Achieving zero emissions in commercial vehicles

Dr. Luciana Caminha Afonso,
System Architect Commercial Vehicles – Infineon

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1 Abstract

While much has been written, discussed, and achieved in moving passenger vehicles to more environmentally friendly forms of energy, the commercial vehicles market is somewhat less advanced. For a greener future, electrifying the commercial road transportation sector is a key building block since, while commercial vehicles represent 5 percent of road traffic, they contribute 25 percent of emissions, according to the European Environment Agency.

Although battery electric solutions are preferred in smaller vehicles, other technologies such as hydrogen fuel cells are firmly on the agenda for heavier commercial vehicles. Anticipated to be a complementary technology that exists alongside battery electric solutions, fuel cells offer a number of substantial and unique benefits.

In this whitepaper, Infineon will highlight how things are shaping up in the commercial vehicles market and how different fuel sources suit different use cases. The paper will also look at the needs of this market, the challenges development engineers are facing, and some of the technologies required for success.

2 Introduction

While much of the focus on technology advancement in the automotive space is on passenger vehicles, commercial vehicles form an important sector that will benefit from electrification in the near future. The commercial vehicles sector encompasses construction vehicles that build our infrastructure, agricultural machinery that sow and harvest our food, and commercial transport vehicles that move and deliver absolutely everything we need for our modern lives. Infineon refers to this market segment as CAV: Commercial, Construction and Agricultural Vehicles.

While much of this fleet remains powered by diesel Internal Combustion Engines (ICE), work is at an advanced stage to develop new forms of reduced-emission propulsion. Similar to passenger vehicles, technology will play a key role in commercial vehicle safety, particularly in the provision of Advanced Driver Assistance Systems (ADAS). It will also feature enhanced connectivity from vehicle-to-vehicle as well as allowing vehicles to connect to the environment around them – all of which will enhance comfort, convenience, and safety.

While fleet operators play a significant role in demanding these enhancements, so too are governments through a number of regulations. In the European Union (EU), new emissions standards mandate that CO_2 emissions from new trucks must be 15 percent lower than 2019 by 2025, and by 2030, the reduction must reach at least 30 percent.

While gas emissions are the most often voiced concern, there is increasing evidence that particulate matter emissions should also be reduced. This year in the United States, the Environmental Protection Agency (EPA) published a proposed rule that would reduce emissions from heavy vehicles starting in 2027. Under the proposal, for certain classes of vehicles, Nitrous Oxides (NOx) would be significantly reduced and Greenhouse Gases (GHGs) would be subject to more stringent standards.

Greater China is expected to follow the EU with engine design standards by implementing more strict emission limits (China VI). Besides reducing greenhouse gases, these regulations also improve particulate emissions. Engine design also has a significant role to play in reducing audible noise, which is becoming more of a concern, especially in densely populated urban areas.

3 Drivetrains – competing or complementary?

Based on Infineon's market understanding, there were about 3.4 million trucks and buses produced in 2022. This includes medium trucks with a Gross Vehicle Weight (GVW) between 6 – 15 tons, heavy trucks (GVW > 15 T), and large buses (GVW > 6 T). However, more than 95 percent of these vehicles were powered by ICE.

The primary markets during this decade for electrified trucks and buses are expected to be the EU, United States, and Asia. However, things are changing rapidly in terms of the propulsion methods deployed, as well as local market dynamics fueled through their respective legislation.

While the overall market will show a Compound Annual Growth Rate (CAGR) of 3.7 percent between 2022 and 2030, the market for commercial Battery Electric Vehicles (BEV) is expected to see a CAGR of 42.1 percent in the same period, and Fuel Cell Electric commercial Vehicles (FCEV) are predicted to grow at a CAGR of 53.4 percent. While it can be argued that these growth rates are from a very small installed base, it does indicate the direction the market is moving – and the speed at which it is going. In fact, Infineon predicts that, in 2030, almost 600,000 BEV trucks and buses will be produced, along with around 225,000 FCEV versions.

In the future, there will be at least three powertrain options available for commercial vehicles – battery electric, hydrogen, and diesel. While it might seem that there would be a free choice to decide which is "better" or preferred, in reality, the use case for the vehicle in terms of vehicle size, load to be carried, and distance to be travelled will determine the optimal drivetrain for each application. And certainly, government regulations, infrastructure development, industry standards, and energy cost development will play a significant role in the adoption of the different drive train solutions.

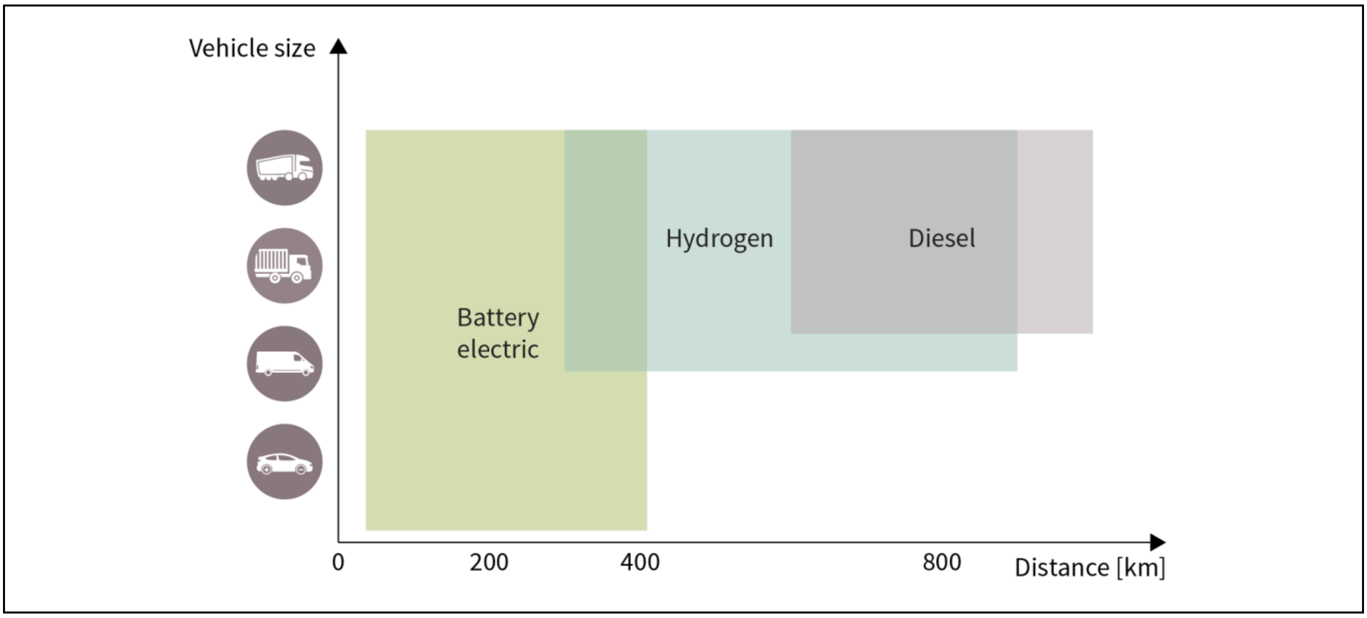

Figure 1 The size and range of the commercial vehicle will determine the drivetrain

Looking from a technical point of view with today's available technology in mind, there will be some overlap where choices will exist but, in general, Battery Electric Vehicles (BEV) will be used for all vehicle sizes where the driving range does not exceed approximately 300 km. Hydrogen will dominate for larger (medium and heavy-duty) vehicles that will be required to travel between 300 and 800 km, while diesel-based ICE will be used for medium and large vehicles travelling more than 500 km. However, these generalizations could change in the future due to innovations like cheaper, lighter, and smaller batteries. The development of infrastructure such as megawatt chargers or hydrogen fueling stations will also be key to the success of a particular solution.

Cost will also be an important factor, in terms of the long-term running costs (maintenance and fuel), as well as the initial cost of the powertrain. The UK-based Advanced Propulsion Centre built a projection of system costs based on a Nikola motor BEV and Hyzon Motors FCEV, both with 44-ton capacity.

Table 1 System costs will change significantly over the next decade

	2025	**2035**
Diesel	Ca. $ 19k	Ca. $ 25k
BEV	Ca. $ 77k	Ca. $ 51k
FCEV	Ca. $ 61k	Ca. $ 31k

Note: 44t long-haul trucks & system cost predictions of the Advanced Propulsion Centre UK, 2021

Clearly, with greater adoption of both BEV and FCEV, the system costs will reduce significantly over the next decade. Subsequently, changes in the Total Cost of Ownership (TCO) means that one technology may eventually outperform the other in the race between FCEVs and BEVs.

While many may make a claim that one technology is "better" than the other, this statement cannot be made with any accuracy. There are many factors to consider, including environmental effects, acquisition costs, and operating costs to arrive at a TCO – and this will vary for each and every use case. Even with this, local legislation and policy may well change the TCO over time. Clearly both technologies have their merits and Infineon offers full product portfolios and in-depth knowledge about both.

However, for the purposes of this whitepaper we will focus on FCEV.

4 Value proposition for FCEV

In order to fully comprehend the value of FCEV, it is necessary to look beyond the vehicle itself and consider the wider picture, including the supply chain for the powertrain and fuel, benefits for the vehicle operator, and the infrastructure required to support a mass rollout of the technology.

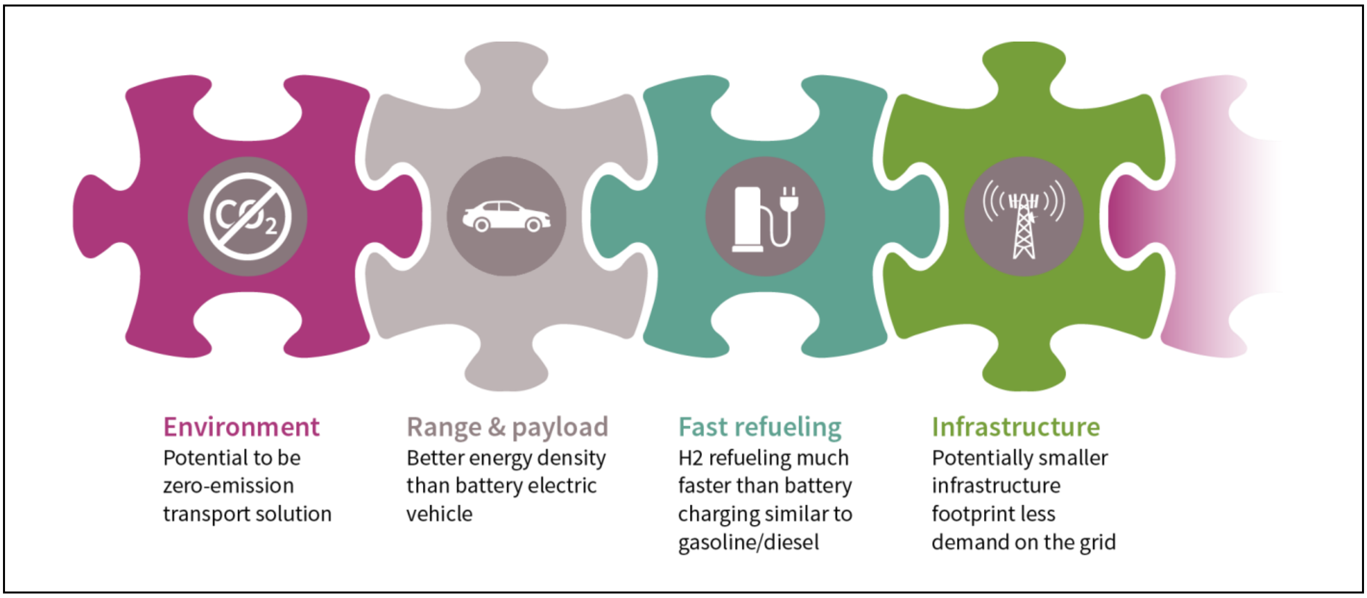

Figure 2 FCEV delivers a number of benefits and advantages, alongside the vehicle technology

In the case of FCEV, there is a clear benefit to the environment as there is no harmful exhaust emission at all. With vehicle pollution being linked to health and other issues, the improved air quality will be a significant benefit to the environment, as well as being a key contributor to the achievement of CO_2 emissions targets.

FCEV will offer a longer range than BEV and, as the weight of the FCEV system is about one-third of a BEV system (3,000 kg vs. 9,000 kg) the vehicle will have an enhanced payload, giving greater flexibility for vehicle operators.

While charge time for BEV will have little impact on daily operation, provided that the vehicle is not required to travel further than a single charge will allow, this does put a hard limit on daily range. FCEV can be refueled in the same way as ICE vehicles, dispensing a liquid fuel from a pump at a filling station. Additionally, advances in hydrogen production, combined with greater usage in multiple applications, is expected to reduce the cost of this fuel – a critical factor for widespread adoption of FCEV.

A rollout of commercial BEV will require a significant enhancement of the grid and the provision of a significant number of charging stations that are capable of replenishing a commercial battery vehicle when it is not in use. FCEV will also require infrastructural upgrades such as cooling and high-pressure equipment to store, transport, and dispense hydrogen. However, compared with current battery technologies, a single hydrogen pump can replenish many more vehicles in a day than a single battery charging station as the filling time is minutes, not hours.

There are other benefits of FCEV that contribute to its value proposition for operators. Firstly, it is able to operate in temperatures as low as -30°C and, as heat is generated, this can be used to warm the cabin – eliminating the need for an energy-sapping electric heater. Additionally, the battery required is much smaller than that of a BEV, significantly reducing the environmental impact of battery products. Lower amounts of rare earth metals are needed, and FCEV batteries can be recycled in a more environmentally-friendly way.

5 Success factors in FCEV development

For developers to be successful in the rapidly developing FCEV market, there are a number of requirements that must be met. Vehicles must be delivered to market quickly to capitalize on the market opportunity, they must be safe and protected against undue outside influences, and they must be efficient and backed by a strong and resilient supply chain. Designs must continue to evolve to take advantage of new technologies while continuing to meet changing legislation and operator requirements.

Infineon can support developers in all of these areas. With a comprehensive range of products, Infineon enables complete system solutions. In many cases, these products may be identical or similar to other applications, dramatically shortening the learning curve.

Safety and security are an integral part of the Infineon development process, and with extensive experience in Functional Safety (FuSa), their products are ideally suited to critical automotive applications.

Leadership in energy efficiency comes from Infineon's extensive experience in new semiconductor technologies including Wide Bandgap (WBG) materials such as Silicon Carbide (SiC) that offer far greater efficiency and robustness. This is backed by Infineon's dependable supply chain that is based on multi-site manufacturing for resilience.

6 Overview of Infineon solutions for FCEV

There are many electronic systems within a FCEV, although the primary two are the Fuel Cell Control Unit (FCCU) and the DC-DC converter. Together they require a broad range of components including MCUs, power switches, sensors, and data security solutions.

The fuel cell stack integrates more than 300 fuel cells that generate between 200 V to 350 V in an ambient temperature that can be as high as 80°C. Each fuel cell has a voltage of less than 1.2 V and several cells can be monitored by connecting them in series.

The FCCU manages process control for the complete fuel-cell system and requires a broad portfolio of solutions to allow for flexibility and fast time-to-market, as well as Functional Safety (FuSa) support.

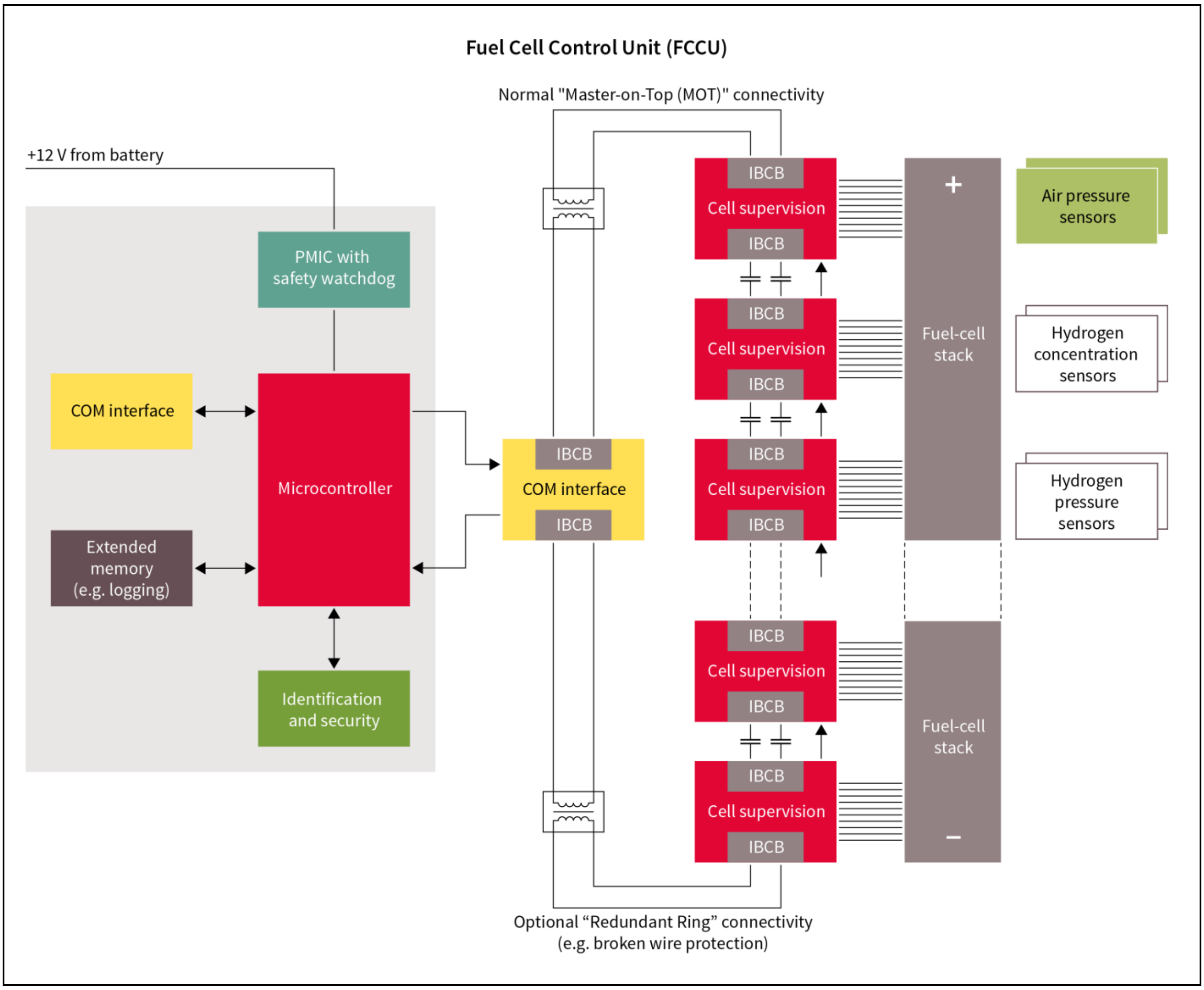

Figure 3 The FCCU requires a broad range of solutions

Infineon offers a broad range of industry-leading solutions that are ideally suited for use in automotive applications, including the FCCU in commercial vehicles:

- AURIX™ TriCore™ microcontrollers combine a RISC processor core, a microcontroller and a DSP into one single MCU that is suited to a wide range of automotive applications including the control of fuel cell systems, electrical and hybrid vehicles, transmission control units, chassis domains, braking systems, electric power steering systems, airbags, connectivity, and Advanced Driver Assistance Systems (ADAS).
- OPTIREG™ Power Management Integrated Circuits (PMIC) are integrated, multi-rail supply solutions for demanding automotive systems covering applications such as chassis, safety, ADAS, powertrain, and drive train. OPTIREG™ delivers efficient, reliable and safe voltage regulation, including pre- and post-regulator architectures, and DC-DC, linear, and tracking regulators. In-built additional monitoring and supervision functions simplify design of the safety concept where required.
- Security is delivered by the OPTIGA™ TPM SLI 9670, a quality-hardened Trusted Platform Module (TPM) specifically designed for use in automotive applications. The device is based on a tamper-resistant, hardware-secured microcontroller that can be flashed with securely coded firmware that meets TCG family 2.0 specifications. The SLI 9670 is qualified to the AEC-Q100 standard and also security-certified according to Common Criteria EAL4+.
- Battery management ICs, such as the TLE9012DQU, are designed to work with AURIX™ microcontrollers and FuSa- capable PMICs. This delivers voltage and temperature sensing, as well as balancing and communication across a variety of battery and fuel cell solutions, ensuring that the battery or cell operates safely to comply with FuSa requirements. Infineon battery management ICs meet safety requirements up to ASIL-D and are ISO 26262-compliant.
- The TLE9015DQU is a battery monitoring transceiver IC designed for connecting several TLE9012DQU devices in a daisy chain. With two UARTs, it can support ring communication, thereby improving system availability and supporting bidirectional information flow.
- A transceiver is required to connect the FCCU to the wider system. The Infineon portfolio is centered around the LIN and CAN protocols supporting network speeds from 20 kbit/s (LIN) up to 8 Mbit/s (CAN FD SIC). All of devices are ideally suited to the challenging automotive environment as well as being designed to meet and exceed the latest ESD and EMC requirements.
- Barometric Absolute Pressure (BAP) sensors have multiple automotive applications including ECU management and seat comfort. However, measuring the hydrogen pressure inside the fuel cell is a key safety requirement. BAP sensors can be digital or analog, producing a ratio metric analog voltage or digital SPI protocol data Infineon’s XENSIV™ sensors offer excellent accuracy of up to 1.0 kPa over a wide temperature range and an available pressure range from 40 kPa to 200 kPa.
- FRAM (Ferroelectric Random Access Memory or FeRAM) is a stand-alone nonvolatile memory that enables the instant capture and preservation of critical data when power is interrupted. They are ideal for mission-critical automotive data-logging applications where low-power consumption, small footprint, instant non-volatility and virtually unlimited endurance are required.

The second unit within a commercial FCEV is the DC-DC converter that adapts the voltage generated by the fuel cell stack to the required DC link voltage. A special DC-DC profile is used to warm up the fuel cell for cold starts and also to shut it down correctly after use.

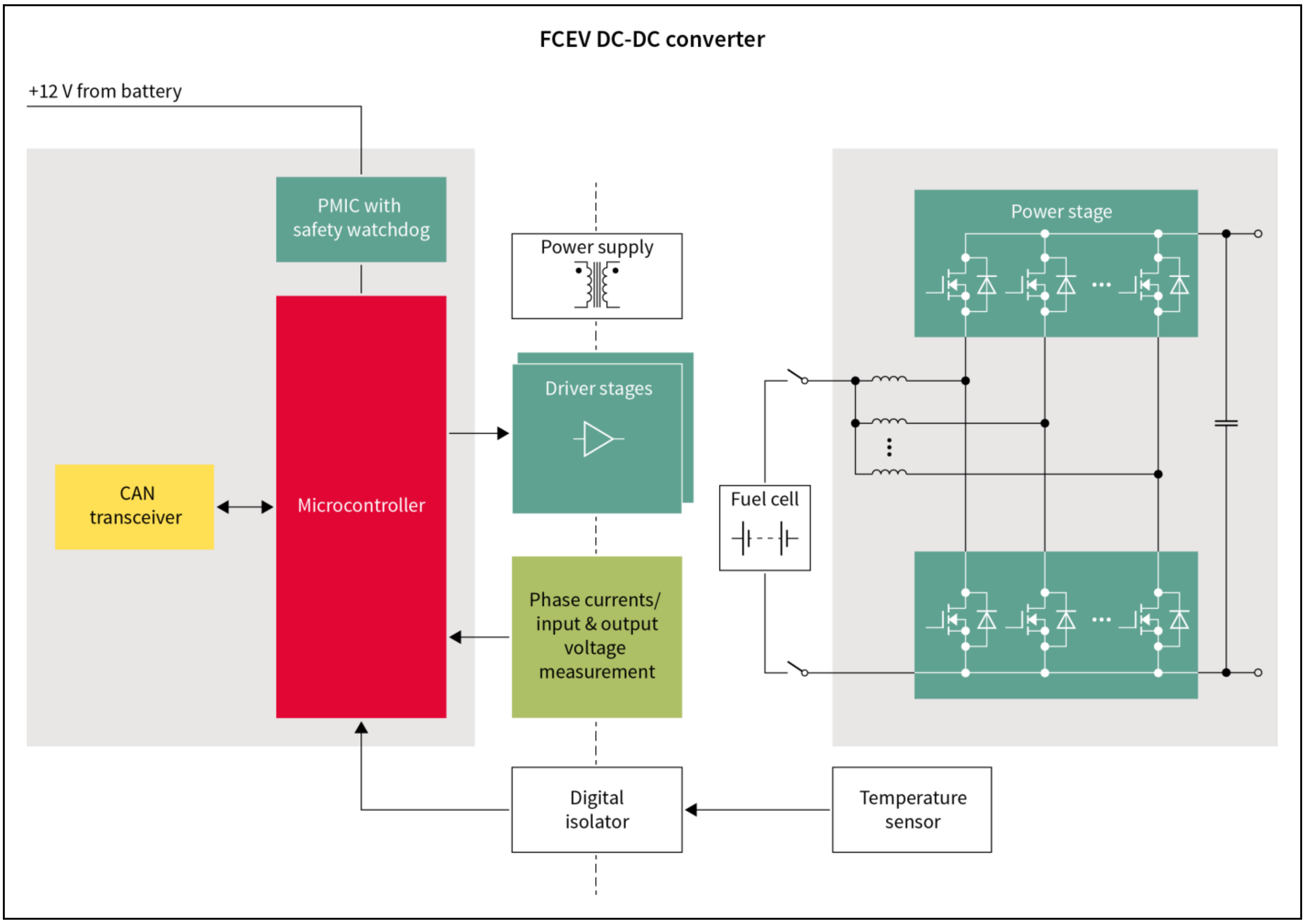

Figure 4 The DC-DC converter produces the DC link voltage from the fuel cell stack voltage

Several technologies used in the FCCU are also used in the DC-DC including the microcontroller, PMIC, transceiver, and XENSIV™ sensors. However, there are other technologies which are required for power conversion that are not used in the FCCU:

- Silicon Carbide (SiC) diodes and transistors are essential to achieve the efficiencies and power densities demanded by modern power electronics. Use of a SiC diode in combination with a silicon IGBT extend the capabilities of IGBT technology, enhancing the efficiency with this hybrid approach. CoolSiC™ hybrid products create a price-performance bridge between pure silicon solutions and high-performance designs, made entirely of SiC MOSFETs.
- In order to operate at optimum efficiency, it is essential that the power switches receive the correct gate driver. Infineon offers more than 500 EiceDRIVER™ gate driver ICs that are suitable for any power switch, and any application – including FCEV DC-DC. These devices provide a wide range of output current options, from 0.1 A up to 10 A and include protection features such as fast short-circuit protection (DESAT), active Miller clamp, shoot-through protection, fault, shutdown, and over-current

protection. EiceDRIVER™ ICs are well-suited to silicon and wide bandgap power devices, including CoolGaN™ and CoolSiC™.

- Infineon current sensors are also part of the XENSIV™ range and they provide accurate and stable current measurement in 48 V, as well as high-voltage applications such as fuel cell DC-DC, traction inverters, industrial drives, photovoltaic inverters, or battery disconnect systems. These coreless open-loop sensors are based on precise and stable Hall technology, thereby ensuring that the output signal is highly linear over temperature and lifetime. Designers can program the sensitivity of the sensor as well as the threshold levels of the two dedicated overcurrent signals and thus adapt them to individual requirements without any external components. The sensor also provides a signal, in case of an over or under-voltage condition for the supply voltage. The XENSIV™ TLI4971 offers best-in-class thermal performance due to its innovative TISON-8 package, as well as isolation against high voltages. The XENSIV™ TLE4972 is an ISO 26262 Safety Element out of Context (SEooC) for safety requirements up to ASIL-B and measures currents up to 2,000 A.

7 Summary

The need for efficiency and significant emissions reductions is driving unprecedented change in the automotive industry. The choice of alternative energy sources for commercial vehicles is currently focused on two technologies – the battery and the fuel cell.

For larger commercial vehicles that have to travel longer distances, fuel cells make more sense as they are a completely zero-emission technology that put no load on the electrical power grid. Indeed, they can be refueled in minutes at filling stations, once they have been adapted to dispense hydrogen. Costs will fall rapidly as adoption increases, ultimately leading to a significant number of commercial FCEV on the roads in the near future.

Designing these vehicles for reliability and efficient operation requires a broad range of semiconductor products including MCUs, security, power, sensing, and more. With their background in automotive applications and experience in FuSa, along with a product range encompassing MCUs, MOSFETs, SiC devices, gate drivers, memory, security ICs, monitoring ICs, and sensors, Infineon is uniquely positioned to offer comprehensive solution sets to support the design of commercial BEV and FCEV drive trains.

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