Catapulse report series

January 2022

Net Zero

For transportation in the UK

csa.catapult.org.uk

CATAPULT Compound Semiconductor Applications

About CSA Catapult

Compound Semiconductor Applications (CSA) Catapult is focused on bringing compound semiconductor applications to life in three key areas: the road to Net Zero, future telecoms and intelligent sensing.

CSA Catapult is a Not for Profit organisation headquartered in South Wales. It is focused on three technology areas: Power Electronics, RF & Microwave and Photonics. As well as the three technology areas, CSA Catapult is also working in Advanced Packaging for these high-power innovations.

The next wave of emerging applications will have an enormous impact on our lives. Compound semiconductors will enable a host of new and exciting applications in the electrification of transport, clean energy, defence and security and digital communications markets.

CSA Catapult exists to help the UK compound semiconductor industry grow and collaborates across the UK and internationally.

About Compound Semiconductors

Semiconductors are at the heart of almost all modern electronic devices. Silicon semiconductors have widespread commercial applications, but this technology has its limits.

Compound semiconductors combine two or more elements to create capabilities that cannot be achieved with conventional silicon devices, delivering performance improvements in power, speed and signal quality. This makes them ideal to use in areas such as energy efficiency, electrified and autonomous vehicles, mobile applications, new smart-sensing devices for the Internet of Things and 5G applications.

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What is Net Zero?

Lately, Net Zero has become the buzzword of choice when referring to the environment. But what does it actually mean? In laymen's terms, Net Zero means achieving a balance between the quantity of greenhouse gases produced and the quantity removed from the atmosphere.

The two main ways to achieving Net Zero are reducing emissions from the current sources and eliminating emissions from the atmosphere. This Pulse report primarily looks at the first area, which can be achieved by improving the efficiency of power generation systems, employing renewable energy sources, and notably it will focus on the need to move to ultra-low and zero emission passenger vehicles.

The UK is the first major economy that has committed to reducing the net emission of greenhouse gases by 100% relative to 1990 levels by 2050, meeting the recommendations of the Committee on Climate Change.

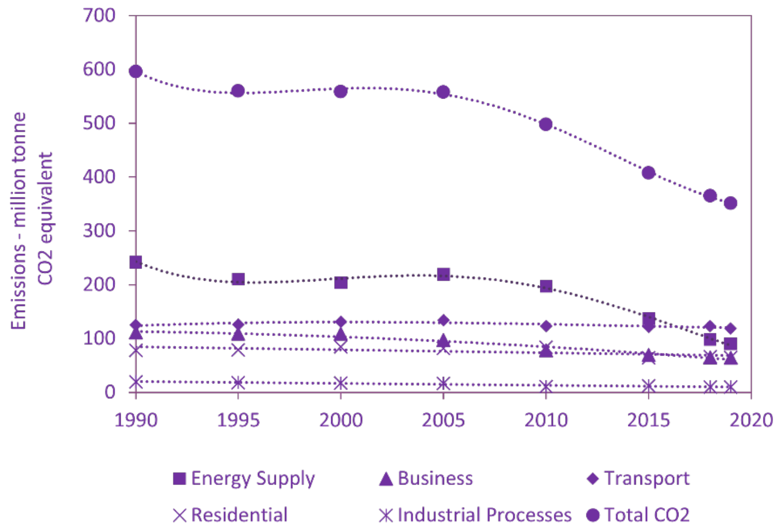
UK's current emissions

According to BEIS (Department for Business, Energy & Industrial Strategy), if you look at the bar chart below in Figure 1, the main contributors to greenhouse gas emissions in the UK are transportation, energy supply, industrial/business activities, and residential (heating).

Source: Department for Business, Energy & Industrial Strategy

Figure 1: Emissions from different sectors as a percentage of total for the UK

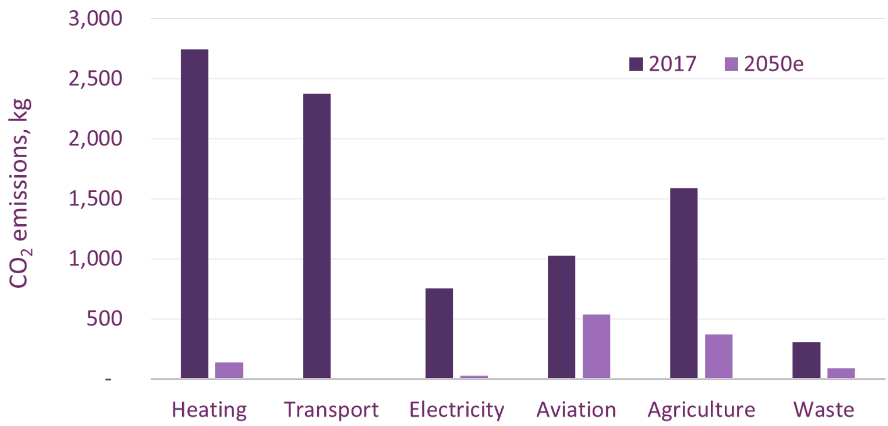
Figure 2 shows that carbon dioxide (CO_2) emissions have actually declined over the past three decades due to the adoption of renewable energy sources such as wind and solar power. However, the emissions from transportation, agricultural, industrial, and residential sectors have remained mostly unchanged.



Source: Department for Business, Energy & Industrial Strategy

Figure 2: Emissions in million tonnes of CO_2 equivalent from different sectors

Figure 3 shows the impact of Net Zero on different sectors in a UK household, according to a study done by the Energy Systems Catapult. The most significant CO2 reductions are expected to come from heating and transport. For instance, it is estimated that the average household produces over two tonnes of CO2 every year using different means of transportation, and new forms of heating will be required to meet our 2050 targets.

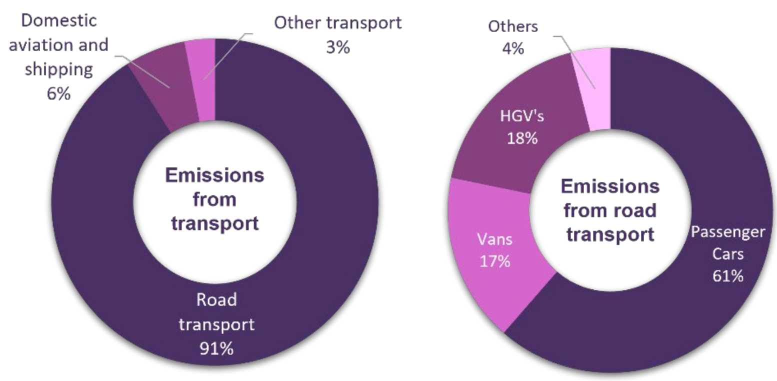


Source: Energy Saving Trust

Figure 3: Recent (2017) vs emissions by 2050 from an average UK household

The passenger transport sector is the most significant source of greenhouse gas emissions in the UK, contributing to 28% of the nation's total emissions. These emissions come from freight, home deliveries, commuting, domestic aviation, and shipping.

Taking a closer look at emissions from the most current transport and environment statistics from the Department for Transport, in figure 4, road transport is the main contributor to emissions from the transport sector at 91%; within road transport, passenger cars are the primary source of emissions at 61% of total road transport emissions.



Source: Department for Business, Energy & Industrial Strategy

Figure 4: Total carbon emissions from transport for the UK along with a breakdown of classifications of road transport that account for more than 91%

The Road to Zero

The Road to Zero is a key plank of the Net Zero strategy, which aims to reduce transport emissions to zero by 2050. This will be achieved by phasing out petrol and diesel cars and vans by 2030 and replacing them with zero-emission vehicles.

The UK is at the forefront of the design, development, and manufacturing of zero-emission vehicles. For example, the Industrial Strategy Challenge Fund invested £246M in the 'Faraday Battery Challenge' to research and develop next-generation battery technology and £400M to help accelerate charging infrastructure deployment under the 'Charging Infrastructure Investment Fund'. Most recently the 10-point plan will mobilise £12BN of government investment in green technologies.

The role of compound semiconductors in the Road to Zero

The Road to Zero will require switching to electric vehicles (EV) which have no tailpipe emissions. Compound semiconductors will play a crucial role in the development of the power electronics needed to manage and optimise power transfer between the battery and motor. The key advantages of the compound semiconductors include the following:

Improved efficiency

Compound semiconductors, with Wide Band Gap technology, have proven to be 90% more efficient than Si-based semiconductors. They reduce the losses that occur during the flow of power from batteries to the motor, thus improving efficiency and prolonging battery life. The main compound semiconductor materials for the application in the EV industry are gallium nitride (GaN) and silicon carbide (SiC). The latter material, in particular, has shown superior efficiency and faster-charging capabilities, as witnessed in the Tesla Model 3, which was the first volume-produced electric car to utilise a SiC power module.

Tesla has achieved this engineering advantage through an exclusive agreement with Swiss-based ST Microelectronics to supply the SiC MOSFETs (metal-oxide-semiconductor field-effect transistor) that power their in-house built electric drive unit (EDU). It's a customised solution, whereas most EV manufacturers currently use silicon-based IGBTs (insulated gate bipolar transistor) discretes or power modules sourced from Infineon and OnSemi and other off-the-shelf system solutions, such as inverters from Bosch, Continental, and ZF. This can be cheaper than the bespoke system employed by Tesla but may take up more space and/or may not perform as well.

Better thermal management

SiC generates significantly less heat as compared to Si-based systems at higher power applications. Therefore, the cooling systems required are smaller, reducing weight and size and ultimately reducing the cost.

Increasing battery range

One of the primary considerations while making a purchase decision for an EV is the battery range. With compound semiconductors reducing the weight and size of the vehicle, the battery range is improved. The SiC inverters also support fast charging, thus reducing mileage anxiety.

Source: Tesla

Figure 5: The Tesla Model Y is one of the first volume-produced battery electric vehicles to utilise a silicon-carbide power module. Smaller, lighter, and more efficient than its silicon equivalent, allowing for a smaller capacity battery yet up to 350 miles range and charging speed of up to 250 kW

Reducing cost

Compound semiconductors have already proven that the cost associated with some of the key components of an EV can be reduced. For instance, the cost associated with cooling systems. It is also interesting to note that the running cost of an electric car is three to four times cheaper than an equivalent petrol or diesel car of a similar size.

The economics of EV

Global EV and compound semiconductor market forecast

The global EV market is estimated to be worth between £1-2TN a year by 2030 and £3.6-7.6TN a year by 2050. The compound semiconductor market was valued at £68.8BN in 2019 and expected to grow to £122BN by 2024 and £155BN by 2027.

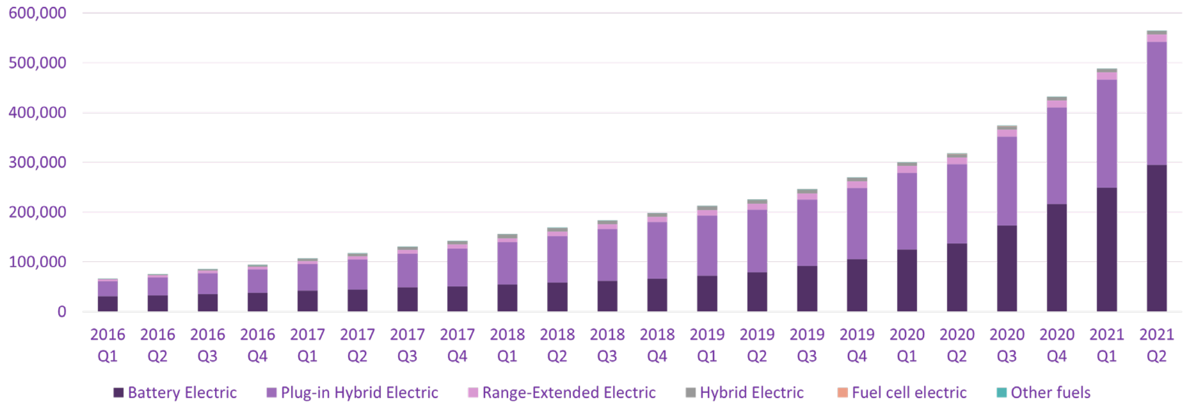
Current UK market

The ULEV fleet is growing in the UK, with over 80 vehicles available currently. The Tesla Model 3 has been the most registered new ULEV, quarter on quarter for the last two years, followed by the Kia Niro and the plug-in-hybrid BMW 3 series.

Interestingly, the UK-based luxury car manufacturer, Jaguar, has committed to going all-electric by 2025 and has cancelled all new vehicle launches until that date, due to a total rethink in its EV platform strategy and the global shortage of critical components due to the pandemic. Its sister brand, Land Rover, produces off-road vehicles and is aiming for 60% all-electric by 2030 and 100% by 2035.

According to the latest figures from the DoT (Department of Transport), there are over half a million ULEVs on the road in the UK. Demand for BEVs overtook the plug-in hybrid category (PHEV) for the first time, with 295,584 battery electric vehicles recorded on the road in 2Q21, which is around 52% of the ULEV market.

This drop in demand for PHEVs could possibly be due to the reduction of incentives ranging from plug-in grants to high traffic areas where such vehicles were previously exempt from the congestion zone fee in London. That said, plug-in hybrid electric still accounts for 44% or 246,814 vehicles on the road.



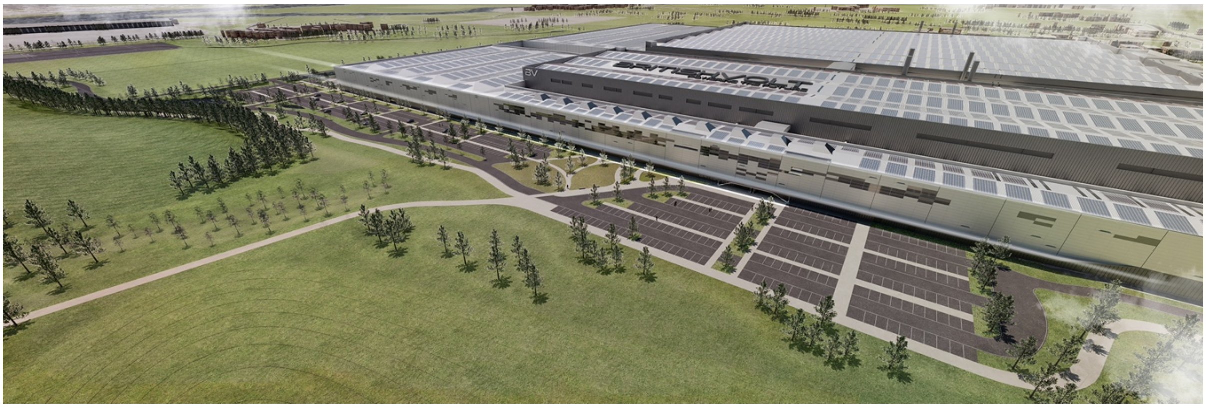
Source: Vehicle Licensing Statistics, Department for Transport (published: Sept 2021)

Figure 6: Ultra low emission vehicles (ULEVs) licensed at the end of quarter (2016-2021)

Affordability of batteries

The prices of Lithium-ion battery packs have fallen by 87% from 2010 to 2019; however, with the uptick in demand for EVs and the shortage in certain rare metals required to produce the cathode, some analysts suggest that battery prices may actually go up.

But with the application of compound semiconductor materials in the powertrains along with standardised designs and simplified manufacturing operations, the overall cost of EVs is expected to come down. According to the Energy Savings Trust, a conventional petrol/diesel car costs around £13-16 per 100 miles, whereas an electric car costs around £4-6 for the same number of miles.



Source: Britishvolt

Figure 7: A number of gigafactories will need to be built in order to manufacture batteries to service the vast number of EVs being built to replace conventional cars. This is a rendering of Britishvolt's gigaplant currently being constructed in Blyth, Northumberland

Manufacturing high-capacity batteries at scale in this country will further reduce both the environmental footprint as well as the cost of producing zero-emission vehicles. To achieve this leaner footprint, a number of gigafactories will be required to make the estimated 140 GWh (gigawatt hour) of batteries necessary to supplant all classes of ICE vehicles on the road by 2040.

Thankfully, the UK gigafactory footprint is starting to build out now. AESC Envision (who took over Nissan's battery production in 2018), have planning permission to expand their existing facilities that will eventually generate 35 GWh of capacity by 2030. Meanwhile, newcomer, Britishvolt broke ground on their gigaplant, in Northumberland in the summer of 2021 and expect the first stage (of a three phase plan) in Blyth to be operational by the end of 2023, each with a production capability of 10 GWh. Finally the West Midlands Gigafactory in Coventry will be the largest facility in the UK, that plans to produce 60 GWh of batteries by 2025.

Expanding the charging infrastructure

AC	DC
Level 1 AC: < 11 kW	DC fast: 50 kW
Level 2 AC: 11-22 kW	DC rapid: 150 kW
Level 3 AC: 22-43 kW	DC ultrafast: ~350 kW

Table 1: Classification of EV charging speeds

The complete electrification of the transport sector will require a rapid expansion of the current EV charging infrastructure. The number of public EV charging devices have grown by five times since 2015, with a growth rate of 363% in what are classed as fast charging devices.

There are currently around 28,000 EV charging devices in the UK, providing over 47,000 charging connectors. Over 50% of these are classified as fast chargers (7-22 kW), around 15% are rapid (25-99 kW), and about 5% are ultra-rapid (100 kW+) chargers.

Charging devices can be classified based on the AC and DC technology, the former being the dominant technology, with over 80% of that charger types in service.

Charging at home

Perhaps unsurprisingly, AC charging is the most popular means of EV charging at home because of the convenience of charging overnight. However, it is limited to level 1 due to the domestic supply and also those with a private garage or driveways. To strengthen the charging infrastructure, the Electric Vehicle Homecharge Scheme offers financial support for the purchase and installation of charging devices.

Source: Audi

Figure 8: Being able to charge at home is the most popular means of EV charging for many

On-Street Charging

On-street charging is an option for residents who do not have a private garage or driveway. This requires installing columns/poles integrated with EV charge points, many of which are already available in various parts of the country. Local authorities are provided with financial support, such as the On-street Residential Chargepoint Scheme (ORCS) to further grow the infrastructure. Furthermore, in this year's Spending Review the Chancellor outlined £620M of new investment earmarked over the next three years to support the transition to electric vehicles. This new funding will be spent on public chargepoints in residential areas and targeted plug-in vehicle grants.

Source: Ubitricity

Figure 9: On-street charging devices such as converted lamp posts offer those that have an EV but no driveway the opportunity to recharge their cars within the vicinity of their home or neighbourhood

Charging at the workplace

Having the ability to charge your car at work will be necessary for people who do not have off-street parking. Businesses in the UK can benefit from the Workplace Charging Scheme, which offers financial assistance for installing EV charge points at workplaces.

Smart charging

Akin to economy 7, smart charging involves charging EVs during off-peak periods when the demand is low, for example, overnight. Smart charging could also provide cheaper charging costs during off-peak periods. Smart meters would be able to communicate with a third party to assess the electricity demand and supply. This is where the Vehicle-to-Grid concept will become important. This will involve charging an EV when the electricity system has spare capacity, discharging the battery when requested, and supplying power back to the grid. This is especially poignant right now, as the wholesale price of electricity is at an all-time high, which in itself has created a challenge for energy providers, especially those that rely on renewable sources which have suffered low wind speeds.

Rapid requirement

Ultimately though, rapid roil out of DC charging, along with future electric vehicles capable of accepting a high rate of charge, is what will be required for the UK to successfully transition to electric vehicles.

The widespread availability, affordability and reliability of the charging devices will be crucial to the adoption of EVs. According to statistics released in October 2020, there were 29 normal and about five rapid public charging devices per 100,000 of the population in the UK; this number will have to increase rapidly to meet future demand.

Ofgem, Britain's energy regulator, has approved a £300M investment to triple the number of ultra-rapid electric car chargers across the country, including 1,800 at motorway services stations as well as a further 1,750 charge points in towns and cities. Furthermore, the government has said it will commit £1.3BN to accelerate, among other things, the rollout of rapid charge points across major A roads and motorways across England. The first of which are being deployed by the likes of Fastned by Oxford's ring road and most recently in Wolverhampton by Osprey who are operating a dynamic charging hub that will optimise grid usage when multiple vehicles are connected to their chargers.

Source: Osprey Charging

Figure 10: Rapid charging hubs along A roads and adjacent to motorways will need to become commonplace to meet the 2030 deadline for the replacement of ICE (internal combustion engine) vehicles

Gridserve's first 'Electric Forecourt' in Braintree, Essex is what the filling station of the future may become. It's a charging hub for up to 36 vehicles of all shapes and sizes, from Level 1 AC all the way up to Ultra-fast DC. They have also just announced two additional forecourts to be constructed, in Norwich and notably at Gatwick Airport's South Terminal.

Electricity at the Braintree site is generated from a range of sources, including solar power canopies above the chargers and a network of hybrid solar farms operated by Gridserve around 40 miles down the road. There is also a 6 MWh (megawatt hour) battery onsite which helps to balance the local energy grid. Like some Tesla supercharger sites in the US, there are shopping facilities, the post office, and a coffee shop to break up the down time while your car is charging.

Source: GRIDSERVE

Figure 11: While some conventional filling stations are already integrating EV chargers alongside diesel and petrol pumps, someday, there may be forecourts exclusively for charging EVs like the Gridserve one in Essex

New technology developments in EV charging

There is research into high power charging, up to 350 kW, for bigger battery sizes. Wireless charging for cars has also garnered interest, and there are some static wireless EV chargers already available in the market. The material of interest for wireless chargers is GaN because of higher switching frequencies. There is also research into dynamic wireless charging, where an EV would be able to charge while on the move. A future Pulse Report will look at this subject in greater detail.

Challenges on the Road to Zero

Increased electricity demand

It's estimated that electricity demand will increase by 30% with the electrification of the transport sector by 2050. This creates enormous challenges to generate sufficient power, with storage and network capability to meet the high demand. The energy system will have to be agile so that it can respond to changes in demand.

The long development cycle of EVs

The technology development cycle for EVs is typically four years. The industry needs to find a way to reduce this cycle duration and respond quickly to integrate emerging technology. Some ways to achieve this include standardisation of key components and a common mechanical package with a standard connector system that can accommodate new technology without changing the whole package.

Skills development

As we move from conventional petrol and diesel engine cars to electric vehicles, it is anticipated that skilled engineers and technicians will be in strong demand. Early work by the CSA Catapult has identified the importance of upskilling and the role of academia in training the next generation of engineers.

Societal acceptance

The technological advances discussed above are likely to accelerate societal changes including the way we work and travel. For example, future travel might involve a combination of public transport, walking, cycling and shared vehicle ownership. This combination would not only reduce greenhouse gas emissions but would also reduce congestion and encourage a healthier, more active lifestyle.

Societal acceptance will be crucial in achieving the targets of Net Zero for the transport sector. For example, how will EV rollout be affected by users' access to shared charging facilities? The reluctance of the people in adopting EVs could be a challenge for the industry.

While plug-in grants will persuade some people to switch to electric cars, perhaps the recent introduction of green number plates to potentially reward clean vehicle owners, e.g. priority parking, will have a greater effect.

The Catapult's role in helping industry achieve Net Zero

So far, we have shown that Net Zero is likely to have a significant impact on the following areas: energy supply, industrial operations, domestic/residential heating, and transport. Compound semiconductor materials, owing to their superior efficiency, faster speeds, better thermal management and reduced size and weight, can play a crucial role in developing power electronic systems to help reduce the emissions in these areas.

Compound semiconductors will be fundamental in the development of renewable energy sources, for instance, Gallium Nitride (GaN) in the inverters for wind turbines and solar power systems and micro-inverters etc. The power conversion and distribution systems for photovoltaic converters and solar heating systems can also utilise compound semiconductor technology. The compound semiconductors, especially Silicon Carbide (SiC) and GaN will play a crucial role in the electrification of the transport system and helping the UK on the road to zero emissions for the transport sector.

As we touched on earlier in the report, Tesla ostensibly has had a four-year go-to-market advantage with SiC thanks to its arrangement with ST Microelectronics and in-house manufactured drive unit. Established names in the automotive industry, such as ZF (who signed an agreement with leading US semiconductor manufacturer Cree in 2019), do not expect to have competing SiC power modules until 2022.

With limited choice and availability, there is an opportunity for the UK to become a solution provider to service the SiC power module shortage and speed up adoption of this technology for electric vehicle production both for the home market and for export to other countries.

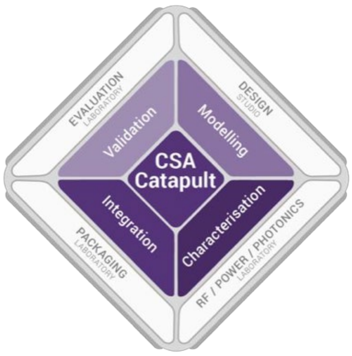
This is why CSA Catapult is part of a UK wide challenge programme called Driving the Electric Revolution (DER). UKRI has invested £80M into electrification technologies focused on making the UK a globally recognised centre of excellence for power electronics, electric machines and drives (PEMD). Crucially, our Innovation Centre is home to one of the four DER Industrialisation Centres (DER-IC) used by industry and researchers to develop and scale up PEMD technologies and manufacturing processes.

The DER-IC's will encourage cross-sector collaboration and encourage industries to invest and collaborate with our network of excellence in academia and Research Technology Organisations. The aim is to grow PEMD supply chains and deliver long term industrial growth to serve both home and global markets.

Equally relevant is the Catapult's role in ESCAPE, a consortium that is building a UK sourced supply chain for SiC-based power electronics. Led by McLaren Applied, the £20M project involving 12 UK partners is developing components and systems for electric vehicles, including a class-leading SiC power module designed and manufactured in the UK.

Our power electronics laboratory, headed by Dr Ingo Lüdtke, is equipped with world-leading modelling and test instruments. According to Ingo, "A £30M project involving BMW called FutureBEV will leverage these capabilities to deliver the components needed for volume production. The demonstrators being developed within the project could be incorporated into new battery electric vehicles as soon as 2024."

The Catapult has developed a unique combination of modelling, characterisation, integration and validation facilities, collectively known as the MCIV framework. Using the framework, we can transform a raw concept into a market-ready product in a process known as Virtual Product Development (VPD). The VPD capabilities of CSA Catapult have been configured to support the flow of commercial, market-or customer-oriented development projects.



Source: CSA Catapult

Figure 12: The Compound Semiconductor Applications Catapult MCIV framework 'diamond'

Conclusion

The UK has pledged to reduce emissions from the transport sector to zero by replacing all the petrol and diesel cars with zero-emission battery-electric vehicles by 2050. It can be estimated that a reduction of around 100 million tonnes of CO_2 emissions per year will be possible with the electrification of the transport sector (based on current emission trends). The success of the Road to Zero project will depend upon three key aspects, the technological advancements in the EVs, robust charging infrastructure and the role of society in adopting the new transport system.

The complete electrification of the transport sector will require the automobile industry to work towards improving the performance of EVs and making them affordable to the general public. The main objectives in terms of EV technology are improving the efficiency of the powertrains, increasing the battery capacity and range, and reducing the weight. The EV charging devices will also require research and development in terms of improving the charging speeds.

Compound semiconductors will play a crucial role in the development of EV technology; they find their application in the powertrains and power electronics required in an EV. They have significantly higher efficiencies than Si-based modules and generate less heat, and hence need smaller cooling systems, thus reducing the weight. They are also being exploited for wireless charging devices for EVs.

The EV industry is set for massive growth in the coming decades due to the Road to Zero legislation; this presents a huge opportunity for compound semiconductor technology to be exploited.

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