

WHITE PAPER AP18

LOW ENVIRONMENTAL IMPACT VEHICLES FOR A SUSTAINABLE TRANSPORT

EXECUTIVE SUMMARY

The Institutes operating in this AP cover many research topics in the field of the green vehicles and sustainable transport system, in strict alignment with H2020 work program. The activities range from the scouting from fundamental studies of systems and processes (TRL1 – TRL2) susceptible for green vehicles application, to the development of advanced technologies (TRL3-TRL4), up to technology transfer for industrialization (TRL6). Research areas cover from the development of sustainable land-vehicles and water-vessels, to the support for the autonomous driving systems and signaling infrastructure for railways, and the monitoring of the environmental impact of the transport.

Each Institute, in its own specific area, operates at the state of the art of the research with a strongly focus on the most important current research topics. In the powertrain sector, huge efforts are addressed to the development of zero-emission systems with lowest possible environmental impact.

Here, **IM**, **ITAE** and **IMAMOTER** are strongly involved in activities related to the performance improvement of propulsion systems for future green vehicles for on-road and non-road, mobile machineries and marine application, such as battery and fuel-cell electric vehicles, fully environmental compatible combustion engines and hybrid architectures.

ICAR, **ISTI** and **IMEM** are involved on the intelligent transport systems and infrastructures, supporting the development of new solutions for the zero-accident mobility target, the implementation of policies for pollutant level reduction through the monitoring the environmental impact of traffic in urban areas and contributing to the improvement cost-efficient railways.

INM covers activities related to the environmental impact reduction from marine vessels, like hydroacoustic noise reduction during navigation, and the propeller efficiency improvement of the vessel with new super-hydrophobic surfaces with strong frictional drag reduction.

Consolidate cooperation and synergies exist among the Institutes, while, due to the fast technology evolution of this sector, new opportunities are expected in the next future. The existing multidisciplinary of the researchers and the availability of very important facilities and infrastructures makes the network unique in the national research community and competitive in a worldwide scenario.

1. STATE OF THE ART OF THE RELEVANT SCIENTIFIC AREA

A fast transition to an **sustainable transport** is one of the most important need of the XXI century. The transport system is facing a global and fast revolution in terms of manufacturing (Industry 4.0), zero-emission and GHG-neutral vehicles (including energy carriers), autonomous driving and connectivity and active safety. In this context the CNR plays a strategic role. The DIITET Institutes cover many research topics in the field of the green vehicles and sustainable transport system, in alignment with H2020 work program. The activities range from the scouting from fundamental studies of systems and processes at level of proof-of-concept (TRL1 – TRL2) susceptible of application to green vehicles, to the development of advanced technologies at TRL3-TRL4, up to technology transfer for industrialization (TRL6).

In the field of **low or zero emission vehicles (IM, ITAE)**, a mix of technologies will be available in the mid-term future, increasing the presence of Battery Electric Vehicles (BEVs), Fuel Cell Vehicles (FCVs) and Hybrid Electric Vehicles (HEVs). Therefore, efforts are addressing to the improvement of BEVs and FCVs. In order to bring the internal combustion engines (ICEs) to be competitive with respect the e-mobility in terms of life-cycle CO₂ footprint, huge efforts are addressed to the development of quasi-zero emission fueled with fully renewable fuels. Relevant R&D activities are related to: innovative batteries and energy management, full electric or hybrid electric FC/battery powertrain, hydrogen and electric charging infrastructures for FCV and

BEV, pollutant-free combustion systems including the exhaust after-treatment. Green hydrogen and gas/liquid fuels (e.g. bio-gas, OME, etc.) will be produced from renewable sources for next-generation automotive powertrains. Anyway, open issues of the future sustainable vehicles still exist as: reduction of the capital costs and operating expenditures, reduction of CO₂ foot-print on the LCA, increase mileage range and robustness of BEVs and HEVs, development of ICEs with actual negligible environmental pollution. Fundamental remains the development of breakthrough technologies able to produce a relevant increase of the brake thermal efficiency of the ICEs (over 50-60%) and the total abatement of exhaust pollutant emission. The research efforts are also oriented to the development of **high efficiency and intelligent mobile operating machines (IMAMOTER)** for agricultural, earthmoving and material handling applications, where there are the same needs of decreasing emissions and enhancing automated functions, towards zero emissions and autonomous machines. However mobile operating machines are quite different from on road machines for their lower production volume and extreme diversification (architecture, mission profile, number of operating hours per year, etc.) then the solution must be tailored, cost effective and covering different technologies.

The operating machines are asked to work in a very unstructured and variable environment, with strong environmental disturbances for artificial sensory perception, thus making the task of implementing and training an autonomous control very challenging, often requiring an extended use of dedicated support infrastructures on the ground.

With respect to the **safety for zero-accident mobility (ICAR, IMEM)**, the number of car accidents owing to driver's distraction is a serious issue for society. Driver's sleepiness, stress and fatigue are the major causes of several traffic accidents. The existing methods for measurement of physiological signals are bulky, uncomfortable, limited to few physiological signals. The efforts of the proposal are focused on using a non-invasive, comfortable and fully integrated system of innovative sensors, together with advanced techniques for multivariate signal analysis, capable of detecting and significantly reducing the role of the human factors in driving and interfacing with the advanced driver assistance system of the vehicle.

Such activities are part of the wider topic of the Advanced Driver Assistance System (ADAS), for which the **computer vision for autonomous vehicles (ISTI)** and the Monitoring environmental impact is a crucial research line. The advent of Convolutional Neural Networks has opened many opportunities for improving autonomous navigation systems based on computer vision technologies. Besides performing obstacle detection, computer vision allows to understand the scene in which the vehicle is moving, making possible to interact in a context-aware manner with the environment. This can have application scenarios for both ground and aerial autonomous vehicles. The management of traffic by using intelligent transport systems (ITS) plays an important role in the urban transports in order to optimize city transfers and reduce emissions. In this respect, the **monitoring the environmental impact of traffic in urban areas (ISTI)** and correlating it with other pollution sources is important to design and support effective policies for a cleaner city. Nowadays, pervasive sensor networks have been deployed making possible to create real time maps of urban pollution.

The family of green vehicles includes also trains, trams and metros are green and safe vehicles by definition. Looking at the **cost-efficient railways (ISTI)**, the cost of the signaling infrastructure for these types of transportation means is relevant, and there is high demand for solutions that are able to drastically reduce costs. Reducing the wayside equipment to be deployed on the ground, and transferring control responsibilities onboard the trains, while maintaining safety, is regarded as one of the main research path to follow to decrease the costs of railway systems.

The theme green vehicles also covers the area of **efficient and low-emission marine vessels and ships (INM)**. The area concerns the development of numerical and experimental tools aimed at the identification and characterization of the main sources of noise for a ship and the prediction of the concerned hydroacoustic field. For analogous propulsion devices (like aeronautical and marine propellers), the research has revealed some unexpected and essential differences between the noise generation in air and underwater related to the specific features and operating conditions of the device itself, which heavily affect both fluid dynamic and acoustic approaches. Recently, unconventional approaches based on simultaneous near- and far- field measurements in combination with conditional and advanced time-frequency signal decomposition techniques, have allowed to effectively address the diagnostics of generation and propagation noise mechanisms.

It is also still crucial to improve the propeller efficiency with new configurations and the development of fast simulation tools to be used at design stage. An open issue is the development of *ad-hoc* Super-Hydrophobic Surfaces (SHSs). Their drastically reduction of frictional drag (up to 35%) has been already demonstrated at lab-scale, but further studies are needed for the final application. Green marine vessels with low hydrodynamic resistance and high efficiency can be also achieved by simulation-based design optimization procedures. Open issues are the dimensionality of the design space, the accuracy and computational cost of the solvers, along with the extension to non-deterministic problems addressing a large variety of environmental and operating conditions.

2. CONTRIBUTION TO THE RELEVANT SCIENTIFIC AREA

In the following a short description of the main activities of each Institute in the PA Green vehicles is reported:

ICAR

Two main research topics are covered:

Zero emission and high efficiency propulsion. New electric KERS for internal combustion engine vehicles, which employs a super-capacitors bank (SC) as electric energy storage system, a motor-generator unit (MGU) to convert vehicle kinetic energy into electric energy and vice versa, and a power converter to manage power transfer between SC and MGU: the system was conceived to recover the vehicle kinetic energy during braking phases by charging the super-capacitor, whose stored energy is employed by the MGU for successive vehicle acceleration.

Safety for zero-accident mobility. To improve the design and development of a novel and high performance transport safety system improved through the adoption of human factors (HF), which combines optoelectronic sensors and bio-signal analysis techniques aimed at monitoring continuously the psycho-physiological status of the driver of a vehicle (car, motorcycle).

IM

Most of the activities are carried out in strict cooperation with the most important automotive, commercial vehicles, mobile machineries and supply component industrial companies in the world.

Looking at the sector of Internal combustion engines (ICEs), they have still a great importance in transport sector. Overall research activities are addressing to develop ICEs fully compatible with future stringent requirements in terms of LCA-based CO₂ footprint and negligible pollutant emissions.

Several technologies are under employing innovative numerical and experimental methodologies at the state of the art. Fundamental studies on liquid and gaseous sprays, in-cylinder combustion and new process sensors are continuously carried out in order to improve the control of engine functionality, while advanced numerical tools for combustion simulation are optimized and validated through the support of innovative diagnostic techniques applied to research engines.

The availability of physics and chemical laboratories for fundamental studies, research engine test cells, real engine test benches (light and heavy duty) and vehicle test dyno-chassis permit the study of new powertrains at different level of complexity: lab-scale for proof-of-the-concept, research engine for pre-validation and full-engine scale or vehicle for final optimization.

As regards the ICEs, the activities look at the development of advanced technologies for efficiency improvement in new generation spark-ignition engines (e.g. ultra lean charge, water injection, cooled exhaust gas recirculation), while new combustion system architectures and ultra-high pressure injection systems are some of the features under analysis for compression ignition engines.

In order to reach the negligible emission level of ICEs (e.g. NO_x, particles down to 10 nm, etc.), many efforts are addressing to the development of ultra-high efficient after-treatment systems (ATS). Finally, great attention is paid to the optimization of future ICE-based powertrains burning clean and fully renewable fuels (both liquid and gas).

Moreover, activities are carrying out on electric-battery and hybrid powertrains, as on the characterization of innovative fuel-cell systems.

In this respect, as for the ICEs technologies, lab-scale experiments are carried out for characterization, optimization and modelling of fuel-cell reactors and state-of-art energy storage systems (e.g Li super-caps), while complete test benches (up to 300 kW) are available for electric powertrain testing.

IMAMOTER

IMAMOTER operates mainly in the sector of high efficiency and intelligent mobile operating machines. In this kind of machines the propulsion is just one of the several function of the machine, thus it is important to take into account of the energy behavior of the multiple functions and of the architectural complexity. Efficient Power Transmissions including Electric, Hybrid, Electro-Hydraulic transmissions and architectures for regeneration must be addressed. Holistic and distributed controls and new sensor are the key factors from implementation of automatic work tasks until the development of autonomous vehicles.

IMEM

The main IMEM's contributions to the platform are related to the development, scouting and testing of state-of-the art devices, technologies and materials for applications in the mobility sectors aimed at increasing energy efficiency and safety and reducing carbon foot-print: magnetic materials and components for hybrid and electric motors, inductors and actuators, Current/magnetic field sensors, thermal and vibration energy harvesters. We also develop bio-sensors on organic cotton fibers for monitoring the health state of the driver (es. sweat and adrenalin).

INM

The INM activities are related to the prediction of the underwater noise from marine propellers and the acoustic mapping of complex, multi-body configurations, which accounts for the interactions of the propeller with hull, rudder, appendices, and for possible scattering phenomena. The analysis is carried out both in time and frequency domain, by coupling the acoustic solvers to suitable hydrodynamic simulations and pointing out the key-strengths and weak points of the different solving techniques. It seems also relevant to write down a reference text (currently missing in the literature) which summarizes the most significant aspects of noise predictions, shows the reliability of the various integral formulations and points out the differences between Aero- and Hydro-Acoustics. In the experimental field, standard methods have been integrated with unconventional approaches to establish source noise in a reverberant environment of a testing facility. Signal conditioning techniques based on synchronous near field and far field measurements along with advanced time-frequency signal decomposition methods have been employed for the analysis of noise generation and propagation mechanisms.

Numerical tools have also been developed to improve the efficiency of propulsion devices and, specifically, to better define the main characteristics of ducted propellers.

The study on SHSs is carried out in close cooperation with ISTE-CNR, experimental tests are performed at high Reynolds number on flat surfaces using the INM high speed channel. Different water repellent surfaces are designed and tested varying the functionalization concept i.e. the viscosity of the liquid-solid interface and the surface roughness to identify the optimal surface parameters in terms of drag reduction and durability.

INM original contribution to simulation-based design optimization includes: linear and nonlinear design-space dimensional methods based on disjoint Hilbert spaces for shape modifications and significant distributed/lumped physical variables; adaptive multi-fidelity metamodels for uncertainty quantification and design optimization; single- and multi-objective hybrid global/local derivative-free optimization algorithms.

ISTI

Three main topics are covered by ISTI.

Cost-efficient railway: ISTI-CNR contributes with the application of formal and semi-formal methods to model and verify novel signaling solutions aimed at reducing deployment and maintenance costs for railways, to guarantee safety and availability by-design. These solutions include the use of GNSS positioning of trains, moving-block technologies, distributed interlocking, and train platooning.

Computer vision for Autonomous vehicles: ISTI-CNR has developed models based on deep learning techniques for detection and classification of objects. The methods are suitable for deployment on embedded devices for on line and real time analysis of the scene.

Monitoring environmental impact: ISTI-CNR has contributed to the realization of pervasive wireless sensor network for traffic monitoring also based on smart cameras technologies. The network allows creating a real time evaluation of traffic, making possible to detect mobility patterns. Further work is in progress towards

the evaluation of traces produced by individual cars in the city. Leveraging advanced imaging technologies, a proposal is being prepared in which each single vehicle is evaluated by analyzing exhausted gases in the plume.

ITAE

The main ITAE's contribution to the platform are related to: the improvement of the performance of electric vehicles and their integration in the transport network; Development of innovative powertrains for BEVs, FCVs, HEVs with greater attention to electric hybrid powertrain (Fuel Cell/Batteries); Development of innovative batteries focused on electrochemical aspects and their performance such as power density, useful life, thermal management, waste heat recovery and valorization, safety and reliability; Development of battery monitoring systems (BMS), Modeling and simulation tools for BMS improvements; Tests, methodologies and procedures for the assessment of functional safety, reliability and duration of battery monitoring systems; Management and monitoring of the energy cycles of on-board storage systems; Conversion and storage of electricity used in different types of electric, hybrid and cogeneration systems; Integration of electricity conversion and storage systems with generation and / or propulsion systems; Development of on-board systems suitable to interface with infrastructures; Intelligent Transport System (ITS); Use of renewable energy sources for hydrogen and electricity production; Development of hydrogen vehicles high pressure storage (up to 750 bar); Development of hydrogen and electric charging infrastructures, recovery of heat from fuel cells for cabin air conditioning. CNR-ITAE is involved in four EU projects dealing with the production of green hydrogen and renewable fuels from CO₂-H₂ co-electrolysis for automotive applications. Efforts are addressed to reduce capital costs through minimization of expensive materials and through novel stack designs. Special attention is also addressed to solar hydrogen production using photo-electrolysis.

3. IMPACT

ICAR

Zero emission and high efficiency propulsion: the low complexity of the system proposed, the reduced volume and weight of the components considered for KERS assembly and their immediate availability on the market, make the solution ready for the introduction in current vehicle production.

Safety for zero-accident mobility. To increase safety in transport systems by early warning the driver and performing a safe stop of the vehicle, thus decreasing the number of accidents and raising the driver's consciousness on her/his health and psychological conditions.

IM

ICE-based powertrains (both full-ICE, hybrid and plug-in) will represent the majority of the propulsion systems also in the long-term scenario (>80% in 2050 from IEA analysis). Even if the technology portfolio on the market will change from continent to continent and country by country, such foreseen will not change, also for the Italian case. Therefore, any technology improvement in terms of fuel consumption, GHG impact and pollutant emission reduction will represent an enormous contribution for the environment and will have a huge impact at scientific, industrial, social and political level. Simultaneously, the research on alternative zero-emission propulsion system must be strengthened in order to guarantee their market penetration as fast as possible.

From the point of view of scientific impact, the scouting of new breakthrough technologies from fundamental studies is the frontier of the research in this field, and the discovery of new solutions for future fully eco-compatible ICE-based powertrains and/or robust and long-mileage e-vehicles, it represents an extremely important task for the long-term sustainable mobility.

At the same time, the Europe and Italy, maintains a worldwide industrial leadership in the powertrain sector, therefore the technological advancement is absolutely strategic to preserve such position, and to expand it also to the most innovative systems (e.g. e-mobility). CNR institutes strongly contribute to this process through a relevant technology transfer activity to the most important OEMs of the sector.

Future eco-compatible vehicles have to be accessible from the majority of the population for personal and goods mobility, without any negative impact on human health and safety. Therefore, any effort addressed

to the development of zero-emission and cost-effective technologies and/or eco-compatible energy carriers for the large-scale mobility will have an enormous impact at social and political level.

IMAMOTER

High Efficiency and Intelligent Mobile Operating Machines: The OEM of Mobile Machines must enhance their products implementing energy saving and intelligent control architectures to respond to the global challenges of lowering the emissions and increasing the safety of operators and the automatization of the work.

IMEM

Advanced magnetic materials and technologies are massively used in vehicles for the realization of components, motors, sensors, actuators, safety systems etc. Their optimization can have a strong impact in energy efficiency, safety and smart monitoring. Hybrid and multifunctional systems can be exploited in proof-of-concept devices and sensors to improve the driver safety (e.g. flexible bio-sensors).

INM

In recent years, the acoustic pollution of the seas and the environmental impact of maritime transport on marine fauna have represented themes of considerable interest. Not by chance, the EU financed several research projects focused on topics related to acoustics, not only for on-board safety and comfort issues, but also (and above all) for problems related to underwater noise. These topics are of critical relevance for the shipbuilding industry, due to the more and more stringent (national and international) regulations, which assume the noise as a quality-parameter of the marine environment and can even prevent navigation in specific areas. In addition, many important and strategic military issues are related to the underwater noise, concerning the ship's identification and traceability. In this context, the integration of numerical and experimental tools able to provide an overall, physically-consistent estimation of the hydroacoustic field appears, from both a scientific and industrial viewpoint, an essential resource.

The development of simplified numerical tools are aimed to provide fast predictions of the propulsive configuration in the preliminary design stage.

The use of water repellent coatings on the surface of marine vehicles can significantly reduce fuel consumption of surface ships and increase the mission range of underwater autonomous vehicles. Furthermore, they can potentially modify wake-induced vibration and cavitation inception for marine propellers increasing the ship efficiency.

Efficient approaches to simulation-based design optimization (design-space dimensionality reduction, adaptive and multi-fidelity metamodeling, hybrid global/local optimization methods) significantly reduce the computational cost of deterministic/stochastic optimization procedures of waterborne vehicles while retaining accurate performance predictions by high-fidelity solvers.

ISTI

Cost-efficient Railway: A reduction in the cost of railway transportation is expected to increase the diffusion of railways, and, in turn, the number of passengers and freight trains. This would lead to a reduction of road transport in favor of the greener railways.

Computer vision for Autonomous vehicles: Inclusion of advanced computer vision methods is expected to increase the applicability of autonomous vehicles to new scenarios.

Monitoring environmental impact: Although the long-term target is to have zero emission vehicles, nevertheless there is still a transition period in which accurate monitoring of the environmental impact of the current fleet will be necessary. Advanced technologies will be able to support adaptive policies for not exceeding allowed pollutants concentrations.

ITAE

The main impact of new technologies for a future environmental sustainable transport and green hydrogen technologies is on the reduction of the air pollution and environmental issues while contributing to mitigate climate changes. The technologies proposed are aimed to enhancing the potential of the RES plants by operating synergistically both on the hydrogen vector and on the electric energy. Regarding the production of Hydrogen from Electrolysis, in line with the National Strategic Framework (QSN) for compliance with the DAFI (Directive 2014/94 / EU) high-pressure storage systems will allow the use of distribution infrastructures to the FCV and HEV vehicles on the market (700 bar). Creation of new jobs, technology transfer from CNR Institutes to the co-operating companies, increasing knowledge, expertise and methodologies to speed up

the design, development and validation of the enabling technologies for environmentally friendly vehicles in this field is another important outcome.

4. EMERGING RESEARCH CHALLENGES

Most important challenges in which DIITET Institutes are involved are:

- Zero emission and sustainable propulsion systems/vehicles in terms of CO₂ footprint;
- Safety for zero-accident mobility;
- Cost-efficient and intelligent Mobile Operating Machines;
- New material/sensors for green vehicles and marine vessels;
- High-efficiency ships and marine vessels;
- Advanced numerical tools for robust design and manufacturing of vehicles and vessels;
- New learning methods and artificial intelligent methods for autonomous vehicles;
- Intelligent infrastructure for cost-efficient railways;
- New methods for the monitoring of the environmental impact of the transport;

5. CONCLUSIONS

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Institutes of the PA cover several and important research areas of the green vehicles, and they are well placed in the international scientific network. Most of the human resources are directly involved in powertrain development, in the broadest sense, from conventional Internal Combustion Engines to alternative zero-emission propulsion systems (Battery Electric Vehicles, Fuel Cell Vehicles etc.), while other important resources are directly involved in most recent emerging challenges, such as: low noise and high efficient marine vessels, autonomous vehicles, zero-accident mobility, intelligent infrastructure for mobility.

Consolidated cooperation and synergies among Institutes already exist, while, due to the fast technology evolution of this area, new opportunities are expected in the next future. The existing multidisciplinary of the researchers and the availability of very important labs and infrastructures makes the network unique in Italy and competitive in a worldwide scenario. Example are the potential synergies between the artificial intelligent methods under development for autonomous vehicles and the requirement of control tools for very complex hybrid powertrains, as the study of new intelligent sensors for the improvement of the control of connected vehicles.

All industrial players operating in the sector (from the automotive to the marine vessels) and the related infrastructure are involved in the evolution process of the transport system, characterized by a fast & ferocious competitiveness. Most of them are large multinational enterprises having consolidate cooperation with the Institutes of the PA. In order to expand and reinforce such cooperation, so increasing the CNR participation to the progress of the science and technology in this PA, the networking among the Institutes should be strengthened, with particular attention to the external communication of all activities toward the industrial partners.

PROJECT AREA 18: LOW ENVIRONMENTAL IMPACT VEHICLES FOR A SUSTAINABLE TRANSPORT

Editorial team and

Contact person (CP)

Institute

Email

ALBERTINI FRANCA	IMEM	franca.albertini@imem.cnr.it
BEATRICE CARLO (CP)	IM	c.beatrice@im.cnr.it
CIAPPI ELENA	INM	elena.ciappi@cnr.it
DISPENZA GIORGIO	ITAE	giorgio.dispenza@itae.cnr.it
FERRARI ALESSIO	ISTI	alessio.ferrari@isti.cnr.it
IANNIELLO SANDRO	INM	sandro.ianniello@cnr.it
MARANI PIETRO	IMAMOTER	p.marani@imamoter.cnr.it
VENIERO GIGLIO	IM	v.giglio@im.cnr.it
VITALE GIANPAOLO	ISSIA	vitale@pa.issia.cnr.it