

## Electric Cars - Where, Why, What Next?

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## 1. Introduction

This white paper provides an introduction to hybrid and pure electric cars EVs and a pointer to the best sources of further information. It shares some of the information in the 17 up-to-date IDTechEx reports on EVs and their components and infrastructure.

### 1.1. What is an EV?

The term electric vehicle EV is limited to free running vehicles by land, sea and air, so it does not include trams, trains and trolley buses. However, some of these can act independently for some of the time as when rails or superstructure are too ugly to be allowed in historic city centers. To that extent they have an electric vehicle mode. The term does not include vehicles lacking a large traction battery or similar power source on board. Yet what remains is already a fast growing \$53 billion business at ex-factory prices. The car part of that is rising strongly to become 48% of electric vehicle sales by value in 2022. However, at nearly 10 million vehicles sold in that year, cars will be under 8% of all electric vehicles sold in 2022, mainly because of all those electric bikes in China dominating the numbers.

Electric vehicles can be pure electric with only an electric power source – a battery and/ or a supercapacitor bank - on board or hybrid meaning with another major power source on board as well. That would usually be a fuel cell or an internal combustion engine of some kind. The latter may drive the wheels when extra power is needed ie a parallel hybrid – or simply charge the battery – a series hybrid.

The world's best-selling pure electric car the Ingersoll Rand Club Car sells at around 100,000 units a year. It is mainly for golf but is street legal in some jurisdictions.

Fig. 1.1 *Ingersoll Rand Club Car*



Source Ingersoll Rand

The world's best-selling hybrid car the Toyota Prius sells in hundreds of thousands a year, soon one million.

Fig. 1.2 *Toyota Prius*



Source Toyota

## 1.2. Why have them?

For superlative performance, an electric vehicle is often the answer. For example, 0 to 96 kph/ 60 mph in one second is achieved by some pure electric motorcycles and under four seconds for some pure electric sports cars so most manufacturers of designer sports cars are racing to make hybrid and pure electric versions because these make their existing products look jaded and old-fashioned.

## 2. Decade of the hybrid but pure electric cars coming up fast

### 2.1. Decade of the hybrid

We are in the decade of the hybrid because this is an incremental not a disruptive technology. You can drive a hybrid car in just the same way as a conventional car gaining up to 90% reduction in pollution and 50% reduction in fuel consumption. An increasing number can be plugged in and go a useful distance - more than 16 km/ 10 miles - in all-electric mode saving money and permitting use in restricted areas. However, you do not have to learn how to use the plug-in option or find a charging point. Although the oil price has dropped in 2011/2, the medium term trend is upwards and this, together with cars such as the Chevrolet Volt with 80km/ 50 miles all-electric range and double that in prospect, means that hybrid cars are a strong proposition despite the higher up-front price for all but one pioneering Ford model. There is another trend. Suppliers will increasingly swallow the extra cost of hybrid models in order to gain competitive advantage, just as Japanese car manufacturers gained dominance partly by offering extras free in the 1970s and superior reliability. Others will throw in the plug-in option free of charge so the race is on.

Toyota is leader so far, with its Prius reaching one million yearly output within a few years. However, its Plug –in version does not have the best range, the car is relatively expensive and it uses a rather conventional engine rather than the much smaller, lower cost, fuel-agnostic or non-fossil fuel “range extenders” so competition has many ways to beat Toyota if it pays attention.

### 2.2. Pure electric cars – niches and later mainstream

By contrast to hybrids, pure electric cars are a disruptive technology with no emissions, almost no noise, the least maintenance, potentially the longest life (when battery life is improved) and potentially very green energy. But, so far, they call for major changes in driver behaviour and expenditure. They rely heavily on government support that can go at the stroke of the pen, just in the way governments suddenly destroyed the Spanish and Japanese solar energy industry.

Where needed, pure electric cars already have the fastest acceleration. For example, the Tesla Roadster gets to 96 kph/ 60 mph in 3.5 seconds – faster than some famous brands of conventional designer sports car. That vehicle was profitable in the year General Motors and Chrysler entered Chapter 11 – a nice one for the historians. But there is bad news. Because pure electric cars are a disruptive technology there is a lot of customer education and improvement to be done before they are mainstream, overtaking hybrids. Almost no one will pay the large price premium for a pure electric family car just to save the planet. The cost of the huge lithium-ion batteries is so high – in the \$10,000 region – that when they wear out in maybe 6-10 years, the car itself may be scrapped, which is not environmental. Renting the battery is only a partial solution to this.

The good news is that the smallest simplest electric cars are already cheaper than the conventional alternative, the leading golf car from Club Car Ingersoll Rand outselling the most promoted pure electric family car the Nissan Leaf by three to one in 2011. Fiat is majoring on pure electric microcars mainly because it believes they can be cheaper and Pihsiang, leader in the 1.4 million a year market for mobility for the disabled (all pure electric) is starting to make pure electric microcars, announcing that they can be a cottage industry because they are so simple.

Other good news is that one million charging stations are being installed in the world over the next ten years, half of them in China. Outside the home and the depot (for fleets), there is no payback for these as they will be seldom used by pure electric cars but the money is coming from power utilities and governments burnishing their green credentials and such charging stations are essential in reducing range anxiety, so pure electric on-road cars start selling in large numbers. No wonder manufacturers such as Nissan and Mitsubishi, that are prioritising pure electric over hybrid cars, are taking such an interest in infrastructure.

And yet, And yet. The vast majority of car purchasers have range anxiety that stops them buying pure electric cars. Only when they have one do they realise that they very rarely want to travel more than the range, which is typically 160km/ 100 miles today with a little nursing. In trials worldwide it is repeatedly shown that city users become so comfortable that they only charge their pure electric car at home and they only do that on average every 2.5 days, the charging taking place overnight. "Aha!" say the minority of car manufacturers and enthusiasts majoring on pure electric vs hybrid, "Educate the public and sales will rocket."

Unfortunately it is not that simple. Few people can afford a second car or have the space to park it. In an emergency, people do not want to go home and get the long range car. Although electric fuel is one fifth of the cost of fossil fuel, that is a quirk of taxation, not real. What happens to taxation when pure electric vehicles become popular and what about those hideously expensive large batteries? If that were not enough, the public is beginning to hear about the explosions caused by irresponsibly designed and made lithium-ion battery systems in pure electric cars. How can they tell if a car manufacturer is supplying a safe battery?

There are over 100 Chinese manufacturers of pure electric cars if only because it is the easy way to meet government mandates requiring you to have a green car in your line up. Because a pure electric car battery is equivalent to over 10,000 laptop batteries analysts have done a sum. At the percentage of exploding laptops, one in 70,000 pure electric cars would explode without better battery assembly and a proper battery management system. This is much less of an issue with hybrid cars because their batteries are one tenth of the size with one tenth of the chance of a fire. Car manufacturers such as Toyota and Nissan have an advantage in making their own batteries and often the BMS as well. Toyota files more lithium-ion battery patents than most of the independent battery suppliers. See the IDTechEx report, "Advanced Energy Storage Technologies – Patent Trends and Company Positioning".

One of several incidents in China is shown below. The driver and passengers were fortunate enough to escape in time. For more see, the IDTechEx report, "Electric Buses and Taxis 2011-2021".

Fig. 2.1 *Chinese pure electric taxi with one of the “safer” lithium iron phosphate traction batteries made in China*



Source ZJOL

How does the man in the street tell the superb machine from the firework? The 150,000 a year sales of perfectly safe golf cars is not a reassurance because these have lead acid batteries giving performance that would cause backups on most roads. An electric golf car is cheaper to make than an internal combustion one and easier and cheaper to refuel with minimal infrastructure, yet it lasts longer, needs less maintenance and has simpler parts.

Fig. 2.2 *The superb premium-priced Tesla pure electric Roadster has a perfect safety record*



Source Tesla

A huge number of improvements are planned for both hybrid and pure electric cars. For example, structural batteries and smart skin coming along where power electrics and electronics become part of the structure of the vehicle. In all cases, reduced maintenance is welcomed in military applications because that equates to greater security and operational flexibility not just cost control.

Fig. 2.3 *Polaris Industries Neighborhood Electric Vehicles NEVs and Ranger leisure truck with lead acid batteries*



Source Polaris Industries

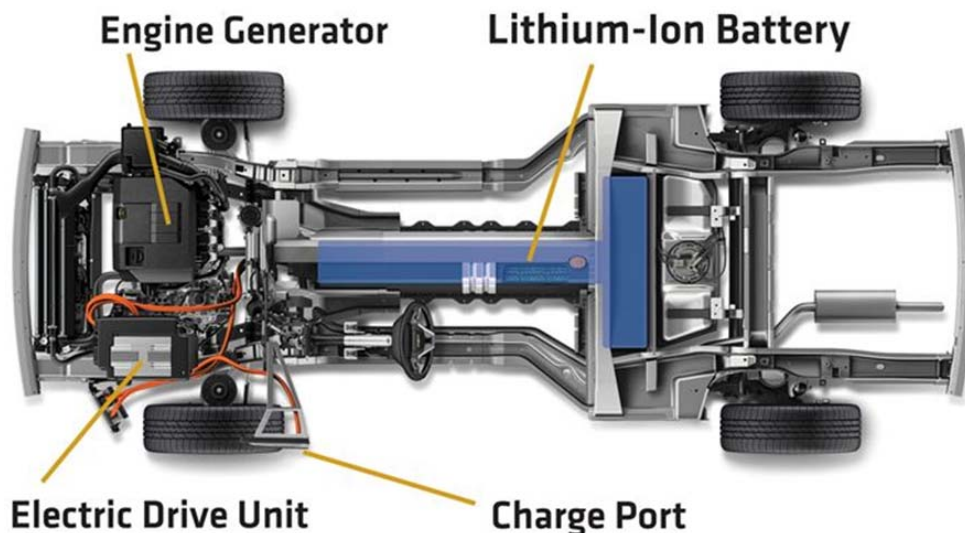
### 2.3. Pure electric car range

The range of affordable pure electric cars is problematic at only 160 km (100 miles) recently and 50% more than that for the best affordable ones today. In the Tesla class it is already hundreds of kilometres.

### 2.4. Hybrid car range

The successful Chevrolet Volt hybrid car powertrain provides plug-in charging giving 80 km/ 50 miles pure electric range. It is a series hybrid and sales are stronger than those of equivalent pure electric cars because there is no range anxiety. We are in the age of the hybrid electric land vehicle.

Fig. 2.4 *The successful Chevrolet Volt hybrid car powertrain*



Source Chevrolet

IDTechEx has detailed forecasts for electric cars and their key components and we expect pure electric cars to rise from 12% to 26% of electric cars sold in the world in the next decade, the golf car part being static and on-road pure electric cars having accelerating growth in five years as charging stations reach critical mass in certain parts of the world and range and price improves further. Paradise delayed.

### 3. Technology in ferment

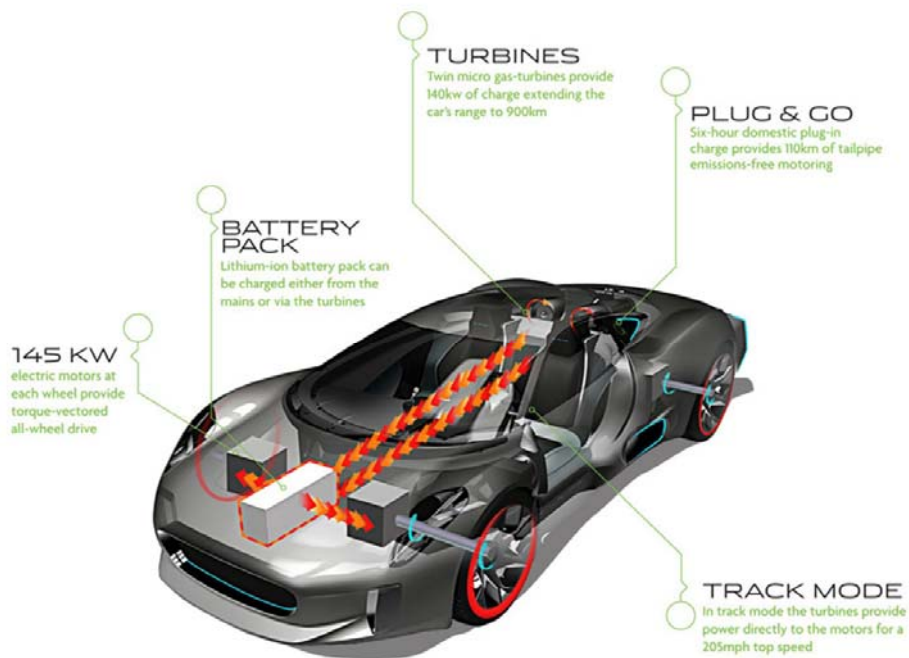
The technology of land EVs is changing extremely rapidly, offering a stream of improved user benefits and affordability. Many electric buses and bikes use supercapacitors instead of batteries or to enhance batteries and hybrids are starting to employ designed-to-purpose range extenders to charge the batteries.

Such range extenders vary from fuel cells in imminent Mercedes, Toyota, Tata Motors and other vehicles but other range extenders include very small jet engines and other options. Printed electronics and electrics is removing up to 40% of cost, weight and wasted space. Read the IDTechEx report, "Printed, Organic & Flexible Electronics: Forecasts, Players, Opportunities 2012-2022". Three generations of lithium-ion battery are coming in to replace lead acid and make new things possible. Exceptionally lightweight, more powerful electric motors are on the schedule. Energy harvesting is beginning to grab back up to 15% of wasted energy and this is additive, with energy harvesting shock absorbers, regenerative braking, thermovoltaics and photovoltaics together adding up to huge gains in range even before fast charging by the roadside becomes ubiquitous.

#### 3.1. Many new forms of range extender

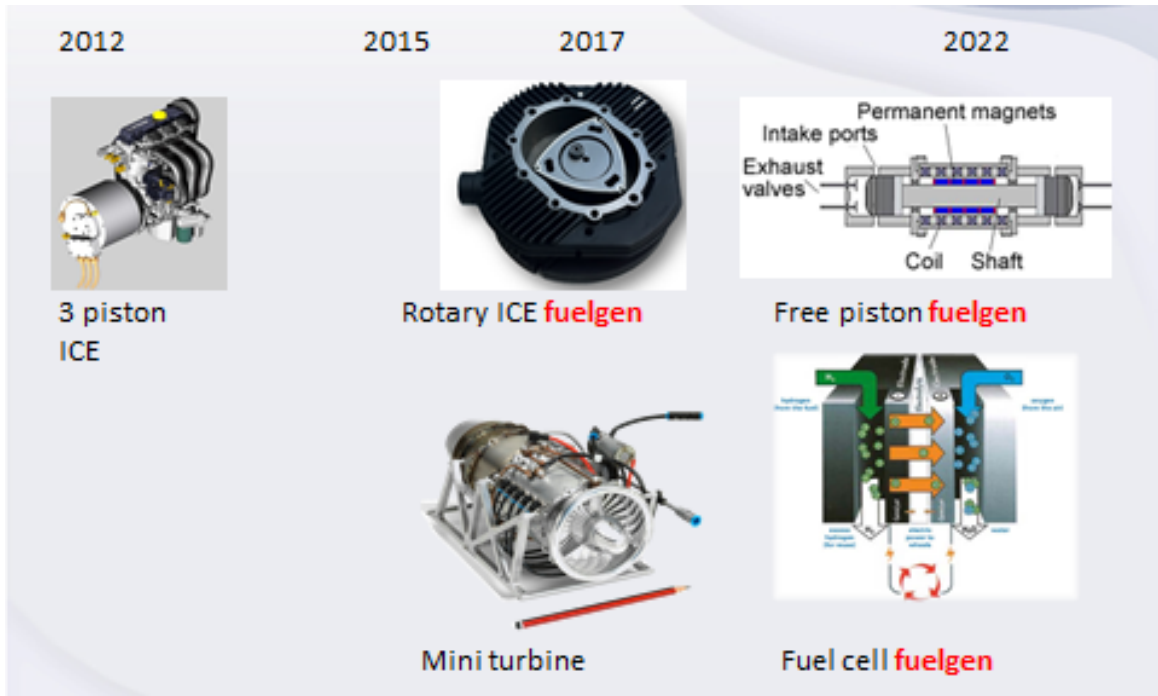
Range extenders that simply charge the battery are appearing in many guises from fuel cells to mini turbines (jet engines). Fuel generators are forms of range extender that inherently produce electricity without a rotating shaft driving a separate generator. See the IDTechEx report, "Range Extenders for Electric vehicles 2012-2022". The more savvy pure electric vehicle manufacturers will off a tiny, drop in range extender with tiny fuel tank. It will charge the battery for that occasional long journey. Pop it in when you are worried.

Fig. 3.1 *Planned Jaguar long range supercar with two micro turbine range extenders generating 140kW total*



Source Jaguar

Fig. 3.2 *Examples of range extenders using a generator and ones with inherent electricity generation marked fuelgen*

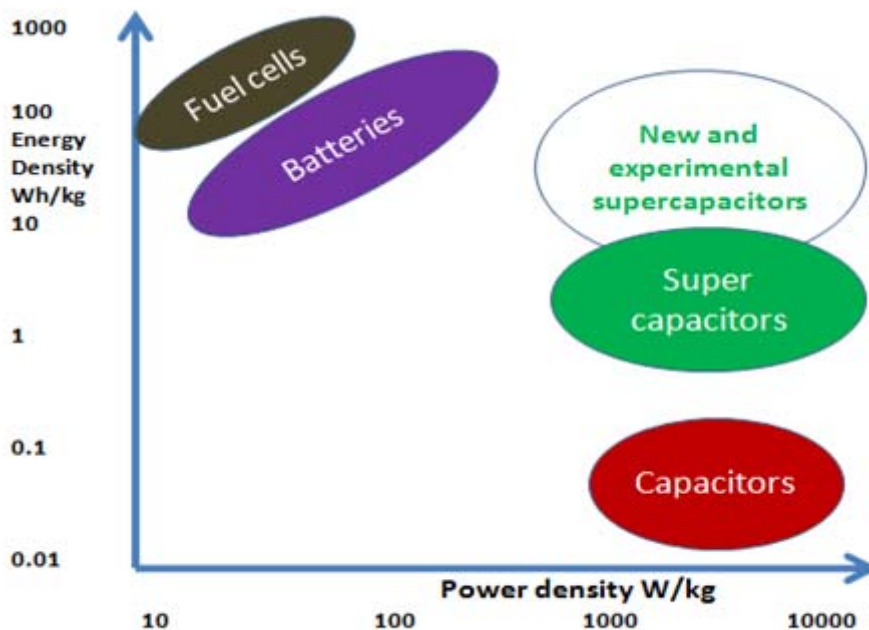


Source IDTechEx

### 3.2. Supercapacitors

Look out for deployment of supercapacitors that take over much of the function of traction batteries beyond today's assistance with fast charge and discharge. This will be because supercapacitors and later supercabatteries (Asymmetric Electrochemical Double Layer AEDL capacitors) will offer much longer life and greater reliability and possibly other benefits in electric car design.

Fig. 3.3 *Performance of new and improved supercapacitors and their variants*



Source Industry

### 3.3. Energy harvesting

The main forms of energy harvesting being used or considered are harvesting of motion (vertical, horizontal when braking, vibration), heat and light. Primarily, capturing motion consists of the favoured brushless traction motors working in reverse or flywheels capturing and electrically returning up to 15% of braking energy and, soon to be introduced, dampers (shock absorbers) capturing vertical energy – up to 1kW per damper on a large vehicle. However, complete energy harvesting active suspension is being researched and there are dreams of body flexing also generating energy.

Next most popular after motion capture is capturing light using photovoltaics (solar cells). Here the progression is towards transparent or translucent film over the whole vehicle, even underneath, as it is developed to capture infrared not just light. Indeed, in the laboratory, some photovoltaics captures ultra violet as well. Meanwhile, structures that unfold or expand when parked gain more area and therefore electricity and some vehicle manufacturers are looking at self-sufficient rear lights etc thanks to local photovoltaics, reducing the large cost and vulnerability of wiring.

Cars with photovoltaic panels – but much more than 100W peak is a rarity until large area conformal versions are used that do a better job harvesting infrared not just light. We have already seen one version that is on a car window, being semi-transparent, but it is not ready for market.

Fig. 3.4 *Cars with photovoltaic harvesting. Top pure electric, bottom the hybrid Fisker Karma car.*



Source Bollore, Geely, IDTechEx

Examples of further photovoltaic development include nantenna+diode printed photovoltaics promising flexibility with double the best efficiency achieved with pn junction and photoelectrochemical “DSSC” photovoltaics today. Meanwhile, we expect Copper Indium Gallium Diselenide CIGS photovoltaics to be a front runner for long life flexible, conformal photovoltaics. The much needed photovoltaics that harvests UV, visible and IR and/or that is transparent is probably several years away, however.

### 3.4. Printed electronics and electrics

Printing car electronics and electrics will save up to 40% of weight, space and cost of control clusters and other human interfaces and wiring in electric vehicles, eventually encompassing much of the battery pack electrics and Vehicle Management System VMS and motor controller electronic circuitry. Several forms of energy harvesting will feed the battery, with multi-mode harvesting becoming commonplace, first in marine military vehicles the in air and land military vehicles. Printing and thin film technology will dominate both the harvesting elements and the electrics and electronics attached. For more on this see the IDTechEx report, “Printed Organic and Flexible Electronics Forecasts, Players & Opportunities 2012-2022” and “Energy harvesting for Electric vehicles 2012-2022” .

### 3.5. Structural components and smart skin

Dumb vehicle bodies and chassis will progress to smart forms with advanced structural composites married to smart skin performing many functions including energy harvesting, storage and sensing condition in real time. Something of a halfway house is the incorporation of components into the body of the vehicle as with T-Ink printed tape replacing the much bulkier and heavier copper wire. Then there are the structural batteries in the Drayson racing cars being built in the UK in 2012 that have lessons even for the military. Battery geometry is changing with this. Flat, wide batteries employed in aircraft wings, such as those of surveillance UAVs at over 10,000 meters up, turn out to have faster charge-discharge and simpler cooling when well-made and this is now being applied to land vehicles. In-wheel motors are another devolution of function to the outer parts of the vehicle. See, “Electric Motors for Electric Vehicles 2012-2022”.

Fig. 3.5 *Drayson electric racing car in the UK pioneers many new technologies including continuous charging and structural batteries.*



Source Drayson Racing Technologies

### 3.6. Innovative charging

Drayson Racing Technologies and HaloIPT have teamed up to develop a new on-the-go charging system for electric cars. HaloIPT had previously announced that they were working on the technology and have now brought Drayson Racing Technologies into the project. The technology will be tested on race cars with the technology built into the track to wirelessly provide power so drivers don't have to stop to charge the vehicle. This copes with misalignment over the transmitter pads, which is a common problem with on-the-go charging. Primarily developed by HaloIPT (IPT standing for inductive power transfer), the technology got its start from UniServices a University of Auckland commercial subsidiary in New Zealand. In EVs best practice often comes from all over the world and in the more unusual types of vehicle. See "Electric Vehicle Charging Infrastructure 2011-2021".

### 3.7. Military land vehicles and in-wheel motors

The US Army sees hybrid-electric powered trucks and the hybrid-electric Future Combat Systems FCS as key in its objective of 75% lower fuel consumption by 2020. This is as much to do with operational flexibility - permitting previously impossible speed of deployments – as cost saving and reduction of pollution. Significant savings have already been demonstrated.

Operating as a hybrid, with a 24-gallon tank, a truck travels 375 miles without refuelling compared to a conventionally powered vehicle, travelling less than 60% of that range. Primarily, savings do not relate from the cost of fuel itself, but to reduced army logistical transportation requirements - as fuel takes up about 70% of the logistical tonnage haul in a heavy armored division. Several military EVs have in wheel motors – up to six of them. This permits better steering and traction but it involves extra cost, often involving a completely new vehicle platform in a car, so in-wheel motors are little used in non-military cars applications as yet since the up-front cost of both hybrid and pure land EVs is already much more than the traditional equivalent. The exception is in-wheel motors in two wheel vehicles, particularly the popular e-bikes ie with a throttle. For more see, "Electric Vehicles for Military, Security, Police 2011-2021", "Light Electric vehicles 2011-2021" and "Electric Motors for Electric Vehicles 2012-2022".

Fig. 3.6 *Millenworks light hybrid vehicle ie not plug-in.*



Source Millenworks

### 3.8. Third generation traction batteries















The increasingly favoured lithium-ion traction batteries come in three generations. First generation is high energy density but sub optimal temperature stability and safety unless considerable external means are employed such as cell sensing into a sophisticated battery management system and often water cooling. Lithium cobalt oxide cathodes are employed, just like those in a laptop or phone battery.

Second generation is inherently safer, when properly made, due to cathodes such as lithium iron phosphate that tolerate higher temperatures and/ or polymer + gel electrolyte instead of the flammable organic liquid electrolytes traditionally used.

Third generation batteries are intended to offer the best of both worlds – high energy density and thermal stability - though no lithium-ion cell is inherently fully safe. An example of a third generation battery is the Oxis Energy lithium-sulfur version to be shown in a motor cycle and a microcar in 2012. Earlier use of lithium sulphur was seen in military land vehicles and Unmanned Air Vehicles UAVs, in both cases using Sion Energy versions. All this is driven by the demand for longer electric range for both plug in hybrid and pure electric vehicles and the next decade will see all three generations of lithium-ion battery being successfully deployed in cars. For more see, “Car Traction Batteries – The New Gold Rush 2011-2021”.

# 4. IDTechEx Electric Vehicles Reports

Table 4.1 *IDTechEx Electric Vehicles Reports*

<b>Electric Vehicles by Application</b> <i>All these reports forecast numbers, ex-factory unit value and total market value for ten years</i>							
<b>MASTER REPORT</b>  Electric Vehicles 2012-2022							
 Industrial and Commercial Electric Vehicles 2012-2022	 Electric Buses and Taxis 2011-2021	 Electric Vehicles for Military, Police & Security 2011-2021 <i>including land, sea and air</i>	 Hybrid & Pure Electric Cars 2011-2021	 Light Electric Vehicles 2011-2021 <i>including e-bikes and mobility vehicles for the disabled</i>	 Electric Aircraft 2011-2021 <i>including manned and unmanned aircraft and airships</i>	 Marine Electric Vehicles 2011-2021 <i>including surface craft, AUVs, private &amp; commercial submarines, sub-aqua scooters</i>	
<b>Electric Vehicle Technologies</b> <i>All these reports forecast numbers, ex-factory unit value and total market value for ten years except for the Advanced Energy one</i>							
 Electric Motors for Electric Vehicles 2012-2022	 Range Extenders for Electric Vehicles 2011-2021	 Electric Vehicle Traction Batteries 2011-2021	 Car Traction Batteries - The New Gold Rush 2011-2021	 Advanced Energy Storage Technologies - Patent Trends and Company Positioning	 Energy Harvesting for Electric Vehicles 2011-2021	 Electric Vehicle Charging Infrastructure 2011-2021	 Wireless Power Transmission for Consumer Electronics and Electric Vehicles 2012-2022
<b>Geographical</b>							
 Electric Vehicles in East Asia 2011-2021 <i>with forecasts for China, India, Japan, South Korea, Other East Asia</i>							
<b>EV Encyclopaedia free with each publication</b>							

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