White Paper

Intel Automotive

# Vehicle Platform Power Management Standard Proposal

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Revision #1.1

## Vehicle Platform Power Management Standard Proposal

The automotive industry is on the brink of a supply-chain sustainability crisis. For battery production to meet surging demand, there is an extensive and urgent need for natural and industrial resources. If supply chains do not scale quickly—and sustainably—there could be an imminent threat to the global transition to Electric Vehicles (EVs). Furthermore, the weight of EV batteries accelerates tire and road wear, resulting in the release of microplastic particles that can harm ecosystems [1].

Current vehicle platforms have traditionally been centered around internal combustion engines (ICE), with electrical and electronic components designed for continuous peak power consumption. With an average of 100 Electronic Control Units (ECUs) in today's vehicles, the cumulative energy usage by these components stands at approximately 316 Wh/mi on average [2].

EV efficiency is also brought to light by the lack of standardization in automotive power management, because each automaker designs the electric and electronic architecture of their vehicles differently. As the industry advances, there is a realized need for a power management standard with vehicle-level intelligence on energy management for individual ECUs to meet efficiency needs. By embracing standards from the PC industry, like the Advanced Configuration and Power Interface (ACPI) specification that helped reduce up to 60% the power consumption of a CPU [3], [4] — and extending those concepts to software-defined vehicles — we could yield substantial power savings at the vehicle level. This, in turn, could reduce battery size requirements and increase EV operational range, reduce weight and cost and ultimately enhancing the long-term sustainability of the global EV supply chain.

The proposed standard will define ECU interfaces and functions necessary to enable OEMs to develop and deploy context-aware, vehicle-wide optimal power generation and consumption while allowing differentiation in implementation. For example, an OEM could determine when an individual ECU should enter a low or high-power state based on different driving modes—providing improved energy savings. Further, the ECU supplier would be able to implement differentiated energy savings algorithms while still being compliant to the standard. By defining a standardized power management protocol, we can significantly reduce power consumed across the vehicle, improving the long-term range and degradation of electric batteries without compromising the performance or safety of the vehicle.

Achieving this outcome hinges upon the industry's collective collaboration to establish an open, industry-wide standard that can be universally embraced by the supplier community. This prospect is within reach, and this whitepaper underscores the pressing need for the industry to unite and seize this opportunity.

## Introduction

The modern vehicle architecture is based on a distributed ECU architecture, where every feature, no matter how big or small in the vehicle, typically results in a new ECU. Whether it be the air conditioner, seat controls, infotainment, or driver assistance system, each new feature brings an individual controller box with its own electrical and electronic components.

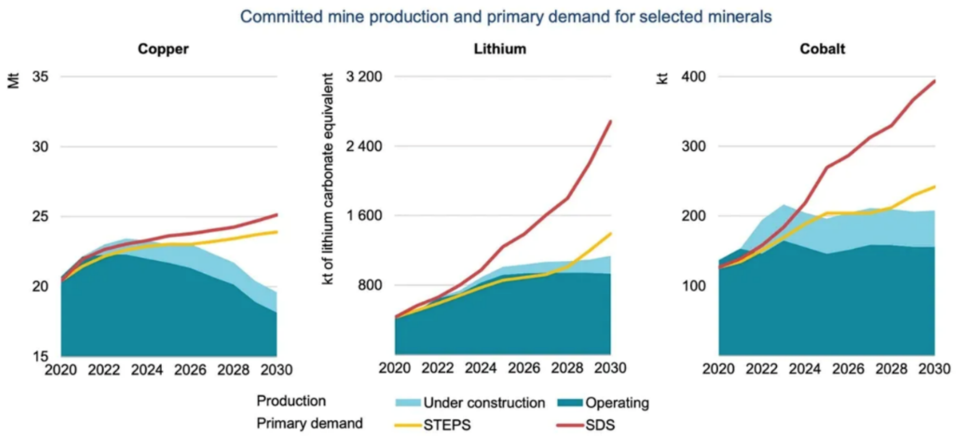
For over a century, vehicles have been built around an ICE that provides a plentiful source of energy—an amount that allows most ECUs to run at peak power almost continuously. Since energy is available (and can be quickly replenished), why introduce the extra complexity required to design reduced power consumption states when there is no significant benefit in doing so?

Parallels to the first laptop computers abound, early laptops were simply a desktop PC board laid flat with a battery attached, inherently designed to run at peak power all the time (unless explicitly turned off) because the PC was plugged into the wall. Later, with the implementation of standards like Advanced Configuration and Power Interface (ACPI), a reduction of up to 60% in power consumed by a CPU was achieved [4] .

Just like early laptops in the 1990s, modern EVs often start with the same ICE vehicle platform but swap out the mechanical engine for an electrical one powered by a multi-cell battery, exposing the wasteful energy consumption that is built-in into the modern vehicle by design.

## A Supply Chain Crisis

The production of minerals needed for the world to transition to clean energy is likely to fall behind demand by 2026 if nothing changes (see Figure 1). Additionally, geopolitical reasons may hinder global production as minerals used to manufacture EV batteries, for example, are concentrated in very few countries [5].



"STEPS" is the "stated policy scenario," i.e., where we're heading with current policies. "SDS" is the "sustainable development scenario," consistent with Paris Agreement goals. (IEA)

Figure 1 – Raw mineral production and projected demand (source: [5])

Moreover, extracting raw minerals to product EV batteries requires massive efforts, resources and can contribute to human and environmental injustice. For example, wastewater from mines reaches lakes, rivers, and oceans polluting drinking water and ground water reserves. On top of that, mining one ton of lithium requires more than two million liters of water, stressing the water supplies of the communities where the mining happens [6].

Battery packs account for 30 to 40% of a vehicle's total cost [7], therefore, disruptions to the EV battery supply chain can have significant impact on accessibility and prices of this central piece of an EV.

While battery capacity in vehicles have increased in the past years and went from about 17 kWh in a 1996 GM EV1 [8] to 118 kWh in a 2022 Lucid Air Dream Edition R [9], the industry has reached a point at which the vehicle's efficiency is more important than ever for mass adoption of EVs. Even with steady improvements in battery technologies, solving this problem requires an order of magnitude reduction in the amount of energy required to power a modern vehicle.

While many countries are heavily investing in domestic and cleaner ways to produce batteries, the discovery and exploitation of new minerals can have a lead time of 15 years or more [5]. However, there is a known path already paved over the last 20 years in PCs and other battery powered devices that can bring significant benefits to the energy efficiency of modern electric vehicles without needing to wait for an unlikely breakthrough in battery technologies.

## Section I: The Modern Vehicle Architecture

In this section a summary of the modern vehicle electric and electronic (E/E) architecture is presented with emphasis on in-vehicle communication networks, the ECUs that interact with them, and automotive standards.

As illustrated in Figure 2, the modern vehicle architecture is a complex mix of legacy and newer communication busses including Controller Area network (CAN), Logical Interconnect Network (LIN) and Automotive Ethernet based ECUs. Typically, there are more than 100 ECUs and more than one mile of copper cabling, with low-speed legacy busses.

Even as the vehicle architecture evolves from a more traditional distributed to zonal architectures (see Figure 3), legacy busses and legacy ECUs are often persisted for more than one or two generations of vehicle architectures; losing momentum on the adoption of newer power management techniques or faster communication buses inside the vehicle.

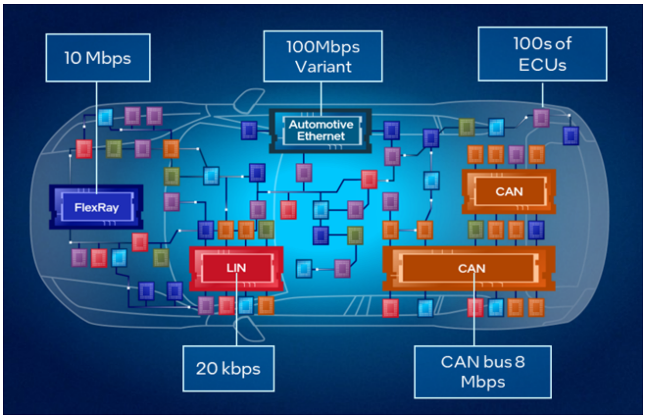


Figure 2 - Modern Vehicle Architecture (distributed and decentralized)

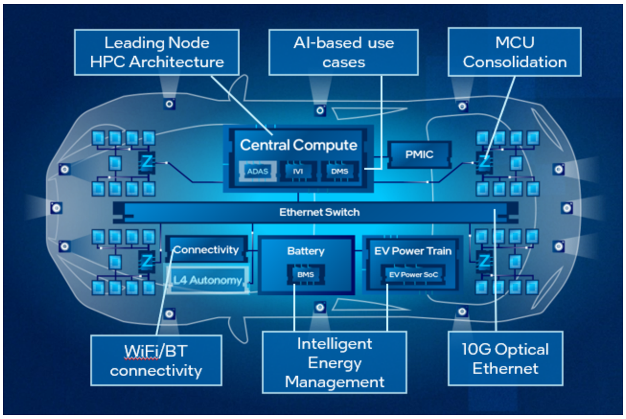


Figure 3 - Future Vehicle Architecture (Domain/Zonal Controllers, Centralized compute)

## Electric Vehicle Efficiency

While some EV makers and suppliers are taking steps to introduce advanced power management techniques and products, there are two main challenges left to address:

1. Even in cases where the vehicle has been designed with more efficient energy consumption in mind (typically in ECUs that the EV maker has under direct control), the vast majority of ECUs in the vehicle come from the larger automotive supplier ecosystem. A system which may not be designed with modern power management capabilities.

2. In the cases where some EV makers or suppliers are bringing intelligence to the ECUs, they are doing it in a proprietary fashion. This method limits the scope of impact of these concepts to only parts of the vehicle rather than the entire vehicle platform.

Others may argue that the adoption of Software Defined Vehicle (SDV) concepts—where workloads are consolidated onto central compute platforms—obviates the need for ECUs to support advanced power management techniques. That misses the fact that the central compute system is an ECU itself—and likely the most powerful and power-hungry in the entire vehicle. Advanced power management techniques are even more necessary as workloads are consolidated onto HPC-style compute systems. These may feature dozens of CPU cores, GPUs, and other accelerators that all individually can be power managed as necessary to support the specific workloads necessary for current vehicle state.

An additional challenge is that traditional Automotive safety standards, like ISO 26262, ironically discourage the use of lower power states in safety critical ECUs. The logic is that even deterministic sleep and wake-up states introduce variability not worth the risk for safe operation of vehicles. Consequently, there are no vehicle-level energy management intelligence in vehicle architectures of today.

### Vehicle Communication Buses

An ECU typically gets its input data from other devices and sensors which it then incorporates into calculations. The actions determined by the ECUs are subsequently employed by actuators during the normal operation of the vehicle. The need to exchange data quickly and reliably has led to the adoption of various communication technologies inside the vehicle, intensified by the addition of more complex and safety-critical use cases (e.g., like Advanced Driver Assistance Systems). Therefore, the vehicle architecture is now a mix of legacy low speed communication protocols and modern high bandwidth ones, where each of the vehicle busses has its own unique properties.

The CAN bus [10], [11] is the most widely used bus in modern vehicles. Every message on the CAN bus is broadcasted to all listeners, requiring each ECU connected to the bus to filter out messages addressed to it. CAN (and its successors, like CAN-FD) supports maximum bandwidth of up to 8Mbps depending on the length of the message [12].

The LIN bus [13], is a single wire, serial network that supports speeds of only 19.2 Kbps, and is used for Body Control ECUs.

Automotive Ethernet [14] is the automotive industry's variant of Ethernet that is customized for automotive use cases, in particular the use of a single twisted pair (vs. two twisted pairs in regular Ethernet) helps reduce cost but also limits bandwidth as Automotive Ethernet peaks at 150 Mbps.

As it will be discussed later, the variety and different characteristics of the different vehicle buses presents unique challenges for vehicle-level energy management.

## Section II: Foundational Power Management Concepts

This section introduces foundational concepts from PC power management standards such as ACPI, which has contributed to the energy efficiency of devices that we enjoy today.

At the highest level, the intent is for all ECUs in a vehicle to support multiple power operation states. This capability allows situationally aware, intelligent decision making for optimal power consumption by each individual component across the vehicle, neither performance nor safety is compromised.

Such an architecture consists of three distinct concepts—description, discovery, and control. With the ability to initially discover and subsequently control the power state of all ECUs in the vehicle, the opportunity then exists to optimize energy consumption across the entire platform.

## 1. Description

At the core of whole vehicle power management is the ability of the ECU to provide a description of its capabilities. Certainly, one would expect basic information like manufacturer name and model, but important for power management is detailed information such as power states the ECU supports.

Does the ECU support *System* states (S-states) where the entire ECU can be powered off or on? What about lower power system states? Meaning, something in-between off and on where some functionality may still be available? And how much time does it take to enter or exit any given state?

Within the ECU, perhaps there are various *Device* states (D-states) for sensors or other peripheral components inside or related to the ECU which it may have control over. For example, a Driver Monitoring System (DMS) ECU may have an interior facing camera. A park assist ECU may have exterior facing ultrasonic sensors that may or may not be always needed. This presents an opportunity to support lower power *Device* states where some sensors may be able to be turned off.

Further, nearly all ECUs will have other potentially power-hungry silicon which are associated with *Compute* states (C-states). For example, within an ADAS ECU, there is certainly an SoC at the heart of that function. However, does the SoC need to be at full power all the time with all 12 cameras and significant amounts of data being processed constantly as well? Are there use cases where only a subset of the cameras is needed, and so the ADAS SoC could enter a lower power operational state where only a subset of the cameras is in use without compromising vehicle safety?

With this hierarchy of *S-states*, *D-states*, and *C-states* along with the description of what the ECU does and how long it will take to enter or exit any of the defined states, we have the basic building blocks for intelligent whole-vehicle power management.

## 2. Discovery

With an ability to describe its capabilities, each individual ECU must be discoverable in order to share its description. We consider two different approaches for discovery: static and dynamic.

In a static discovery the location and addressability aspects of an ECU are defined in a static configuration format, such as a file, object store, or database. The inherent limitation of a static discovery method is that it must be manually created by the vehicle manufacturer. Any after-market enhancements or in-field repairs also present a challenge as the static configuration file would require updates.

Dynamic discovery provides flexibility to discover ECUs without having to predefine them. This method also supports the possibility that an ECU's capabilities might evolve and change over time. Firmware or software updates could add new power states or other control mechanisms useful for new use cases. This mechanism enables remote feature rollout and the flexibility for after-market enhancements, allowing seamless integration between the vehicle platform and power management capabilities.

3. **Control**

Once described and discovered, there then needs to be a mechanism to control the power states of each ECU.

This requires a defined interface within the ECU that can be invoked to effect change in a *System*, *Device*, or *Compute* state. Control interfaces should include methods and mechanisms to put an ECU, its device or compute elements into both a lower power state and higher power state.

Critical to the control interfaces is a deterministic (and typically atomic) state transition. While entering lower power states could take a variable amount of time without consequence (other than inaccuracies on expected power savings), wake up operations for most ECUs must be deterministic. This is especially important for safety-critical components as the consequences for a delay could be severe.

The final control element is the context-aware central arbiter that discovers and configures power management states for compute resources across the vehicle. This centralized intelligence will provide advanced power management across the inherently distributed vehicle platform. We believe that an opportunity exists for OEMs to innovate in their solution to this challenge in ways that can drive differentiation in the end-user experience.

## Section III: A Power Aware Vehicle Platform

Let us now extend these basic building blocks of intelligent whole-vehicle power management in an effort to achieve significant power savings.

### Mission Profiles

To assist in the coordination of power management components it would be useful to have predefined guidelines that provide a default level of guidance on ECU power states, which we term Mission Profiles.

Mission Profiles provide a baseline of situationally aware guidelines for powering commonly used components based on variables such as driving conditions, environmental factors, and safety concerns. For example, during EV charging, there are some ECUs that may not be needed, such as ADAS-related components. Further, a vehicle operating in the Arizona summer might not need to power the seat heater ECU; conversely, when driving in the Michigan winter any air conditioning components would be powered down.

In the case a driver wanted the seat heaters operational in the Arizona summer or the air conditioner blowing during a Michigan winter, those ECU can be woken up—with the latency defined in the ECU description. In most cases the vehicle occupant will barely notice a slight delay, which in these examples would be entirely acceptable considering the benefits gained.

It is possible for enhanced dynamic refinement of mission profiles beyond the above examples. Just as some modern vehicles turn off the engine while at a full stop, an ADAS system also may not be needed. At the least, it may not need to fully power every individual component while waiting for the vehicle to start moving again.

In any specific instance such events may not seem material, but when taken in aggregate over the lifetime of a full battery charge, the energy saving from situationally aware Mission Profiles could be significant.

**Dynamic Variable Voltage**

Once Description, Discovery and Control are implemented across the vehicle platform, measurable energy savings will emerge. This process creates the opportunity to reduce consumption, ultimately reducing energy production.

Why should an EV battery run at 800V consistently when there is now (due to whole-vehicle energy management) no longer a constant need for such energy?

As achieved in PC platforms over 20 years ago through the introduction of OS-controlled power performance states with ACPI [3], Dynamic Variable Voltage (DVV) adjusts the amount of energy inverted from the battery—so that the energy stored within can be conserved and only be tapped when needed.

**Advanced Component Telemetry**

Further optimization can be achieved by leveraging the extensive telemetry data collected by the central arbiter controlling in-vehicle power management. Data concerning component utilization and driver behavior form the foundation for insights that provide for continual optimization of both power generation and consumption.

For example, unexpectedly high utilization of HVAC ECUs on an EV in the previous 24 hours might influence battery charging algorithms. Further, patterns across a fleet of vehicles could identify either further optimizations for predefined Mission Profiles or even opportunities to create new Mission Profiles to achieve incremental power savings.

The possibility also exists to design and build differentiating services and features based on this advanced component telemetry data.

## Section IV: Call to Action

In this paper we documented the significant challenges that the EV industry is facing in supply chain and efficiency. Only a breakthrough in battery technology or an order of magnitude change in the amount of energy needed in an EV will move the industry forward.

We have proposed a whole vehicle energy management approach inspired by advancements in PC and IT equipment energy efficiency. If we apply these concepts to a vehicle platform for the first time, we believe central energy management for a vehicle platform is possible.

Such an architecture only works if an entire industry is invested. A more sustainable EV future cannot be delivered through proprietary innovation. A vehicle itself is comprised of ECUs from dozens of different suppliers—and only by industry cohesion and a common standard will we all benefit from more efficient EVs.

Join us in this effort to be part of a more sustainable EV future.

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