USING VEHICLE-TO-CLOUD CONNECTIVITY TO EXTEND ELECTRIC VEHICLE RANGE

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What would happen if fossil fuels were banned tomorrow? Does it sound unlikely? Maybe. Perhaps the idea isn't so far-fetched; there are currently strong indicators that the world's dependence on fossil fuels is weakening.

The COVID-19 pandemic triggered a 20% slump in demand for oil and a corresponding price collapse.[1] Although there has since been a partial recovery, analysts agree that a return to previous levels is unlikely. In its latest "World Energy Outlook" report, BP predicts that demand for oil has peaked and will soon go into steep decline.[2] It is generally recognized within the industry that an ongoing lack of demand, rather than supply, will drive production levels down. At the same time, the public, governments and investors are all demanding alternative, clean energy sources. Clean power stocks have recently risen by over 45%, in sharp contrast to the fortunes of ExxonMobil, an oil giant which has recently slipped out of the Dow Jones Industrial Average for the first time since joining in 1928.[12]

As a major contributor to global emissions, at approximately 12% of 2018 levels, road transport is a major consumer of fossil fuels and, incentivized by increasing levels of government regulation, automobile manufacturers are innovating to reduce dependence on the internal combustion engine (ICE).[2] China, the world's largest automotive market, has announced ambitious plans to lead the global move away from the ICE, aiming for a 50% to 60% market share of new energy vehicles (NEVs) by 2035.[4] Norway is targeting to have all passenger car sales be zero-emission vehicles by 2025. Elsewhere, India is pushing for 30% electric car sales by 2030 and, in Europe, France and the U.K. are targeting 2040 for a total ban, with Germany announcing an even more aggressive date of 2030.[5]

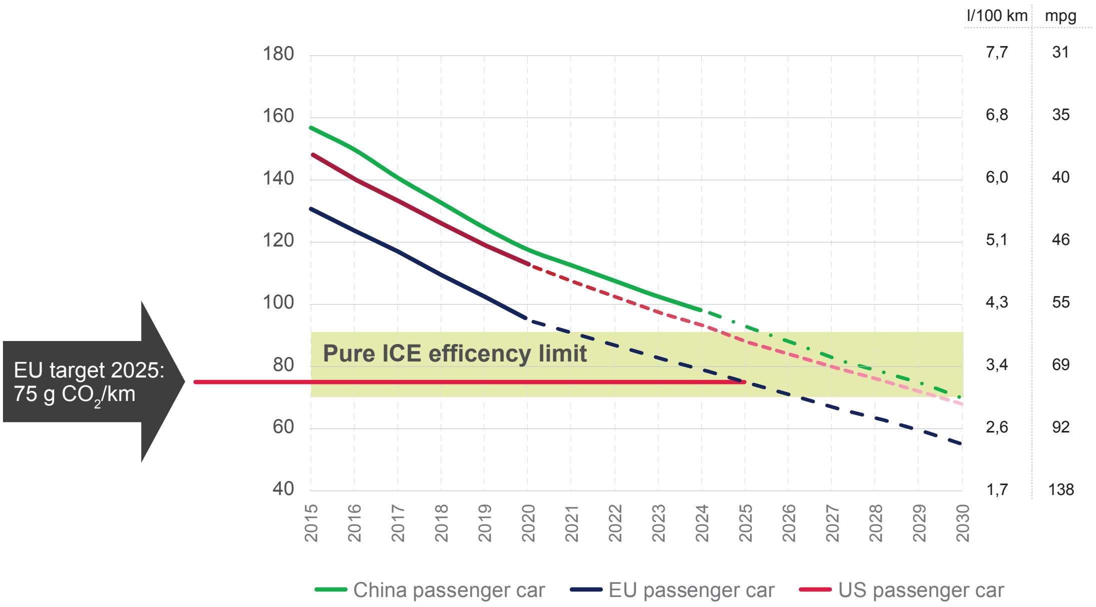


Figure 1: Selected carbon dioxide emissions targets (Source: NXP Semiconductors)

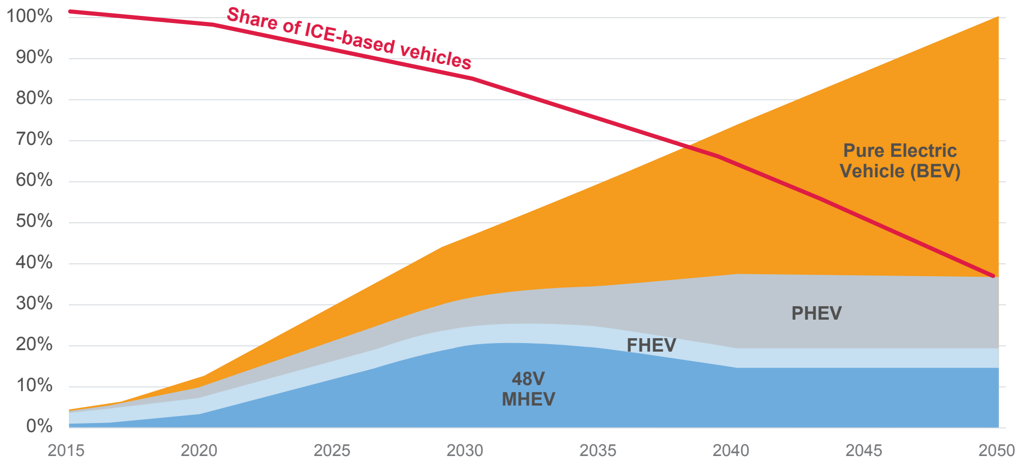
These increasingly strict targets impose challenges on ICE design that cannot be met without electric drivetrain components. In response, carmakers are increasing the proportion of Electric Vehicles (EVs) within their ranges. With a 2019 market share of 18%, driven mainly by the launch of its Model 3, Tesla is the current market leader, but all major manufacturers, including Volvo, Daimler, Volkswagen and Ford have announced massive investments in hybrid and electric vehicle development programs. All have aggressive plans to introduce many new electric vehicle models within the next few years.[6,7]

Global EV sales have grown strongly in recent years—65% between 2017 and 2018, with the European and Chinese markets performing particularly well. Although COVID-19 has affected sales in 2020, market penetration of EVs has actually increased, from 2.5% in 2019 to 2.8% in the first quarter of 2020. This early sign that EVs are taking market share from traditional ICE vehicles confirms longer term forecasts (Figure 2), which predict that, by 2032, 50% of vehicles will have an electric motor assisting with the drivetrain.[6,7]

In reality, the actual rate of adoption of hybrid or electric vehicles will depend on several social and economic factors, including:

- The relative prices of petrol and diesel vs. electricity
- Continued technological advances, including economies of scale, reduction in battery costs, improvements in battery capacities (and hence EV range), and implementation of charging infrastructure
- Growing concern about the environment and climate change and how that is reflected in changes in government legislation and regulations on fuel economy, CO2 emission, and pollution
- Changes in consumer behavior, attitude to vehicle ownership, and acceptance of EV technology
- Successful experience of the early adopters with driving, owning, servicing, etc., the xEVs

This paper examines some of the ongoing technological advances in more detail, particularly those affecting the efficiency of the EV drivetrain. It looks at how NXP, a world leader in secure connectivity solutions for embedded applications, is driving innovation in the automotive market.



Sources:
Strategy Analytics, Evercore, NXP CMI

Figure 2: Aggregation of forecasts for EV adoption (Source: NXP Semiconductors)

THE EVOLUTION OF EV TECHNOLOGY

Figure 2, above, illustrates the main types of EV currently on the market, ranging from the Mild Hybrid (MHEV) through Full Hybrid EV (FHEV) and Plug-in Hybrid EV (PHEV) to Pure Battery EV (BEV). The first hybrid vehicles were FHEVs, popularized by the Toyota Prius, launched in 1997. Since then, EVs have seen many advancements, with the PHEV, adding plug-in capability to enable charging of the battery, and the REEV, which has a small ICE to charge the battery, instead of driving the wheels. Recent FHEV and PHEV models are equipped with two electric motors, one optimized for regenerative braking and charging of the battery and the other optimized for torque and power to propel the vehicle. The high torque generated by electric motors at low speeds enables the ICE to be downsized and/or run with more fuel-efficient control strategies.

Over the years since their introduction, manufacturers have been striving to find innovative methods of improving EV efficiency, including:

- Improving battery management and monitoring
- Increasing battery capacities
- Reducing electric drive system losses (although more efficient than ICE, there are still 16% of energy lost through the electric drivetrain)[8]
- Increasing use of regenerative braking—recovering energy when brakes are applied, the vehicle's inertia turns an electric motor-generator, producing electricity that is then stored in the battery
- Reducing charging losses—when charging the battery, energy is lost in converting AC from the electrical grid to DC for use in the battery, as well as in overcoming the battery's resistance to charging, which increases as the battery reaches its capacity
- Evolving the science of electric motors to reduce mass and improve efficiencies

As a result of this continual innovation, the modern automobile contains a number of electronic subsystems that are each responsible for managing different areas of vehicle safety and functionality, as seen in Figure 3.

Each of these subsystems contributes to the EV's safety, comfort and overall driver experience. However the powertrain and vehicle dynamics functionality plays a significant role in vehicle energy optimization – and hence range. Since vehicle range is a key factor in the marketability of an EV, it is no surprise that increasing drivetrain efficiency is a key focus area for manufacturers.

The following sections will discuss how various aspects of EV technology have developed to enable advances in sophisticated propulsion control techniques, which are central to EV efficiency.

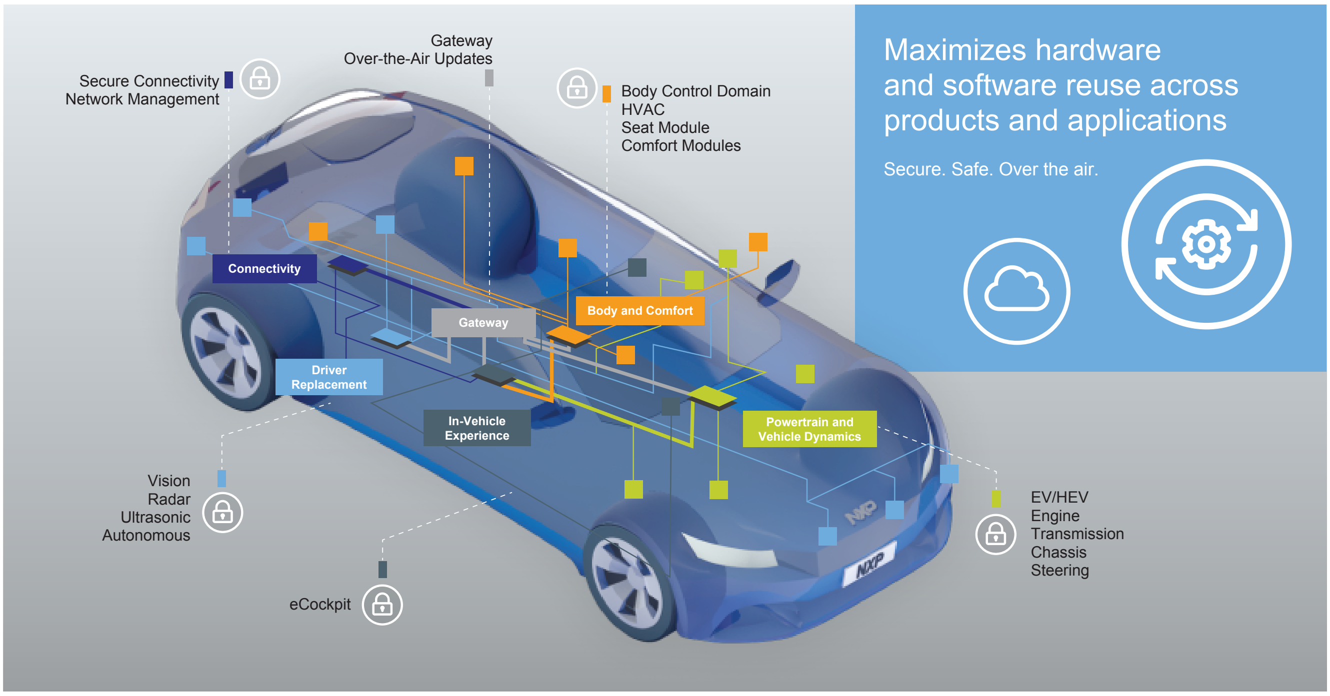


Figure 3: Electronic subsystems in the modern automobile (Source: NXP Semiconductors)

THE EVOLUTION TO DOMAIN CONTROL ARCHITECTURE

Automotive electronic design has traditionally been based on the concept of the electronic control unit (ECU), a device containing a dedicated chip, running its own software or firmware, with responsibility for the control of a specific function. As more and more functionality is added to modern vehicles, it is not uncommon for them to contain in excess of 100 ECUs, leading to issues with space and power consumption. Additionally, the combined demands of increased vehicle connectivity and autonomy are driving the need to share high bandwidth, low latency data between ECUs. As a consequence, EV electrical systems are evolving to a domain control architecture, as shown in Figure 4, where each functional area is split into its own collaborating sub-network with a domain controller acting as the access point from the vehicle.

Within a domain control architecture, each controller in the electrical hierarchy collaboratively implements a specific domain's functionality, making appropriate decisions for that domain's purpose. This decision-making concept on behalf of the domain underpins the domain control philosophy; not every decision needs to be passed up to the domain controller. Some tasks or functions can reside anywhere, provided the node has access to the relevant data. The domain controller is a natural place for this decision-making because it is the hub and has access to most of the data from the domain.

In the case of the powertrain and vehicle dynamics domain controller, this node must support the computationally intensive algorithms required for energy optimization. The node must also be powerful enough to host the consolidated ECU functionality within the domain architecture. This capability is enabled both by the underlying processing hardware and also the application of virtualization techniques. Modern controller architectures use advanced virtualization techniques to separate tasks within an MCU into virtual machines (VMs), enabling the reservation and assignment of processing resources (e.g., memory, communications, timers, etc.) to each task and guaranteeing freedom of interference. Virtualization is particularly important in consolidated ECUs since most tasks or functions are safety-critical and different software development teams—or even different companies—may have developed them. With virtualization, individual malfunctioning tasks can be reset without affecting other tasks on the device. Also, access to shared resources, such as Ethernet, HSE, or EEPROM, can be scheduled and prioritized.

Although virtualization techniques have been common on PCs and application processors for many years, they are only now being brought to embedded real-time microcontrollers, enabled by advanced hardware support mechanisms such as dual-level MPU, VM ID assignation, and VM-aware system-level resources.

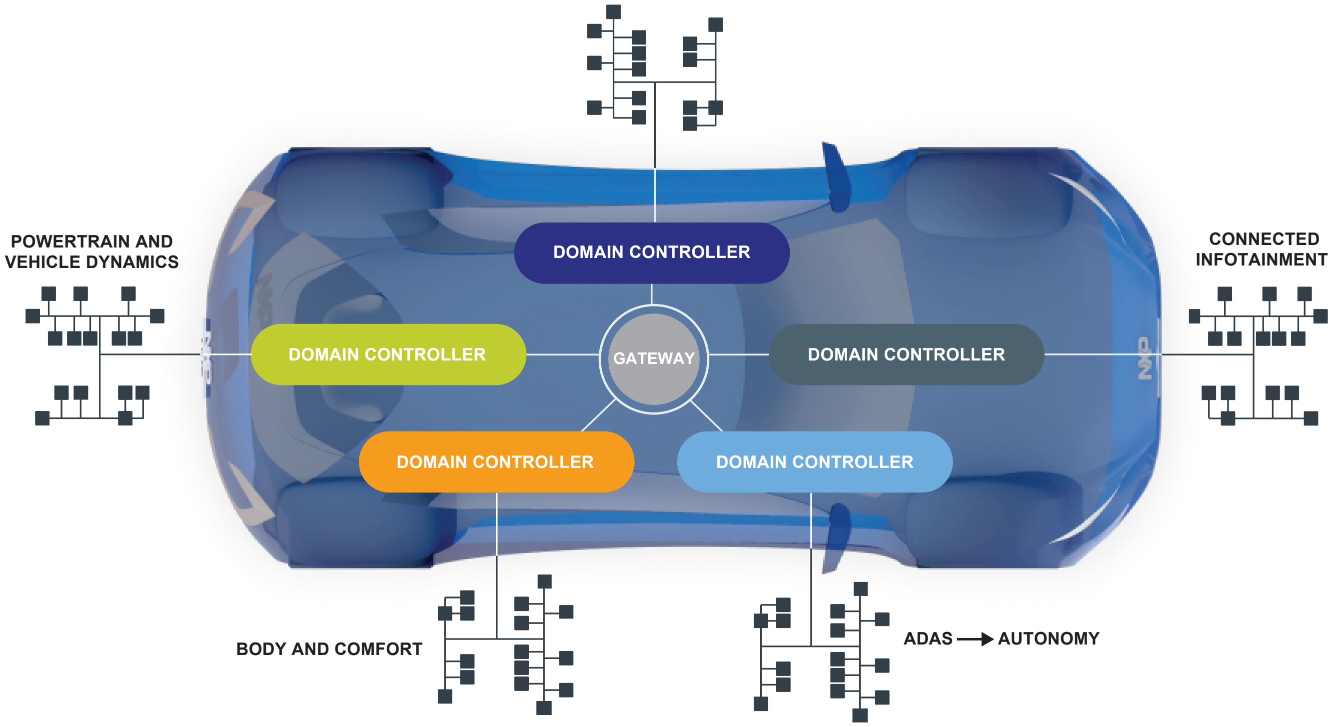


Figure 4: Vehicle domain control architecture (Source: NXP Semiconductors)

VEHICLE-TO-CLOUD CONNECTIVITY ENABLES MULTIPLE USE CASES

Along with the above enhancements to domain control architecture, reliable vehicle connectivity is enabling cloud-edge computing and AI techniques to enrich the capabilities of key automotive applications.

Improvements in the coverage and performance of wireless networks, particularly with the rollout of 5G, are making the concept of the connected car a reality. C-V2X is an LTE-based technology standard, defined in 2016 by the 3rd Generation Partnership Project (3GPP), which enables a broad range of use cases for connected vehicles, including vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-pedestrian (V2P). 3GPP Release 14 defines two transmission modes for C-V2X: Direct C-V2X, which enables communication in the absence of a cellular network; and V2N, which uses traditional mobile licensed spectrum.[9]

It is estimated that 44 million connected vehicles were shipped in 2019, most equipped with multiple sensors and some capable of generating over 4 TB of data per hour.[9] This level of connectivity opens up a wide spectrum of additional applications and use cases for the connected car, such as energy optimization, insurance, fleet management, preventative diagnostics, and intrusion detection, as seen in Figure 5. Onboard sensors can share information externally, improving the driving experience, and giving the vehicle the capacity to become self-reliant by gathering input for independent decision-making.

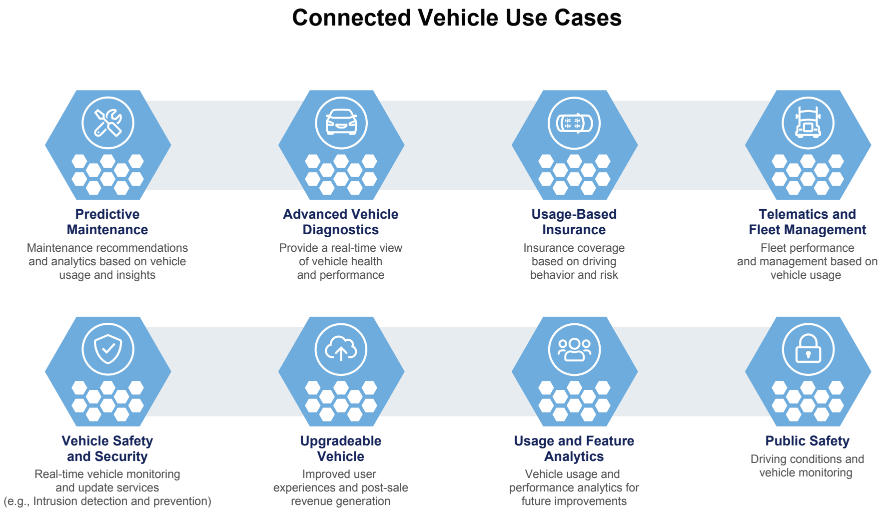


Figure 5: Connected vehicle use cases (Source: NXP Semiconductors)

Advanced vehicle connectivity increasingly enables cloud-edge processing techniques to be deployed to enrich the above uses cases. Deep Learning frameworks such as Tensorflow, Caffe, and Pytorch can train machine learning (ML) models in the cloud. Then, these models are deployed to the processing units (edge nodes) in the vehicle, as illustrated in Figure 6. The ML models running at the edge operate on real-time data generated from the vehicle's sensors to make predictions based on the trained model, using a process known as inferencing. Data from the vehicle is continuously synchronized with the cloud, enabling the models to be continually updated.

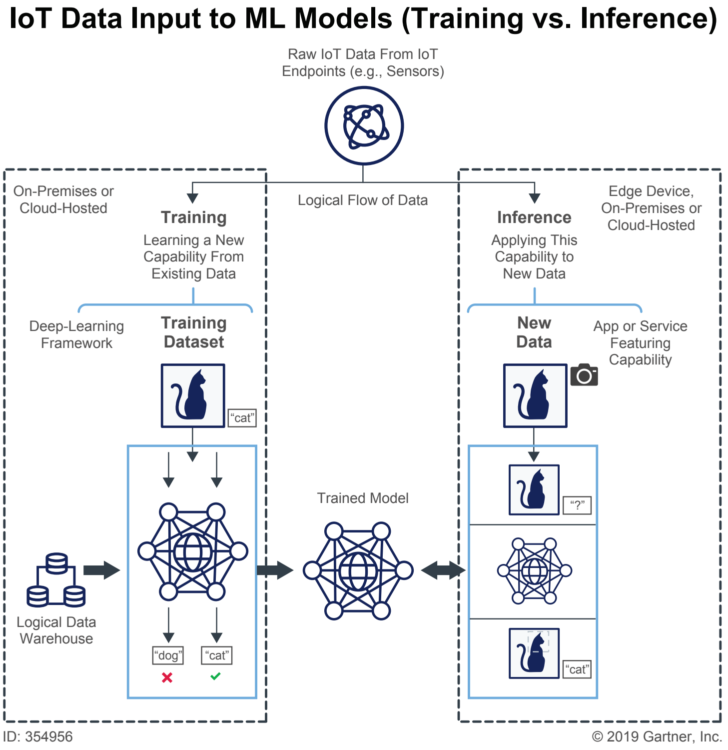


Figure 6: Cloud–Edge processing[10]

In the predictive maintenance use case, cloud-edge processing supports the use of digital twin modeling to identify any vehicle maintenance issues before they occur and identify the root cause of the problem. A digital twin is a cloud-based replication of a physical entity (the automobile in this case), providing both the elements and the dynamics of how the entity operates. The digital twin model continuously learns and updates itself in near real time from the connected car, using sensor data. The digital twin can also learn from other inputs, such as engineering data, simulation tools, data from similar vehicles, and environmental data.

In the public safety use case, the inferencing ability of the ML models deployed to the automobile enables automatic recognition of obstacles or objects in the road or predicting hazardous events.

THE EV ENERGY OPTIMIZATION CHALLENGE

The electric propulsion motor's role in a hybrid vehicle is to assist the ICE over portions of the journey. As the relative percentage of these portions increases, CO2 emissions are reduced at the expense of the distance that the vehicle can cover between charges (the range).

Ongoing research and development activity is focused on increasing drivetrain and overall vehicle efficiency by improving the torque source's decision-making (i.e., ICE or electric motor) during the journey. The existence of multiple torque sources in the vehicle poses three control challenges:

- Deciding which torque source to use
- Controlling the stability of the vehicle with multiple torque sources, particularly in safety and failure scenarios
- Optimizing use of the fixed (and limited) energy stored in the vehicle battery

In modern xEV architectures, the propulsion domain controller (Figure 7), which sits above the ICE control, electric motor control, battery management system, and braking controllers, is responsible for executing this vehicle torque and energy strategy.

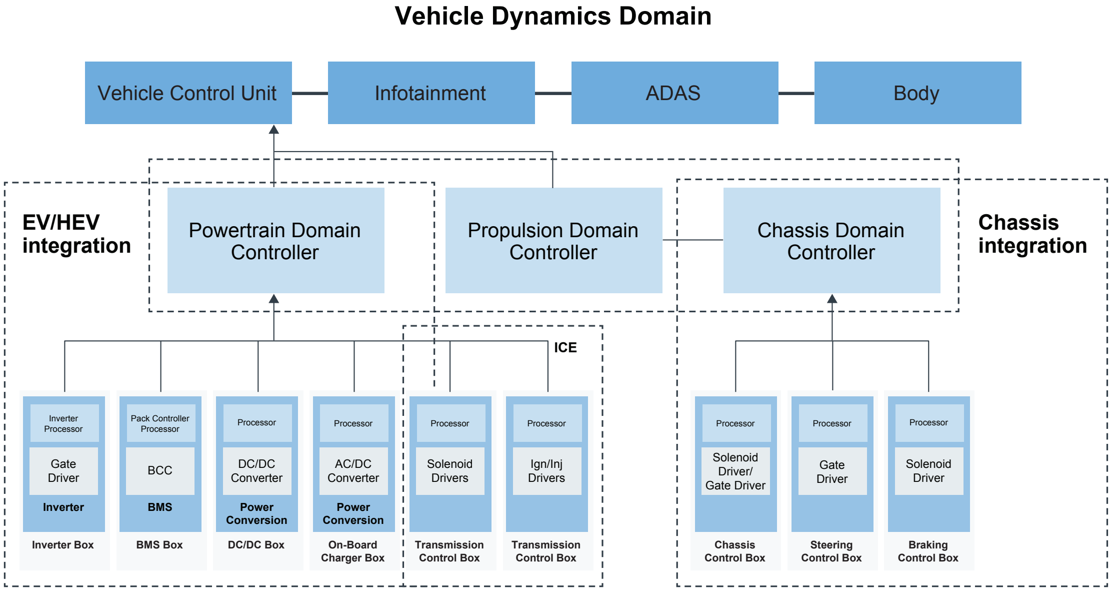


Figure 7: Location and content of the Propulsion Domain Controller (Source: NXP Semiconductors)

While basic decision-making can be performed instantaneously using available data from the vehicle's current situation, the decision's quality is vastly improved by adding more information and extending the decision-making time to cover the entire journey, with the goal of reaching the destination with a fully depleted battery. For example, if contextual knowledge of precise location, traffic conditions, average speed of route, expected duration of journey, charging station locations, gradients on the planned route, and driver style are all known; then predictions can be made for where to use the ICE, where to use the electric motor and where regenerative braking will be used to increase the battery charge state.

The propulsion domain control software has access to a wealth of data from onboard sensors, including cameras and GPS systems, and can use this in combination with the ML techniques described above to improve decision-making. Studies have shown that when more predictive control is granted to the propulsion domain controller, such as predictive gear select (from GPS knowledge of hills or camera observing traffic) and speed; efficiency savings of up to 30% are possible, Figure 8.[11]

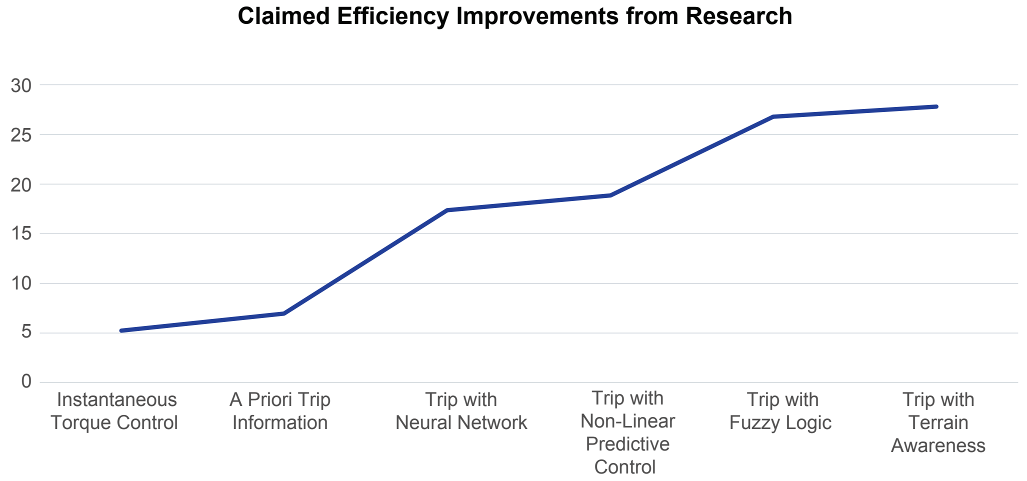


Figure 8: Claimed efficiency improvements from research[11]

Systems such as this are already on the market, delivering real fuel savings in commercial operations such as trucking.

As well as using data generated from onboard sensors, the propulsion controller can access other road users' crowdsourced data in the cloud to enhance the modelling process and improve efficiency. Jaguar's I-Pace EV, for example, can receive OTA software updates which are based on data gathered from the I-Pace eTrophy race series as well as from over 500 million miles of real-world journeys. These updates refine existing control algorithms, giving improvements in areas such as torque distribution, aerodynamic control, regenerative braking, and range calculations.

These mathematically intense control strategies require significant processing capability levels and are only achievable as onboard embedded processing power has increased. The technology required to support this advanced functionality is hugely complex. Only a few manufacturers can reliably provide this technology along with the requisite tools and support environments that developers require.

NXP IS A KEY PLAYER IN THE EV ECOSYSTEM

With over 60 years of combined experience, 29,000 employees, and a presence in more than 30 countries, NXP is a true global leader in embedded applications and drives innovation in the automotive, industrial, IoT, mobile, and communications infrastructure markets.

In the rapidly evolving EV market, NXP's broad portfolio of products and system solutions addresses all EV types with several building blocks, including:

- Propulsion domain control—controls distribution, energy storage, engine, and motor to enhance the efficiency of the xEV powertrain
- Battery management—controls individual cells and overall battery pack, balancing cells to optimize capacity while maintaining safety
- Converter and charger: the DC-DC and AC-DC charger interfaces with the BMS to ensure a safe and efficient high-voltage conversion
- Electric motor driver solutions—focus on safety as well as motor control efficiency

NXP's propulsion domain control solution is built upon the advanced S32S microcontroller, an ASIL D device with four Arm® Cortex®-R52 processors in lockstep architecture for a total of eight cores (Figure 9).

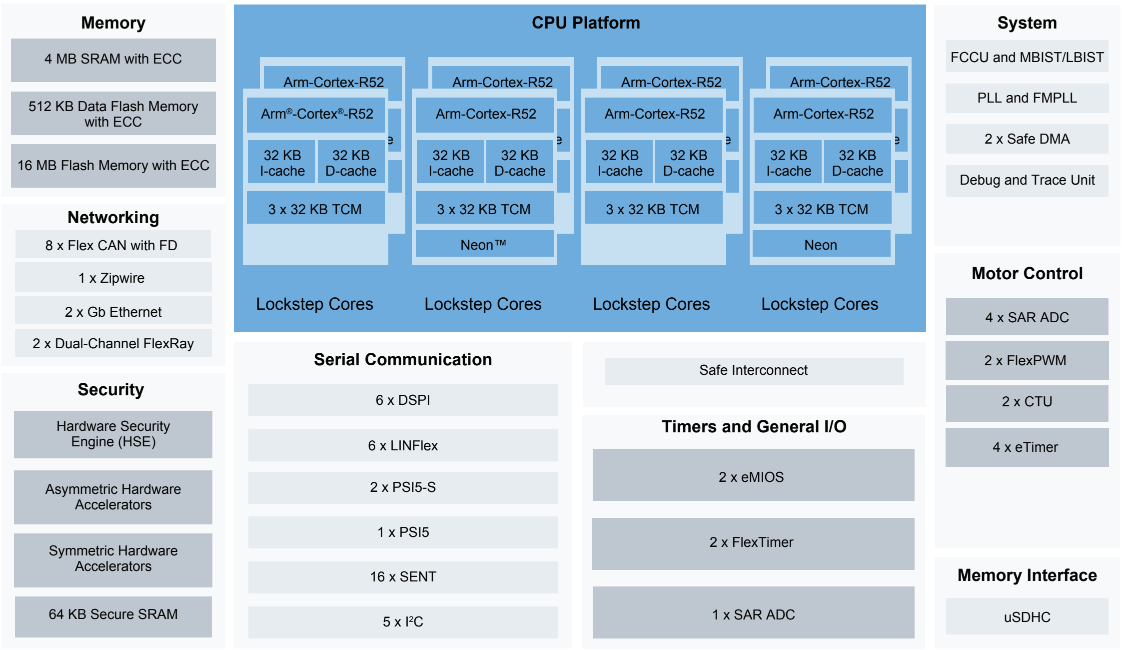


Figure 9: The S32S microcontroller (Source: NXP Semiconductors)

NXP'S INNOVATIVE EV BUILDING BLOCKS

The S32S is part of NXP's S32 automotive processing platform, a family of MCUs and MPUs for automotive and industrial applications that are architected to address current and future connectivity, security, and safety challenges. With ten times the performance of NXP's previous family of automotive devices, the S32S can support the advanced processing requirements of the HCU control algorithms, including virtualization and hypervisor. This processing capability is integrated into the SIP and a range of peripheral functions such as advanced timers and analog subsystems optimized for motor control.

The S32S247TV (S32S) is the first example of an MCU developed using NXP's innovative system-in-package approach. Automotive MCUs must typically combine CMOS logic with non-volatile memory and high-precision 5 V analog and I/O capability. This technology's complexity mean that the performance of automotive MCUs has tended to fall behind Moore's law predictions by as much as seven years. NXP has overcome this performance compromise by splitting the MCU into its constituent functions, applying the optimum process technology for each, and then combining the resultant, separate die into a system-in-package (SIP), which has the full performance of the base CMOS process.

From the same platform, the S32G vehicle network processor targets high-performance real-time and application processing and network acceleration for service-oriented gateways, domain controllers, and safety coprocessors. The S32G is integrated with the network interfacing and acceleration functionality required to support edge processing demands.

To support automobile manufacturers and their suppliers and enable them to begin early and accelerated development of next-generation hybrid and electric vehicle applications on the S32 platform, NXP has released two powerful tools—the GreenBox development platform, and the GoldBox reference design.

The GreenBox development platform will support the next generation of hybrid engines and electrification. This high-performance processing platform supports the design and test of HCU control algorithms and energy management tasks.

Complementing the GreenBox platform, the NXP GoldBox reference design supports development on the S32G MCU. It enables the implementation of a service-oriented gateway that provides the connectivity and processing power required to run ccloud-edge processing (Figure 10).

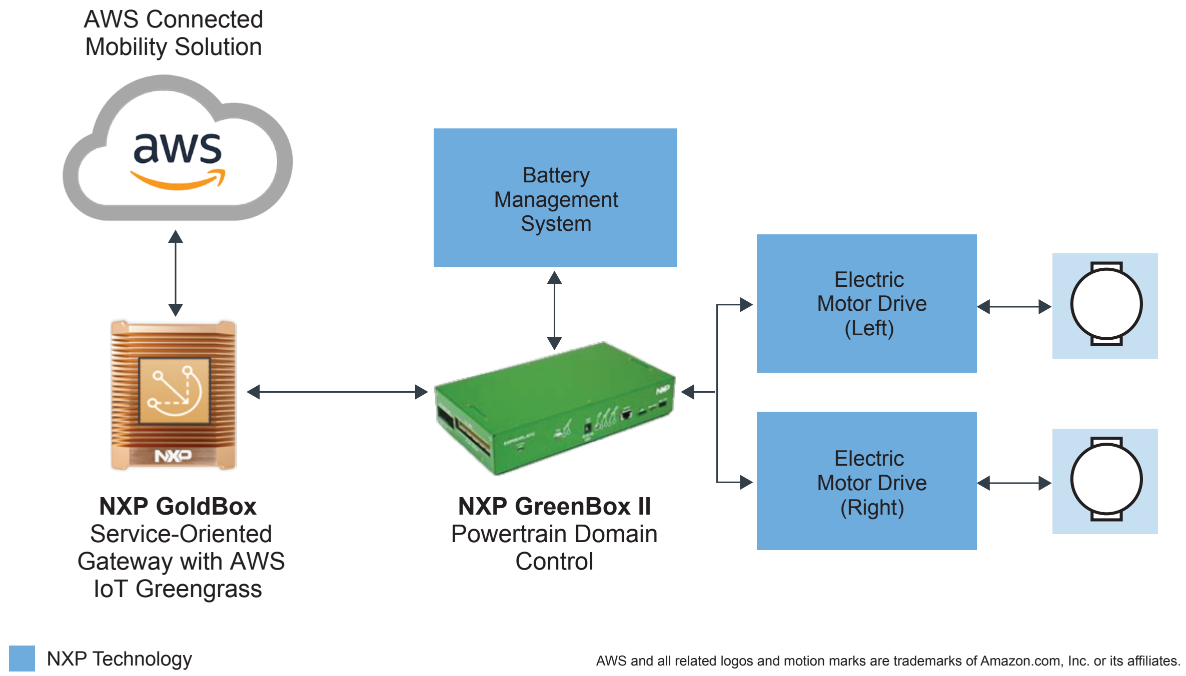


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Figure 10: The NXP GreenBox and GoldBox development platforms in a vehicle-to-cloud demo configuration (Source: NXP Semiconductors)

CONCLUSION

As the effects of climate change become more evident, governments worldwide are tightening emission regulations, and automobile manufacturers are responding with increasingly innovative EV models.

Range is a key differentiator for an EV and, over the years, significant investments have been made in areas such as batteries, regenerative braking, electric motor performance and drive-train performance—all with the aim of improving efficiencies.

With energy optimization fundamental to EV efficiency, complex mathematical algorithms have been developed to improve real-time decision-making on a propulsion power source. Improvements in vehicle connectivity have enabled these algorithms to be enriched by cloud-edge processing techniques with onboard, embedded processors accessing cloud-based AI capabilities and big data gathered from other road users.

NXP, a global leader in embedded technologies, is at the forefront of EV development, providing a range of innovative, technological building blocks, which power the sophisticated capabilities of the modern EV. Recognizing the complexity of these building blocks and understanding that speed to market is critical for their customers, NXP has also invested in tools such as the GreenBox and GoldBox development systems, which enable accelerated development of complex EV control systems.

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