



MOTOR VEHICLE TECHNOLOGY

ELECTRIC VEHICLE MAINTENANCE AND REPAIR

2023-2-TR01-KA210-VET-000180148

New Applications in Electric Vehicle Technology According to 4.0 Standards



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EXPLANATIONS

AREA	Motor Vehicle Technology
PROFESSION	Electric Vehicles
MODULE NAME	Electric Vehicle Maintenance and Repair
MODULE DESCRIPTION	This learning material aims to provide knowledge and skills on an introduction to electric vehicle (EV) technologies, basic components, maintenance differences with internal combustion engine (ICE) vehicles, basic maintenance and repair procedures of EV systems (battery, motor, power electronics, brakes, cooling, charging), safe working methods (PPE, LOTO) in high voltage systems, necessary special tools and equipment, predictive maintenance techniques, battery life management and recycling, technician competencies and related occupational health and safety (OHS) issues.
PROFICIENCY	Carrying out basic and advanced maintenance and repair operations of electric vehicles in accordance with high voltage safety procedures and manufacturer standards.
PURPOSE OF THE MODULE	<p>General Objective</p> <p>Participants will be able to identify the systems and components of electric vehicles, identify maintenance and repair needs, perform basic and some advanced maintenance/repair procedures in accordance with high voltage safety regulations, and gain knowledge about related technologies.</p> <p>Objectives</p> <ol style="list-style-type: none"> 1. Explain the basic components of electric vehicles (battery, motor, power electronics, charging system, etc.) and their operating principles. 2. Compare the advantages and disadvantages of different EV

	<p>motor types (PMAC, induction, etc.).3</p> <p>3. Compare the maintenance requirements and costs (TCO) of electric and internal combustion engine vehicles.5</p> <p>4. Perform basic maintenance of EV battery systems (charge management, SoH control, thermal management).7</p> <p>5. Perform basic maintenance checks of electric motors, drivetrains, brakes, and cooling systems.</p> <p>6. Explain the importance of charging infrastructure and vehicle software updates in maintenance processes. 9</p> <p>7. Identify the hazards in high voltage (HV) systems and explain relevant safety standards (ISO 6469, EN 60903, etc.). 10</p> <p>8. Select, use, and inspect the Personal Protective Equipment (PPE) required when working on HV systems. 13</p> <p>9. Implement procedures for safely de-energizing and lockout/tagout (LOTO) high voltage systems. 14</p> <p>10. Identify the basic and specialized tools, diagnostic devices, and lifting equipment required for EV maintenance and repair. 11.</p> <p>11. Explain the concepts of predictive maintenance and remote diagnostics and the technologies used (AI/ML, sensors). 16</p> <p>12. Explain the recycling (hydrometallurgy, pyrometallurgy) and second-use applications of EV batteries. 18</p> <p>13. List the training, certification (ASE, IMI, MYK/TSE), and OHS requirements (including relevant Turkish legislation) required for EV technicians.</p>
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1. ELECTRIC VEHICLE BASICS AND MAINTENANCE DIFFERENCES

With this learning activity, you will understand the fundamental building blocks of electric vehicles (EVs), how they operate, and how they differ from traditional internal combustion engine (ICE) vehicles in terms of maintenance.

1.1. Basic Components and Operating Principle of Electric Vehicles

Electric vehicles (EVs) are vehicles that store energy in rechargeable batteries and use this energy for propulsion through one or more electric motors. While they have a mechanically simpler structure than traditional internal combustion engine (ICE) vehicles, they incorporate advanced electrical and electronic systems.

The main components are: the battery (RESS), battery management system (BMS), electric motors, power electronics units, charging system, cooling system, drivetrain, and regenerative braking mechanism.

1.1.1 Battery (Rechargeable Energy Storage System - RESS)

It can be thought of as the "fuel tank" of an EV. It is a large lithium-ion battery pack, typically located in the vehicle's floor. It is charged from an external electrical source (household outlet, charging station). The battery is the most important component that determines the vehicle's range, performance, and cost. The ISO 6469-1 standard specifies the safety requirements for these batteries.¹¹

1.1.2 Battery Management System (BMS)

It acts as the brain of the battery. It continuously monitors and manages the voltage, temperature, state of charge (SOC), and overall health (SOH) of each cell.⁷ The BMS ensures the battery remains within safe operating limits, prevents overcharging or discharging, balances the cells, and helps maximize battery life.²³

1.1.3 Electric Motor

It converts electrical energy from the battery (which can be direct current (DC) or alternating current (AC)) into mechanical energy (torque) that turns the wheels. The main types of motors used in EVs are:

- **AC Induction Motors (Asynchronous Motors):** They operate on the principle of electromagnetic induction. Its rotor contains windings or bars, and current is induced by the rotating magnetic field created by the stator windings.³ These motors are generally known for their robust construction, relative simplicity, and lower initial cost.⁴ They can provide high power at variable speeds.⁴ However, they generally have lower efficiency (especially at low loads and speeds) and lower power density (they tend to be larger and heavier for the same power) compared to Permanent Magnet Synchronous Motors (PMSMs).³
- **Permanent Magnet Synchronous Motors (PMSM):** Their rotors contain powerful permanent magnets.³ These magnets interact with the magnetic field created by the stator windings to produce rotation.³ PMSMs generally offer higher efficiency (especially over a wide speed range), higher power density (more compact and lightweight design), better torque production (especially at low speeds and even when

stopped), and faster dynamic response (acceleration/deceleration) than induction motors.³ These advantages can translate into better range and performance in EVs. However, initial costs can be higher due to the rare-earth magnets used. ³ Additionally, magnets can be sensitive to high temperatures and run the risk of partially or completely demagnetizing (losing their magnetism) in situations of excessive current or temperature. ³ Control systems are also generally more complex than those of induction motors. ³

- **Other Types:** Other motor types, such as Brushless DC Motors (BLDC) and Switched Reluctance Motors (SRM), are also used in EVs, but AC Induction and PMSM are the most common. ⁴ BLDC motors, due to their brushless nature, require less maintenance and have a longer lifespan. ²⁴
- The choice of motor type determines the overall characteristics of the vehicle. For example, the high efficiency and power density offered by PMSMs has led many modern EV manufacturers to favor them.²⁵ However, this requires technicians to be familiar with the potential issues (e.g., temperature sensitivity, risk of demagnetization, complex control systems) and maintenance requirements specific to PMSMs.³ The robustness and cost-effectiveness of induction motors, however, continue to be an attractive option for some manufacturers.⁴ Knowing the type of engine in the vehicle they are working on helps technicians predict potential failure modes and apply accurate diagnostic methods.

1.1.4 Power Electronic Converters

These are critical components that convert electricity from the battery into the appropriate form for the motor and other systems.

- **Inverter:** Converts the DC voltage generated by the battery into the AC voltage required by AC motors (induction or PMSM). It adjusts the frequency and amplitude of the AC voltage to control the motor's speed and torque.
- **DC-DC Converter:** Reduces the voltage of the high-voltage battery (e.g., 400V or 800V) to a lower DC voltage (e.g., 12V-14V) to power the vehicle's standard 12V electrical system (headlights, wipers, radio, control units, etc.).
- **On-Board Charger (OBC):** Converts AC electricity from home or public AC charging stations into DC electricity to charge the battery. The capacity of the OBC (in kW) determines the vehicle's AC charging speed.

1.1.5 Charging System

These are the components that allow the vehicle to receive external electricity. They include the charging port (input socket), charging cable, and related control units. Different port types (Type 2, CCS, CHAdeMO, etc.) are used for different regions and charging levels.

1.1.6 Cooling System

This system ensures that high-heat-producing components, such as the battery pack, inverter, OBC, and sometimes the electric motor, are maintained within the optimum temperature range for efficient and safe operation. Liquid cooling systems, which typically utilize a specialized coolant, are typically used.

1.1.7 Drivetrain (Transmission/Reducer)

Because electric motors can produce high torque over a wide speed range, EVs typically avoid the need for complex, multi-gear transmissions. Instead, a simple, single-gear reduction gear reduces the engine's high rpm to a speed suitable for the wheels, increasing torque. This makes the drivetrain much simpler, lighter, and maintenance-free compared to ICE vehicles.

1.1.8 Regenerative Braking

When the driver presses the accelerator pedal, the control unit interprets this request and determines how much power to draw from the battery based on information from the BMS. The high-voltage DC from the battery is converted to AC by the inverter (if an AC motor is used) and sent to the motor. The motor converts this electrical energy into mechanical energy, turning the wheels through the gearbox.

When the brake pedal is pressed or the accelerator pedal is released (in one-pedal driving mode), regenerative braking is activated. In this case, the electric motor acts as a generator, using the kinetic energy of the wheels to generate electricity and converting this energy to DC through the inverter, charging the battery. This process both increases energy efficiency and reduces wear on mechanical brakes. When more aggressive braking is required, the traditional hydraulic brake system is activated.



<https://youtu.be/BbIX6RvWFf8>

Scan the QR code or click the link below to watch the video.

1.2. Comparison of Electric and Internal Combustion Vehicle Maintenance Requirements

The maintenance requirements of electric vehicles (EVs) differ significantly from those of traditional internal combustion engine (ICE) vehicles. These differences affect both the skills required of technicians and the total cost of ownership (TCO) for vehicle owners.

Key Differences:

One of the most significant advantages of EVs is that they have significantly fewer moving parts compared to ICE vehicles. An electric motor has only a few moving parts instead of hundreds, and a simple gearbox is often used instead of a complex transmission. This significantly reduces the number of parts subject to wear and tear. As a result, EVs do not require many of the periodic maintenance tasks standard for ICE vehicles, such as engine oil changes, exhaust system inspection and repair, spark plug replacement, and fuel filter replacement.

1.2.1 System-Based Comparison:

● Engine and Drivetrain:

- **EV:** The electric motor and gearbox are sealed units and generally require minimal maintenance. Periodic oil changes are not required (unless specified by the gearbox manufacturer). Maintenance consists primarily of checking connections and listening for abnormal noises.

- **ICE:** The engine requires regular oil and filter changes. The transmission (automatic or manual) may require periodic fluid/oil changes and adjustments. The fuel system (pump, injectors, filters) and exhaust system (catalytic converter, mufflers) are components that require maintenance and repair over time.

- **Brake System:**

- **EV:** Thanks to regenerative braking, mechanical brakes (pads and discs) are used much less frequently, and therefore their wear life is significantly longer than in ICE vehicles.⁶ This is a significant factor in reducing maintenance costs. However, the level and quality (moisture content) of the brake fluid should still be checked periodically and replaced according to the manufacturer's recommendations.⁶

- **ICE:** The brake system relies entirely on mechanical wear. Pads and discs should be checked and replaced regularly.

- **Fluids and Filters:**

- **EV:** Since there are no components such as engine oil, fuel filter, or exhaust system, there are no related fluids and filters. The main fluids requiring maintenance are the coolant used for the battery, engine, and power electronics, and the brake fluid. The cabin air filter is also replaced in the same way as in ICE vehicles.

- **ICE:** Many fluids and filters, including engine oil, oil filter, air filter, fuel filter, transmission oil/fluid, coolant, and brake fluid, need to be checked and replaced regularly.

- **Battery:**

- **EV:** The main propulsion battery (high voltage) and usually a 12V auxiliary battery are present. The main battery may require specialized diagnostics and maintenance (especially SoH monitoring), but it typically carries warranties of 8-10 years or longer and rarely fails prematurely.⁶ The 12V battery, like those in ICE vehicles, has a limited lifespan and may require replacement.

- **ICE:** The 12V starter battery is present only and typically requires replacement within 3-5 years.

1.2.2 Periodic Maintenance Intervals and Costs:

Due to the simpler mechanical structure and fewer wear parts in EVs, periodic maintenance intervals are generally longer than in ICE vehicles. This significantly reduces scheduled maintenance costs. Research shows that maintenance and repair costs for EVs can be between 11% and 50% lower than for ICE vehicles.²⁶

1.2.3 Total Cost of Ownership (TCO):

TCO includes all costs of owning a vehicle (purchase, fuel/energy, maintenance, repairs, insurance, taxes, and depreciation).

- **Purchase Cost:** The initial purchase price of EVs is generally higher than for comparable ICE models.⁵ However, government incentives, tax breaks, and decreasing battery costs are reducing this difference.⁵

- **Energy Costs:** While electricity prices and charging habits depend on the vehicle, electricity is generally cheaper than gasoline or diesel. This difference is particularly pronounced in regions with high fuel prices, such as Europe.⁵ Charging at home is more economical than at public charging stations.⁵
- **Maintenance and Repair Costs:** Lower scheduled maintenance costs are an advantage for EVs.⁶ However, in the case of accident repairs or failure of specific EV components (battery, power electronics), repair costs can be higher than for ICE vehicles.²⁸ Reasons for this include more expensive parts (can be up to 48% more expensive²⁸), specialized lightweight materials used, and the specialized expertise and equipment required for repairs.⁶
- **Insurance Costs:** Due to higher acquisition and repair costs, EV insurance premiums are generally slightly higher than for ICE vehicles (around 12% ⁶%).
- **Depreciation and Residual Value:** While EVs may have depreciated more rapidly in the past, resale values, especially for popular models, are quite strong today.⁵ While rapid technological advancements are still a factor, a high residual value positively impacts TCO.⁵
- **Conclusion:** Numerous studies, particularly in Europe, show that small and mid-range EVs have lower TCOs than comparable ICE vehicles over a given lifetime and mileage, thanks to lower energy and maintenance costs.⁵ This advantage may diminish or even reverse in the luxury segment or in low-mileage situations.⁵

While EVs are generally considered "less" to maintain, this requires a different expertise for technicians. Traditional mechanical skills are being replaced by in-depth knowledge of high-voltage systems, battery health management, software diagnostics, and power electronics. Potentially higher repair costs increase the importance of accurate diagnosis and strict adherence to repair procedures. It's also important for technicians to be able to provide customers with information about the factors that impact TCO calculations (usage habits, charging methods, regional costs).

1.2.4 EV and ICE Periodic Maintenance Comparison

The following table summarizes the key periodic maintenance differences between EV and ICE vehicles:

Maintenance Item	The Case for Electric Vehicles (EVs)	The Case for the Internal Combustion Engine Vehicle (ICE)	Explanation
Engine Oil and Filter Change	Not Required	Required (Periodic)	EVs do not use motor oil.
Air Filter Change	Only Cabin Air Filter Required (Periodic)	Engine and Cabin Air Filter Required (Periodic)	EV engines do not require air filters.
Fuel Filter Change	Not Required	Required (Periodic)	EVs do not use fuel.
Spark Plug Change	Not Required	Required (Periodic)	EV engines do not have spark plugs.
Exhaust System Inspection/Repair	Not Required	Required (Periodic Inspection/Repair)	EVs do not have exhaust systems.
Transmission Oil/Fluid Check/Change	Generally Not Required (Reducer oil may rarely be required)	Required (Periodic)	EVs usually have simple reducers, not complex transmissions.
Brake Pad/Disc Check/Replacement	Necessary (But Longer Lasting)	Required (More Frequent Change)	Regenerative braking reduces mechanical brake wear
Brake Fluid Check/Change	Required (Periodic)	Required (Periodic)	The hydraulic system requires maintenance in both vehicle types.
Coolant Check/Change	Required (For Battery, Motor, Electronics - Periodic)	Required (For Engine - Periodic)	In EVs, the cooling system encompasses more components and is critical.

12V Auxiliary Battery Check/Replacement	Required (Periodic)	Required (Periodic)	Both vehicle types have similar lifespans.
High Voltage Battery Health (SoH) Check	Required (Periodic Diagnostics)	Not Required	It is a critical maintenance item specific to EV.
Software Updates	Required (Periodic/OTA)	Rarely/Not Necessary (For Engine Management)	Software updates for performance, safety, and features are much more common and important in EVs.

Visual 1.1: EV and ICE Periodic Maintenance Comparison



<https://youtu.be/X9h6pjifPts>

Scan the QR code or click the link below to watch the video.

2. BASIC MAINTENANCE OF ELECTRIC VEHICLE SYSTEMS

With this learning activity, you will learn the basic maintenance procedures and key points for critical electric vehicle systems (battery, motor, brakes, cooling, charging, and software).

2.1. Battery Maintenance (RESS - Rechargeable Energy Storage System)

Maintaining the high-voltage battery (RESS), the heart and most valuable component of an electric vehicle, is vital to the vehicle's performance, range, and lifespan. Battery maintenance involves proper usage habits and condition monitoring, rather than a traditional mechanical process.

2.1.1 Proper Charging Habits:

It is one of the most important factors that directly affects battery life.

- **Avoid Overcharging and Deep Discharging:** Constantly charging the battery to 100% or frequently discharging it to levels close to 0% can accelerate capacity loss by creating chemical stress on lithium-ion cells. Ideally, it's best to maintain a charge level between 20% and 80% for daily use. A 100% charge may be necessary before long trips, but it shouldn't be a regular habit.
- **Use DC Fast Charging:** While DC fast charging (DCFC) offers convenience by providing high power in a short time, it can also cause the battery to overheat. Frequent and continuous DCFC use, especially in high ambient temperatures, can accelerate battery degradation. Whenever possible, opting for slower AC charging (at home or at work) is generally better for battery health.

2.1.2 Thermal Management

Lithium-ion batteries operate most efficiently and have the longest lifespan within a specific temperature range. Extreme temperatures (both too high and too low) reduce performance and can lead to permanent damage.⁷

- **Active Cooling/Heating:** Most modern EVs use liquid cooling or heating systems to optimize battery temperature. These systems can activate to protect the battery even when the vehicle is parked.
- **Parking Location Selection:** It is important to avoid leaving the vehicle in direct sunlight or well below freezing for extended periods in extreme hot or cold weather.
- **Preconditioning:** Warming or cooling the cabin and battery before setting off (preconditioning) while the vehicle is connected to the charger not only improves driving comfort but also optimizes range and maintains battery efficiency by using the battery's energy exclusively for driving.

2.1.3 Physical Inspection

The battery pack is usually housed in a protected enclosure underneath the vehicle. However, this enclosure should still be periodically inspected for visible damage (impact marks, cracks, dents), signs of leakage, or abnormal swelling. In case of any suspicion, the vehicle should be taken to an authorized service center immediately.

2.1.4 Electrical Inspection

- **Connection Inspection:** The tightness and corrosion of the high-voltage and low-voltage battery connections should be checked periodically by authorized technicians after the vehicle is de-energized and safety precautions are taken. Loose or corroded connections can cause performance problems and overheating.
- **Insulation Resistance Measurement:** Periodic insulation resistance testing should be performed to ensure adequate electrical insulation of the battery pack and other high-voltage components from the vehicle chassis.¹⁰ This test requires specialized measuring equipment and high-voltage safety procedures and should only be performed by authorized technicians. Low insulation resistance can indicate leakage currents and safety risks.

2.1.5 Battery State of Health (SoH) Check: SoH is a critical parameter that indicates the aging status and remaining capacity of the battery.⁷ Over time and with use (charge/discharge cycles, temperature exposure, etc.), the battery's energy storage capacity decreases.²³

- **Why is SoH Important?** SoH directly affects the remaining range, performance, and resale value of the vehicle. Manufacturers typically base their battery warranties on a specific SoH percentage (e.g., 70% SoH after 8 years or 160,000 km).⁷

- **SoH Checking Methods:**

- **Vehicle Information Display/App:** Some manufacturers provide an approximate SoH value or remaining capacity information in the vehicle menu or mobile app.⁷
- **OBD-II Diagnostic Devices:** Diagnostic devices with specialized EV software or third-party applications (with a suitable OBD-II adapter) can provide more detailed SoH information based on data read from the BMS.⁷
- **Range Test:** While comparing the range achieved on a full charge to the vehicle's original range is a practical method, it does not provide an accurate SoH value because it is affected by many variables, such as driving conditions and weather.⁷
- **Charging Time and Behavior Monitoring:** Significantly longer charging times or premature charging interruptions may indicate battery problems, but they are not, by themselves, indicative of SoH.⁷
- **Professional Service Testing:** Authorized service centers can perform a more accurate SoH assessment by measuring the battery's capacity and internal resistance using specialized equipment and procedures.⁷
- **Approximate Calculation:** Using the energy delivered by the charger (kWh) and the change in battery percentages over a specific charging interval (e.g., from 20% to 80%), the battery's current approximate capacity can be calculated.²⁹ However, this method can contain significant errors because it ignores energy losses during charging (efficiency), the vehicle's own energy consumption (heating/cooling, electronic systems), and the accuracy of the percentages reported by the BMS.²⁹

- **Challenges in SoH Assessment:** Currently, there is no single, industry-wide accepted standard method for SoH measurement and reporting.⁸ Different manufacturers or testing methods may provide different SoH values for the same battery. Therefore, it is important to understand the method used and the reference original capacity (gross or net) when interpreting SoH values.⁸ While 70-80% SoH is generally considered a threshold, the practical meaning of this value (remaining range) is more important to the user.

The role of technicians in battery maintenance is to inform customers about proper usage habits (charging, temperature management) and to assess the battery's physical condition, connections, and most importantly, its state of health (SoH) using appropriate methods during periodic checks. When performing SoH assessments, considering various indicators (vehicle data, diagnostic tool readings, customer feedback, range observations) together, rather than relying on a single method or value, will yield more reliable results.

2.2. Electric Motor and Drivetrain Maintenance

The engines and drivetrains of EVs are mechanically much simpler than their ICE counterparts and therefore require significantly less maintenance. Maintenance activities generally focus on observation, listening, and basic checks.

● Checks to be Performed:

- **Operating Acoustics:** Listen carefully for abnormal noises (high-frequency buzzing, mechanical friction, knocking, bearing noise, etc.) while the engine is operating. Changes in these sounds can be an early sign of a potential problem.
- **Visual Inspections and Connections:** Check the exterior of the motor and gearbox for any damage or leaks (especially from gearbox seals or coolant connections). Visually inspect the connection points, insulation condition, and physical integrity of high-voltage power cables, low-voltage sensor and control cables, and coolant hoses (if applicable). (Safety procedures must be followed before touching HV cables).
- **Motor Bearings and Vibration:** Assess wear in the motor bearings (bearings) by observing abnormal noises or vibrations. Check for looseness or damage along the transmission line (motor-gearbox connection, axle shafts).
- **Cleanliness:** Keeping the motor and surrounding components (especially if there are cooling fins or surfaces) free of dust, dirt, and debris improves heat transfer and helps prevent overheating.
- **Gear Oil:** While most EV gear oils are filled with "lifetime" oil, some manufacturers may recommend periodic inspection or replacement. Checking the level and condition (color, contamination) of the gear oil is essential according to the manufacturer's maintenance schedule. Any leaks should be addressed.
- **Regenerative Braking Performance:** Assess whether the vehicle is effectively recovering energy when decelerating. This can usually be done during a driving test or by monitoring relevant parameters with a diagnostic device. A significant decrease in regenerative braking may indicate a problem with the motor or control system.

Maintenance of EV engines and drivetrains relies heavily on preventative checks. Because there's no need for regular fluid changes or adjustments, technicians' attention should be focused on early detection of potential malfunctions (noise, leaks, decreased performance).

2.3. Brake System Maintenance

The EV brake system uses a combination of regenerative braking and conventional hydraulic braking. This differentiates the maintenance routine from ICE vehicles.

- **Effect of Regenerative Braking:** Using the electric motor as a generator to decelerate the vehicle and recover energy significantly reduces the load on the mechanical brakes (brake pads and discs). As a result, the wear life of brake pads and discs is significantly longer than in an ICE vehicle with similar operation.
- **Required Checks:** Despite their less frequent wear, periodic inspection of brake system components is still essential:
 - **Brake Fluid:** The hydraulic part of the brake system is still present. The level of the brake fluid should be checked regularly, and most importantly, its quality (moisture content, boiling point) should be measured at regular intervals and replaced as recommended by the manufacturer.⁶ Brake fluid that absorbs moisture over time can reduce braking performance and cause corrosion in the system.
 - **Brake Pads and Discs:** Although wear rates are low, pad thickness should be measured during periodic maintenance, and the surface condition of the discs (cracks, excessive rust, warping) should be checked.⁶ Rust or corrosion can occur on the disc surfaces, especially in situations where regenerative braking is used extensively and mechanical brakes are used infrequently. This can cause noise or vibration during braking.
 - **Brake Lines and Hoses:** Visually inspect hydraulic lines and flexible hoses for leaks, cracks, swelling, or other damage.
 - **Brake Performance and Pedal Feel:** Brake pedal response, firmness, and travel should be checked. During the driving test, the effectiveness of the brakes should be evaluated and any abnormal noises (squealing, grinding) or vibrations should be evaluated.

Regenerative braking has transformed EV brake maintenance. Technicians should be aware that the need for pad and disc replacement will be much less, but they should understand that hydraulic system maintenance (fluid replacement, leak check) and overall system inspection are still critical. They should be aware of potential problems specific to EVs, such as disc corrosion due to insufficient use.

2.4. Cooling System Maintenance

In EVs, cooling systems protect not only the engine but also components such as the battery pack and power electronics (inverter, DC-DC converter, OBC), which generate high heat and are critical to the vehicle's performance and lifespan. Therefore, proper cooling system operation is vital.

2.4.1 Circuit Checks

EVs typically have liquid cooling systems that use a dedicated coolant. Depending on the model, there may be separate cooling circuits for the battery, motor, and power electronics, or an integrated system. Each circuit may have its own radiator, pump, and reservoir.

- **Checks to Perform:**

- **Coolant Level:** Coolant levels in the relevant reservoir tank(s) should be checked regularly and ensure they are between the minimum/maximum marks. A low level may indicate a leak or other problem.
- **Leak Check:** Carefully look for signs of leakage (wetness, dripping, colored spots, odor) throughout the entire cooling circuit (hoses, connections, clamps, radiators, pumps, battery housing, inverter, etc.). Even small leaks can lead to serious problems over time.
- **Coolant Quality and Change:** The color, clarity, and contamination of the coolant should be checked. The manufacturer's specified type (usually a specially formulated coolant) should be used. Using the wrong type can cause corrosion or damage to system components. The coolant's freezing and boiling point protection can decrease over time. A complete coolant change should be performed at the manufacturer's recommended intervals (usually a few years or a certain mileage).

2.4.2 Pumps, Fans, and Radiators

It is critical that the electric pumps in the cooling system regularly circulate coolant and that the fans that cool the radiators operate efficiently. Failure of these pumps or fans can lead to overheating of the battery and power electronics. Furthermore, the radiator cores must be kept clear of dirt, dust, insects, or debris that could obstruct airflow; a clean radiator directly increases the system's cooling efficiency.

The cooling system in electric vehicles plays a much more critical role than in internal combustion engine vehicles because it directly impacts the lifespan, performance, and safety of the battery. Overheating or cooling the battery can lead to capacity loss, accelerated aging, and even the risk of thermal runaway. Therefore, cooling system checks and maintenance must be carried out with great care. Another important element of electric vehicle maintenance is the vehicle's charging system and constantly updated software; regular checks of these systems support the safe and efficient operation of the vehicle.

2.5.1 Vehicle Charging Port:

- **Physical Inspection:** The charging port and its pins should be visually inspected regularly. Bent, broken, burnt, or corroded pins can cause charging problems or pose safety risks. The port cover should be checked for proper closing.
- **Cleanliness:** The inside of the charging port should be free of dust, dirt, moisture, or foreign objects. A clean connection is essential for efficient and safe charging. If necessary, it can be cleaned with compressed air or a suitable cleaner (while de-energized).

2.5.2 Charging Cables: Both the portable charging cables supplied with the vehicle and the cables of the charging stations should be inspected regularly. Check for cuts, abrasions, crushing, or burns on the cable insulation, damage to the connectors (plugs), or signs of overheating. Damaged cables should never be used.

2.5.3 Home Charging Unit (Wallbox):

- **Physical Condition:** The unit's casing, display (if applicable), and mounting should be inspected. The condition of the cable should also be inspected as mentioned above.
- **Electrical Inspections:** The electrical connections and grounding of the home charging station should be inspected by a qualified electrician during installation and periodically. Loose connections or inadequate grounding can be dangerous.
- **Software Updates:** Smart charging stations are typically connected to the internet and can receive software updates from their manufacturers. These updates can add new features, improve compatibility, or close security vulnerabilities. It is recommended to install updates according to the manufacturer's instructions.

2.5.4 Vehicle Software Updates: Modern EVs have complex software that manages not only driving functions but also battery management, charging control, infotainment, and many other functions.

- **Importance:** Manufacturers regularly release software updates to improve vehicle performance (e.g., increase range, optimize charging speed), fix bugs, add new features, or implement security patches.⁹
- **Update Methods:** Updates are typically performed in two ways:
 - **Over-the-Air (OTA):** The vehicle downloads and installs updates directly over a cellular or Wi-Fi connection.¹⁶ This keeps the vehicle up to date without requiring a service visit.
 - **Service Center Update:** For some major updates or specific modules, the vehicle may need to be taken to an authorized service center and updated with specialized diagnostic equipment.
- **Maintenance Routine:** Technicians should check the software versions of vehicles arriving for service and install available updates according to manufacturer procedures. A failed or interrupted update can cause serious problems with the vehicle, so the update process should be performed with caution.

2.6 Charging Performance Assessment

If the customer reports charging issues (e.g., slow charging, charging not starting, frequent disconnections), it's important to identify the source of the problem. Is the problem in the vehicle (OBC, charging port, software), the charging cable, or the charging station? Charging parameters (voltage, current, communication protocols) should be checked using diagnostic devices and test equipment.

EV maintenance extends beyond mechanical components to include charging interfaces and software. Technicians must be knowledgeable in these areas, able to perform diagnostics, and

familiar with update procedures. Software, in particular, is now an integral part of the vehicle, and regular maintenance is critical to its safety, performance, and functionality.

2.7 Home Maintenance Control

Normal Maintenance Schedule / Mileage or Month (whichever comes first)			Control
Months	12-36-60-84-108	24-48-72-96-120	
Km x1,000	15-45-75-105-135	30-60-90-120-150	
TSB			
Check if the chassis number (VIN) is affected by the Technical Service Bulletin.	K	K	
Workshop			
Fault scanning (all systems) and Technical Service Bulletin control with KDS/GDS	K	K	
Check whether the remote control is working properly.	K	K	
Check the operation of all interior lighting and indicator lights. Check the exterior lighting and horn.	K	K	
Heating, Cooling and Ventilation System operation controls	K	K	
Seat belt operation and warning control	K	K	
Door, hood, trunk door lock control and lubrication	K	K	
Panoramic sunroof cleaning and lubrication	K	K	
Checking windows, wipers, sprinklers and mirrors	K	K	
Checking the headlight adjustment and adjusting if necessary	K	K	
Pollen filter	K	K	
First aid kit and fire extinguisher (with expiration date), with triangle reflector	K	K	
Checking the charging port	K	K	
Check the charging port cover and insulation	K	K	
eCall system battery replacement	K	K	
Body examination	K	K	
Engine			
Wiper jet water tank level check (complete if necessary)	K	K	
Motor / Inverter cooling system (oil, pipes, connections, radiator)	K	K	
Motor / Inverter Cooler (Normal cooler)			

Brake fluid			
12V Battery (charge, status, terminals, fixing-printing)	K	K	
A/C compressor and System Control (Evaporator discharge)	K	K	
Vehicle Lift			
Reduction gear oil		K	
Visual inspection of nuts and bolts that may affect safety on the chassis and body	K	K	
Steering box, rack and pinion	K	K	
Inspection of Front-Rear Suspension Systems (Tie Rod Ends, Ball Joints, Bushings, Air Springs and Shock Absorbers)	K	K	
Liquid Leakage Controls	K	K	
Checking the brake discs, drums, pads, pipes and parking brake (adjust if necessary)	K	K	
Tire Rotation (Front axle to rear axle)	K	K	
Power Transmission Shafts and bellows	K	K	
Road test			
Control of the pedals	K	K	
Checking the operation of the parking brake	K	K	
Document review / Road test (check of all systems)	K	K	
Tyre condition (Check every 12 months or 15,000km)			
	<i>External Thickness (mm)</i>	<i>Pressure (bar)</i>	TMK SKT (if any)
<i>Front left</i>			
<i>Front right</i>			
<i>Rear left</i>			
<i>Rear right</i>			
K: Check and adjust, edit, clean or replace if necessary. D: Replace.			
Name and Surname of the Technician:	Signature:		

Visual 2.1: Home Maintenance Control Form



https://youtu.be/r2zM_JMwWRI

Scan the QR code or click the link below to watch the video.



<https://youtu.be/29Dw7WcHORQ>

Scan the QR code or click the link below to watch the video.

3. HIGH VOLTAGE SAFETY AND INTERVENTION

This learning activity covers in detail the hazards that can be encountered when working with high voltage (HV) systems in electric vehicles, the safety standards that must be followed, the mandatory use of Personal Protective Equipment (PPE), and de-energization (LOTO) procedures. Compliance with the information and procedures in this section is vital for the safety of technicians.

3.1. High Voltage (HV) Risks and Basic Safety Principles

Electric vehicle drive systems typically operate at voltages between 200 Volts (V) and 800 V Direct Current (DC), and even higher in some newer-generation vehicles. These voltage levels pose potentially lethal hazards to the human body. International standards and local regulations generally classify voltages above 50V AC or 120V DC (50V DC in some newer standards) as hazardous. Main Hazards:

3.1.1 Electric Shock

The passage of dangerously high current through the body as a result of direct or indirect contact with a high-voltage component or cable.¹³ The intensity of the current, the duration of contact, and the path it takes through the body (especially through the heart) determine the severity of the injury. Low body resistance (e.g., moist or sweaty skin) increases the risk by allowing a higher current to flow at the same voltage.¹³ Even a current of 100-200 milliamperes (mA) can be fatal.¹³

3.1.2 Arc Flash

A violent explosion caused by a short circuit between phases or between phases and ground in a high-energy electrical system.¹³ The arc flash produces extremely high temperatures (can be hotter than the surface of the sun), intense light (can cause blindness), a loud sound and pressure wave (can cause throwing), and the scattering of molten metal particles. It can cause severe burns, internal organ damage, and death. ¹⁴ DC arc flashes in DC systems can be more difficult to extinguish and take longer than in AC systems, increasing the danger. ³⁰

3.1.3 Fire

Fires can occur as a result of battery pack damage (accident, puncture), overcharging, internal short circuits, or failures in other HV components. ¹³ Lithium-ion battery fires are characterized by an uncontrolled reaction called “thermal runaway” and present special challenges to extinguish (see Section 3.4). ³²

3.1.4 Chemical Hazards

Electrolyte leaking from a damaged battery often contains flammable and toxic chemicals. ¹³ Skin contact or inhalation of vapors can be harmful.

Basic Safety Principles:

To work safely with HV systems in EE systems, the following fundamental principles must be strictly adhered to:

- **Authorization and Training:** Only personnel who have received special training, are aware of the risks, and are authorized may intervene in HV systems.¹ Intervention by unauthorized persons is strictly prohibited.

- **De-energized Work Principle:** Wherever possible, before any work on HV systems, the system should be completely de-energized, isolated from energy sources, and Lockout/Tagout (LOTO) procedures should be implemented.¹³ Energized work should only be carried out in very specific cases and with additional safety measures.
- **Safe Distances:** A safe distance should always be maintained when approaching HV components and cables that are known or suspected to be energized. The approach distances specified in Turkish Electrical High Current Installations Regulation No. 35 can, in principle, also provide an indication for EE systems (varies depending on the voltage level).
- **Warning Signs and Color Codes:** Work areas should be marked with appropriate warning signs (e.g., "Caution High Voltage," "Danger of Death," etc.).¹³ HV cables and connectors on vehicles are generally coded orange. Components with this color should be treated with extra caution and should never be touched without taking the necessary precautions.
- **Two-Person Rule:** During critical HV interventions, it is generally recommended that one technician work while another acts as a safety observer and is ready to intervene in a potential emergency (e.g., power off, first aid).¹³
- **Health Status:** Personnel with medical devices such as pacemakers or conditions such as epilepsy working near HV systems may be risky and require special consideration.

3.1.5 Relevant Safety Standards

The electrical safety of EVs is regulated by international and national standards. It is important for technicians to be aware of the fundamental requirements of these standards:

- **ISO 6469 Series:** This is the core series of standards specifically developed for the safety of electric road vehicles.
 - **ISO 6469-1:** Covers the safety of on-board rechargeable energy storage systems (RESS/Battery) (thermal, mechanical, and electrical risks).¹¹
 - **ISO 6469-2:** Addresses vehicle operational safety. This includes topics such as the safe operation of the drive system, control systems (preventing unintended acceleration/deceleration), and protective measures against electric shock (insulation, barriers).¹⁰
 - **ISO 6469-3:** Defines general electrical safety requirements (degrees of protection, insulation coordination, marking of high-voltage circuits, etc.).²²
 - **ISO 6469-4:** Focuses on post-crash electrical safety. It specifies requirements for how the HV system will be or will be made safe in the event of an accident (e.g., automatic isolation).¹¹
- **Other Relevant ISO Standards:** Standards such as functional safety (ISO 26262), resistance to environmental conditions (ISO 16750, ISO 19453), and charging communication (ISO 15118) are also indirectly related to EV safety.²²

• Turkish Standards and Regulations

- **TSE Standards:** Standards published or harmonized by the TSE regarding EVs and their components (e.g., charging stations, service qualification TS 12047 36, specific EV standards TSE K 646 36).
- **MYK Occupational Standards:** Standards and qualifications established by the Vocational Qualifications Authority for technicians working in the field of electric vehicles (e.g., Battery Electric Vehicle Service Personnel Level 3 1). These standards also include OHS rules.1
- **OHS Legislation:** Occupational Health and Safety Law No. 6331 and the regulations issued based on this law (such as the use of PPE, Safety Signs, Electrical Regulations, etc.) are binding on EV service centers, as they are on all workplaces.1
- **EMO Regulations:** Regulations of the Chamber of Electrical Engineers regarding engineering services related to electric vehicles and charging stations.39
- **Other Regulations:** Regulations such as the Charging Service Regulation and the Regulation on the Manufacture, Modification, and Assembly of Vehicles (AİTM) may also be relevant.39

Safety in EV service operations is not a matter of personal preference; it is a necessity, both for the technician's own health and for legal obligations. International standards (especially ISO 6469) and national legislation (Law No. 6331, MYK standards, and TSE standards) set the framework for safe working practices. It is essential that technicians are aware of these standards and legal requirements, receive training accordingly, and perform service operations in strict accordance with these rules.1 Safety is an integrated approach that encompasses the entire life cycle of the vehicle, starting from the design phase, through production, use, maintenance and repair, and even post-accident intervention.



<https://youtu.be/svmjBVvwKEQ>

Scan the QR code or click the link below to watch the video.

3.2. Personal Protective Equipment (PPE/PPE)

Using the correct Personal Protective Equipment (PPE) when working with high-voltage systems provides vital protection against serious hazards such as electric shock and arc flash. The use of PPE is not an option; it is a legal and professional obligation. Employers are responsible for providing employees with appropriate PPE and training them in its use. Essential PPE for High Voltage Work:

3.2.1 Electrical Insulating Gloves

These are the most essential and critical PPE for working with High Voltage.

- **Standards and Compliance:** The gloves used must comply with internationally recognized standards (EN 60903 for Europe, ASTM D120 for the USA).

14 They must bear the CE mark and the relevant standard number. 45

○ **Classification:** Gloves are classified according to the maximum operating voltage they provide protection against. This classification is defined in the EN 60903 standard.43:

■ Class 00: 500V AC / 750V DC

■ Class 0: 1,000V AC / 1,500V DC (This class is generally sufficient for typical HV levels in EVs. 13)

■ Class 1: 7,500V AC / 11,250V DC

■ Class 2: 17,000V AC / 25,500V DC

■ Class 3: 26,500V AC / 39,750V DC

■ Class 4: 36,000V AC / 54,000V DC

○ **Material and Construction:** They are usually made of natural rubber (latex) or synthetic elastomers. 43 Flexibility and tactile sensitivity are important, but the primary purpose is electrical insulation.

○ **Need for Mechanical Protection:** Standard insulating gloves are vulnerable to mechanical damage such as punctures, cuts, and tears. Even the smallest puncture that compromises the glove's insulating properties can have fatal consequences. 45 Therefore, appropriately sized leather overgloves must be worn over insulating gloves. 13 Leather gloves protect insulating gloves from mechanical damage. Some "composite" gloves can offer both insulation and a certain level of mechanical protection, but they are generally thicker and less flexible. 48

○ **Requirement for Inspection and Testing:** The reliability of insulating gloves depends on regular inspection and testing:

■ **Inspection Before Each Use:** The technician must visually inspect the glove before each use (cuts, holes, tears, cracks, discoloration, swelling, foreign matter, etc.). 43 They should also test for air leakage by filling the glove with air (rolling it around the wrist). 13 Even the slightest air leakage indicates that the glove is unusable.

■ **Periodic Electrical Testing:** To ensure that their insulating properties do not deteriorate over time, gloves should be electrically tested at regular intervals (usually every 6 months) by an authorized laboratory. 14 The test date and validity period are stamped or labeled on the glove. 14 Gloves that have expired or have not been tested should never be used. 13

○ **Storage:** When not in use, gloves should be stored in special protective bags in a clean, dry, cool place, away from direct sunlight, ozone, and chemicals. 43 They should not be folded or weighted. 48

● **High Voltage Safety Shoes/Boots:** Shoes or boots with electrically insulating soles that comply with standards such as EN ISO 20345. 14 Provides protection against hazards from the ground.

- **Insulating Mats:** Mats that provide insulation up to a certain voltage, especially at fixed work points (e.g., test areas in workshops), provide an additional layer of protection. 14

3.2.2 Face Shield / Arc Flash Face Shield:

Used to protect the face and eyes from intense heat, light, and flying particles in situations where there is a risk of arc flash (work with a high probability of short circuits, opening energized equipment covers, etc.). 14 Standard safety glasses do not provide adequate protection against arc flash. The shield must meet the relevant arc rating (ATPV or EBT) standard.

- **Protective Clothing:**

- **Material:** Work clothes worn when working with HV should be flame-resistant (FR) and, if possible, made of natural fibers (cotton, wool).¹³ Synthetic fabrics such as polyester can melt and adhere to the skin in the event of an arc flash, worsening burns.¹⁴

- **Arc Rating (AR):** For jobs with a high risk of arc flash, clothing must be resistant to a specific arc energy level (in cal/cm²). This is indicated by the clothing's arc rating (AR) and must meet the risk level determined by standards such as NFPA 70E.¹⁴

- **Other PPE:**

- **Insulated Tools:** When working on or near high-voltage components, hand tools (screwdrivers, pliers, wrenches, etc.) certified to be insulated up to 1000V (usually according to the VDE or EN 60900 standard) should be used. 14

- **Insulated Rescue Hook:** This is a long-handled hook made of insulating material used to separate the victim from the energy source from a safe distance in the event of an electric shock. 13 It should be kept in an easily accessible location.

- **Helmet:** To protect the head against impacts or falling objects (EN 397). 52 Electrically insulated types are also available.

PPE Selection and Use:

PPE of the appropriate class and specification should be selected based on the hazards (voltage level, arc flash potential, etc.) determined through a risk assessment of the work to be performed. 14 PPE must be worn and used correctly. For example, leather protective gloves should always be worn over insulating gloves, and the cuffs should extend over the sleeves. All PPE should be kept clean and replaced immediately if damaged.

PPE use is not only a matter of procedure but also a matter of safety culture. Technicians must understand why PPE is necessary, how to use it correctly, and most importantly, how to inspect and maintain it, and they must consistently apply this knowledge. The condition of insulating gloves is particularly crucial; 6-month periodic testing and air leakage checks before each use should never be neglected. These checks are the most fundamental steps for the technician's personal safety.

The table below summarizes the basic PPE recommended for EV HV work, the relevant standards, and maintenance requirements:

3.2.3 Basic PPE Requirements for EV High Voltage Work

PPE Item	Applicable Standard (Example)	Required Class/Type (Typical for EV)	Pre-Use Check	Periodic Testing /Maintenance
Insulating Gloves	EN 60903 / ASTM D120	Class 0 (1000V AC / 1500V DC)	Visual + Air Test	Electrical Test Every 6 Months
Leather Protective Gloves (Overglove)	EN 388 (Mechanical Risks)	Sized to fit insulating gloves	Visual (Damage)	Cleaning / Maintenance
Face Shield (Arc Protection)	EN 166 / GS-ET-29 / ASTM F2178	Suitable Arc Degree (cal/cm ²)	Visual (Scratch, Damage)	Cleaning / Maintenance
Insulating Safety Shoes/Boots	EN ISO 20345 (SB, S1P, S3 + EH)	Electrically Insulated (EH)	Visual (Damage, Wear)	Cleaning / Maintenance
FR/AR Protective Clothing	EN ISO 11612 / IEC 61482-2 / NFPA 70E	Suitable Category/Arc Degree (cal/cm ²)	Visual (Damage, Pollution)	Wash/Care According to Manufacturer's Instructions
Insulating Mat	IEC 61111	Class Suitable for Operating Voltage	Visual (Damage, Pollution)	Periodic Inspection /Cleaning
Insulated Hand Tools	EN 60900	1000V AC / 1500V DC	Visual (Insulation Damage)	Cleaning / Control
Insulated Rescue Hook	-(Special equipment)	Suitable for Operating Voltage	Visual (Damage)	Periodic Control

Note: The standards and classes in the table are examples and may vary depending on the risk assessment of the specific job.

Visual 3.1: Basic PPE Requirements for High Voltage Work



<https://youtu.be/pBXko25OeSM>

Scan the QR code or click the link below to watch the video.

3.3. Safe Response Procedures (De-energize and LOTO)

The fundamental principle of safe operation on high-voltage systems is to de-energize the system and ensure it remains de-energized for the duration of operation. For this purpose, internationally accepted Lockout/Tagout (LOTO) procedures are implemented.¹⁵ LOTO not only disconnects the power supply but also physically prevents the unauthorized or accidental re-energization of the power source.¹⁵

3.3.1 LOTO Procedure Steps (General Approach)

A typical LOTO procedure, based on OSHA (Occupational Safety and Health Administration) standard 1910.147 and other best practices, includes the following steps:

1. Preparation

- Detailedly plan the maintenance or repair work to be performed.
- Identify hazardous energy sources that need to be contained (the primary source for an EV is the HV battery, but stored energy sources such as capacitors may also be present) and the type/magnitude of this energy. 53
- Review vehicle or equipment-specific de-energization and LOTO procedures (manufacturer service manuals, workplace procedures). 53
- Prepare the necessary LOTO equipment (personal locks—keyed differently for each authorized employee, tags, lockout devices—e.g., MSD lockout, circuit breaker lockout) and PPE. 55

2. Notification

- Inform all personnel (operators, other technicians, managers) using the vehicle or equipment to be maintained/repared, or who will be affected by the work area, of the procedure to be performed, the shutdown of the vehicle/equipment, the LOTO application, and the estimated duration of the operation. 53

3. Shutdown

- Completely shut down the vehicle using the manufacturer's recommended normal and safe shutdown procedures. 53 This typically involves turning off the ignition or shutting down the relevant system from the control panel.

4. Isolation

- Physically isolate the vehicle/equipment from all energy sources. In EVs, this means first disconnecting the HV battery.⁵³
- This is typically accomplished by removing a dedicated Manual Service Disconnect (MSD) or similar disconnect plug located in the vehicle.¹³ The MSD is a safety switch that physically interrupts the HV battery circuit.
- Simply turning off the ignition or shutting down the system with a software command is not sufficient for isolation.⁵⁸ Physical isolation is required. It must be ensured that the HV contactors (main switches between the battery and the inverter) are actually opened (they are usually opened when the MSD is removed).¹³

5. Lockout and Tagout (Lockout/Tagout)

- Use a lockout device to secure the device used to isolate the power (the plug of the disconnected MSD, the relevant circuit breaker or valve handle, etc.) in the "Off," "Safe," or "Isolated" position.
- Each authorized employee performing the operation must attach their own personal lock to this lockout device.⁵³ If multiple people will be working on the same equipment, multiple lockouts must be used, and each employee must attach their own lock. Only the person installing the lock should have the key.⁵⁶
- A standard "Tagout" tag must be affixed to each lock.⁵³ The tag must include at least the following information: "DO NOT TOUCH/ACT," the name of the person performing the action, their department, the date/time of the action, and the reason for the lockout. This tag serves as a warning to prevent others from attempting to energize the system.

6. Control and Discharge of Stored/Scrap Energy

- Even after the energy source has been isolated, dangerous levels of energy may still be stored in the system. Large capacitors, particularly in inverters and other power electronic components, can store significant electrical charges.⁵³

Stored energy may also be present in mechanical (springs), hydraulic, or pneumatic systems.

- This stored energy must be reduced to a safe level or completely discharged.⁵³ In electrical systems, this is usually achieved by a specific waiting period. The manufacturer specifies the time required for the capacitors to discharge to a safe level after the MSD is removed (e.g., 5 minutes, 10 minutes).⁵⁵ This time period must be strictly adhered to. Special discharge procedures may be implemented if necessary.

7. Verification of Isolation (Zero Energy Check)

- This is the most critical step in the LOTO procedure. To ensure that the system is truly completely de-energized, assumptions cannot be made; verification is always made through measurement.

- A voltage measuring device (multimeter or special HV voltage detector) with the appropriate safety category (CAT III/IV), known to be working properly, and with a valid calibration must be used.

- The absence of voltage is confirmed by measuring all HV terminals, connection points, and conductors to be studied (both positive and negative lines relative to chassis and to each other).

14 The reading should be zero or at a very low (safe) level.

- The "Live-Dead-Live" (LDL) test method is highly recommended:

1. Test the meter on a known live (safe voltage) source (Live).
2. Measure the circuit assumed to be de-energized (Dead - zero reading).
3. Test the meter again on a known live source (Live).

- HV components should never be touched or interfered with before this verification step is completed.

8. Performing Maintenance/Repair

Once the insulation is verified, the planned work can be carried out safely.

3.3.2 LDL (Live-Dead-Live) Verification

After power isolation is achieved, the system must be verified by measurement to ensure it is truly de-energized. The LDL (Live-Dead-Live) method is used for this process. LDL is a three-step verification process that ensures both the meter's proper operation and the absence of voltage in the circuit:

1. **Live:** Test the meter at a known live point. The expected voltage reading indicates proper operation.
2. **Dead:** Measure the voltage at the circuit assumed to be de-energized. The value at all measurement points must be zero or below the safe threshold.
3. **Live:** Confirm that the meter is still functioning properly by testing the meter again at a known live point.

During this verification:

- A validly calibrated measuring device, rated CAT III/IV, must be used.
- Measurements must be made on the (+ → ground), (- → ground), and (+ → -) lines.
- All checks must be performed with appropriate PPE (insulating gloves, face shield, insulating shoes, etc.).

3.3.3 Removal and Recommissioning of LOTO

1. **Check:** Ensure that the work area is cleared, all tools, materials, and old parts are removed, and all protective covers are replaced.
2. **Personnel Check:** Ensure that no one remains in the work area and the hazardous area.
3. **Notification:** Inform affected personnel that the LOTO will be removed and the equipment will be re-energized. 56
4. **Removal of LOTO Devices:** Each authorized employee removes only the lock and tag installed by themselves. 54 If there is more than one lock, the person who installed the last lock removes their own lock after ensuring that the others have finished.
5. **Isolation Removal:** Return the power isolating devices (MSD plug, circuit breaker, etc.) to their normal operating position.
6. **Re-energization and Testing:** Safely re-energize the vehicle/equipment according to manufacturer procedures and test its proper operation.

LOTO is not only a technical procedure but also a safety discipline. Each step must be meticulously performed, in the correct order, without skipping any steps. Step 7, Isolation Verification, in particular, is the most critical application of the "check to make sure" principle. While actions such as removing the MSD or turning off the switch are part of isolation, they do not prove that the system is truly de-energized. The only proof is a voltage absence test with a suitable measuring device. In technician training, the logic behind the LOTO steps and the potentially fatal consequences of skipping each step (especially the verification) should be clearly emphasized.

3.4. Emergency and Fire Safety

In EV service environments, being prepared for emergencies (electric shock, fire) that may arise from HV systems and knowing the correct response methods are critical.

3.4.1 Emergency Shutdown Procedures

Most electric vehicles have safety mechanisms designed to quickly shut down the HV system, either automatically or manually, in the event of a crash or emergency. These may include:

- **Crash Detection Systems:** Systems that automatically open the HV contactors when a serious crash, such as airbag deployment, is detected, isolating the battery from the system.
- **Manual Emergency Disconnects:** Special buttons or switches, located inside or outside the vehicle and accessible to first responders or technicians, designed to manually disconnect the HV system. 13 Technicians must be familiar with the emergency shutdown procedures for the models they work with.

3.4.2 Response in Case of Electric Shock

1. **Ensure Safety:** Never directly touch the victim! Ensure your own safety first.
2. **Disconnect Power:** If possible, immediately shut off the power source (emergency breaker, circuit breaker, MSD, etc.).
3. **Separate the Victim:** If disconnecting the power is not possible or uncertain, use an electrically insulating material to separate the victim from the power source. This could be a dry piece of wood, rubber mat, plastic pipe, or a specially designed insulating rescue hook. Metal or wet objects should never be used.
4. **Call for Help:** Call for emergency medical assistance (112) immediately.
5. **First Aid:** After safely reaching the victim, check their breathing and circulation and administer basic first aid (if trained).

3.4.3 Lithium-Ion Battery Fires and Response

Fires from lithium-ion batteries used in EVs exhibit different and more dangerous characteristics than traditional vehicle fires:

- **Thermal Runaway:** This is an uncontrolled, self-sustaining chemical reaction that occurs when battery cells are damaged, overheated, or have an internal short circuit. 32 During this reaction, the cells reach very high temperatures (hundreds of degrees Celsius), releasing flammable and toxic gases (hydrogen fluoride, carbon monoxide, etc.), which can spread to neighboring cells and cause a chain reaction. 32
- **Intense Heat and Energy:** A large amount of energy is released during thermal runaway, making the fire very intense and difficult to extinguish. 33
- **Risk of Reignition:** Even if a battery fire appears to be extinguished, chemical reactions within the cells can continue, and the fire can restart hours or even days later. 32

- **Anaerobic Combustion:** Battery cells use their own oxidizers to produce. Because it contains oxygen, the combustion reaction may not require external oxygen to continue.³² This reduces the effectiveness of smothering-type extinguishers (such as CO₂).
- **Multiple Fire Class Hazards:** Li-ion battery fires are complex due to the presence of both solid materials (plastic casing - Class A), flammable electrolytes and gases (Class B), and electrical energy (Class C). Even metals within the battery casing (aluminum, etc.) can burn (Class D potential).³³

Extinguishing Methods and Their Effectiveness:

- **Water:** The primary purpose of Li-ion battery fires is cooling. Water is the most effective cooling agent due to its high heat capacity. ³² It may be necessary to apply very large amounts of water over a long period of time to slow or stop thermal runaway and prevent reignition. ³² Water mist technology can provide more effective cooling and oxygen dilution while using less water. ³² Important Note: Water can cause hazardous reactions in batteries containing pure lithium metal (often referred to as disposable "lithium batteries," not Li-ion). ³⁴ However, since Li-ion batteries do not contain free metallic lithium, water can generally be used safely. Managing contaminated extinguishing water is an environmental concern. ⁶⁵
- **Foam:** Generally ineffective on Li-ion fires and does not provide sufficient cooling. ⁶³
- **Dry Chemical Powder (ABC, BC):** While partially effective in suppressing flames, they lack cooling capacity and do not stop thermal runaway. Therefore, they are generally considered ineffective on Li-ion fires. ³²
- **Carbon dioxide (CO₂):** Their cooling effect is very low and they are ineffective due to the possibility of burning without oxygen. ⁶³
- **Class D Powder Extinguishers:** These extinguishers are designed for flammable metal fires such as magnesium, titanium, sodium, and lithium metal. Because Li-ion batteries do not contain free metallic lithium, Class D extinguishers are generally ineffective or have very limited effectiveness on Li-ion fires. ³² Their use on Li-ion fires is generally not recommended.
- **Specialized Extinguishing Agents:** New agents specifically developed for Li-ion fires are available. For example, Aqueous Vermiculite Dispersion (AVD) acts by providing cooling while also forming an insulating layer on the burning surface. ³⁴ Commercial products such as Lith-Ex also use such agents. ⁶⁵

3.4.4 Workshop Fire Safety Precautions

- A sufficient number of fire extinguishers of the appropriate type should be available. Given the risk of Li-ion, water-based extinguishers (water, water mist, AVD) should be considered first. General-purpose ABC or CO₂ extinguishers can also be available for other fire risks. It should be noted that Class D extinguishers are not suitable for Li-ion.
- Fire blankets.

- Good ventilation (especially in charging areas).
- Clear and marked emergency escape routes.
- Fire detection and alarm systems.
- Personnel training on fire types and extinguisher use.
- Emergency response plan and drills.

Technicians must be aware of the unique hazards of Li-ion battery fires and understand that standard fire extinguishing information may not be sufficient for these types of fires. The priority of cooling and the risk of reignition should be kept in mind. Workshop safety planning should take these specific risks into account and appropriate equipment and procedures should be made available.

4. NECESSARY TOOLS, EQUIPMENT AND ADVANCED TECHNOLOGIES

This learning activity covers a wide range of topics, from basic hand tools to specialized diagnostic devices, from lifting equipment to advanced technologies like predictive maintenance, required for EV maintenance and repair.

4.1. Basic Hand Tools and Insulated Tools

Standard automotive repair tools (various wrenches, sockets, screwdrivers, pliers, etc.) are still required for EV service. However, due to the presence of high-voltage systems, additional safety precautions and specialized tools are also required:

- **Standard Hand Tools:** Used for general mechanical work, trim removal, low-voltage connections, etc.
- **Insulated Hand Tools:** These are tools that are highly recommended or mandatory when working on or near high-voltage components (even when the system is de-energized, as an additional safety precaution). These tools (screwdrivers, pliers, side cutters, open-end/Phillips wrenches, etc.) typically have special coatings that provide insulation up to 1000V AC / 1500V DC. Compliance with international standards such as EN 60900 or VDE must be tested and marked. The insulation coatings of insulated tools should be checked regularly, and damaged tools (cracks, peeling, etc.) should not be used.
- **Torque Wrenches:** It is crucial to strictly adhere to the manufacturer's specified torque values, especially when installing battery modules, HV connections, and other critical components. Loose connections can cause high resistance and heat, while overtightening can cause damage or short circuits. Therefore, the use of calibrated torque wrenches is essential.

4.2. Diagnostic Tools

Specialized diagnostic tools and measuring equipment are required to accurately diagnose faults in the complex electrical and electronic systems of EVs:

- **Digital Multimeter (DMM):** This is an indispensable tool for basic electrical measurements (AC/DC voltage, resistance, continuity). It is essential that the multimeter used for measurements in HV systems has the appropriate safety category (CAT III or CAT IV) and a sufficient voltage rating. It is used to verify the absence of voltage, a critical step in the LOTO procedure. Features such as auto-ranging and True RMS are useful.
- **Insulation Resistance Tester (Megohmmeter):** This is used to measure the insulation resistance of HV components (battery, motor, cables, etc.) and circuits against the vehicle chassis or other circuits. This test is important for detecting potential leakage currents and insulation faults. It should be used with caution because it applies high test voltages.
- **Diagnostic Scan Tool / Scanner:** Used to communicate with the electronic control units (ECUs) of modern vehicles to read and clear fault codes (DTCs), monitor live

sensor data (parameters), perform component tests (actuator tests), and perform various service functions (adaptation, coding, reset).¹⁴

- **EV-Specific Capabilities:** Standard OBD-II scanners often lack access to EV-specific systems (HP battery, BMS, inverter, charge control, etc.). For EVs, manufacturer-specific or advanced multi-brand scanners are required. These scanners must be able to read EV-specific data such as cell voltages and temperatures, SoH estimation, insulation resistance value, inverter operating status, and charging parameters, and perform diagnostics on related systems.¹⁴
- **Oscilloscope:** Used primarily to visualize and analyze the waveforms of sensor signals, communication data lines (e.g., CAN bus), and power electronic switching signals. They are an invaluable tool for diagnosing momentary or complex electrical problems.
- **Battery Analyzers:** These are specialized testing devices used to further analyze the capacity, internal resistance, and overall health of a battery pack or individual modules. They are typically found in service centers.
- **Thermal Cameras:** Used to detect abnormal heating (indications of loose connections, high resistance) in HV components, connections, or cables.

4.3. Lifting and Carrying Equipment (EV-Specific Considerations)

Lifting EVs during service and handling some of their heavy components (especially the battery pack) requires special care and equipment:

- **Vehicle Lifts:** Due to their large battery packs, EVs are generally significantly heavier than ICE vehicles of the same size. It is important to ensure that the lifting capacity of the vehicle lifts (two-post, four-post, scissor, etc.) used in service is sufficient for the vehicle's weight. Furthermore, because the battery pack is usually located on the vehicle floor, the lifting points where the lift arms are positioned must align with the safe points specified by the manufacturer. Lifting from the wrong points can damage the battery case or other components.
- **Battery Lifting and Carrying Devices:** EV battery packs can weigh hundreds of kilograms. When the battery needs to be removed or installed from the vehicle, specialized equipment is required to perform this task safely and in a controlled manner. These typically include:
 - *Battery Lift/Jack:* These are special lifts, usually hydraulic or electric, with wheels and adjustable tables, used to lower or raise the battery by supporting it from below after the vehicle is lifted.
 - *Battery Carriers:* These are special carts used to safely transport the removed battery within the workshop.
 - *Cranes/Slings:* In some cases, special cranes or slings may be required to lift the battery from above.
 - This equipment must be capable of supporting the weight of the battery and designed to protect it from damage.

- **Other Lifting Equipment:** If standard floor jacks or mobile jacks are used, they must be rated for the weight of the EV and used at the correct lifting points.

4.4. Predictive Maintenance and Remote Diagnostics

With advancements in automotive technology, EV maintenance is evolving from a reactive (post-failure repair) approach to a proactive (pre-failure prediction and prevention) approach. Predictive maintenance and remote diagnostic technologies play a key role in this transformation.

- **Predictive Maintenance (PdM):** This is the process of predicting when components or systems may fail or require maintenance by using data collected from vehicle sensors and advanced analysis methods (especially Artificial Intelligence (AI) and Machine Learning (ML)). 16 The goal is to prevent unplanned downtime, optimize maintenance costs, and increase safety by intervening before failures occur. 17

- How Does It Work?

- 1. Data Collection:** Numerous sensors on the vehicle continuously collect data (battery cell voltages/temperatures, engine current/vibration, inverter temperature, charging data, driving patterns, etc.). 17

- 2. Data Transmission:** This data is typically transmitted over-the-air (OTA) to the manufacturer's or service provider's cloud platforms via telematics systems. 16

- 3. Data Analysis (AI/ML):** AI and ML algorithms running in the cloud or sometimes on-board (edge computing) analyze this large dataset. The algorithms learn normal operating conditions, detect abnormal deviations or degradation trends in the data, and predict potential failures or remaining life (RUL) using statistical models (e.g., Weibull regression) or learning models (e.g., Neural Networks - BPNN). 16

- Application Areas:

- **Battery Health (SoH) and RUL Prediction:** This is the most common application area. Factors such as charge/discharge cycles, temperature history, and the number of deep discharges are analyzed to predict when the battery's capacity will drop to a critical level or require replacement. 16

- **Motor and Power Electronics Monitoring:** Abnormalities in motor windings, wear in bearings (through vibration analysis), and deterioration trends in IGBTs or capacitors in the inverter can be detected at an early stage. 16

- **Other Systems:** The performance of other critical systems, such as the braking system and cooling system, can also be monitored to predict potential problems.

- **Benefits:** Reduces unplanned breakdowns and associated high costs, optimizes maintenance scheduling (prevents unnecessary maintenance), increases vehicle safety and reliability, and extends component life. 16

- **Remote Diagnostics:** This involves remotely diagnosing potential problems in the vehicle before it arrives at the service center, using data transmitted through telematics systems. This can expedite the repair process upon arrival. Some software-related issues or settings can be resolved with over-the-air software updates (OTA), eliminating the need for a service visit. 16 Vehicle owners can also obtain information about their vehicle's basic health status, often through mobile apps.

Predictive maintenance and remote diagnostics are technologies that are fundamentally changing the EV service industry. Technicians of the future will not only troubleshoot mechanical or electrical faults but also be able to analyze data, effectively utilize diagnostic platforms, and interpret alerts generated by AI/ML-based systems. These technologies should not be viewed as replacing technicians, but rather as tools that enable them to work more proactively and efficiently. It is becoming increasingly important for VET programs to equip students with these new digital skills.

4.5. Battery Recycling and End-of-Life Management

With the widespread use of electric vehicles, the management of end-of-life (EoL) high-voltage batteries has become a significant environmental and economic issue. These batteries contain valuable materials such as lithium, cobalt, nickel, manganese, copper, and aluminum. 71 They also contain hazardous substances that can harm the environment if mismanaged. Therefore, the safe collection, transportation, and processing of EoL batteries is critical.

Battery Recycling Methods

Two primary industrial methods are used to recover the valuable materials in EoL batteries:

4.5.1 Pyrometallurgy (High-Temperature Processing)

In this method, batteries are melted (usually after pretreatment or sometimes directly) in furnaces at very high temperatures (e.g., above 1400°C). 18 During the melting process, the metals are collected in the alloys or slag (waste) phase and then separated.

- Advantages: Generally requires less complex pretreatment and can process different battery chemistries together.
- Disadvantages: Consumes very high energy, light metals such as lithium generally have low or no recovery efficiency (they mix with slag), and can create potentially harmful air emissions (flue gases). 18 Metals such as cobalt, nickel, and copper can be recovered more efficiently.

4.5.2 Hydrometallurgy (Chemical Process)

In this method, batteries are usually first mechanically shredded, and components such as plastic and metal casings are separated. The "black mass," which contains the remaining active materials, is subjected to leaching using chemical solutions (usually acids). 18 In this process, precious metals (lithium, cobalt, nickel, manganese) are released into solution and then recovered through various chemical separation and purification methods (precipitation, solvent extraction, etc.).

- Advantages: Generally lower energy consumption than pyrometallurgy, higher recovery efficiency for many metals, including lithium, and less air pollution. 18

Efficiency can be further increased with techniques such as ultrasonically assisted leaching. 18

- Disadvantages: Involves more complex chemical processes, requires pretreatment (fragmentation, separation), and wastewater and chemical waste management is important.

4.5.3 Direct Recycling (Emerging Method): This approach aims to reuse battery electrode materials (especially the cathode) directly in the production of new batteries, preserving as much of their original structure as possible, without melting or chemically dissolving them. It is still in the development phase but could potentially be less costly and more environmentally friendly.

4.5.4 Second-Life Applications

Even when an EV battery loses sufficient capacity for vehicle use (typically 70-80% of its original capacity), it can still store significant amounts of energy. Repurposing these batteries for less demanding applications is called "second use."

- Application Areas:

- Stationary Energy Storage: Used for purposes such as storing energy generated from solar panels in homes or businesses, providing power during peak demand hours (peak shaving), and regulating grid frequency.

- Mobile Charging Stations: Can be used as a portable power source to charge other EVs.

- Uninterruptible Power Supplies (UPS): Can be used to provide backup power for critical systems.

- Other Applications: Potential applications include telecom base stations and street lighting (Japan example 19).

- Benefits: Extends the battery's total lifespan, enables more efficient use of valuable resources, reduces environmental impact by reducing the need for new battery production, creates additional value before recycling, and contributes to the circular economy model.

Battery lifespan management is a vital issue for the environmental sustainability and economic feasibility of the EV ecosystem. It's crucial for technicians to adhere to safety procedures during battery disassembly, handling, and storage, and to be knowledgeable about directing batteries to the correct channels (recycling or reuse facilities) at the end of their life. As recycling technologies and the reuse market mature, new expertise and job opportunities will emerge in this area.

5. TECHNICIAN COMPETENCIES AND OCCUPATIONAL HEALTH AND SAFETY

This learning activity addresses the training, certification, and competencies required of technicians working in electric vehicle maintenance and repair, as well as the legal and practical requirements for occupational health and safety (OHS).

5.1. Training and Certification

The maintenance and repair of electric vehicles (EVs), unlike traditional internal combustion engine (ICE) vehicles, requires specialized knowledge, skills, and, most importantly, safety training due to high voltage (HV) systems, battery technologies, and complex electronic controls.¹ The current knowledge of a standard automotive technician is often insufficient to safely and effectively service EVs.

5.1.1 Training Contents

The training required of EV technicians should cover the following:

- Fundamentals of Electrical and HV Systems: AC/DC theory, HV components, hazards (electric shock, arc flash), safety precautions.
- Battery Technology: Lithium-ion chemistry, Battery Management Systems (BMS), charging principles, SoH assessment, thermal management, safety risks.
- Power Electronics: Operating principles and diagnostics of inverters, DC-DC converters, and OBCs.
- Electric Motors: Different motor types (PMSM, Induction, etc.), operating principles, control, and diagnostics.
- Charging Systems: Charging standards, protocols, charging stations, vehicle-side components, and troubleshooting.
- EV-Specific Diagnostic Methods: Use of diagnostic tools, interpretation of specific parameters, insulation testing, CAN bus communication.
- Safety Procedures: Selection and use of Personal Protective Equipment (PPE), Lockout/Tagout (LOTO) procedures, emergency response, fire safety.
- Relevant Standards and Regulations: Legal and technical requirements such as ISO 6469, EN 60903, national OHS legislation, and MYK/TSE standards.⁷³

5.1.2 International Certifications (ASE, IMI)

Some certification programs that are particularly important for European Union projects and international validity are as follows:

- **ASE (Automotive Service Excellence - USA):** Especially common in North America, ASE offers a two-level safety certification for EVs called "xEV High-Voltage Electrical Safety Certification."²⁰
 - **Level 1 (Awareness):** Provides basic safety awareness for personnel who may come into contact with EVs (sales, service advisors, washers, etc.) but who will not directly interfere with HV systems.²⁰

- Level 2 (Technician): Designed for technicians who can safely de-energize HV systems, use PPE, and work on HV components (in a de-energized state). 14 This certification is generally valid for 3 years. 20
- IMI (Institute of the Motor Industry - UK/International): Recognized in Europe and many other countries, IMI offers different levels (Levels) for EVs and hybrid vehicles. vocational qualifications (from Level 1 to Level 4) are offered.21
 - Level 1: Basic awareness.74
 - Level 2: Hazard management (for emergency personnel) or routine maintenance activities.74
 - Level 3: Repair and replacement of HV systems.74
 - Level 4: Advanced diagnostics, testing, and repair (at the component level).74
 - These levels determine the level at which a technician is authorized to work on HV systems. IMI certificates are accepted as standards in many European countries.73

5.1.3 MYK/TSE and Brand Training in TÜRKİYE

In Türkiye, there are national regulations and standards that technicians and services working in the EE field must comply with:

- MYK (Vocational Qualifications Authority): MYK publishes national occupational standards for various occupations and provides professional qualification certification based on these standards. Occupational standards and relevant qualifications exist for the EV field, such as "Battery Electric Vehicle Service Personnel (Level 3)." MYK certification is required for certain jobs or is planned to be required. 37 These standards also include OHS regulations. 1
- TSE (Turkish Standards Institution): TSE sets standards and certifies both products and services. There are standards such as TS 12047 (Authorized Services - General Rules) for automotive services. 36 In addition, TSE has specific standards (e.g., TSE K 646 36) related to EV technologies and maintenance, and organizes training and examinations on these topics. 36 Some regulations require those responsible for electric vehicle maintenance and repair to hold a certificate of competence issued by the TSE or MYK. 37
- Brand-Specific Training and Authorization: Vehicle manufacturers organize comprehensive training programs to train authorized technicians who are familiar with the technological features and service procedures of their models. To work in authorized service centers, it is generally necessary to complete brand-specific training and obtain certification.2 This training typically includes the most up-to-date and model-specific information.
- **Competence and Continuous Development:** While certification is important, what truly matters is the technician's ability to apply theoretical knowledge accurately and safely in practice.2 Because EV technology is rapidly evolving, technicians must

constantly update themselves, stay informed about new technologies and procedures, and receive periodic refresher training.

Consequently, becoming an EV technician requires documented expertise that complies with both international standards (for safety and basic technology) and the legal requirements of the country of employment (MYK, TSE for TÜRKİYE). For those wishing to work in this field, receiving the appropriate training and obtaining the relevant certifications is a prerequisite for both career development and regulatory compliance. VET programs should prepare their graduates for these dual (international and national) requirements.



<https://youtu.be/H5iHp64PFxY>

Scan the QR code or click the link below to watch the video.

5.2. Occupational Health and Safety (OHS) Practices

Occupational Health and Safety (OHS) in electric vehicle repair shops is not limited to high voltage hazards; it requires a comprehensive approach that also includes chemical, mechanical, ergonomic, and environmental risks. In Türkiye, OSH practices are primarily regulated by Occupational Health and Safety Law No. 6331 and regulations based on this law.¹

5.2.1 Legal Framework (TÜRKİYE)

- OSH Law No. 6331: It specifies the fundamental obligations of employers and employees regarding OSH.³⁸ Employers have responsibilities such as conducting/commissioning a risk assessment, informing and training employees, providing the necessary PPE, and conducting health surveillance.¹ Employees, on the other hand, have obligations such as complying with OSH rules, acting according to instructions, and not endangering their own safety or the safety of others.³⁸

● Relevant Regulations

- Regulation on the Use of Personal Protective Equipment in Workplaces: This regulation specifies which PPE may be used for which tasks, as well as the rules regarding the selection, use, and maintenance of PPE.
- Regulation on Health and Safety Signs: It specifies the standards for warning, prohibition, and informational signs that must be used in workplaces.¹ HV warning signs are included in this scope.
- Regulation on Health and Safety Conditions in the Use of Work Equipment: This regulation includes requirements for the safe use and periodic inspection of work equipment such as lifts, jacks, and hand tools.
- Regulation on Health and Safety Measures in Working with Chemical Substances: This regulation addresses the risks and safe use of chemicals such as coolants, cleaners, and battery electrolytes.
- Regulations on Electrical Equipment: Regulations such as the Grounding in Electrical Installations Regulation and the High Current Electrical Installations Regulation are important for the safety of a workshop's electrical infrastructure.

- Regulation on Waste Management: This regulation specifies rules for the management of hazardous waste, particularly end-of-life batteries, used oils, and chemicals.¹

5.2.2 Workshop and Equipment Safety

- **Workplace Layout:** The workshop must be clean, tidy, and well-lit. Walkways and emergency exits must be kept clear.
- **High Voltage Work Areas:** Areas where work will be carried out on high voltage (specific compartments or designated areas, if any) must be clearly designated, marked with warning signs, and unauthorized persons must be prevented from entering.¹ Additional precautions, such as insulating mats, may be taken in these areas.
- **Ventilation:** Adequate ventilation must be provided, especially in battery charging areas and areas where chemicals are used (to prevent the accumulation of flammable or toxic gases).
- **Emergency Equipment:** Emergency equipment such as fire extinguishers (see Section 3.4), first aid kits, eyewash solutions, and insulating rescue hooks should be readily available and periodically inspected. ¹⁴

5.2.3 Chemical and Waste Management

Chemical Safety: Safety Data Sheets (SDS/MSDS) for chemicals such as coolants, brake fluids, and cleaning solvents should be available, their risks should be known, and appropriate absorbent materials and response procedures should be prepared in case of spills or leaks. ¹ Caution should be exercised regarding electrolytes that may leak from damaged batteries.

- **Waste Management:** Hazardous waste (EoL batteries, contaminated liquids, chemicals) must be collected separately from other wastes in properly labeled containers and sent to licensed waste treatment facilities.¹
- **Mechanical Safety:** Vehicle lifts, jacks, and other lifting equipment must be used only by trained personnel, in accordance with the manufacturer's instructions and carrying capacity.¹ Periodic maintenance and inspections of this equipment must be performed regularly. Additional safety precautions (such as stands) should be taken when working under the vehicle.

5.2.4 Ergonomics and Emergency Preparedness

Repetitive movements, awkward work postures, and manual lifting of heavy loads should be avoided. Auxiliary lifting/carrying equipment should be used when necessary.

OH&S in EV services is a shared responsibility of technicians and employers. Complying with legal requirements, accurately assessing risks, taking necessary precautions (PPE, LOTO, safe working procedures), and consistently establishing a safety culture are essential to prevent accidents and ensure a healthy working environment. VET programs should provide students with OSH awareness and practices as well as technical skills.

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