The World of Electric Vehicles Land, Sea & Air

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1. Welcome to the World of Electric Vehicles: Land Sea Air

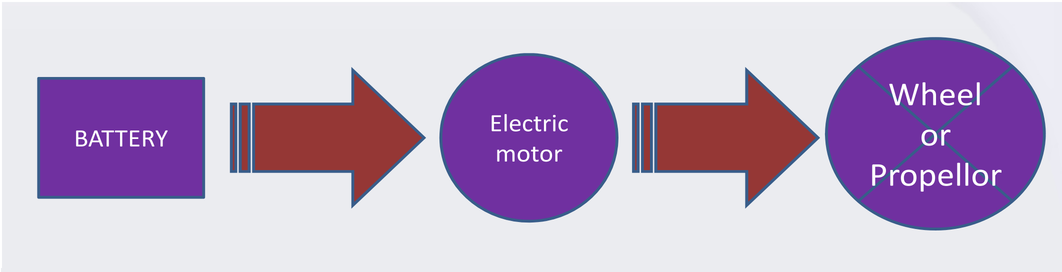
1.1. Why the fuss?

In ten years, electric vehicles EVs will be a business as big as today's car industry. This is partly because only half of the electric vehicle market value will lie in cars. Indeed, no more that 25% of cars produced in 2021 will be electric – possibly far less. Electric vehicles will help to save the planet and the automotive industry and they will reduce local stress from noise, air, land and water pollution. Electric vehicles will reduce dependency on expiring oil reserves controlled by unstable and unpredictable regimes. Many new applications will be created. Aircraft will take off and land silently at night in residential districts. Unmanned underwater vehicles will stay at sea for years without maintenance, monitoring oil rigs and fish, prospecting for minerals, and executing military missions. There will be military hummingbirds, jellyfish, unmanned airships and more carrying out surveillance. A cheap alternative to satellites will be upper atmosphere unmanned aircraft cruising for years on sun power without maintenance. Tugboats will pull harder and not pollute – new regulations encourage such reduction in pollution . The list goes on and on. Come back Faraday. All is forgiven.

1.2. What is an electric vehicle?

There is no official definition of an electric vehicle but all agree that an electric vehicle uses an electric motor to propel itself some or all of the time. In common parlance, the term electric vehicle is used more narrowly. See the IDTechEx report, "Electric Vehicles 2011-2021" for the detail and the forecasts by sector. The basics are given below, with the most popular basic components. The electric motor may be powered without a battery and the vehicle can still be called an electric vehicle.

Fig. 1.1 Electric vehicle basics



Source IDTechEx

Excluded

In our statistics, like most other analysts, we exclude toys, military submarines, large ships and large railway locomotives with electric drives because these are not usually referred to as electric vehicles and they have little in common with them. At the heavy end they tend to use diesel-electric, nuclear-electric or gas turbine-electric power trains with no pure electric mode that relies on energy from a large traction battery. We also omit mobile ordnance and tethered vehicles such as trains, trolley buses, trams and underwater vehicles connected to a control point by wires, torpedoes being an example.

1.3. The key enabling technologies

The key enabling technologies for EVs are currently batteries, motors and control electronics. For example, the Chinese government requires foreigners participating in its EV market to cede intellectual property on at least one of these as well as settling for only a minority share of any venture. (Savvy foreigners treat this with great caution. For example, the potential for electric cars in China is less than popularly believed because there can never be enough roads and parking spaces and competition is fierce. Car licenses in Beijing are already frozen at 20,000 a month). Energy harvesting is rapidly becoming another key enabling technology for electric vehicles – from solar panels to braking and dampers that create electricity.

1.4. Why EVs are bought

Pure electric vehicles are demanded where it is illegal to pollute – indoors with mobility aids for disabled and indoor forklifts, for instance. They are also appreciated where they are lower cost and more reliable than a conventional vehicle and less noisy as with golf cars, golf course mowing machines and e-bikes. EVs have legal push on an increasing number of inland waterways because conventional engines are banned. On the other hand Autonomous Underwater Vehicles AUVs and solar powered Unmanned Aerial Vehicles UAVs are difficult to make any other way. Silent aircraft have to be electric and this may allow them to take off and land in residential districts at night. A military electric vehicle is more covert, with less for a missile to home in on. Few people or organisations buy an electric vehicle in order to save the planet but they increasingly tolerate higher up-front cost when running cost is low enough to give a payback. Electric delivery vans tolerate very frequent stop start much better than conventional versions and with less disruption.

Mobility vehicles for the disabled are a misnomer. Most are impulse buys by the fat or elderly, a substantial growth market, so to speak, 1.3 million being bought in 2011. Meanwhile, designer sports cars ("toys for boys") are out accelerated by the more reliable electric versions. You can even choose what noise to make, the sound of alien space invaders being of particular interest.

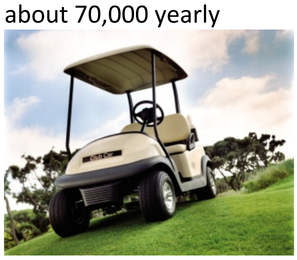
1.5. Pure electric vs hybrid

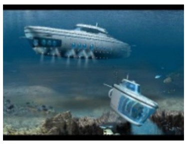
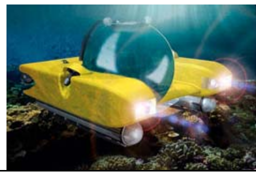
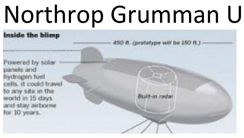
Electric vehicles that use electric power and nothing else all the time and having only electrical power sources such as batteries are called pure electric vehicles. Hybrid electric vehicles have a non-battery power source on board in addition to the traction battery such as an internal combustion engine, fuel cell or turbine. (In due course fuel cells may be usable without batteries to manage load changes). That non-battery power source can propel the vehicle when needed if it is a "parallel hybrid" or simply charge the battery in which case it is a "series hybrid". Some combine both capabilities and are called "series parallel hybrids".

A wide variety of vehicles fit the usual definition of electric vehicle that we have discussed. Today, 95% of EVs are pure electric – mainly bikes and mobility for disabled – but the most money is spent on hybrids – mainly cars. Read the IDTechEx report "Hybrid and Pure Electric Cars 2011-2021". The types of EV are summarised below:

Table 1.1 The main electric vehicle types and applications. Manned unless stated otherwise. "Not yet" means that there are very few or none in existence as yet.

Type	**Sub type/ market leader**	**Hybrid market leader**	**Pure electric market leader**
On-road	Car	Toyota Japan makes about 800,000 yearly 	Tesla USA makes about 1,000 yearly 
	Bus	Daimler Orion Germany makes about 1000 yearly 	Fragmented

Type	Sub type/ market leader	Hybrid market leader	Pure electric market leader
	Other commercial vehicles	Fragmented 	Fragmented
	Two wheeler	Not yet	Jiangsu Xinri Electric Vehicle China makes about 1.8 million yearly 
Off-road	Golf car	Not yet	Ingersoll Rand USA makes about 70,000 yearly 
	Forklift	Mitsubishi Japan 	Toyota Japan makes about 10,000 yearly 
	Military	Fragmented	Fragmented
	Mobility vehicles for disabled	Not yet	Pihsiang Taiwan makes about 100,000 yearly 
On water	Inland boat	Fragmented	Kopf Solarschiff Germany 

Type	**Sub type/ market leader**	**Hybrid market leader**	**Pure electric market leader**
	Sea boat	Bénéteau France 	Not yet
Under water	Leisure submarine	US Submarines USA 	US Submarines USA 
	Autonomous Underwater Vehicle UAV - unmanned	JAMSTEC Japan 	Kongsberg Norway 
Aircraft	Plane, hang glider	Not yet	Yuneec China  
	Unmanned airship	Northrop Grumman USA 	Not yet
	Other Unmanned Aerial Vehicle UAV	AeroVironment USA 	AeroVironment USA makes about 3000 yearly 

Source IDTechEx

Read the IDTechEx reports “Electric Buses and Taxis 2011-2021”, “Marine Electric Vehicles 2011-2021”, “Electric Aircraft 2011-2021” and “Electric Vehicles Military, Security, Police 2011-2021”.

1.6. New EV components rarely appear first in cars

New EV components rarely appear first in cars because of extreme safety concerns, reluctance to change and long development cycles. Benchmarking must be done elsewhere. Batteries, motors etc developed for military and other land vehicle propulsion were then adapted for boat propulsion. For cost or safety reasons, some, such as lithium sulphur batteries, first appeared in unmanned aircraft and then military land vehicles. Zinc air third generation batteries will first appear in the relatively easy application of e-bikes. AC motors proved useful in forklifts before they were widely adopted in cars but lithium-ion batteries are only slowly being adopted in forklifts though they are now commonplace in land vehicles. So far, multiple energy harvesting is most common in AUVs. Energy harvesting shock absorbers generating a massive ten kilowatts per vehicle will probably first appear in trucks, buses and military vehicles but the principle will later be used in AUVs and cars. Thermoelectric heat harvesting will appear on hybrids and later on pure electric vehicles: pure electric components also get hot but not as hot. The latest copper indium gallium diselenide CIGS flexible conformal solar cells find readiest adoption in surface boats so far. We discuss energy harvesting more fully later because it is becoming one of the key enabling technologies for all forms of electric vehicle.

Consequently, to benchmark best practice, it is essential to track the whole industry. Indeed, component suppliers usually sell horizontally into many types of EV. They know that new EV technologies rarely appear first in cars and easy profits are never obtained by pursuing the obvious.

1.7. EV manufacturers diversify to win

It is important to look at the complete picture because it is increasingly true that one company will produce EVs for many end uses and even make key components. Examples are shown below. This achieves the product reliability and cost advantages that come from highest volume manufacture based on standardisation and shared research. For instance, number one in electric vehicles overall by a big margin is Toyota. It is the most widely diversified across EV types and it even makes its own traction batteries. Toyota’s industrial and bus EV developers share their discoveries with the car divisions. For example, the early use of AC motors in Toyota fork lift trucks had lessons for other types of electric vehicle: Toyota now uses them in some electric cars, for example.

Table 1.2 Examples of the increasing number of vehicle manufacturers addressing more than one EV sector.

Type	Sub type/ market leader	Hybrid	Pure electric
On-road	Car	Toyota Japan Daimler AG Mahindra India Tata Motors India GM USA Hyundai Korea	Toyota Japan Daimler AG Mahindra India Tata Motors India Nissan Japan
	Bus	Toyota Japan Tata Motors India Designline New Zealand Daimler Germany GM USA 	Toyota Japan Tata Motors India Designline New Zealand 
	Other commercial vehicles	Toyota Japan GM USA	
	Two wheeler		
Off-road	Golf car		
	Forklift	Toyota Japan Mitsubishi Japan	Toyota Japan Mitsubishi Japan Nissan Japan Hyundai Korea 
	Military	Lockheed Martin USA Tata Motors India Daimler AG Mahindra India	Lockheed Martin USA Tata Motors India
	Mobility vehicles for disabled	Toyota Japan	Toyota Japan
On water	Inland boat		
	Sea boat		
Under water	Leisure submarine	US Submarines	US Submarines
	Autonomous Underwater Vehicle UAV - unmanned		Lockheed Martin USA
Aircraft	Plane, hang glider		
	Unmanned airship	Lockheed Martin USA Northrop Grumman USA	
	Other Unmanned Aerial Vehicle UAV	AeroVironment USA Lockheed Martin USA Northrop Grumman USA	AeroVironment USA

Source IDTechEx

1.8. Charging an electric vehicle

1.8.1. Stupid plugs

Most pure electric vehicles and some hybrid electric vehicles ("plug in hybrids") have their battery charged by an external charging station. This may deliver AC or DC but the DC version is increasingly preferred as it reduces the weight carried by the vehicle, since it is DC that must be applied to the battery to charge it. For more, read the IDTechEx report, "Electric Vehicle Charging Infrastructure 2011-2021". To outsiders, it seems curious that the industry is stuck in the dark ages with most EV chargers using plugs with contacts and all sorts of expensive safety, reliability and weatherproofing measures to make it less risky and troublesome. Worse, the plugs differ from continent to continent, with a struggle for the world standard interface set to last for at least another decade. Virtually all mobility vehicles for the disabled have the charger electronics as part of the vehicle so it is simply plugged into a domestic plug. Electric bikes will be next to offer this delightful simplicity.

1.8.2. Inductive charging

Some charging stations charge inductively through the air, like an electric toothbrush, which is more convenient – you need not get out of the vehicle and do anything - reliable and weatherproof. Unfortunately, it typically wastes 7% of the electricity – sometimes much more - and it calls for accurate positioning of the vehicle. Resonant charging is slowly being introduced and this wastes only a few percent of electricity.

1.8.3. Slow, fast or faster?

Charging can be Level 1 which is slow eg overnight and typically at home, Level 2 which is faster and found at home and in the street and Level 3 which is very fast – minutes to one hour - and seen at fleet depots and occasionally by the street. Level 3 is impeded by lack of global standards, the fact that it can damage some batteries and the trend to longer range vehicles because larger batteries usually take longer to charge. It is also ten times as expensive. Because of this, fleets will be among the first to use fast charging.

1.8.4. Elegant sunpower

Some pure electric vehicles charge partly or entirely from the sun using photovoltaic panels on board or, in the case of cars and boats in some locations, charging stations partly or entirely reliant on solar power. Some golf cars, inland boats, seagoing boats and AUVs and most UAVs do this using photovoltaics on the vehicle – elegant indeed.

1.8.5. Battery swapping is splendid for fleets

Battery swapping is done with some forklifts and is suitable for the relatively standardised pure electric bus, truck, taxi and delivery van fleets. A charged battery is exchanged for an exhausted one. Automated swapping is being tried for electric cars but the variety of battery types, shapes and fitments makes this of questionable practicality from the point of view of both financing a stock and quickly exchanging so many different batteries. An automated battery swapping station costs about $500,000 whereas the popular Level 2 charging stations can be installed for as little as a few thousand dollars. That said, the Better Place auto swapping system can get you on your way faster than if you were putting in gasoline, they say and it can comfortably deal with up to six different battery types, they say.

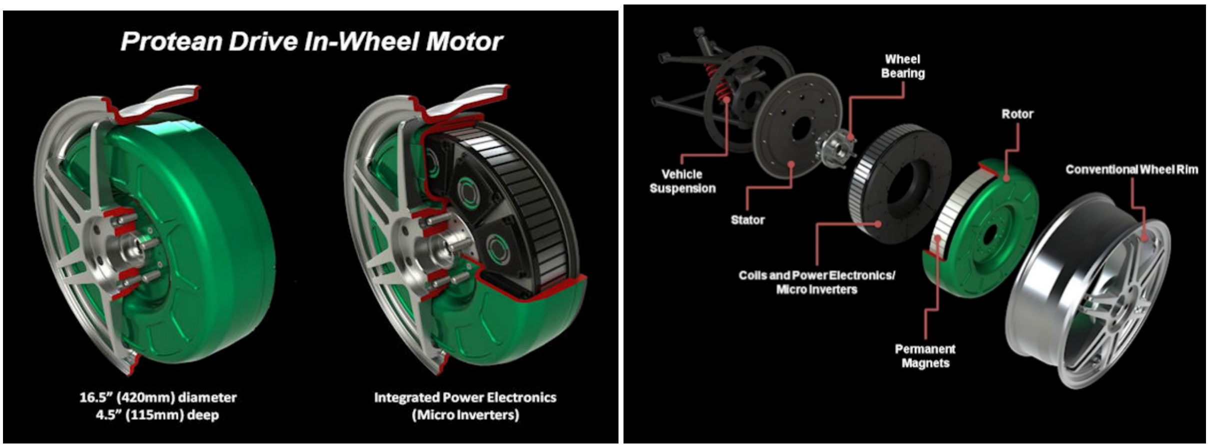
Fig. 1.2 Battery swapping

Source Better Place

1.9. Major changes in how EVs are made

Many new components, power trains and assemblies are making the construction of electric vehicles very different over the years. We shall explain how hybrids are becoming more like pure electric vehicles, the interim stage being a “range extended electric vehicle”. This is because users are underwhelmed by the pitiful 23 kilometers or so of all electric range of many of today’s plug in hybrids. There is also a trend to using many electric motors rather than one. For example, in-wheel motors release more space and permit better control and distributed motors in a military vehicle make it more damage tolerant.

Fig. 1.3 Protean Electric DC synchronous in-wheel motor for a car or pickup truck



Source Protean Electric

1.10. Battery needs change

The smaller, better performing but usually more expensive lithium-ion rechargeable batteries are being used in an increasing majority of electric vehicles, hybrid and pure electric, though some hybrids still use nickel metal hydride. Most boats, forklifts, golf cars, e-bikes and mobility vehicles for the disabled enjoy the low cost of lead acid traction batteries because range and performance are not onerous for these vehicles. However, lithium-ion is penetrating even here.

Whereas hybrid car batteries were optimised for fast and frequent delivery and acceptance of power ie “power density”, the demand for longer all electric range for hybrids is leading to energy density – as with pure electric vehicles – becoming the primary concern ie the maximum amount of affordable power storage per unit of volume and weight.

More on this later.

1.11. Second generation batteries – going backwards to go forwards

The safer second generation lithium-ion batteries now designed into most of leading larger vehicles sold in volume, notably cars, are often worse than the old ones in energy per unit of volume or weight. Typical pure electric vehicle range is therefore only 160 kilometers (100 miles) on or off road, in the air or under the water despite most of these users demanding much more. Pure electric range of a hybrid is usually one tenth of this, as we noted.

Source IDTechEx

The change to second generation is in order to improve safety, cost and other aspects of performance by abandoning the chemistry of those exploding lithium cobalt oxide laptop batteries. Second generation lithium-ion traction batteries are inherently safer due to factors such as higher temperature capability making the cells less vulnerable to thermal runaway though there is still no usable cell that is entirely inherently safe . Second generation batteries are also less vulnerable to material cost escalation thanks to using less cobalt or no cobalt. A favourite cathode is lithium iron phosphate but lithium manganese and other cocktails are also widely used to improve cost and performance.

A favourite form of electrolyte containment is now solid polymer electrolyte with gel, this being referred to as lithium polymer. Favourite anodes are carbon or – beginning to come in - titanium dioxide. All this makes second generation traction batteries more tolerant of pressure (eg under water), impact and fast charging but not usually higher energy density at the cell level despite that being what the customers want. However, at the battery pack level (circuitry and containment added) the circuitry may be simpler with less safety circuitry needed for example and the encasement may be lighter and thinner with little or no liquid electrolyte to trap. All this is seen with EVs for land, water and air, hybrid and pure electric – these people need to share experience.

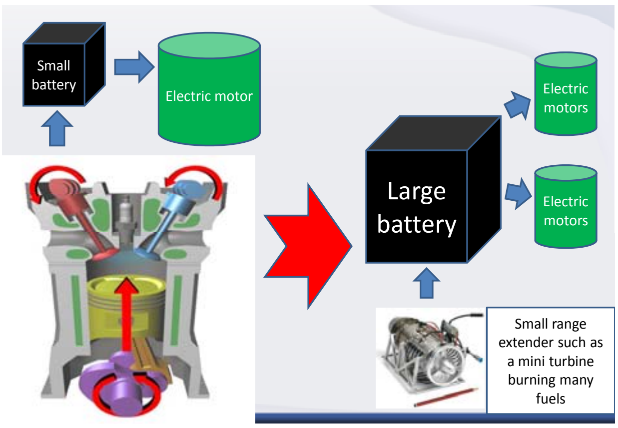
1.12. Third generation batteries give longer range

Third generation traction batteries will be fully solid state in the main and characterised by higher energy density thanks to new chemistry and construction. Issues with safety and life are being tackled. A trend to thinner wider batteries for space saving and better cooling could even end up as conformal batteries forming part of smart skin with photovoltaic layers, structural sensing layers and so on but this is some way off.

1.13. Hybrids become more like pure electric vehicles

In addition, the hybrid vehicle designer is replacing its nostalgic conventional engine not intended for the job with a “range extender”, partly because users want longer pure electric range from hybrids. Using electricity can be one tenth of the cost of using gasoline due to a quirk of taxation. The second generation range extender is a simplified internal combustion engine ICE made more reliable, smaller, lighter and lower cost by optimising it for near constant torque and revolutions, the traction battery managing the varying load. The third generation range extender abandons the ICE for a fuel cell or mini turbine (jet engine) or two to improve these parameters even more and gain independence from oil.

Fig. 1.4 Hybrids become range extended EVs



Source IDTechEx

Fig. 1.5 Jaguar CX75 supercar with jet turbine range extenders

Source Jaguar

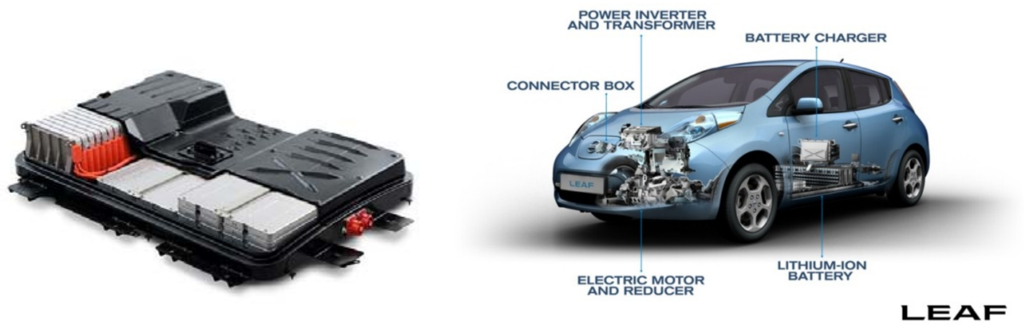
1.14. The battery is the car

The traction battery is the largest single part of the cost of most electric vehicles. It can be up to half the cost of a pure electric vehicle and, painfully, not last as long as the vehicle does. This can lead to a huge replacement cost possibly leading to premature scrapping of the vehicle. Nothing very environmental about that. The battery also controls performance of an electric vehicle more critically than do other components.

1.15. Battery cost greatly affects EV sales volume

Battery cost greatly affects EV sales volume. This is disguised by heavy subsidies and tax breaks in many countries but such support can be prematurely withdrawn as happened in Japan and Spain with photovoltaics replacing power stations: a whole industry collapsed. The motor industry is therefore in a rush to get battery costs down in particular.

Fig. 1.6 Large lithium-ion battery across the underside of the pure electric Nissan Leaf



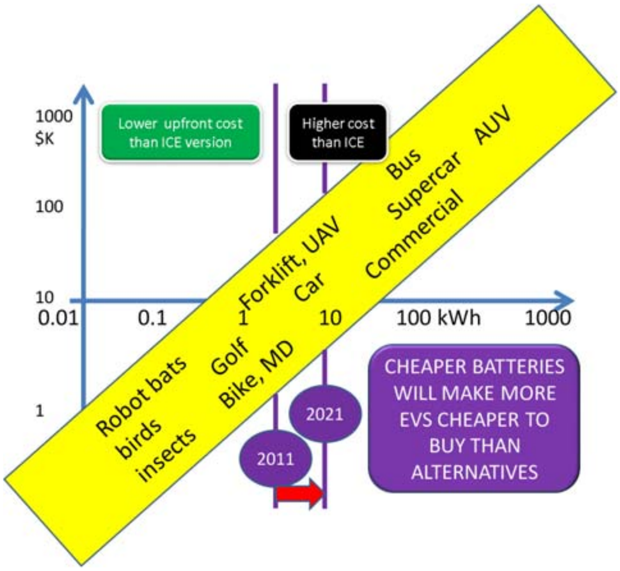
Source Nissan

Small electric vehicles are typically lower cost to buy than internal combustion engine alternatives: golf cars and electric bicycles are examples of this. Mobility vehicles for the disabled MD are at the crossover point but here electric wins because they go indoors. The bigger electric vehicles such as large Autonomous Underwater Vehicles with the equivalent of six pure electric car batteries often cost more than the conventional alternatives but they win on reliability, maintenance, stealth and environmental credentials.

As battery costs tumble down in the next decade, more types of electric vehicle will be viable on an up front cost basis. This is illustrated below but it is important to realise that many electric vehicles are purchased for other reasons than cost, any cost advantage being a sweetener. Indeed, cost over life of a hybrid or pure electric bus or truck typically beats cost over life of ICE equivalents despite upfront cost being up to 65% higher. We best understand this by looking at the big picture of all electric vehicles.

The figure below shows electric vehicle upfront cost vs their traction battery energy storage in kilowatt hours showing how the point at which they are lower cost than internal combustion engine alternatives is improving over the years as traction battery costs reduce. However, the factor of five improvement shown below is currently a triumph of hope over reality.

Fig. 1.7 Electric vehicle upfront cost vs their traction battery energy storage



Source IDTechEx

Manned pure electric fixed wing aircraft will probably be near the centre of the above plot as they become more prevalent. Meanwhile, Fiat is developing pure electric microcars because it believes that, like pure electric golf cars, they can be cheaper to make than the conventional equivalent. By contrast, hybrids are starting to be sold at price parity with conventional cars not based on cost but as a powerful ploy to gain market share that can itself lead to reduced costs. This is very important because, with on-road vehicles, we are in the decade of the hybrid.

1.16. Hybrids at no price penalty

IDTechEx forecasts of sales of hybrid cars presume that, as the decade progresses, more and more of them will be offered at no price premium. This is not because costs will converge fully during that time – there will be no outselling of conventional cars to provide superior economy of scale - but because such tactics confer huge marketing advantage. There will be no reason for users not to buy the hybrid option. It will be rather like the Japanese offering all accessories at no price premium in the 1970s thus gaining huge market share culminating in Toyota becoming the world's largest automotive company, though many other factors also assisted this process.

Bellwether of all this was Ford with its bold plan to sell its Lincoln MKZ Hybrid at the same price as its non-hybrid, conventionally-powered stablemate, from 2010. As we predicted, it is paying off in sales. Ford has just announced that sales of the hybrid are running ahead of expectations. The company projected that the hybrid version would represent around 15% of sales within the MKZ product line. However, since January 2011, it has hit more than 20% of sales. Both models are priced at $34,605 MSRP. Ford stresses, “No other four-door luxury sedan – gasoline, diesel or hybrid powertrain – can top the MKZ’s certified 41 mpg city and 36 mpg highway EPA rating.” (A US gallon is smaller than a UK gallon).

Fig. 1.8 Lincoln MKZ Hybrid

Source Ford

A large part of the reason that Ford can make this groundbreaking offer is because it is using the same drivetrain found in the Fusion Hybrid, which is essentially the same car as the MKZ, but with fewer refinements. Ford rivals Honda for number two slot in hybrid car sales worldwide and its new model program is currently outgunning Honda.

For more see the IDTechEx report “Hybrid and Pure Electric Cars 2011-2021”

1.17. Trend to AC motors

The DC electric motor was invented in 1821 but the AC motor was only invented in 1900. Synchronous DC motors became ubiquitous in electric vehicles around 1880. The more reliable, relatively maintenance-free brushless DC traction motors later proved popular and remain so today, but now three phase AC asynchronous induction motors – basically rotating transformers - are showing signs of taking over.

There are many reasons for this, some being summarised below.

Table 1.3 Benefits of DC synchronous traction motors for vehicles vs AC asynchronous motors used for the same task.

DC motors	**AC motors**
Well proven and mass produced for e-bikes Lower cost in the past - controller is lower cost than the inverter needed for an AC motor (but other complexity for programming, regen, reverse, forced cooling etc can swing the balance the other way for certain applications) Very small versions for eg bikes are viable Can be designed for high torque and high speed- such as the pure electric motorcycle that recently achieved the world speed record. Electrified nosewheels that make an airliner into an electric vehicle when on the apron are DC motor driven as are the leading pure electric and hybrid cars and some electric buses, trucks and military vehicles etc.	Reliable Increasingly lower cost. Easily programmed Relatively maintenance free and long life Can work backwards as a generator without adding complexity and cost Less need for gears– the Tesla Roadster has only one gear yet it accelerates faster than many conventional performance cars Easily made low voltage as favoured in simple vehicles or high voltage where high rpm and optimally efficient electrics are sought No dependence on the potentially high cost and short supply of neodymium used in the permanent magnets of DC motors. Good temperature range unimpeded by potential damage to magnets from overheating. Largely self-cool

Source IDTechEx

AC motors are increasingly favoured in hybrid cars and buses (eg market leader Daimler Orion) and they appear in most pure electric golf cars, forklifts and an increasing percentage of pure electric cars, to name just a few. Problems such as the cost, partly due to lack of mass production, the complexity of the inverter producing the AC and the sometimes less than superlative size and performance are rapidly being overcome. Indeed, Evans Electric in Australia is preparing to launch an in-wheel AC motor system that will deliver a total of 280kW and a 0-100km/h time of less than three seconds. Already the Tesla Roadster AC motor gets it there is just over three seconds, achieving a 130 mph top speed.

Needless to say, all this is an oversimplification and motors combining some aspects of the above-described AC and DC motors are also used. It will be interesting to see what Remy International does with its $60.2 million Department of Energy DOE grant in the USA. For electric vehicles, Remy makes both DC traction motors with a permanent magnet in the rotor for high performance and AC versions “for simpler controls and cost advantage”. The grant is to help accelerate standardization and commercialization of the electric vehicle traction motor of the future.

1.18. Electric vehicles become electronic

About 80% of the value of a military jet aircraft lies in the electronic and electric circuitry. About 50% of the value of a civil airliner lies in its electric and electronic circuits, whereas, for the family car, the figure is around 30%, all these percentages steadily rising. The point is that an aircraft has far more than the radar, communications and other instruments accessed by the pilot: it is a sea of sensors, fuel controls and servo systems in the engines, wings and elsewhere. Even the family car has much more than the lighting, wiper, window and seat controls, satnav, proximity sensors and other electronics directly assisting the driver. The

MEMS accelerometer controlling the air bags is one of an increasingly huge number of out-of-sight safety and other measures controlled by circuitry.

1.18.1. Electric vehicles fill with circuitry

The advent of hybrid and pure electric vehicles accelerates this trend to more and more circuitry. Even that painfully expensive battery pack can have as little as 50% of its value lying in the cells the rest being circuitry called the Battery Management System (BMS) and the casing. Lithium Balance is therefore taking a new approach to the BMS design. This electric and electronic circuitry converts the battery voltage and current to what is needed by the motors etc. It also monitors cell temperature, protects the cells from overload, stores and provides power surges with ultracapacitors, converts multiple energy harvesting and charger station inputs into the appropriate DC currents and voltages where necessary and manages shut down on impact, fire, cell runaway or other excursion. The BMS is being asked to do more.

1.18.2. Electronics takes over motors, other electrics proliferates

It is not just the traction battery pack that is becoming an electronic device. We have seen that traction motors have become mainly AC induction rather than DC. In effect, commutators in synchronous DC motors are being with replaced by circuitry in AC electric motors – another part of the move from metalwork to circuitry in electric vehicles. In parallel with these changes, the control electronics of the vehicle is becoming more sophisticated and capable and leading to more electrics and electronic circuitry.

1.18.3. Simplifying the bird's nest of electronics and electrics

So how do we improve the ever larger bundle of wiring and circuits that constitute the electric vehicle of the future? Rogers Corporation replaces the bent metal of copper power conductors with its Directly Bonded Copper (DBC) on ceramic. Lower power and signals are increasingly handled by fully or partially printed electronics. Eventually much of the printed circuitry, laminar lighting, photovoltaics, wide area sensors and so on may form smart skin on the vehicle or at least in the battery pack. This may have the advantage of self cooling and saving cost, weight and space in many ways.

T-Ink has already made overhead and dashboard control clusters using conformal printed and laminar lighting, actuators etc on top of each other – plywood electronics if you will. This will soon appear in a leading electric car saving up to 40% of space, weight and cost over conventional mechanical/ electric devices, while improving weatherproofing and reliability. The electric inks literally stretch to shape as the subsequent plastic structural part is moulded. T-Ink is raising $20 million in order to go mainstream on this capability, even replacing the kilograms of expensive copper wiring throughout electric vehicles with printed conductors on tape.

Flexible Electronics Concepts is producing innovative concepts and samples of printed electronics and electrics and Daimler AG researches smart electric fabrics. The next generation traction battery cells from

Oxis Energy will be printed or use printing-like processes as do the flexible, conformal CIGS photovoltaics on Kopf Solarschiff solar boats for example.

1.19. Energy Harvesting for electric vehicles

Energy harvesting is the conversion of ambient energy into electricity in small, portable or mobile equipment – not to replace power stations. Consider the bike dynamo and regenerative braking of a car. Where propulsion is by propeller rather than wheel we are starting to similarly harness rotary movement. The propeller of some new sea yachts can reverse when under sail and the propeller of one electric light aircraft can work in reverse when soaring – both charging the battery. Some superyachts scoop in water when under sail. This drives a turbine that charges huge traction batteries in a very short time. For more, read the IDTechEx report, “Energy Harvesting for Electric Vehicles 2011-2021”.

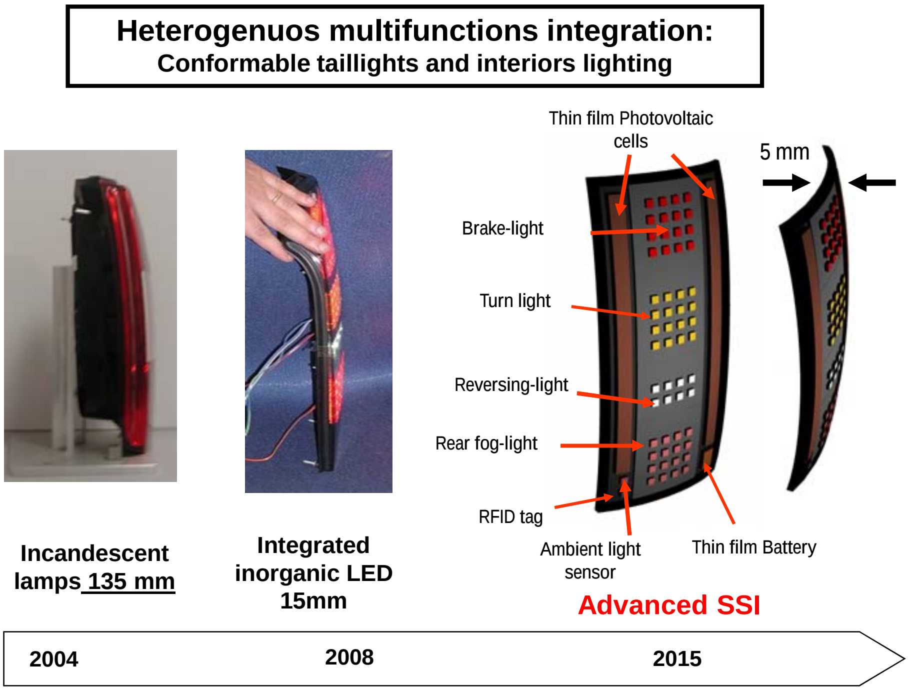
Energy harvesting on and in vehicles maybe huge for charging traction batteries or tiny for operating myriads of embedded sensors wirelessly. It may turn heat, movement or light etc into useful electricity. Some harvesting generates hundreds of watts to tens of kilowatts to provide significant power to traction batteries. Harvesting shock absorbers (dampers) and active suspension and unfurling or unfolding photovoltaic solar panels qualify here.

Fig. 1.9 Unfolding solar panels charging electric vehicles

Source Sanyo, Library

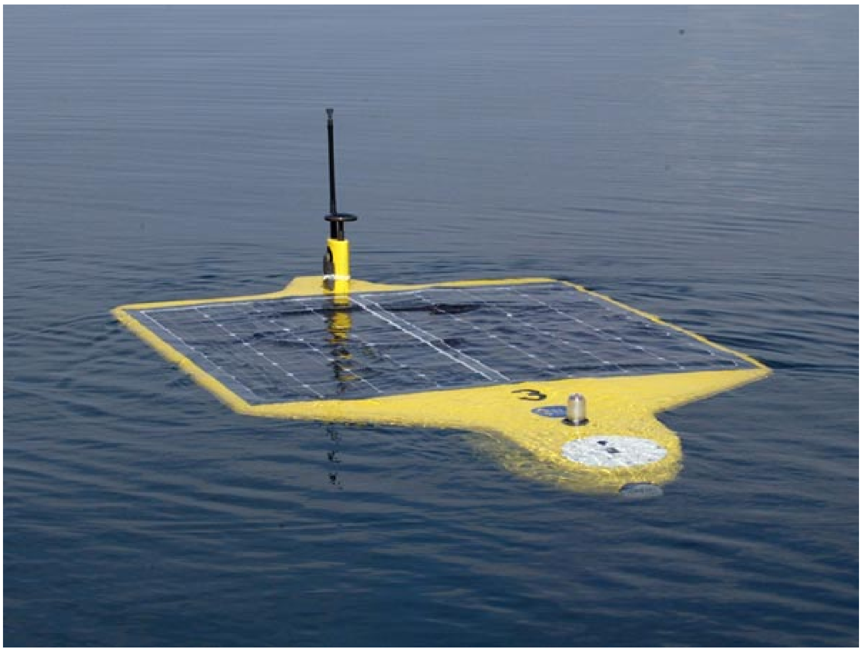
Thermoelectric harvesting of heat also has a place, the trend being to uses of two, three or four types of harvesting in any one vehicle. The high power versions can increase on-road vehicle range by up to 10%, but more will be possible. After all, some boats and golf cars use nothing but solar power today. On the other hand, low power miniature harvesting will increase range in a more subtle fashion – by permitting myriads of small sensors and actuators and even the new low-power lights to work wirelessly, monitoring more things to conserve energy and eliminating the need for heavy copper wiring that reduces range. For example, Fiat is looking at wireless rear lighting clusters on cars.

Fig. 1.10 Self sufficient corner accessory cluster



Source Fiat

Fig. 1.11 Multiple energy harvesting. The glider type of AUV harvests wave power and sun when necessary. It never needs a charging station.



Source Falmouth Scientific

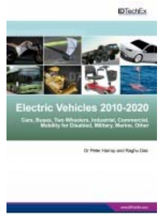
1.20. Ultracapacitors

Ultracapacitors are otherwise known as supercapacitors. They have 1000 times as much capacitance per unit of volume or weight because they have an “electrochemical double layer” that is 1000^{th} of the thickness of the dielectric in conventional electrolytic capacitors. They are used across batteries to help them accept fast charging (as with regenerative braking) and discharge fast when needed as when starting or climbing a hill. However, their life is much longer than batteries at over 20 years. Their self discharge and energy storage – both poor – are being improved to the point where there is interest in making them do more of the work. Indeed, Sinautec and others have tested buses with no batteries, the ultracapacitors being charged every five kilometers or so using inductors set in the road. Elon Musk of Tesla Motors believes that the future of EV power storage lies in ultracapacitor improvements not batteries and several developers such as Nanotecture are combining one ultracapacitor electrode with one battery electrode in one device. This is called an asymmetric electrochemical double layer capacitor or supercabattery and it may combine the benefits of both batteries and ultracapacitors. Ultracapacitors may become one of the key enabling technologies of electric vehicles by land, water and air.

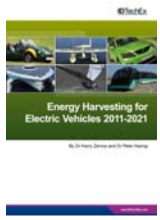
2. Electric Vehicle reports from IDTechEx

Electric Vehicles

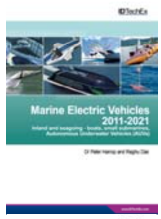
Electric Vehicles 2011-2021
This report, brand new for 2010, is based on ten years of researching the subject, intensive desk research, visits and interviews. There are chapters on Heavy Industrial, Light Industrial and Commercial, Mobility for the Disabled, Two Wheelers, Golf Cars, Cars, Military, Marine and Other vehicles. That even extends to electric mobile robots, surveillance jellyfish and other Autonomous Underwater Vehicles AUVs, bats and electric aircraft. Detailed forecasts for these vehicle categories by numbers and value and the key components are provided for 2010-2020. The trends, technology and planned vehicles are clarified in 185 figures and 58 tables including the historical context. Winning and losing strategies are evaluated. Timelines are given of events to come.



Energy Harvesting for Electric Vehicles 2011-2021
This report gives a wealth of examples of energy harvesting in action on electric vehicles by land, water and air. It summarises trends in diagrams, tables and text to make it easy to compare essential information. Forecasts for adoption in 2011 and 2021 are backed by ten year forecasts for electric vehicle sales by type, 2011-2021 by category - number, unit value and market value. A critical explanation of all the technologies is given with the good and bad aspects and assessment of likely future progress. The work of a large number of suppliers and adopters is assessed..

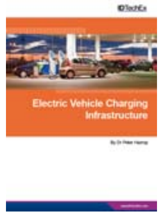


Marine Electric Vehicles 2011-2021
Those making electric vehicles or their components seek to expand their business. To do this, they need to look beyond the oversupplied on-road sector. Marine electric vehicles are interesting as a market that is more profitable and often more open to innovation. However, until now, there has been no report assessing this substantial market sector. No longer. In 2011, IDTechEx has just completed a report "Marine Electric Vehicles 2011-2021". It is the world's first comprehensive report on marine electric vehicles with latest ten year forecasts and important new projects such as submarines that will fly.



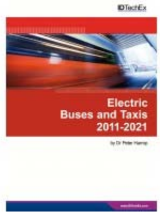
Electric Aircraft 2011-2021
This is the first and only report to analyse all forms of electric flying vehicle from robot insects to new solar airships, light aircraft and airliners and give timelines to 2021. It covers manned and unmanned aircraft, technology, funding, standards and other aspects for hybrid and pure electric versions across the world. Unusually, we compare what is happening in aviation with progress in land and water based electric vehicles that are in some ways further progressed yet use similar components and powertrains to achieve largely similar objectives.

Electric Vehicle Charging Infrastructure



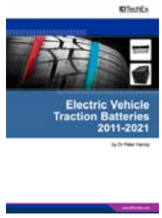
This report covers the full picture of how electric vehicles by land, water and air will be externally charged. They are hugely increasing in number – we give the forecasts by type - and most will have a plug in feature to save money and the planet. Charger market value will increase more than fivefold over the decade but car charging grows much faster and other vehicle charging peaks, for reasons we explain. In this new report with its comprehensive scope, we examine slow, fast and fastest charging stations, including contactless charging and battery swapping with a blunt appraisal of the pros and cons. Each option is illustrated by many supplier profiles.
Energy harvesting to power up the charging station is analysed - solar is not the only option here. The standards situation is holding things up to a lesser or greater extent across the world and the content, timelines and issues involved are examined. Forecasts of charging station numbers, unit value and total value are given, detailed by charging speed and territory.

Electric Buses and Taxis 2011-2021



The electrification of commercial on-road transport is now being progressed strongly by both paybacks and mandates of local and national governments across the world. Even where paybacks are underwhelming, the green agendas of the participants is driving things forward but there are impediments too, including up-front cost and the poor range and reliability of some versions and the practicality and cost of infrastructure. This report gives numbers and value for hybrid and for pure electric buses and taxis, market drivers and overall transport statistics to put this in context. The most active countries are identified and projections specifically for China are given. Large numbers of suppliers are identifies and some interesting ones are profiled. Drive trains and batteries are examined.

Electric Vehicle Traction Batteries 2011-2021



This comprehensive report has detailed assessments and forecasts for all the sectors using and likely to use traction batteries. There are chapters on heavy industrial, light industrial/commercial, mobility for the disabled, two wheel and allied, pure electric cars, hybrid cars, golf cars, military, marine and other. The profusion of pictures, diagrams and tables pulls the subject together to give an independent view of the future ten years. Unit sales, unit prices and total market value are forecast for each sector for 2011-2021. The replacement market is quantified and ten year technology trends by sector are in there too, with a view on winning and losing technologies and companies.

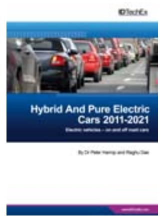
Electric Vehicles in East Asia 2011-2021

56% of the value of sales of electric vehicles is and will remain in East Asia and cars only account for about half of the value of the electric vehicle business worldwide. It is therefore important to look at the big picture and, in particular, the latest ten year forecasts for EV activity in East Asia. Uniquely this report provides that information. Entirely researched in 2010 and regularly updated, the report draws many valuable conclusions

Car Traction Batteries - the New Gold Rush 2011-2021

This report is intended for industrialists, investors, market researchers, legislators and others interested in the large new market now being created for batteries that propel hybrid and pure electric cars along the road. It will also inform those studying associated technology and industrial and government initiatives and legislation. The report is suitable for the non technical reader, with introductory appendices and glossary for those new to the subject. However, there are many comparison graphs, tables and sections concerning technical aspects, so those with appropriate technical training will find much to interest them as well.

Hybrid And Pure Electric Cars 2011-2021



Electric vehicles just became exciting. For 111 years, electric cars that rely only on a battery - "pure EVs" - have had a range of only 30-50 miles and the humble golf car has been the only type selling in hundreds of thousands every year. However, huge changes have been announced in recent years. Electric vehicles will penetrate the market rapidly to constitute 35% of the cars made in 2025 - 25% hybrids, 10% pure EV. Any motor manufacturer without a compelling line up of electric vehicles is signing its death warrant.