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TECMEHV–Training & Development of European Competences on Maintenance of Electric and Hybrid Vehicles

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Abstract

The growing up diffusion of the electrically propelled vehicles brings the problem of the establishment of an appropriate infrastructure network and of adequate technical assistance support for their maintenance and repair, over their cycle life. A specific professional formation is a requisite for all people acting in these new technology field. The Project TECMEHV, initiated in October 2011, in the frame of the EU Lifelong Learning Programme Leonardo da Vinci is addressing these needs.
The objective of TECMEHV is to create a professional Qualification for Electric and Hybrid Vehicles maintenance and technical assistance, to be accredited to the operators acting in this field.
The method to reach this goal is the establishment of a Competence Framework according to the intended EC Vocational and Educational Training.
Units of Competence have been identified on the basis of the State of Art of the electric vehicle technology on the key technology topics: Powertrain, Energy Storage, Charge, Energy Management & Communication and Peripherals.
Units of Competence for the operational activities have been defined as: Diagnosis & Verification, Planning for intervention, Battery Pack refurbishing and Safety.
An e-learning platform and relevant supporting on-line materials in several languages is being developed.
A web based Learning Management System will be set up, to host online multilingual training modules based on the Social Constructionist Pedagogical Model, which are planned to be validated in pilot testing in the different Countries by expert groups formed by industrial and academic representatives.
The project activity is coordinated by ASCAMM Technology Centre and performed by a consortium comprising five partners and two associated partners from five European Countries.

Keywords: Electric Vehicle, Maintenance, Repair, Formation

1 Introduction

The growing up diffusion of the electrically propelled vehicles brings the problem of the establishment of an appropriate infrastructure network and of adequate technical assistance support for their maintenance and repair, over their cycle life.
A specific professional formation is a requisite for the operators in the field of electric and hybrid vehicles, which are presently starting the diffusion in the ground mobility system.
Addressing these needs, the Project TECMEHV has started in October 2011 in the frame of the EU Lifelong Learning Programme Leonardo Da Vinci.
The aim of the Project is to define a method to induce a professional competence in the dedicated experts involved in the technical assistance, maintenance and repair of electric and hybrid vehicles and in the relevant infrastructure for energy supply. The final goal is to create a Professional Qualification for technical assistance, to be accredited to the operators acting in this field.

The project activity is performed by a consortium comprising five partners and two associated partners from five European countries, bringing together experience and resources in the areas of: training programmes, professional qualification advice, research and development, automotive industry knowledge and technical aftermarket maintenance:
ASCAMM Technology Centre, Coordinator
ATA, Associazione Tecnica dell'Automobile
EPFL, Ecole Politechnique Federale de Lausanne
NORAUTO
Universitat DUISBURG ESSEN
Centro Ricerche Fiat, associated partner
Sociedad de Tecnicos de Automocion, associated partner.

2 Formation of New Skills for New Jobs – Training policy

The overall objective of TECMEHV is to create a professional Qualification for Electric and Hybrid Vehicles maintenance and technical assistance, to be accredited to the operators acting in this field.
The method to reach this goal is the establishment of a Competence Framework according to the intended EC Vocational and Educational Training, to ensure homologation for the whole European Community territory.

The training initiative should be consistent with the strategic framework "European Education Environment". The long term strategic objectives of EU education and training policy are:

- making lifelong learning and mobility a reality;
- improving the quality and efficiency of education and training;
- promoting equity, social cohesion and active citizenship,
- enhancing creativity and innovation, including entrepreneurship, at all levels of education and training.

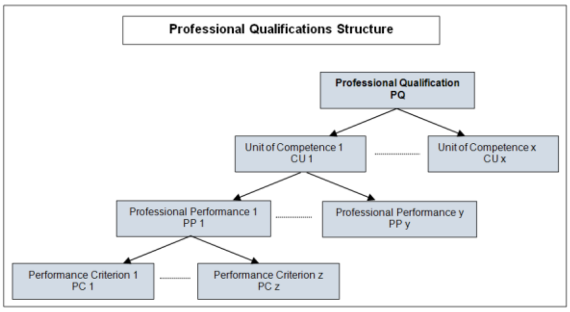
An acknowledge of degrees of training, at the international level, can be assured by a credit-transfer system for academic recognition, for example the "European Credit Transfer System (ECTS) and the "European Credit system for Vocational Education and Training (ECVET), allowing transparency and recognition of vocational education and training.
A professional qualification system is proposed by TECMEHV project, to balance the training offer and implement the new professional skills addressing the electric and hybrid maintenance and repair market.

2.1 Professional Qualification Structure

A Professional Qualification (PQ) is considered as a set of professional competences that can be achieved through vocational education and training modules, or any kind of learning structure, as well as through work experience. From a formal point of view, a professional qualification is a group of knowledge and capabilities that satisfy occupations and job posts in the labor market.
Each qualification has a general competence that defines in synthesis the essential tasks and functions of the operator. Other elements are also described, including the professional environment in which the qualification takes place, the corresponding productive sectors and the relevant occupations or posts, that can be accessed with the qualification.

2.2 The Competence Units and the Training Modules

A competence unit is the minimum set of professional competences that can be partially recognised and accredited. Every competence unit is linked to a **learning module** that describes the necessary learning to acquire that particular competence unit.
This structure facilitates the assessment and accreditation of every competence unit acquired by an employee, both through work experience and non-formal or informal learning. Recognised and accredited competence units can be accumulated in order to obtain the accreditation of a qualification.
Each **competence unit** will have a standardised format, which includes its identification information and the specifications of that competence.
The competence units are divided into **Professional Activities** (PA). These establish the expected behaviour of one person, i.e. the expected consequences or results of the activities performed by that person. They help to show whether person is competent in a competence unit.
The **Performance Criteria** (PC) express the acceptable level of one professional activity to meet the productive organisation's targets and are reference guides for the assessment of professional competences.

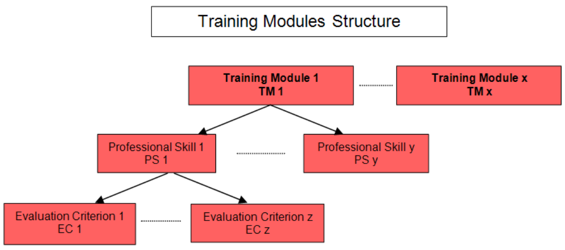


Each **competence unit** is associated with a **Training Module**, which describes the **necessary learning to acquire that competence unit**.

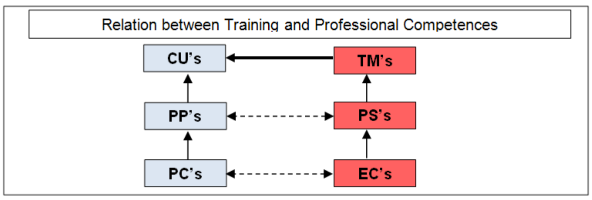
A **Training Module** (TM) is a coherent set of training associated with the units of competence that make up skills. It is the **smallest unit of training** to determine the diplomas and professional certificates.

Training specifications contain **Professional Skills** (PS), the expression of the expected outcomes of peoples' learning situations at the end of the training module.

The **Evaluation Criteria** (EC) is a set of details for each capacity that indicate the degree of detail acceptable to it. They define the scope and level of ability and the context in which it is to be evaluated.

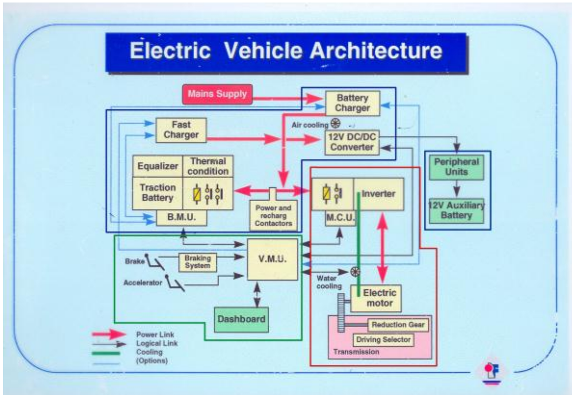


The competence units are associated to the corresponding training modules, which describes the learning content, which is required for their acquisition.



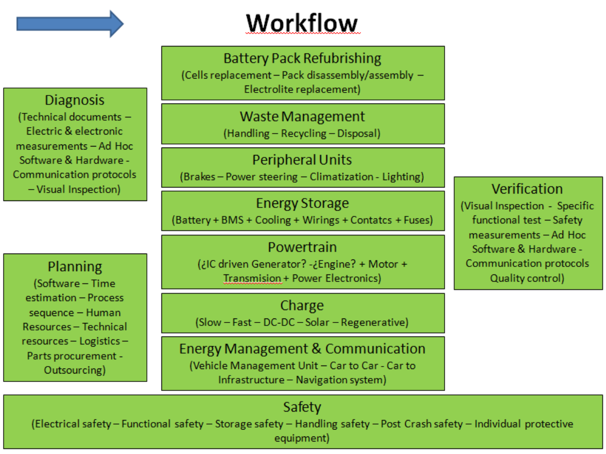
CU's for maintenance and repair electric and hybrid vehicles have been identified in relation with the technical areas of intervention in the vehicle system and in relation with the procedure to follow for the intervention. The CU's related to the technical areas have been defined and developed on the basis of the technology state of art of electric and hybrid vehicles, which was object of a first part of the project.

The following schematic shows the technical areas considered for the definition and description of the Competence Units

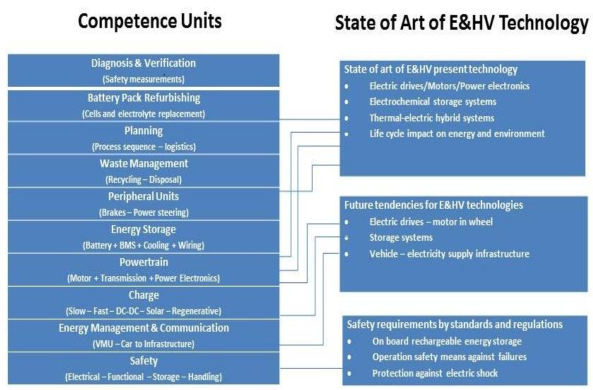


In the schematic the areas are identified related to Energy Storage and charge, Power train, Energy Storage and Communication and Peripheral Units.

The following figure shows the workflow of the sequence of operations for the maintenance and Repair of E&HV in which the competence units are framed.



The following figure shows the link between the items of the **state of art** and the **competence units** defined.



2.3 The State of the Art

2.3.1 Electric drives [1]

Fig. 1 shows a general frame of the electrical machines for electric vehicle traction application.

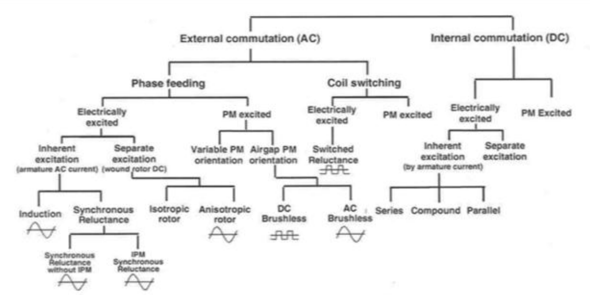


Fig. 1 Electrical machines and wave forms of the related electric drives

The mostly considered electric machines and relevant power electronics for application on electric and hybrid vehicles and to be primarily considered for maintenance and repair are the following ones:

DC motor separately excited,
adopted in the past for various types of electric vehicles, many of which still in use.
It features good controllability and efficiency, with simple power electronics, however the electromechanical commutation requires higher attention for maintenance, with periodical substitution of brushes and restoring of the commutator.

AC asynchronous induction motor,
widely diffused at the industrial level, robust, featuring simple construction and good reliability.
It can be designed for high speed, with low weight and volume, easy to be cooled also with liquid.
A large number of electric vehicles of the present generation makes use of AC induction motor.
The maintenance requirements are little demanding.

Synchronous wound rotor machine
The structure is reverse of that of the DC separately excited machine: The rotor incorporates the excitation coils, which are fed through slip rings and are externally controlled. The stator incorporates the armature windings, which are fed by the external inverter.
Positive features of this type of machine are the easiness of control, through the double circuit of armature and excitation. A disadvantage is the presence of the slip rings and small brushes for feeding the excitation coils, which could require some maintenance. No special materials are involved.

Synchronous Permanent Magnet machine
The excitation flux is produced by permanent magnets, which are integrated in the rotor in typically two positions: Surface mounted and Internal mounted.
The synchronous Permanent Magnet machines can be fed and controlled according to two concepts:

- The “DC Brushless” is fed by rectangular current wave form on two or three phases, impressed by the inverter
- The “Synchronous Brushless” is fed by the inverter, which generates sinusoidal wave forms, as in an asynchronous motor.

The firs mode is to some extent simpler as far as sensors and control is concerned, but can produce torque ripple, while the second mode assures a smoother torque performance.

Synchronous reluctance machine
The synchronous reluctance is a brushless machine featuring a stator similar to that of the asynchronous machine and an anisotropic rotor, featuring paths of minimum reluctance.
The rotor follows synchronously the magnetic rotating field generated by the stator currents, due to the preferential channelling of the flux into the minimum reluctance paths.
Permanent magnets, in limited quantity, can be integrated in the rotor, in the direction of maximum reluctance paths, which increase the phase cos φ, with the effect of reducing the size of the inverter (fig. 3), furthermore the increase of field weakening range and increase the torque

density up to the limit of the synchronous permanent magnet machines.

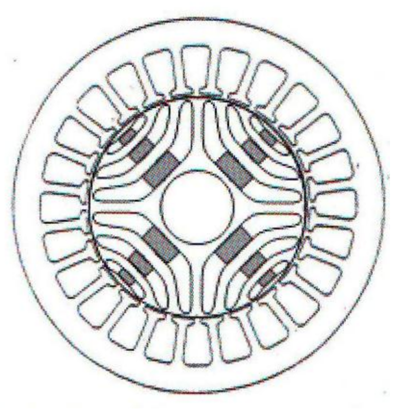


Fig. 2 Synchronous reluctance machine with permanent magnet compensation.

Switched reluctance machine

The machine is constituted by a stator featuring excitation windings and a toothed rotor, with a number of poles different from that of the stator (fig. 4), without magnets or windings.
The stator coils are cyclically fed by DC current and the torque is produced by the magnetic attraction of the rotor poles with the stator poles.
The construction of the machine is simple and with conventional materials; the limits are given by the low utilization of the magnetic path (just two poles a time are active) and the discontinuity of feeding of the coils, which can impact on the reactive components of the power electronics and can produce torque ripple and noise. This can be minimized with appropriate profiles of the poles and wave form of excitation currents.

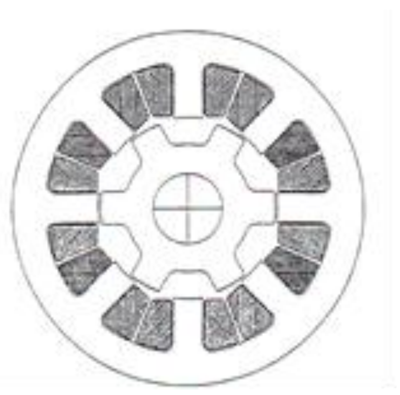
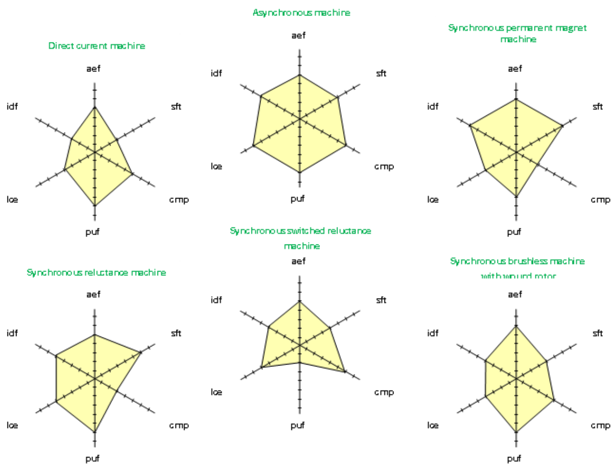


Fig. 3 Switched reluctance machine

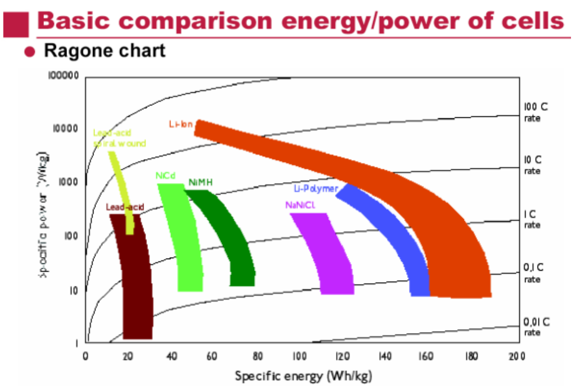
In the following diagrams a qualitative presentation is given of the most characterizing features of the above described machines, which can impact the relevant performance, the manufacturing, the vehicle integration attitude the materials involvement, the energy effectiveness and the life cycle efficiency.



aef: average (high power/low speed), efficiency (TTW)
cmp: critical material presence
idf: integration design flexibility
lce: life-cycle efficiency
puf: performance - low torque ripple and NVH, user friendliness and comfort
sft: specific power and torque (high speed capability)

2.3.2 Electrochemical storage systems

The Electrically Rechargeable Storage System, which is a key element of the traction system of electric and hybrid (especially plug-in) vehicle, can be classified on the basis of its functional performance, energy efficiency, thermal requirement, use dependability (recharging, self discharging, maintenance and safety), cost and life cycle impacts on energy, environment, materials, recycling.
Following figure shows the functional performance of the storage batteries, most appropriate for the application to electric vehicles.



The **Lead-acid** accumulator, based on the electrochemical couple Pb/PbO_2, with interposed electrolyte solution of H_2SO_4, is presently the most diffused type for the electric traction.
For the present applications various types are commercially available, with positive electrode either flat or tubular and with gas recombination, either with gel electrolyte or micro porous separator, which do not require water refilling.

The **Alkaline Nickel-Cadmium (Ni-Cd) and Nickel-Metal Hydride (Ni-MH)** batteries are applied in electric and hybrid vehicles: the Ni-Cd was used especially in France, due to specific energy higher than Lead-acid; presently they are less considered, mainly for to management, manufacturing and after-use problems due to the toxicity of Cadmium (specific European Directives give prescription on this matter).
The trend is to substitute them with Ni-MH batteries, with different design for electric and hybrid vehicle applications (more energy or power performance oriented).

The battery **Sodium-Nickel metal Chloride (Na-$NiCl_2$)** also known as “Zebra” is a derivation from the previously developed Sodium-Sulfur battery.
For the cell operation the sodium must be liquid, at a temperature of 250 – 290 °C.
For vehicle application the cells are included in a thermal insulating package, in which also a resistor is provided for the thermal conditioning.
The battery is particularly indicated for the missions demanding a frequent utilization, with regard to the thermal management of the battery itself.

The **Lithium batteries** are presently widely considered, developed and already in use for the electric vehicles, due to their high specific performance.
In the lithium batteries a variety of electrodes and electrolyte materials are in use; this gives development to various electrochemical couples and to a range of products, which are presently commercially available or in the phase of advanced development.
The most prominent technologies for automotive applications are lithium-nickel-cobalt-aluminum (NCA), lithium-nickel-manganese-cobalt (NMC), lithium-manganese-spinel (LMO), lithium titanate (LTO) and lithium-iron phosphate (LFP).

Each combination has distinct features in terms of specific energy and power, life cycle span, performance stability against temperature and cost.
Fig. 8 presents the trade-offs among these five principal lithium-ion technologies, with indication of the position of the different types of technology with respect to the various parameter features.

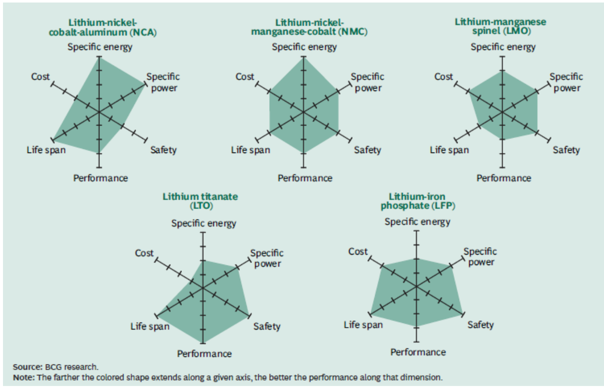


Fig. 5 Parameters tradeoff for the different yypes of lithium-ion batteries

2.4 Energy and environmental aspects

The energy has to be considered for the whole life cycle of the vehicle, from production, operation, maintenance and recycling.
In particular the battery is to be focused, as consumable element in the life cycle of the vehicle and incorporating materials to be appropriately treated.

2.4.1 Production

Assuming as a reference the lithium battery and a medium class car, a battery pack requires approximately 1000 MJ per kWh installed.
For the electric motor and power electronics production the energy requirement is of the order of 70 MJ/kg.
Assuming as an example, an electric car integrating an 18,7 kWh, 110 kg lithium battery pack and a 65 kg weight electric drive, the energy required for the production of the traction system is 23250 MJ.
As a comparison, the energy required for the production of the power train of a conventional car of the same class is considered in terms of 150 MJ/kg; thus, assuming as an example a car with a 170 kg power train, the energy required for power train production is 25500 MJ.

2.4.2 Operation

The typical consumption for battery charging of an electric vehicle is of the order of 150 – 200 Wh/t*km, from the grid. Such a low consumption “Tank To Wheel” is due to the high efficiency of the electric traction system and to the energy recovery during braking (up to some 25% in urban operation).

Regarding the total energy consumption “Well To Wheel”, considering the mix of primary energy sources use in Europe for electricity production, at the 2010 horizon, for a medium class vehicle (cat. M1) with Lithium or $Na\text{-}NiCl_2$ battery, has been evaluated not higher than 470 Wh/km [2].

The consequent equivalent CO_2 total emission necessary for the operation of this electric vehicle is evaluated to be not higher than 75 g/km. The involvement of the primary energy sources of fossil origin would be 10% petroleum, 52% natural gas and 12% coal [2]

2.4.3 Environmental impact – Life Cycle Assessment

In performing the operations related to technical assistance and maintenance of electric vehicles, the energy involved in substituting or repairing the components and the relevant impact on the environment has to be considered and minimized.

All stages involved in in the vehicle life cycle has to be taken into account, from the extraction of natural resources to the final transformation of fuel to mechanical energy.

The environmental impact of the fuel production and utilization stages have been evaluated in numerous life cycle assessments for fuel vehicles.

The analysis shows that the electric vehicles have advantages over the other types of vehicles. The economics and environmental impact associated with an electric car depends significantly on the source of the electricity: if the electricity is produced from the mix of European primary energy sources, the electric vehicle is advantageous over vehicles with thermal engines (see also previous paragraph discussion).

A deeper analysis has been performed by Ecole Polytechnique Federale de Lausanne on the components of the traction system.

The results of this study has been considered for the ranking done for electric drives previously presented, especially for the life cycle efficiency and the critical materials presence.

As far as the batteries are concerned, according to the same study, the environmental impact ranking in decreasing order is: nickel-cadmium, lead-acid, nickel metal hydride, lithium-ion and sodium-nickel chloride [3]. It is also remarked that the impact of the assembly and production phases can be compensated to a large extent when the collection and recycling of the batteries is efficient and performed on a large scale.

As a conclusion, the maintenance and repair operation on electric and hybrid vehicles should be performed having in mind and evaluating the consequences on energy and environment that the operation can produce.

3 The e-learning Platform

Based on the Unit of Competence previously identified, a set of e-learning courses on several selected key topics is under development.

The procedure followed is to develop an e-learning platform and relevant supporting on-line materials in several languages. The e-learning platform is considered the best way to ensure high range for dissemination of knowledge.

A web based Learning Management System will be set up, to host online multilingual training modules based on the Social Constructionist Pedagogical Model, which are planned for validation in pilot testing in different Countries by group of experts from industry and academic representatives.

The training Modules (TM), related to the various Competence Units (CU) and relevant Professional Skills (PS) and Evaluation Criteria (EC) are presently under development.

As an example the frame of **Training Module** related to **Safety (TM9)** is here reported with related Professional Skill (**PS**) and associated Evaluation Criteria (**EC**, selected as examples):

PS 9.1: To react on electrical human accident accomplishing with the manufacturer’s and law regulations, including:

-EC 9.1.1: To carry out firs aid techniques and procedures

-EC 9.!.2: To activate emergency service in emergencies

-EC 9.1.3: To use the defibrillator in case of emergency

PS 9.2: To guarantee the safety of crashed electric and hybrid vehicles accomplishing with technical, risk prevention and environmental protection regulation and procedures, including (as excerpts):

-EC 9.2.1: To secure for safety the crashed vehicles by separating the conductivity between the battery pack and the high voltage components.

-EC 9.2.2: To protect the crashed vehicles for safety against direct contact to the live parts from any direction of access by using protection barriers and shielding.

-EC 9.2.3: To transport the crashed vehicles in consideration with manufacturer's specified procedures, risk prevention and environmental protection procedure.

-EC 9,2.6: To identify the personal protective equipment to be used in case of emergency corresponding to the manufacturer's manuals.

-EC 9.2,7: To describe the handling procedure for chemical hazards, according to the manufacturer's specifications.

-EC 9.2.8: To describe how to handle submerged vehicles, according to manufacturer's specified procedures.

-EC 9.2.9: To describe how to react in case of hot battery cells and battery fumes, according to the manufacturer's specified procedures, the risk prevention procedures and the law regulations.

PS 9.4: To carry out functionality tests accomplishing with technical, risk prevention and environmental protection regulation, including:

-EC 9.4.1: To describe the procedure to perform a test drive to check the functionality of the vehicles, according to the manufacturer's specifications, the risk prevention and the environmental protection procedures.

-EC 9.4.2: To describe the test procedure for charging system, according to manufacturer's specifications, the risk prevention and the environmental protection procedures.

-EC 9.4.3: To describe the check procedure for the state of charge referring to high and low voltage batteries, according to repair manual.

-EC 9.4.4: To describe the test procedure to evaluate the state of brushes in electric motors, according to the manufacturer's specifications the risk prevention and environmental protection procedures.

PS 9.5: To work safely on electrical high voltage or non-high voltage components of electric and hybrid vehicles, in particular:

-EC 9.5.1: To describe the procedure to ensure the electrical safety by removing the connector which Is responsible for the connection between the high voltage battery and the high voltage components and measuring at special measuring location with special measuring tools.

-EC 9.5.5: To describe the basis of electrical risk and related safety measures.

-EC 9.5.6: To describe the procedure to measure the insulation resistance of high voltage components and associated parts.

-EC 9.5.7: To describe the procedure to check the isolation monitoring equipment for isolation errors of high voltage system.

PS 9.6: To drive and move electric and hybrid vehicles according to their function, in consideration with the manufacturer's, the risk prevention and the environmental protection specification, as well as the legal policies, including:

-EG 9.6.1: To describe the procedure to eliminate all hazards to safely handle electric and hybrid vehicles.

-EG 9.6.2: To describe the procedure to use all reachable tools to safely handle electric and hybrid vehicles, accomplishing the manufacturer's and law regulations.

PS 9.7: To perform the charge procedure of electric and plug-in vehicles according to their function, in consideration with the manufacturer's, the risk prevention and the environmental protection specification, as well as the legal policies, including:

-EC 9.7.1: To identify the relevant charging cable to charge the electric and plug-in hybrid vehicles.

-EC 9.7.2: To identify the different types of charge for electric and plug-in hybrid vehicles, accomplishing to the manufacturer's and law regulations.

PS 9.8: To perform repair and maintenance operations of electric and hybrid vehicles according to their function in consideration with the manufacturer's, the risk prevention and the environmental protection specification, as well as the legal policies, in particular:

-EC 9.8.1: To describe the procedure to safely separate the conductivity between the battery pack and the high voltage components, according to the manufacturer's specified procedures, the risk prevention and the environmental protection procedures.

PS 9.10: To store safely disassembled battery packs accomplishing with technical, risk prevention and environmental protection regulations and procedures, in particular:

-EG 9.10.1: To describe the general conditions to safely store the disassembled battery packs, according to manufacturer's specifications, the risk prevention and the environmental protection procedures.

3 The ECVET System

TECMEHV project's major challenge is to develop a qualification and accreditation system to standardize training in maintenance and repair operations (MRO) for Hybrid and Electric Vehicles (HEV) for whole European Community and the development of training contents to be offered to HEV MR Operators, according to the needs of the productive system.

The outcome of the Project is intended to support the development of national and sectorial qualifications systems by incorporating ECVET, according to the Recommendation of the European Parliament and of the Council.

ECVET is a European system of accumulation (capitalization) and transfer of credits designed for vocational education and training in Europe. It enables the attesting and recording of the learning achievement/learning outcomes of an individual engaged in a learning pathway leading to a qualification, a vocational diploma or certificate.

It enables the documentation, validation and recognition of achieved learning outcomes acquired abroad, in both formal VET or in non-formal contexts. It is centered on the individual accumulation of learning outcomes, in terms of knowledge, skills and competences necessary for achieving a qualification. ECVET is a system designed to operate at the European level, interfacing with national systems for credit accumulation and transfer.

4 Conclusion

TECMEHV project intends to offer a learning platform, dedicated to the technology of electric and hybrid vehicles and to their assistance, maintenance and repair operation. The specific training modules, to be offered on line and on special courses are finalized to the professional formation of the operators in the electric and hybrid vehicle field and relevant infrastructures.
It is believed that TECMEHV project outcomes can contribute to the diffusion of electric and hybrid vehicles, by offering a tool for enhancing the effectiveness of the service and operation support through new highly qualified jobs.

Furthermore, the dissemination of the dedicated courses for handling and supporting the technology of electric and hybrid vehicles and their infrastructures is a tool to pave the future developments and to diffuse the culture and the interest of these ecological and energy effective means of transportation.

5 Referencing

[1] G. Brusaglino, G. D'Anzieri, "Electric vehicles integration within the energy system", SPEEDAM 2012 International symposium, Sorrento, 26/6/2012

[2] G. Brusaglino, G. Pede, E. Vitale "Sistemi di propulsione elettrica e ibrida" by ENEA, ATA, CEI-CIVES, Focus Tecnologie 2009

[3] P. V. d. Bossche, F. Vergels, J.V. Mierlo, J. Matheys, W.V. Autenboer, "SUBAT: An assessment of sustainable battery technology", Journal of Power Sources, vol. 162, no.2, 2005

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