electrics car which is to travel much longer distances than formally on a single charge of a battery. In the attention to an innovative vehicle has been developed at Western Washington University (Seal and Campbell, 1995), adopting advanced solutions for materials, aerodynamic drag reduction and PV power maximization with peak power tracking.

The French company venturi has realized in last year's different concept cars, as Venturi Eclectic (Fig.10) and Venturi Astrolab (Fig.11), presented as the first hybrid solar vehicle in sale. Venturi Eclectic Car as 3-seater which is charged by electro-solar or wind vehicle is the first production energy-autonomous vehicle in history and Ni-MH battery is to store energy . It offers a range up to 50 km at a speed of 50 km/hr and can also be recharged from the grid in 5 hours. In the Venturi Astrolab is a 2-seater tandem electro-solar vehicle uses photovoltaic cells covered by a film of nano-prisms concentrating solar energy to recharge Ni-MH batteries. It has a range of 110 km and a top speed of 120 km/hr. solar recharging provides a daily range of 18 km or it can be recharged from the grid in 5 hours. First delivery is scheduled for January 2008.

Some "Green car" options as manufacturers saw potential market opportunities demonstration by the success of Toyota Prius in 2007, 2009 .Honda Civic hybrid car in 2011which is utilized PV panels can be added to a car just to power some accessories, as ventilation or air conditioner, as in Toyota Prius Solar shown in the below in figure 12and figure 13 as Toyota Prius [23]. Honda Civic hybrid car is used to electric charge and IC engine vehicle which is to increase the output power of its. Electric motor is generally preferred in 20 hp at 2,000 rpm when compared with the first generation. The output of battery is increased by around 30 percent to 158.4 V. The battery

storage box is designed for better cooling performance and vibration resistance to enhance long-term reliability. The higher output of electric motor enables the car to run on electricity only, at a steady 15 to 20 mph when cruising on a flat surface. Honda Civic hybrid car is shown in below as figure 14.

The Fiat Phylla (green car) was developed by Centro Ricerche Fiat for demonstrator vehicle. It is powered by a 1kW hydrogen fuel cell and comes equipped with 340W of photovoltaic solar cells and weight 750kg and energy is stored by the batteries. The compact four-seat car is 2,995 mm (117.9 in) long equipped with 15-inch wheels wrapped in green tiers. Mazda Roadster is a solar powered vehicle which is used solar panel across in hood. And remove the engine and gas tank; replace them with a battery and an electric motor. It vehicle is two-seat arrangement and light weight. It is shown in figure 15for FIAT Phylla and figure 16 for Mazda Road star And last A prototype of Hybrid Solar car with series structure (Fig. 17) has also been developed at the University of Salerno in 2008 with considering performance, fuel consumption, weight and costs of the components (I.Arsie et al., 2007, 2008). In This study, that has determined optimal vehicle of dimensions and power train sizing for various scenarios, has shown that economic feasibility (pay-back between 2 and 3 years) could be achieved in a medium term scenario, with mild assumptions in terms of fuel price increase, PV efficiency improvement and PV cost reduction.[20][29].

3. Reviews work

In the over last 10 year research work are proceeding on solar energy operated car with solar cell and detailed study of hybrid solar car (HSV) as below:-

.In this paper present with a detailed study of optimal sizing, fuel consumption of a solar car based on a longitudinal vehicle dynamics mode and energy flow, weight, overall cost of vehicle. It is shown that fuel saving can be achieved for intermittent use with average power and economical feasibility [1][2][3]. In this work is present for usage pattern to development an electric operated auto rickshaw with recharging station which is collected solar energy and stored them after they will be supplied for recharged battery. And all work is investigated the driving pattern of the auto rickshaw drivers in India in order to develop a standard driving cycle with GPS data collected for auto rickshaws in operation was used.[5].this paper is also focuses on the general technologies issues and challenge a head of plug-in hybrid electric vehicle s in relation to major components which can be used for detail of design consideration and selection of component for electric motor, battery system, control strategy and other technical challenge as light weight of material used in a vehicle ,low resistance tires and better aerodynamic structure . It type of vehicle is importance of economics and successful deployment of this plug-in hybrid technology. [8] We investigate the use of photovoltaic systems as auxiliary power generators in hybrid and electric vehicles. This technology provides an as yet unexploited possibility with the advantages of a new power source, which is light, noiseless, maintenance-free and continuously working. A notable reduction of air emissions can be achieved through a synergy of various technological breakthroughs, such as the method we present of introducing photovoltaic arrays and additional electrochemical energy storage capacity in vehicles. Solar cars are also considered as a case study in order to demonstrate the use of solar panels in electric cars. [16], Delhi university as developed a solar car in India because its are generally used in world solar Challenge car race in 2011and to provide a platform in Indian team for participation of world solar car racing event [21]. and other paper of hybrid car as to its greater simplification and recent advances in the electric motor and generator technology, or series architecture for the solar hybrid vehicle, as in the prototype recently developed in Queensland university [22], The use of multi-converters configurations could be advisable to solve the problems of solar generators such as PV modules mismatching and partial shadowing. A comparative study of three different configurations for a hybrid solar vehicle has been recently presented and development at the University of Salerno in 2008[24]. The hybrid electric vehicle (HEV) system that consists of mechanical engine, electric motor and batteries has gained increased interests because of the interest's drawback of IC engine such as pollution. For used Advance control strategy of control the pollution level of city by using total electric operated system of vehicle and perform the preliminary test and road test of a vehicle.[25] further prototype of solar hybrid car powered with a gasoline engine and an electric engine has been proposed and tested by other Japanese researcher [27].

3.1 Objective of work

It is seen from various over last 10 year research works of application and utilization of renewable energy for hybrid solar car. And forecast more and more relative issue of future to presence of Global Warming and clean renewable energy source will be used in run down the solar car because it is helpful reduced pollution. The objective of this work is to estimate the potential of both energy as solar (PV) panel produce electrical energy and IC engine power.

And both powers will be utilization in future work for study and design of hybrid solar operated car. Further implementation of hybrid solar car (solar energy and IC engine powered) which is minimization of fossil fuel (petrol, LPG) consumption, reduce pollution, improved the efficiency of vehicle because vehicle is more light weight, and utilization of solar energy.

3.2 Future of hybrid solar car

In the present scenario is increase the car efficiency and more utilization of car design, aerodynamic structure of a vehicle or using a renewable energy in our research work, minimum consumption of fuel etc all requirement of model car.

In the last 10 years research work is utilization of over work from proposed a design of a solar energy with IC engine (specified petrol operated engine) used a car which is more effective and efficient energy utilization in the vehicle running time as firstly start in IC ensign and full charging system then after vehicle is fully run down in solar energy in day time. In case of winter climate and night ride for vehicle run down for IC engine because its time minimum time of sun light are provided in the earth surface as this reason for vehicle battery operated charging system are not properly work.

4. Solar hybrid car models

In this work is going to justified and studies of different type a hybrid solar car models and structure, as series, parallel and combination of parallel–series as followed are below .all the study of four wheeler solar operated car as the relative to drive mechanism, and structure as shown in figure 18 and figure 19 as below with detailed of vehicle driving system rear wheel drive and operating system of vehicle is run down by using in energy for electric or solar energy.

A model and structure are given by research of hybrid mild car .In this modeling assumes the following main component of its. EM, electric motor which is drive the wheel of motor or work as population of wheel .EG electric generator which is drive by running condition of vehicle as deliver electric energy for EM, PV panel, ICE and battery system and CM is a control mechanism of car which can be rundown the vehicle drive line as front wheel drive or rear wheel drive. It is run down only one drives either rear or front wheel drive. It is shown in figure 20.

5. Technologies parameter of Hybrid solar car

Several types of technologies parameter to be implemented in the next generations of hybrid solar car are found on the horizon. There is a lot of technical parameter to overcome in our work, particularly in the area of hybrid solar car. Hence, the present challenges for researchers are in the development of low weight and high capacity batteries, drives, control system and transmission. Some of these technological challenges are discussed below.

5.1 Calculation of car weight

A parameter for the weight of a hybrid solar car can be obtained all the weight of the specific components as battery, PV panel, IC engine (specified petrol engine), electric motor, electric generator, investor and to weight of car body. [1][6][7] And the solar car can exhibit a weight corresponding to90% of the commercial car, at the same power $\gamma = 0.90$.

$$M_{car} = \gamma M_{base} P_{max} + M_{pv} A_{pv} + M_{EG} P_{av} + M_{EM} P_{max} + M_{batt} E \quad \ldots\ldots (1)$$

Where M_{base} = mass of basement of car, Pmax= maximum power of car, Mpv =mass of PV panel ,Apv = Area of PV panel, + M_{EG} =mass of electric generator system, P_{av} = power of electric generator system, M_{EM}= mass of electric motor, P_{max}= maximum power is used in electric motor, M_{batt} = mass of battery pack , E_p= total power of solar energy

5.2 Solar power utilization of car

The energy will be producing by PV panel obtained from two type of energy contribution as shown in below in equation 1 and equation 2 form by the adopted in G.Rizzo and Ivan Arise paper as[6][7]

5.2.1. Driving time; the energy producing during a running period of a vehicle by calculated by this formula.

$$E_d = \eta_p A_p e_{sun} \frac{h_{sun} - h_d}{h_{sun}} \alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

5.2.2. Parking time; the energy produced during the parking period of a vehicle by calculated by this formula

$$E_p = \eta_p A_p e_{sun} \frac{h_{sun} - h_d}{h_{sun}} \beta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where η_p = PV panel efficiency, A_{pv} = PV surface area, e_{sun}=The average energy daily enough by solar panel captured (4.3 K hr/day), = solar energy h_{sun} captured during a sun at (7 AM to 6 PM), =solar energy during a parking time h_d

Total power = Driving time + Parking time

$$E=E_d+E_p \quad \text{..... (4)}$$

5.3 Energy storage devices (battery pack)

Battery pack is to used in solar powered vehicles performs main functions as to store electricity gained from the PV during daytime and parking time, to supply direct current when it is required, and medium to smoothen the fluctuation of the current and voltage output from the array into the loads of solar car

Most of hybrid car system and components with exception of energy storage devices have been matured to an acceptable level efficiency performance and reliability. As per the studies, the energy stored in the Hybrid Electric Vehicle storage unit is much smaller i.e., in the range of 26.3–77 Wh/kg. However, batteries for plug-in hybrid electric vehicles require both high energy density and high-power capability based on the driving requirements. Battery characteristics for EV and HEV applications are given in Table 2. It is seen from Table 2 that batteries for HEVs are quite different compared with those for EVs in several ways [30].

And normal of battery is required by the model of solar car as figure. 10 which can be obtain by this equation shown as the battery normal size by this formulation.

$$P_B = P_{EM} - P_{EG} \quad \text{..... (5)}$$

5.4 Electric motors

Electric motor and control technologies, methods to eliminate speed, inverter current have been and power used in motor system of car under investigation for several years. The technology development effort needs to be focused on the speed and operation of electric machines and the reduction or elimination of current. [8]

The development of low cost, high temperature magnets would lead to the widespread use of permanent magnet (PM) motors. PM motors have higher efficiency and need lower current to obtain the same torque as other machines. This would reduce the cost of power devices as well. This cost reduction is critical for market viability. The future technological challenges for the electric motors will be light weight, wide speed range, high efficiency, maximum torque

and long life

5.5. Number of modules

The power contribution from the PV array is not accounted for unpredictability of sunshine availability (e.g. raining day, night) and small PV nominal power that can be installed on car at technology stage. Therefore the number of battery modules is shown in equation (6). [1][6][7]

$$N_B = P_{EM} - P_{EG} \,/\, P_{B,u} \quad \text{..... (6)}$$

Where P_{EM} = power of electric motor, P_{EG}= power of electric generator , / $P_{B,u}$ is the nominal power of signal battery module.

6. Conclusions

It can be finally concluded from the above considerations that large research have done in the last 10 year as described in the text to be followed which have been utilized or to be utilized in the nearby the future .

1. Solar car
2. Hybrid solar energy and electric operated car
3. Hybrid solar energy and IC engine operated car

The First two have been developed and are being utilized and third one is the future of solar car .Finally in this study we have considered all issues such as technical issues like capacity of car sizing, running , visibility and seating . Length and height of car of hybrid car is big issues because solar car maximum length as compared to normal car ,integration such as plug-in car with IC engine as petrol is used with charging system are also used. Hybrid cars which is noticed and further used in our research work of hybrid solar operated car.

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Fig .1 TOKAI developed by Tokai University Japan in 2011

Fig .2 OSU Model developed by Osaka Sangyo University Japan in 2009[9]

Fig .3 Sun swift developed by University of New South Wales Australia in 2009[9]

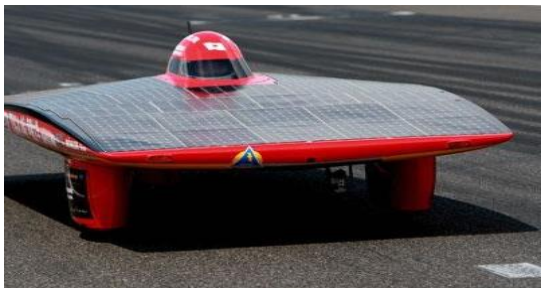


Fig 4. TIGA developed by Ashiya University, Japan in 2007[9]

Fig.5.NUNA 3, NUNA 4 developed by Delft University Netherlands, winner of World Solar Challenge in 2003 and 2005[25].

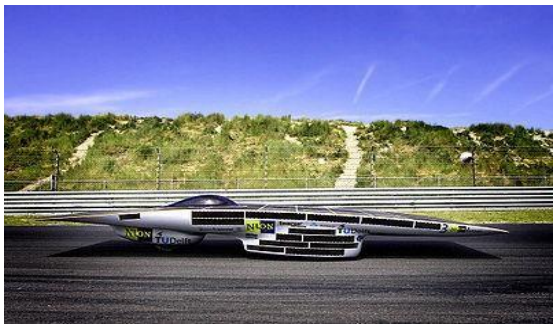


Fig. 6 NUNA 1 developed by Delft University Netherlands, winner of World Solar Challenge 2001[25]

Fig.7 The model is inspired by a National Kaohsiung University of Applied Sciences race car [9]

Fig.8 The model is inspired by a Neta Ji Subhas Institute of technology in India race car .[21]

Fig.9 The model is inspired by a Delhi University in India, solar car in World Solar Challenge 2011[9]

Fig.10. Venturi Eclectic Concept Car in 2007 [26]

Fig.11. Astrolab Venturi as electro-solar vehicle in2008[26]

Fig.12. Toyota Prius Solar car in 2007 [23]

Fig.13 Toyota Prius Solar car in 2009 [23]

Fig. 14 Honda Civic hybrid car in 2011[26]

Fig.15. the FIAT Phylla a green car in 2010 [26].

Fig .16 a Solar Mazda Roadster car in 2007[26]

Fig.17. A prototype of Hybrid Solar Vehicle with series structure developed at the University of Salerno in 2008 [24] Where EN= electric node, EM= electric motor,

Fig.18. A Structure and model of mild solar racing car. [9]

Front wheels Plug-in Rear wheels

Where EN= electric node, EM= electric motor, PV panel and batteries .Plug –in electric

Fig.19. A Structure and Model of solar energy and solar energy used car.[9]

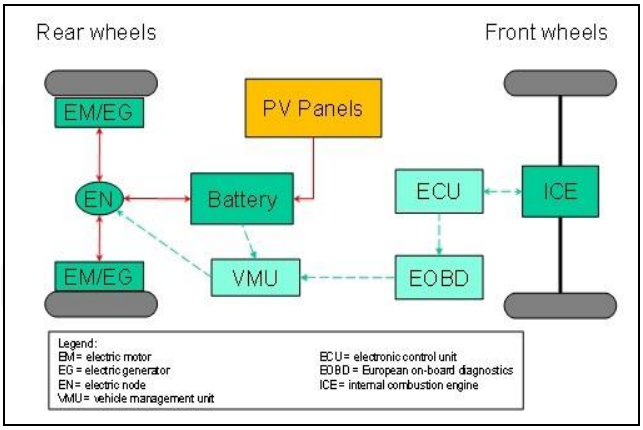
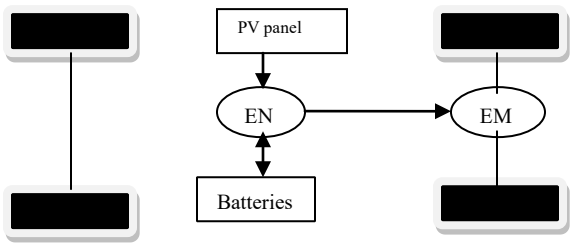


Fig.20. A Structure and model of mild hybrid solar



car. [6].

Table 1. Last 10 year work record in solar race car with World Solar Challenge

Race Year	Class	Vehicle Number	Winner Team	Country	Total race time (hrs :min)	Average Speed (km/h)
2001		37	Alpha Centauri Team 1/ ΓUNA TU Delft	Netherlands	32:39	91.8
2003		33	Nuon Solar Team NUNA 2/ TU Delft	Netherlands	31:05	97.02
2005		30	Nuon Solar Team NUNA3/ TU Delft	Netherlands	29:11	102.8
2007	Challenge	23	Nuon Solar Team NUNA4 / TU Delft	Netherlands	33:00	90.87
2007	Adventure	18	TIGA / Ashiya University	Japan	32:03	93.57
2009	Challenge	32	Tokai Challenger / Tokai University	Japan	29:49	100.54
2009	Challenge Class Silicon	25	Sunswift Ivy / University of New South Wales	Australia	39:18	76.28
2009	Adventure	24	OSU Model S' / Osaka Sangyo University	Japan	34:45	86.27
2011	Challenge	1	Tokai Challenger / Tokai University	Japan	32:45	91.54

Table 2. Detailed studies of Batteries for HVS and EV with application, battery type and technology

Battery Technology	Company name of battery	Application type	Ah	V	Wh/kg at C/3	W/kg 95% eff.
Lead acid	Panasonic	HEV	25	12	26.3	77
	Panasonic	EV	60	12	34.5	47

Ni-MH	Panasonic	HEV	65	12	46	207
	Panasonic	EV	6.5	12	68	46
	Ovonic H	HEV	12	12	45	195
	Ovonic H	EV	85	12	68	40
Li-ion	Saft	HEV	12	12	77	256
	Saft	EV	41	12	140	90
	Shin-Kobe	HEV	4	12	56	745
	Shin-Kobe	EV	90	12	105	255