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Usage of Energy Storing Supercapacitors in Body Panels of EV/HEVS

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ABSTRACT: Most automobiles on the road currently run on fossil fuels in the form of petrol or diesel. Very few use Electric or Hybrid Electric Vehicles, which are a lot eco-friendlier due to their shortcomings in terms of power among other issues. Supercapacitors overcome some of these issues and their use in cars has become a major field of research in the automotive industry. This paper gives an introduction to supercapacitors and their advantages. It also talks of how they are being used currently in electric and hybrid vehicles along with a comparison between supercapacitors and conventional batteries that clearly shows the advantages of supercapacitors over existing batteries for powering EVs and HEVs.

KEYWORDS: Supercapacitor, Electronic double-layer capacitance, Body-panels

I.INTRODUCTION

As time passes, more and more major automobile manufacturers, such as Toyota and Tesla are releasing cars using supercapacitor technology in their hybrid models. A lot of research is being put into this field with the hope of producing an energy storage technology that is completely eco-friendly and reliable as well as cost-effective. These supercapacitors are often made a part of the body panels of cars to achieve a high reduction in the weight of the car, thus forming energy-storing body panels.

1.1 Supercapacitors

Batteries and capacitors are both different ways of storing electrical energy, but they work in different ways. The two terminals of a battery serve as electrodes, separated by an electrolyte, whereas the two terminals of a capacitor are plates separated by a dielectric material such as air or ceramic. While batteries are capable of storing much larger amounts of energy in smaller packages, capacitors have other advantages over batteries. They normally do not contain toxic or harmful substances, they are light in terms of weight and can be charged and discharged nearly infinite times without wearing out [1].

To take advantage of these plus points of capacitors and overcome their greatest drawback, scientists and researchers discovered a way of implementing capacitors in the form of supercapacitors. A supercapacitor is basically a capacitor having very large plate, having maximum surface area, separated by a much smaller distance. This is done as the capacitance of a capacitor is directly proportional to the area of the plates and inversely proportional to the distance between them [1] [2].

To increase the effective surface area of the metal plate, it is coated with porous substances. One such substance is activated charcoal powder. The pores increase the surface area and thus substantially the amount of charge it can store. Instead of a dielectric, the plates are soaked in an electrolyte and kept separated with a very thin layer of insulation. Considering their composition, they are relatively cheap as well. Though still incapable of storing large amounts of charge for a long period of time as compared to batteries, supercapacitors can store and release energy much faster than batteries and are much lighter [2] [3].

1.2 Supercapacitors in EV/HEVs

Supercapacitors are being incorporated more and more into the design of electric and hybrid vehicles. If these are substituted for batteries in a car, the overall weight of the car reduces significantly, thus requiring a lesser amount of power overall for movement. Also the much faster ability to store and release energy can increase the performance of an electric vehicle by far. Considering no harmful materials are a part of the device, and is does not consume fuel, it is an eco-friendly option. As of now, usage of supercapacitors in EVs or HEVs is still gaining ground as better designs are still in the process of being made. Supercapacitors are usually made a part of the body panels of a car, which allows for the maximum decrease in the weight of the car. The life cycle of such supercapacitors are nearly four times that of a conventional EV battery and can produce more than 50% more power. With time, more manufacturers will include supercapacitors once large-scale manufacturing becomes more cost-effective and the price reaches low enough to attract consumers [2] [4] [5].

1.3 Conventional Battery Sources for Electric Vehicles

Plug-in Electric vehicles (generally known as EVs) are automobiles which derive all or part of their power from the electricity supplied from the electricity grid. These are different from Hybrid vehicles, which uses an internal combustion engine along with a rechargeable battery, but cannot be plugged in to a source. Plug-in Electric Vehicles can be classified into All- Electric Vehicles (AEVs) and Plug-in Hybrid Electric Vehicles (PHEV). All Electric Vehicles are those which run only on electricity. All- electric vehicles are again categorized into Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs). In addition to charging from the electrical grid, these types of vehicles also are charged by regenerative braking. Plug-Hybrid Electric Vehicles run on electricity for shorter ranges and then use Internal Combustion Engines when battery is depleted [6].

EVs unlike the conventional petroleum driven internal combustion vehicle, are run by a large electric motor, which is powered through a rechargeable on-board battery system. The different types of batteries used in EVs are:

Lead Acid Batteries: These types of batteries were used in the early electric vehicles. Nowadays, these are considered obsolete for use in Electric Vehicles. These can be seen used in conventional petroleum driven vehicles and are comparatively inexpensive. This type of battery has the least specific energy (34 Wh/Kg) among other battery sources. Lead acid batteries also have low energy density when compared to other batteries [7].

Nickel Metal Hydride Batteries: NiMH batteries are considered superior when compared to lead acid batteries, as they have twice the specific energy (68 Wh/Kg). This makes the vehicles using NiMH, much lighter, causing a reduction I energy cost for propelling. NiMH batteries also have higher energy density when compared to the lead acid batteries, making the batteries more compact. NiMH, even with these advantages has the least charging efficiency. There are also problems of self-discharge (up to 12.5% per day under room temperature), that increases drastically when the battery is used at high temperatures. These batteries also have legal controversies regarding its large format, which has affected its use in EVs [8].

Lithium Ion Batteries: These batteries are considered a standard for modern EVs. Many varieties of Li-ion batteries are available each having different characteristics, but generally variants providing excellent longevity are preferred. Even though this is not as mature as the previous two batteries, this offers many benefits. This has excellent specific energy (140 Wh/Kg) and energy density making it most suitable for EVs. These are good energy retainers and have negligible self-discharge rate (5% per month). Li-ion also has a few drawbacks. Li-on is very expensive when compared to other battery sources. There are also safety concerns on overheating and over charging these batteries. Li-on batteries experience thermal runaway which might cause fire-accidents [9].
Here, an example of batteries and their charging rates in different cars can be seen in Figure 1.1 [10]:

Model	Battery	Charge Times
Toyota Prius PHEV	4.4kWh Li-ion, 18km (11 miles) all-electric range	3h at 115VAC 15A; 1.5h at 230VAC 15A
BMW i3 Curb 1,365kg (3,000 lb)	Since 2019: 42kWh, LMO/NMC, large 60A prismatic cells, battery weighs ~270kg (595 lb) driving range: EPA 246 (154 mi); NEDC 345km (215 mi); WLTP 285 (178 mi)	11kW on-board AC charger; ~4h charge; 50kW DC charge; 30 min charge.
Nissan Leaf*	30kWh; Li-manganese, 192 cells; air cooled; 272kg (600 lb), driving range up to 250km (156 miles)	8h at 230VAC, 15A; 4h at 230VAC, 30A
Tesla S* Curb 2,100kg (4,630 lb)	70kWh and 90kWh, 18650 NCA cells of 3.4Ah; liquid cooled; 90kWh pack has 7,616 cells; battery weighs 540kg (1,200 lb); S 85 has up to 424km range (265 mi)	9h with 10kW charger; 120kW Supercharger, 80% charge in 30 min
Tesla 3 Curb 1,872 kg (4072 lb)	Since 2018, 75kWh battery, driving range 496km (310 mi); 346hp engine, energy consumption 15kWh /100km (24kWh/mi)	11.5kW on-board AC charger; DC charge 30 min

Fig 1.1: Various Batteries and their Charging Rates

II.SUPERCAPACITORS

Supercapacitors (technically called as “Electrochemical Double Layer Capacitor”, i.e., EDLC) was discovered in the year 1957 when General Electric was performing experiments on devices which involved the working of porous carbon electrodes.

This led to an era of supercapacitors where it was observed that porous carbon can store energy and they act as electrodes [11].

Construction

A supercapacitor is constructed constituting two electrodes, a separator and an electrolyte and current collectors as depicted in Figure 2.1.

Supercapacitors derive the energy storage properties of batteries with the power discharge characteristics of capacitors and this account for its superior performance [13]. Supercapacitors are composed of electrodes which possess high surface area of activated carbon and a molecule-width layer of electrolyte. The energy storage capacity of a capacitor is proportional to the surface area of the electrode plates and inversely proportional to the distance between the electrode plates. Due to this proportionality, Supercapacitor has an extremely high energy density. This makes them able to store a huge amount of electrical charge which is stored in its static form. As opposed to conventional batteries which depend on chemical reactions for its charge and discharge cycles, Supercapacitors have no chemical reaction which account for rapid charge and discharge cycles. This feature also extends the charge-discharge lifecycle of super capacitor to almost unlimited duration [14].

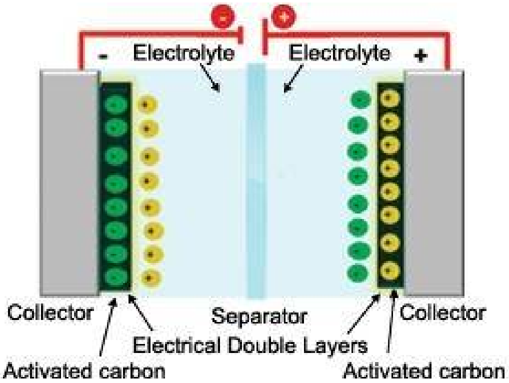


Fig 2.1: Supercapacitor Construction

2.1 Working

A conventional capacitor has two metal plates working as electrodes and a dielectric layer between its electrodes. Supercapacitors also have two metal plates, but they are coated with a sponge-like, porous material known as activated carbon. These electrodes are immersed in an electrolytewhich is usually ionic liquids made of positive and negative ions dissolved in a solvent. One carbon-coated electrode is positive and the other is negative. These electrodes are separated by a thin insulator which can be made of carbon, paper or plastic [15]. A super capacitor in contrary to conventional capacitor has no dielectric layer. In a supercapacitor, the electrolyte has an equal number of positive and negative ions that are uniformly dispersed. Like capacitors, supercapacitors store energy in an electric field, which is created between two oppositely charged particles when they are separated. When a potential is supplied to the electrodes of the super capacitor, this drives an opposite charge on either side of separator. Similar to a capacitor, negative charge builds on one side and positive charge builds on the other. This causes each electrode to attract ions of the opposite charge. This results in each carbon electrode having two layers of charge coating its surface i.e., formation of a double layer. Thus, supercapacitors are also called as the “double layer capacitors”. Hence, a supercapacitor constitutes two capacitors in series where each capacitor is at each of the electrodes. During discharging, the charge on the plates decreases as electrons flow through an external circuit. The ions are no longer attracted to the plate as strongly, so they break off and once again distribute themselves evenly through the electrolyte.

The Energy storing capacity of the capacitor is due to the magnitude of its capacitance. The capacitance of a capacitor is given by the following Equation:

$$C = \epsilon A / d$$

Where, C = Capacitance of the capacitor,
ϵ = Permittivity of the Electrolytic medium
A = Effective surface area of the Electrode plates
d = Distance of separation between the Electrode plates

The width of the double layer created, is equal to a molecule’s width as opposed to the width of dielectric in a conventional capacitor, which ranges from a few microns to a millimetre. Super capacitors owe their large capacitance to large effective surface area (A) provided by porous activated carbon and to the lower separation distance (d) between the electrodes due to the effective double layer effect [16].

2.2 Carbon Electrodes for supercapacitors

The most efficient choice for super capacitor electrode is highly conductive carbon with a large surface area. The most common materials for electrodes after research has been found to be: forms of activated carbon, carbon Nano-tubes, and graphene [17]. These materials do offer a very high capacitance but pose a drawback of high production cost. This drawback makes it suitable only for research purposes and impractical for commercial large-scale usage. Another alternative is chemically manufactured graphene oxide/chemically reduced graphite oxide (CRGO) which showed satisfying performance characteristics [18].

2.3 Electrolytes

Electrolytes consist of a solvent and dissolved chemicals that dissociate into positive cations and negative anions, making the electrolyte electrically conductive. The electrical conductivity of the electrolyte is directly proportional to the number of ions it contains. Electrolytes are the electrical medium of connection between the oppositely charged electrodes in the supercapacitor. The electrolyte contributes the molecules for the separating layer of the Helmholtz double-layer and also provides the ions for the pseudocapacitance.

Capacitance values of 160 F/g, while an organic electrolyte achieves only 100 F/g. [21]

The characteristics of the capacitor such as operating voltage, equivalent series resistance (ESR), temperature range and capacitance is determined by the electrolyte. With the same activated carbon electrode an aqueous electrolyte achieves

The electrolyte must possess inert behaviour chemically rendering it chemically inactive and unreactive with other materials in the capacitor to ensure the stability in the capacitor's electrical parameters for a long time. The electrolyte must possess low viscosity enabling it to wet the porous, sponge-like structure of the electrodes. An ideal electrolyte does not exist, forcing a compromise between performance and other requirements. [22]

2.4 Supercapacitor Characteristics

- Charge/Discharge Time: Milliseconds to seconds
- Operating Temperature: -40°C to +85C°
- Operating Voltage: Aqueous electrolytes ~1V; Organic electrolytes 2 – 3V
- Capacitance: 1mF to >10,000F. [10]
- Operating Life: 5,000 to 50,000 hrs which is determined by temperature and operating voltage
- Power Density: 0.01 to 10 kW/kg
- Energy Density: 0.05 to 10 Wh/kg
- Pulse Load: 0.1 to 100A
- Pollution Potential: No heavy metals [17]

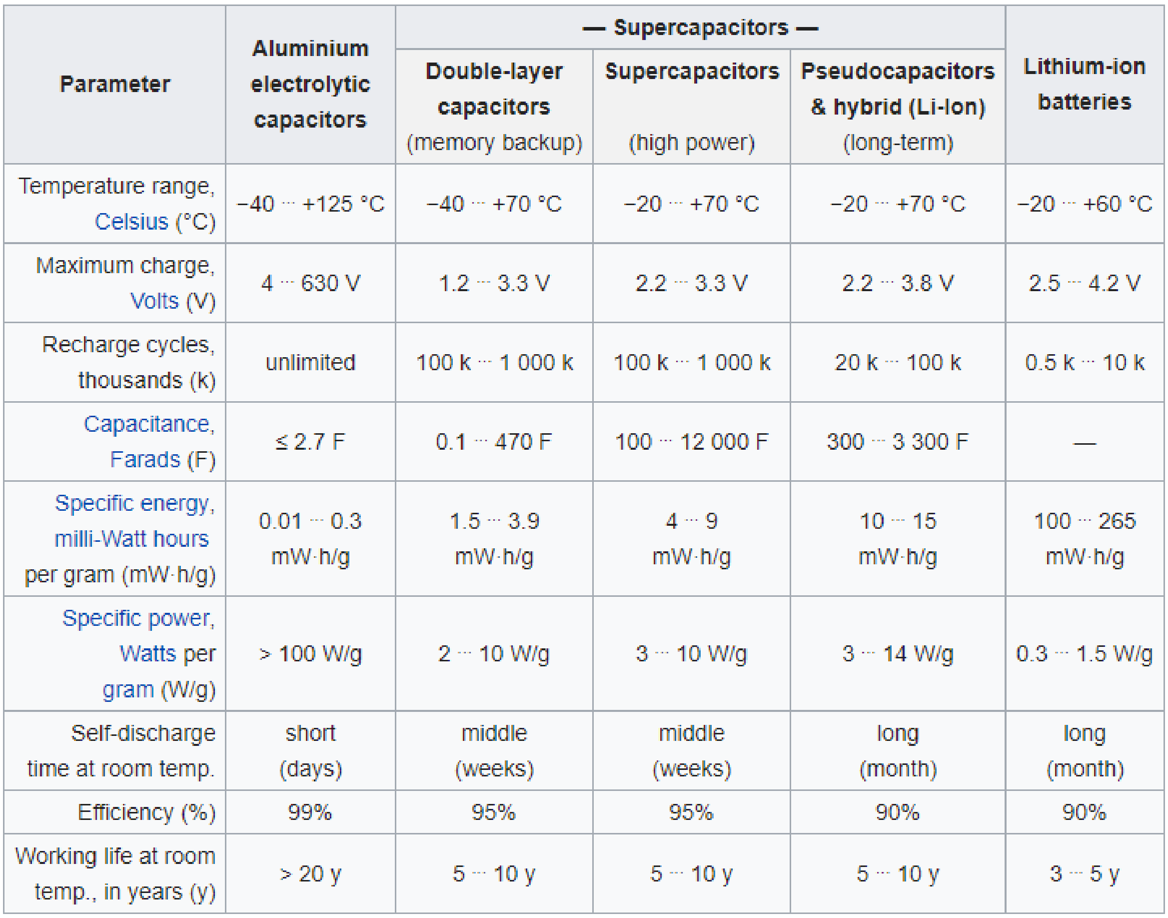
2.5 Supercapacitor Advantages

- Provide peak power and backup power
- Extend battery run time and battery life
- Reduce battery size, weight and cost
- Enable low/high temperature operation
- Improve load balancing when used in parallel with a battery
- Delivers source balancing and energy storage if used with energy harvesters
- Cut pulse current noise
- Lessen RF noise by eliminating DC/DC
- Minimize space requirements
- Meet environmental standards. [19]

2.6 Limitations

- Low specific energy constituting only a fraction of a conventional battery
- Linear discharging nature of voltage prevents usage of the complete energy spectrum
- High self-discharge; higher than most batteries
- Low cell voltage and needs series connection as a compensation for higher voltage
- High cost per watt. [20]

2.7 Comparison between Supercapacitors and Conventional Batteries



Parameter	Aluminium electrolytic capacitors	— Supercapacitors —			Lithium-ion batteries
		Double-layer capacitors (memory backup)	Supercapacitors (high power)	Pseudocapacitors & hybrid (Li-Ion) (long-term)	
Temperature range, Celsius (°C)	−40 ··· +125 °C	−40 ··· +70 °C	−20 ··· +70 °C	−20 ··· +70 °C	−20 ··· +60 °C
Maximum charge, Volts (V)	4 ··· 630 V	1.2 ··· 3.3 V	2.2 ··· 3.3 V	2.2 ··· 3.8 V	2.5 ··· 4.2 V
Recharge cycles, thousands (k)	unlimited	100 k ··· 1 000 k	100 k ··· 1 000 k	20 k ··· 100 k	0.5 k ··· 10 k
Capacitance, Farads (F)	≤ 2.7 F	0.1 ··· 470 F	100 ··· 12 000 F	300 ··· 3 300 F	—
Specific energy, milli-Watt hours per gram (mW·h/g)	0.01 ··· 0.3 mW·h/g	1.5 ··· 3.9 mW·h/g	4 ··· 9 mW·h/g	10 ··· 15 mW·h/g	100 ··· 265 mW·h/g
Specific power, Watts per gram (W/g)	> 100 W/g	2 ··· 10 W/g	3 ··· 10 W/g	3 ··· 14 W/g	0.3 ··· 1.5 W/g
Self-discharge time at room temp.	short (days)	middle (weeks)	middle (weeks)	long (month)	long (month)
Efficiency (%)	99%	95%	95%	90%	90%
Working life at room temp., in years (y)	> 20 y	5 ··· 10 y	5 ··· 10 y	5 ··· 10 y	3 ··· 5 y

Fig 2.2: Comparison between Supercapacitors and Conventional Batteries

III.IMPLEMENTATION

Automobile engineers and car manufacturers are regularly introducing new technologies in cars. It has been quite some time that electric cars have been running on roads, and auto makers are constantly working on new cars which can run on alternative fuel options. Such innovations will play an important role in providing clean environment, and allow automakers to adopt new hybrid technologies. Offering electric cars bring some hurdle for automakers such as the massive space and weight of batteries. So innovators around the world are experimenting new technologies in cars to tackle these issues.

The leading trend by automakers is to integrate super capacitors into the car's body panel like roof, bonnet, door panels etc. Alternative power sources such as solar power, regenerative braking etc., are considerable options [21]. These integrated body panels must possess the mechanical properties of a conventional body and hence, major automakers are researching on the usage of carbon fibre and polymer resin for the body panel. Carbon fibres and polymer resins have high mechanical strength and also have the characteristic of high flexibility which allows for it to be moulded into any shape. Engineers have designed these panels to absorb energy from multiple ways, including regenerative braking and plugging-in overnight. The energy is then stored and released as per the demand. The super capacitor when used additionally with light weight batteries provide high specific energy and power which results in lighter weight cars with better performance and acceleration. This technology will contribute significantly to newcars by reducing the size of electric car batteries, removing the wasted energy used up in moving the extra weight in batteries. The integration of this technology in automobiles greatly reduces the damage to the environment due to zero emissions, preserves the fossil fuel reserve and also in turn saves the human race [22].

This approach to powering EVs is not without its drawbacks, though. While carbon fibre is very strong, some parts of a car are designed to collapse in the event of an accident. By absorbing some of the energy from impact, the crumple zones can protect your squishy human body from the worst of it. That means more damage to the power panelling in places like the hood and trunk, which will be expensive to repair. Emergency crews could also face a new challenge trying to rescue people from such a vehicle after a crash — they would essentially be trying to fish someone out of a giant damaged battery. [31]

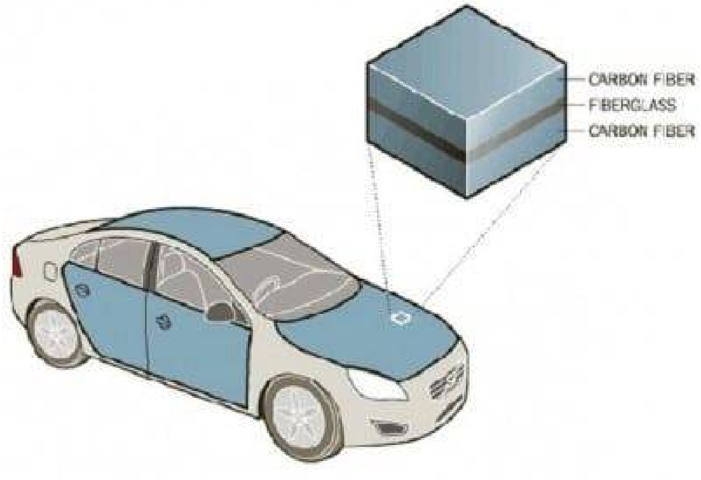


Fig 3.1: Energy storing Body-Panels

IV.FUTURE SCOPE

The advancements in battery technology have enabled the research and implementation of modern Electric Vehicles, Hybrid Electric Vehicles and Plug-in Hybrid Electric Vehicles technology to re-shape the automobile sector. As Electric Vehicles become popular and widely available, consumers will be able to save money, be energy independent, have a lower impact on the environment, pollution, and greenhouse gases and have an enjoyable driving experience [23].

With the advantages of energy storing body panel cars established, the next challenge will be the manufacturing process of said panels. There has been considerable research put into this aspect too and with further development, the manufacturing process will be no more complex than a simple automotive painting [24].

Research is needed to continue improving the specific energy and energy density of batteries being used by vehicles, while at the same time reducing the cost of the technology. Infrastructure to support incorporation of electric vehicles at a large scale will also need further development and implementation [23].

Energy storing panels are not limited to usage only in electric vehicles but also find applications in conventional fuel-powered vehicles. It is possible for traditional gas powered vehicles to incorporate the energy storing panels into their design which would invariably eliminate the need for traditional batteries. When the technology is finally in production, the goal is that it should be simple enough for every automobile company to implement it [24].

The automobile industry is moving towards sustainable sources of energy and electric cars are at the forefront of this shift. As the demand for electric vehicles increases, the cost per unit decreases. With the establishment of the growth of electric vehicles in general, the main worries of electric vehicles are production cost, maximum speed achievable and maximum distance on a single charge. Energy storing body panels alleviates the impact of these drawbacks as described.

With large auto manufacturing companies like Volvo and Toyota investing heavily into research into this aspect of

Electric Vehicles, the future for Energy Storing Panels is bright. From recent developments and trends in the industry, a body panel powered car may soon be in production and on our streets [25].

V. CONCLUSION

In this paper, we have established the need and advantages of using Electric Vehicles using supercapacitor technology and the scope for such vehicles in the future. Battery technology is essential to such vehicles and we have outlined one such aspect of Electric Vehicles, namely, Energy Storing Body Panel cars.

We have followed the feasibility and advantages provided by this technology and also the drawbacks and challenges it faces in implementation. After analysis of the current Nano battery technology and innovations in the super capacitors field, we can observe the advantages it provides to Electric Vehicles with respect to weight, size and maximum speed achievable.

Electric Vehicles with energy storing body panels have great potential of becoming the future of transport while saving this planet from imminent calamities caused by global warming. They are a viable alternative to conventional vehicles that depend directly on the diminishing fossil fuel reserves [26]

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