



Whitepaper

Transportation



# Temperature sensors are enabling the continued transition to hybrid and fully electric vehicles

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# Executive Summary

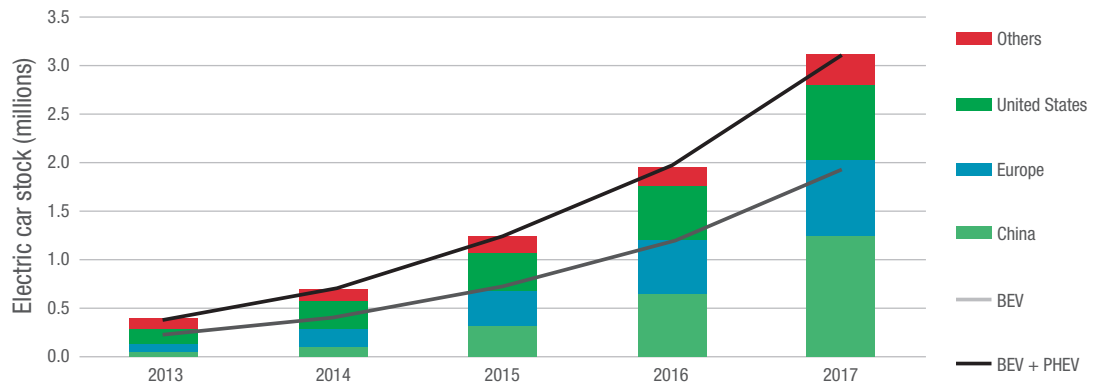
According to the International Energy Agency (IEA) there are now more than 3 million electric vehicles on the roads worldwide, 1 million of which were sold in 2017. Over half of that 1 million were purchased in China, but other nations are breaking records, too. In some counties the revolution is still nascent; in 2017 Bulgaria saw over a 700% increase in the number of electric vehicles on its roads, but in real terms that still only equates to just over 100. Norway continues to dominate in absolute figures, now with well over 60,000 electric vehicles in operation. These figures point to the increased adoption of Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) in general, while the continued downwards pressure on battery price, coupled with an upward trend in capacity and energy density, is seeing the increased adoption of commercial electric vehicles such as busses for mass transport, delivery vehicles for logistics and industrial applications such as fork-lift trucks.

This Whitepaper provides an overview of the EV/HEV market and takes a deeper dive into the sensor technologies being developed and deployed in EV/HEV vehicles. It will highlight the need for temperature measurement in EVs and focus on the need for Battery Thermal Management Systems (BTMS) and the temperature sensors being developed to support them.

# Article

With around 3 million electric cars now on our roads it may seem like it's just a drop in the ocean, but considering that 1 million of those were sold in 2017 – a growth of over 50% from 2016 – it would suggest that the rate of adoption is increasing rapidly. Figure 1 represents the evolution of the global electric car market between 2013 and 2017.

*Figure 1: Global electric car stock, 2013-2017*



*Notes: The electric car stock shown is primarily estimated on the basis of cumulative sales since 2015. Where available, stock numbers from official national statistics have been used (provided that the data can be shown to be consistent with sales evolutions). Sources: IEA analysis based on country submissions, complemented by ACEA (2018); EAF0 (2018a).*

The global market for electric commercial vehicles is expected to grow at around 40% per year between now and 2025, which covers all types of propulsion including battery, hybrid, plug-in hybrid and fuel cell. The adoption of electric propulsion for busses and vans is, in particular, driving this growth, due in large part to various governments' legislation against pollution. The region expected to account for the majority of electric commercial vehicle sales is Asia Pacific, where urban pollution is of particular concern. Of all propulsion types, battery electric vehicles are expected to dominate.

There is also evidence to show that there is growing demand in the tourism industry for electric bicycles, enabling city visitors to move around dense urban areas at their own pace and without contributing to the congestion on mass transport infrastructures. However, it is the potential for electric vehicles to supplant more traditional fossil-fuel powered vehicles that this paper will focus on.

While they are intended to look and behave in a similar way to internal combustion engine (ICE) vehicles, EVs and HEVs represent a massive change in terms of the infrastructure needed to support them and the manufacturing processes used to make them. While disruptors like Tesla and Google are leading the charge (so to speak), they are considered Technology Companies; it will be the incumbent automotive manufacturers who will really define the EV/HEV market. This will require support from within its existing supply chain, as well as significant commitment from its target markets.

Governmental policies around the world are key to the continued adoption of EV and HEV technology, part of that involves putting in place the charging infrastructure on both public and private property to support the shift from ICE to EV. We can expect public funding to initiate this process, but it will eventually fall to the private sector to maintain the momentum, in order for the EV industry to become self-sustaining. The availability of charging stations in general, whether private or public, is not likely to match the number of EVs on the roads; as the market grows not all owners will have the opportunity to install a charging station at home, and not all EV owners will have access to a charging station at their place of work. This disparity will further drive the development of batteries that offer higher energy density, to provide longer time between charges, and solutions that can support faster charging for shorter time spent recharging.

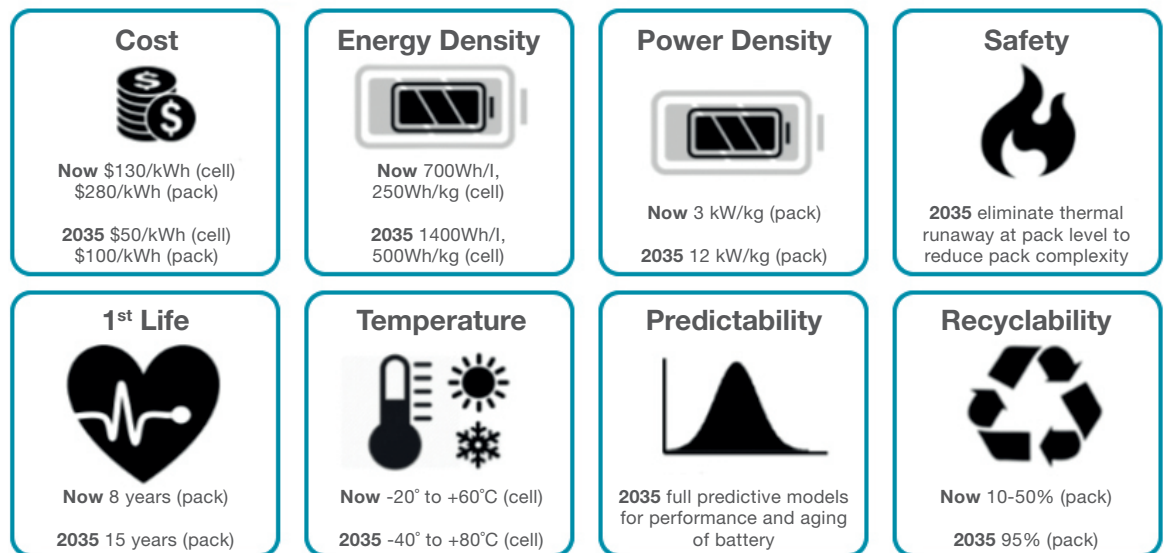
The IEA is also running the EV30@30 Campaign, which aims to see EVs representing at least 30% of all new car sales by 2030. This echoes the fact that countries and governments around the world are making bold statements about their plans to phase out ICE and usher in EV/HEV with relatively short timescales, suggesting the IEA's goal is achievable.

The IEA also coordinates the Electric Vehicles Initiative (EVI), which was launched in 2010 by the Clean Energy Ministerial, comprising energy ministers from the world's leading economies including the UK, the USA, Canada, Chile, China, Finland, France, Germany, Norway, Portugal and Sweden. The EVI's mandate is to help the worldwide adoption of electric vehicles.

From an infrastructure point of view, the public sector (and ultimately the private sector) is investing in installing charging points in numbers and locations commensurate with the uptake of electric vehicles. The high voltage and currents involved is creating new demand for solutions suited to this application area, such as high-voltage DC contactors that can safely switch the high power required to deliver rapid charging. This would include the Kilovac high voltage contactor and relay range from TE Connectivity, for example.

A major part of the change necessary will involve battery technology and its management, both within the car and throughout the infrastructure of charging points that will need to be put in place. The opportunity here is expected to be significant, at least according to research carried out by the University of Warwick, with the support of the Innovate UK Knowledge Transfer Network and the UK Chemistry Growth Partnership. The research carried out by Warwick University indicates eight areas where improvement is required, including power density, energy density and safety (Figure 2).

**Figure 2: Battery technology targets**



Source: WMG 2018

The Faraday Battery Challenge is a UK government programme intended to support R&D into automotive battery technology, with the aim of making the UK a critical part of the global supply chain for rechargeable and recyclable battery technology suitable for the automotive, aerospace and rail sectors. With a budget of £246 million, it intends to close the productivity gap by addressing the eight areas of concern highlighted above, stating that the European market for batteries will be worth £50 billion by 2025.

# The Chemistry of Physics

The chemical reaction that takes place during the movement of charge carriers in a secondary (rechargeable) battery generates heat, this is an inescapable part of the physics involved. Managing that heat is crucially important and it is a task that falls to the Battery Thermal Management Systems, or BTMS. At a high level, this is a closed system that uses temperature sensors to detect the thermal condition of the battery, which is then interpreted by a processing element to determine if the battery is operating within its allowable temperature window and in a way that is commensurate with the operating conditions. The loop is closed by the Electronic Control Units (ECUs) that will either allow or inhibit that operating condition to continue.

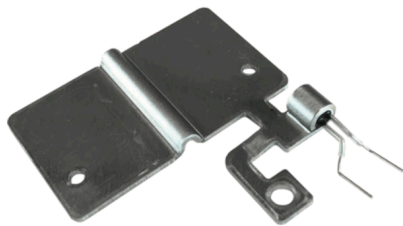
Batteries based on today's technology vary in capacity and cost, depending on the size and type of vehicle, as well as the profile of the target market. Typically batteries range from 20kWh to 100kWh and, in general, the size of the battery has a direct impact on its cost, as well as the cost and complexity of the BTMS.

As well as the proportional cost and overall durability of the battery, charge time is a crucial aspect of owning an EV. Most current or potential owners will probably agree that battery charge time influences their decision to move away from an ICE powertrain. It is largely agreed that current battery technology can support fast charging (approximately 80% charge in 60 minutes or less) without degrading the battery, however in order to make owning an EV more like owning an ICE vehicle there is a great deal of motivation throughout the industry to bring charge times down, to something more like refuelling at a petrol station.

Supporting ultra-fast charging by modifying the battery's structure would probably mean the energy density of batteries based on existing technology would decrease. In addition, the cost would go up, while lifetime would go down; all unfavourable consequences that could significantly impact consumer adoption.

In addition to recharging, it is clearly crucial to the overall user experience that the battery is capable of delivering its charge reliably over its entire lifetime. Many factors impact a battery's functionality; the electrochemical composition most prevalent in EVs and HEVs today is Lithium Ion (Li-Ion), which comes in many variations, depending on the application. Thermal management is critical with the use of any Li-Ion based rechargeable battery, so the balance that needs to be achieved, using today's technology, is to deliver fast and safe charging and discharging.

## Thermal Management



**Figure 3: The Bus-Bar Integrated Temperature Sensor from Amphenol Advanced Sensors**

examples of where cells are housed in a sealed enclosure and completely immersed in a coolant. This modular approach lends itself to using temperature sensing solutions designed for larger assemblies, like the Bus-Bar Integrated Temperature Sensor from Amphenol Advanced Sensors (Figure 3), which has been designed specifically for EV/HEV/PHEV battery packs in passenger and commercial vehicles. As it has been designed to attach to the battery pack's bus-bar there is no welding required, resulting in a more compact solution. The sensor itself gives a fast response time (T63) of less than 5.5 seconds between 25°C and 85°C in water.

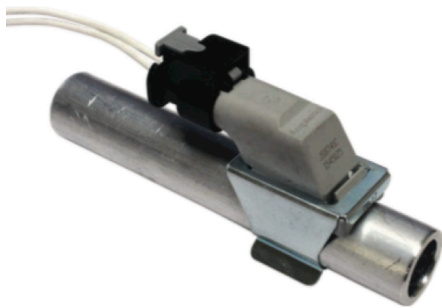
Irrespective of how the coolant is dispersed and circulated, its purpose is to conduct heat away from the battery cells, and as with an ICE vehicle this requires the coolant's temperature to be closely monitored.

The role of the BTMS is to control the battery coolant temperature and, by extension, the battery's own temperature such that it remains within the operational window; not too hot, not too cold. It must do this under all conditions; during slow or fast charge and slow/fast discharge.

For vehicles that employ a cooling system distributed using metal pipes, a sensor like the JS8741 integrated pipe clip surface temperature sensor from Amphenol provides a simple yet effective solution. The sensor attaches to a metal pipe (Figure 4) using spring-loaded clips, creating a direct thermal path to provide high sensitivity in a compact design rated to IP57.

The sensor is formed of a temperature-dependent resistive element and a load resistor, forming a potential divider (Figure 5). It is rated for an operating temperature of  $-40^{\circ}\text{C}$  to  $+120^{\circ}\text{C}$  and is certified to AEC-Q200 Rev (D) – Pending. Along with the spring-loaded clip the sensor features an integrated connector with locking mechanism.

**Figure 4: The JS8741 in a typical application**



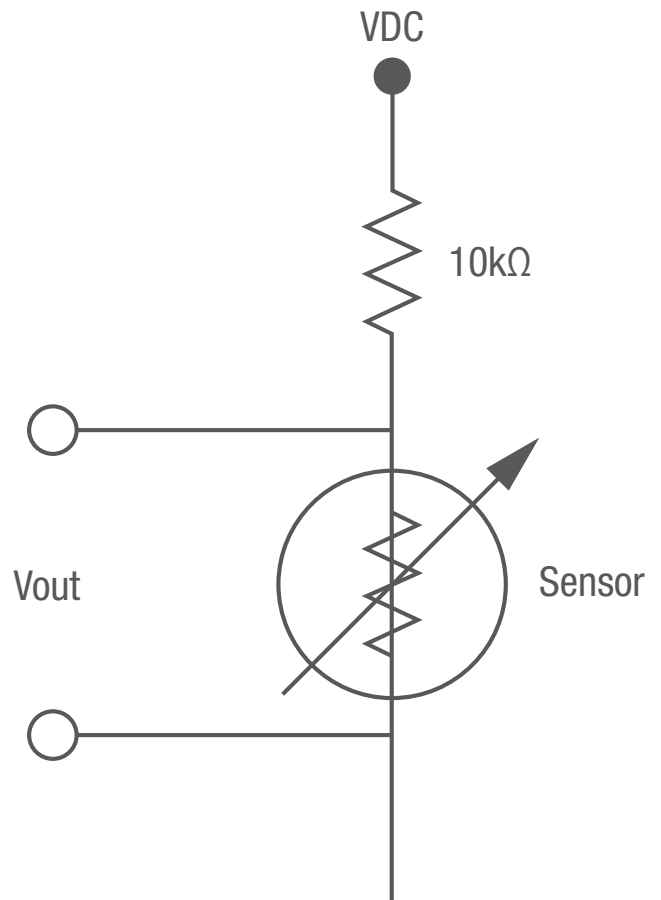
**Figure 6: The A-1984 CTS provide in-line temperature measurement of a coolant fluid.**



**Figure 7: The WTF083B001 is provided in an IP67 rated enclosure**



**Figure 5: Equivalent circuit diagram for the JS8741**



The A-1984 Coolant Temperature Sensor (CTS) from Amphenol is an example of a sensor that is designed to be positioned in-line with the coolant, forming part of the pipework. It features an SAE J-2044 compliant quick-connect interface (3/8in), which is rated to operate at a pressure of up to 5 bar.

Other examples of a CTS from Amphenol includes the WTF083B001 (Figure 7), which offers an IP67 rating in a compact design that includes an integrated connector.

Figure 8 shows another example of an in-line flow-through fluid temperature sensor from Amphenol, in this case featuring an SAE J-1231 interface and available in three standard hose sizes, ranging in weight from 8g to 26g. The temperature-dependent resistor design sees the internal resistance varying from  $332.776\text{k}\Omega$  at  $-40^{\circ}\text{C}$  to  $338.2\Omega$  at  $+120^{\circ}\text{C}$ .

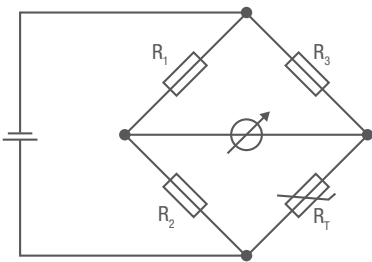
**Figure 8: Flow-through temperature sensors like this are used to control coolant temperatures in battery management systems**



# Flexible Temperature Sensing Solutions

In some cases the use of a fully enclosed sensor may need to be augmented by additional sensors distributed around the cooling system, to detect the temperature in areas as opposed to fluids, for example. In this case it may be appropriate to use a simple device like a Negative or Positive Temperature Coefficient (NTC/PTC) device. These discrete components are easily mounted on a PCB or flying lead and can be used in various configurations. For example, Figure 9 shows how a temperature-dependent device can form part of a classic Wheatstone bridge circuit; as the temperature changes the circuit becomes imbalanced, causing more current to flow through the ammeter.

**Figure 9: A classic Wheatstone bridge featuring a temperature-dependent resistive device such as a Negative- or Positive-Temperature Coefficient thermistor.**



**Figure 10: An NTC as part of a potential divider network can be easily interfaced to a microcontroller**

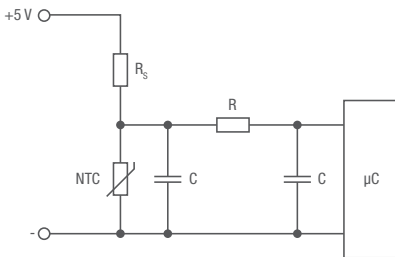


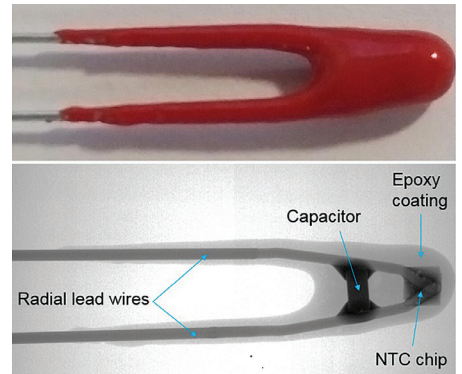
Figure 10 shows how an NTC can be easily interfaced to a microcontroller. In this case it forms part of potential divider network, with additional passive components providing hysteresis.

These types of thermistors are used extensively in the automotive industry, to measure the temperature inside LED lighting or a dashboard, for example. They are also used in ICE vehicles, EVs and HEVs to measure the battery temperature. Examples of devices used in these applications include the S861, S863, S867 and S869 Series of minisensors from TDK, which are supplied with bendable wires already attached to the device's legs, formed of PTFE-insulated leads manufactured from silver-plated nickel wire.

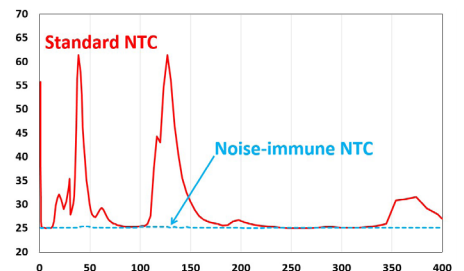
Another automotive thermistor that showcases EMC protection innovation is the Amphenol NKI. This device, see Figure 11, incorporates an NTC element together with an RF decoupling capacitor within the thermistor body. The capacitor significantly improves thermistor noise immunity and the introduction of any RF signal self-heating effects. Figure 12 shows the results of an automotive GMW3097 EMC test on both a standard NTC and the noise-immune Amphenol NKI.

The NKI suits are used in a variety of automotive applications, and particularly for battery management functions in EV/HEVs. Constructed in a ring terminal eyelet tag assembly, the Amphenol Type JRS thermistor incorporates an NKI device. See Figure 13. The JRS thermistor is ideal for surface temperature measurement on EV busbars, battery covers, and semiconductor heatsinks.

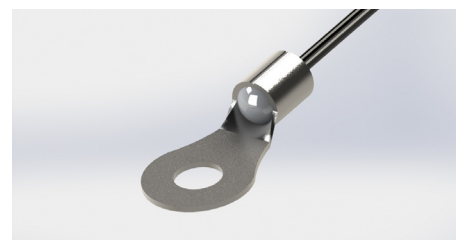
**Figure 11: The epoxy-coated Amphenol NKI NTC thermistor. The x-ray image shows the RF decoupling capacitor located close to the NTC element**



**Figure 12: Plot of thermistor temperature self-heating effects due to presence of stray RF interference**



**Figure 13: The Amphenol JRS eyelet tag thermistor with a cutaway showing the thermistor element and the decoupling capacitor**



## Conclusion

The thermal management of batteries in EVs and HEVs is critical in so many ways. It directly influences the longevity of the battery, it enables the rate of charge and, just as importantly for the driver, it controls the rate of discharge. The faster a battery can discharge safely without entering thermal runaway, the more instantaneous energy can be transferred to the drive motor; all of these features impact the user experience and as a result the propensity of consumers to adopt EV/HEV technology.

The Battery Thermal Management System is fundamental to the performance of EV/HEV technology and, in turn, the BTMS is directly dependent on the performance, stability and reliability of the sensors it employs to accurately detect the temperature of the battery and battery coolant, at all times during charge and discharge.

The solutions presented in this Whitepaper are applicable to EVs and HEVs, as well as batteries found in ICEs, but they have further applications in a range of sectors and industries. Temperature sensors are a fundamental part of system engineering and enable a wide range of modern applications.

The specific requirements found in battery management for EVs and HEVs is perfectly addressed through advanced sensors such as those presented in this paper. As the automotive industry continues to transition to a more sustainable powertrain we can expect to see significant developments in the electrochemical profile of rechargeable batteries. While Li-Ion is expected to dominate for at least another decade, the industry in general fully expects new solutions to emerge and take its place. However, the need for accurate and responsive temperature management in battery systems is unlikely to disappear.



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