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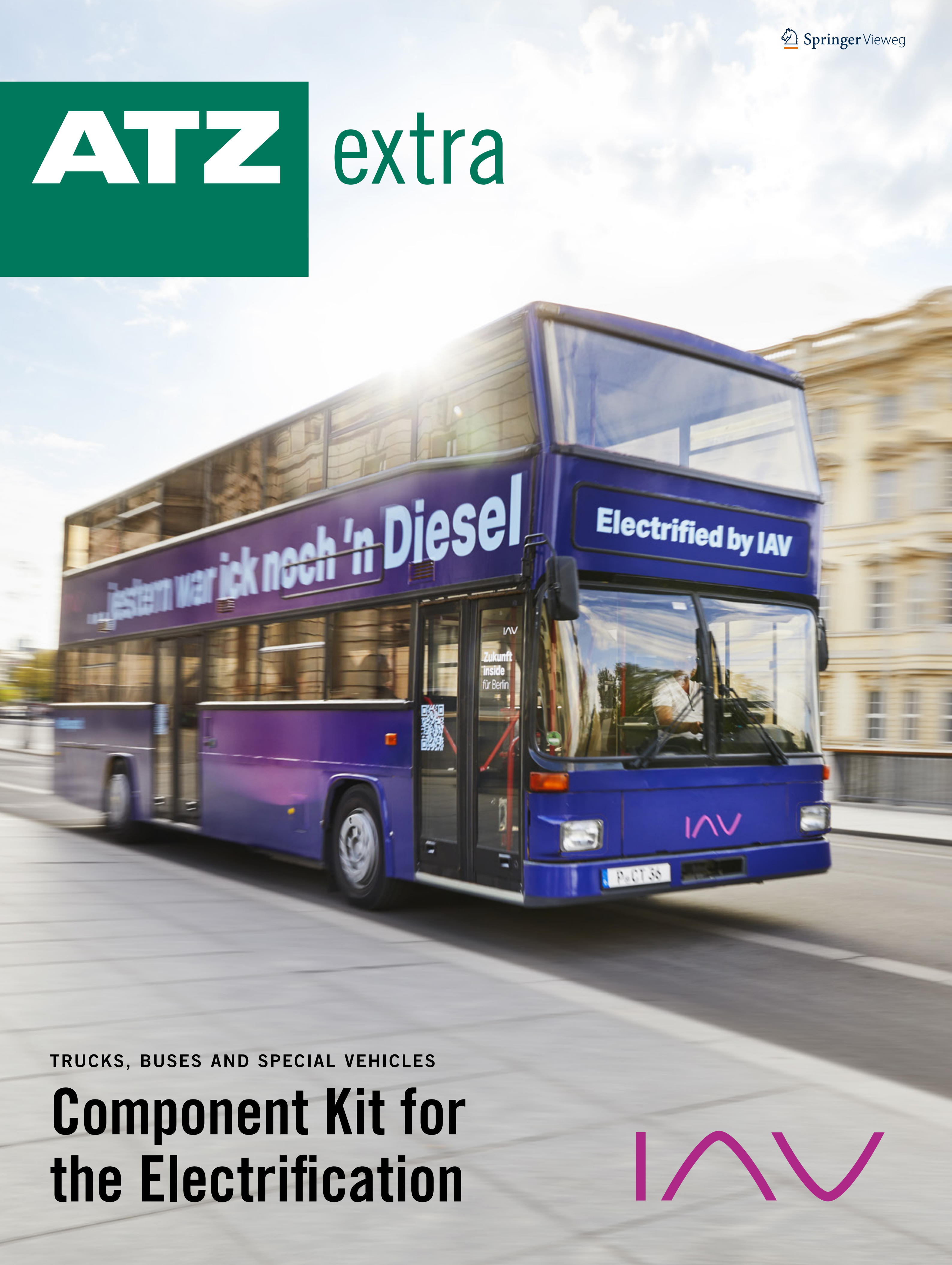

TRUCKS, BUSES AND SPECIAL VEHICLES

Component Kit for the Electrification

Modular Component Kit for the Electrification of Conventional Commercial Vehicles

Based on its development processes for electric vehicles, IAV has developed a modular component kit for the electrification of existing and new vehicles that meets the high customer-specific and regulatory standards. Besides new vehicles the component kit will give long-serving commercial vehicles a second life with a modern and emission-free propulsion system.

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The electrification of commercial vehicles results in a significant reduction of local pollutant and noise emissions and contributes to the reduction of global emissions of air pollutants and greenhouse gases if based on renewable energies [1]. A very good well-to-wheel energy efficiency [2] compared to Fuel Cell Electric Vehicles (FCEV) speaks for the use of battery-electric drive systems in commercial vehicles. However, due to the limited energy storage capability and heterogeneous charging infrastructure, their use currently makes sense mainly in light and medium-duty commercial vehicles as well as in local and delivery traffic.

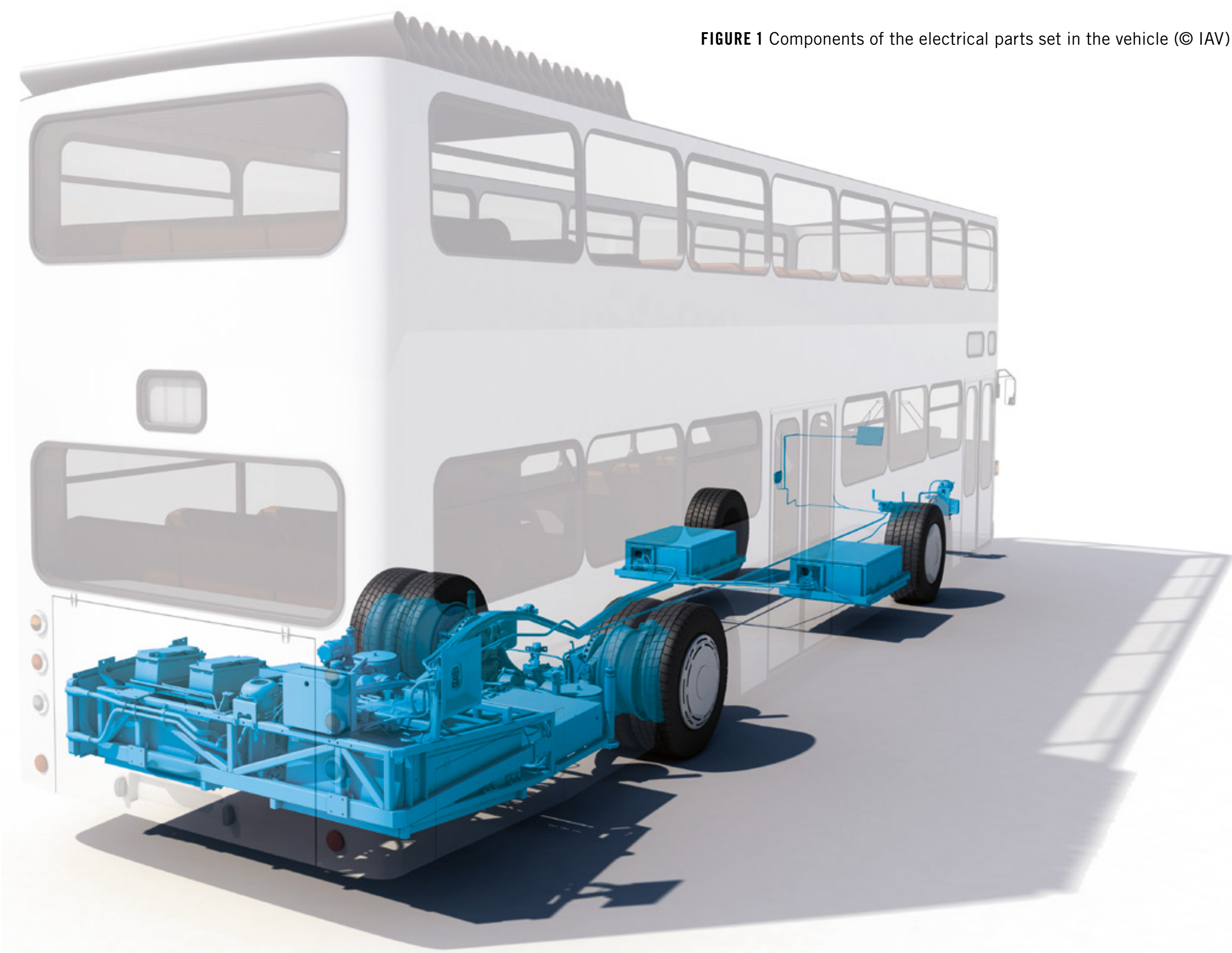
The development of a modern electric drivetrain requires high investments and can often only be implemented by large vehicle manufacturers. To date, many commercial vehicle manufacturers purchase the diesel-engine powertrain and do not possess their own powertrain development. In combination with insufficient economies of scale, this results in a very limited variety of vehicle applications. As a result, the change toward climate-friendly mobility is slowed down by a limited offer, high costs and uncertain boundary conditions [3]. In this context, retroactive electrification (retrofit) of commercial vehicles, which is explicitly subsidized as part of an EU funding directive for clean buses, has an accelerating effect [4].

PRODUCT DESCRIPTION COMPONENT KIT

In the initial application, IAV has specified its component kit for the electrification of commercial vehicles for existing double-decker buses of the MAN SD 200 and 202 series, **FIGURE 1**. These bus types are often still in use by city tour operators and are not equipped with suitable exhaust gas aftertreatment. Besides the propulsion, the main functions of the component kit include the supply and control of auxiliary units and the monitoring of the High Voltage (HV) and propulsion system. The payload and seating capacity of the base vehicle will not be affected by the conversion.

The system architecture shown in **FIGURE 2** covers the functional and regulatory requirements of an electric sightseeing-bus, considering the existing bus architecture and electric components available on the market. The highly integrated propulsion unit is based on an electric axle module with two permanent-magnet synchronous wheel hub machines, **TABLE 1**. The electric energy is provided by an HV battery system consisting of four high-voltage battery trays with battery modules from a series production passenger car. The core element is the central vehicle control system (ECU) consisting of two individual control units. These are based on robust ECUs from an external supplier. The functional software was developed by IAV. The direction of travel is selected via a Drive-Neutral-Rear (D-N-R) selector lever, the acceleration and braking requests are inputs from the corresponding pedal modules. A central display unit with touch display informs the driver about consumption values, range, warning, and error messages and provides camera images. An adjustable HV heater was integrated to ensure that the driver's

FIGURE 1 Components of the electrical parts set in the vehicle (© IAV)



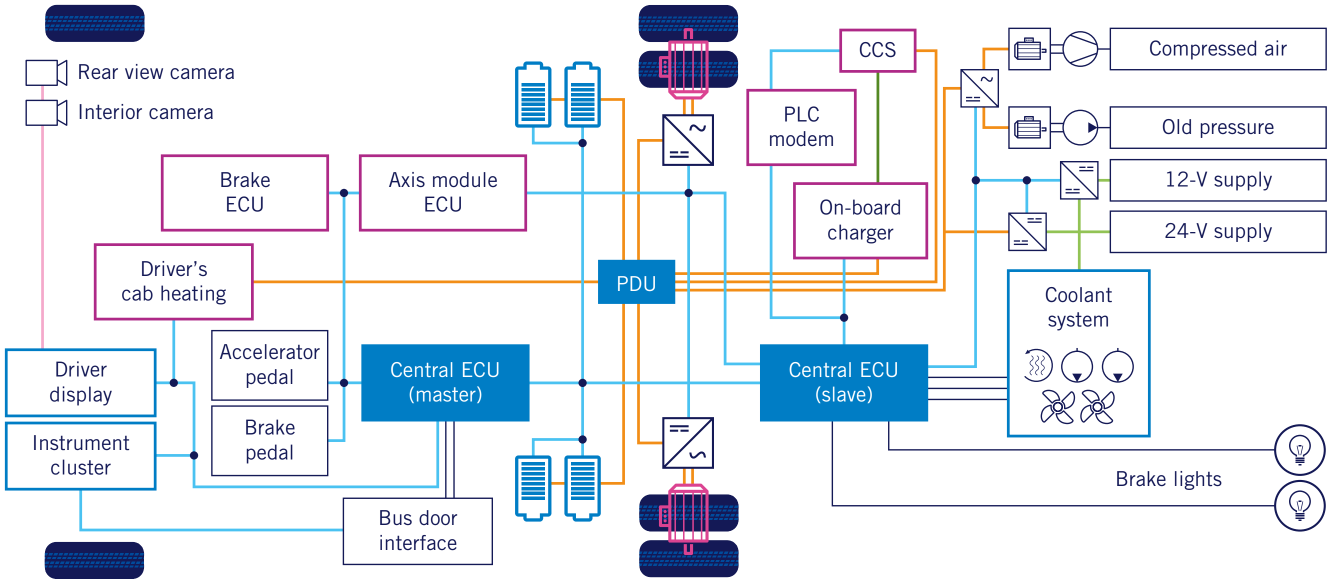


FIGURE 2 Schematic representation of the system architecture (© IAV)

compartment is free of fogging and heated. The brake circuits are supplied by the HV compressor with a maximum system pressure of 8.5 bar. In addition, all vehicles are upgraded with an Electronic Braking System (EBS). This enables the vehicles to be equipped with an Anti-lock Brake System (ABS) and with regenerative braking by means of a modern brake blending function. The steering is supported by a HV oil pressure pump. The on-board charging system is equipped with a modem and standardized HV connectors and accepts both direct and alternating current.

OVERALL SYSTEM DEVELOPMENT

The project assignment included the development of a uniform component kit for the two abovementioned vehicle types in compliance with market and system requirements. The product development was based on IAV's engineering process for powertrain systems along the V model. All system and component requirements were documented using a tool that enables proof of continuity via linkage checks. The system architecture with the corresponding software architecture was derived from the requirements.

To detect possible hazards early on and to ensure safe operation in all operating modes, a consistent safety

Voltage level	800 V
Installed battery capacity	147 kWh
Propulsion power (rated/peak)	2 × 120 kW/200 kW
Wheel torque (rated/peak)	2 × 3700 Nm/8750 Nm
Maximum vehicle speed	65 km/h (limited)
Power consumption (20 °C, sightseeing cycle Berlin)	0.8 kWh/km
Range (20 °C, sightseeing cycle Berlin)	120 km minimum

TABLE 1 Technical data of the MAN SD 200/202 with IAV component kit (© IAV)

concept has been implemented. The basis for this is a hazard and risk analysis, which was developed by experts and is based on the results of corresponding driving tests. The

integration of hardware and software components required the application of functional safety principles. The components procured from external suppliers were formally integrated via a Development Interface Agreement (DIA). Another relevant component in this context is a Battery Management System (BMS), which is compliant with the functional safety specifications. This requirement has been achieved by a component kit-specific adaptation of the BMS by the supplier. On the propulsion side, the requested torques are continuously monitored and checked for plausibility. If defined limits are exceeded, a system shut-down is triggered.

The use of a component-bearing auxiliary frame in the installation space of the former diesel powertrain reduces the effort required for conversion and maintenance. The additional electronic components are housed in the installation space of the existing central electric system or on the auxiliary frame, while the axle module uses the installation space and fastening points of the original rear axle.

The integration of components and systems was executed in two stages. Initially, the mechanical and electrical interfaces to the basic vehicle were evaluated on the basis of prototypes. Afterwards, pre-production vehicles were built using the installation manual and put into operation to check the interaction of all system functions in accordance with the specified requirements. Before the software was installed, appropriate integration and HV safety tests were carried out.

The production preparation of the component kit was executed during the development phase through defined maturity and prototype stages. The drive motors are maintenance-free over a service life of ten years. The HV batteries are designed for a service life of ten years and must be technically checked during the maintenance intervals. To evaluate and validate functional and approval-relevant properties, tests were performed on a proving ground with prototypes of the respective vehicle type. The applicable ECE regulations for electric and commercial vehicles were used for the approval and certification tests, which were carried out in consultation with a technical testing organization. The ABS and the brake performance was tested and calibrated on the test site of the brake system manufacturer. The applicable legal requirements for Electromagnetic Compatibility (EMC) were verified based on individual component tests but also by evaluation of the entire vehicle in an EMC test chamber. System functions were tested and validated with HiL-test benches at control unit level prior to vehicle testing, **FIGURE 3**. The individual

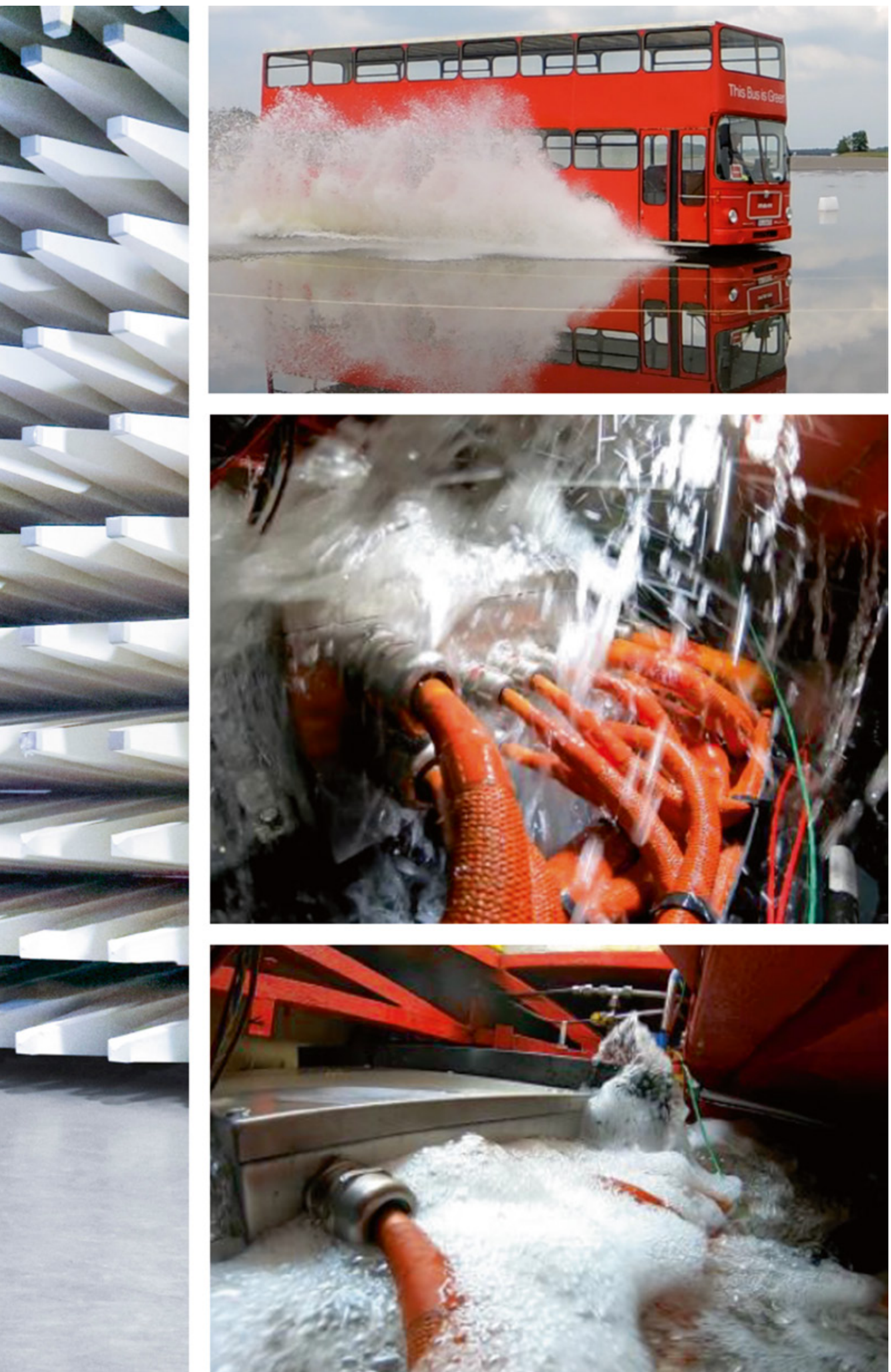
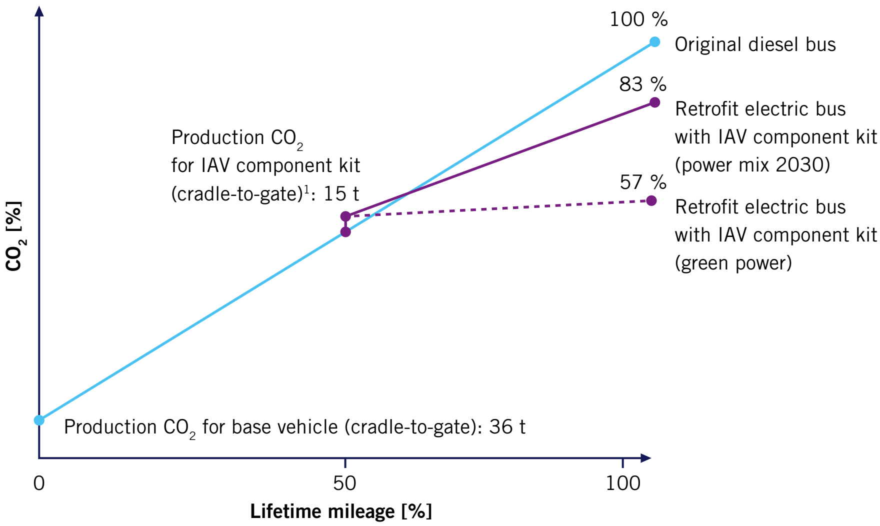


FIGURE 3 Design verification of the entire vehicle in an EMC laboratory and on the proving ground (© IAV)



Assumptions for CO_2 analysis:
Production of base vehicle (diesel): 36 t CO_2 (cradle-to-gate)
Production of IAV component kit: 15 t CO_2 (cradle-to-gate)[1]
City bus (diesel) operation (based on 32 l/100 km): 720 g/km CO_2 → 360 t CO_2/500,000 km
City bus (BEV) operation with IAV component kit (based on 100 kWh/100 km):
Power mix 2030: 216 g/km CO_2 = 54 t CO_2/250,000 km
Green power: 24 g/km CO_2 = 6 t CO_2/250,000 km
[1] Power mix for the production of IAV component kit: 100 % renewable

FIGURE 4 CO_2 saving potential compared to a conventionally powered vehicle (© IAV)

results form the basis for the certification report, which guarantees an uncomplicated registration of the converted vehicle. Currently, fleet testing is taking place using typical sightseeing routes to validate the overall system.

EFFICIENCY AND EMISSIONS

The propulsion concept has a very good efficiency and achieves a power consumption value of approximately 80 kWh/100 km at approximately 12 t vehicle weight (curb weight). This enables the use of smaller batteries with cost and energy savings. With the installed battery capacity, the retrofit vehicle achieves a minimum range of 120 km in customer-specific operating and all load conditions. With a low payload, depending on the topology of the routes, a range of over 200 km is possible, which can be further optimized in future driving tests.

Compared to the base vehicle MAN SD 200/202 with diesel engine, the electrified vehicle is locally emission-free [2]. If green electric power is used for operation, no regulated air pollutants such as NO_x are emitted globally either. Depending on the power mix, the very good efficiency of the propulsion system can significantly reduce the CO_2 footprint per kilometer, **FIGURE 4**, and may result in a favorable TCO balance for the BEV [5]. The possibility of secondary use (second life) extends the useful life of long-serving diesel vehicles, thus avoiding waste in production and disposal and saving energy-intensive materials such as aluminum. Due to the high mileage of commercial vehicles, the CO_2 savings from operation outweigh the savings in production significantly. Due to the gearless propulsion, the driving noise is reduced to a minimum, so that passengers mainly hear rolling, suspension, and braking noises. The stationery and pass-by noise is 71 dB(A) according to 70/157/EEC.

SUMMARY AND OUTLOOK

The modular component kit from IAV enables medium-sized bus manufacturers to enter electric mobility quickly and economically and, thus, contributes to an improved air quality and quality of life in urban areas. The current design with a battery-based energy storage can also be integrated in other bus types as an underfloor solution due to the modular design but requires adaptations and renewed certification tests.

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