National Research Council

STEMS

Institute of Science and Technologies
for Sustainable Energy and Mobility

The Institute of Sciences and Technologies for Sustainable Energy and Mobility belongs to the DIITET, Department of Engineering, ICT and Technologies for Energy and Transport of National Research Council, CNR.

The research activity of STEMS is carried out in the framework of the following eight research areas:

PROCEDURES FOR THE DEVELOPMENT OF REGULATIONS AND NEW CERTIFICATION STRATEGIES

DECARBONIZATION AND ENERGY TRANSITION

SOLUTIONS FOR SUSTAINABLE MOBILITY

SAFETY OF INDUSTRIAL PROCESSES, PLANTS AND MACHINES

DEVELOPMENT OF SUSTAINABLE TECHNOLOGIES FOR THE CIRCULAR ECONOMY

INNOVATIVE CATALYTIC PROCESSES AND ADVANCED MATERIALS

SUSTAINABLE PROPULSION FOR TRANSPORT, OFF ROAD AND OPERATING MACHINES

DIGITAL TRANSITION IN ENERGY, TRANSPORT AND AGRICULTURE

STEMS facts

- **Four location in Italy**
- **Specialized laboratories with advanced equipment**
- **Different size plants from the laboratory scale to the pilot scale**
- **It is involved in national and international research networks**
- **Its staff includes more than 100 researchers, 50 technicians and administratives and over 50 trainees**

DECARBONIZATION AND ENERGY TRANSITION

SOLUTIONS FOR SUSTAINABLE MOBILITY

DEVELOPMENT OF SUSTAINABLE TECHNOLOGIES FOR THE CIRCULAR ECONOMY

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## SAFETY OF INDUSTRIAL PROCESSES, PLANTS AND MACHINES

PROCEDURES FOR THE DEVELOPMENT OF REGULATIONS AND NEW CERTIFICATION STRATEGIES

DECARBONIZATION AND ENERGY TRANSITION

The *decarbonisation* of the energy and mobility sectors requires a rapid and consistent change in the mix of energy sources and carriers.
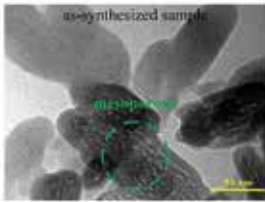
The focus of the activities is on the development of processes and technologies for a progressive replacement of petroleum products with energy carriers from renewable energy sources (RES).
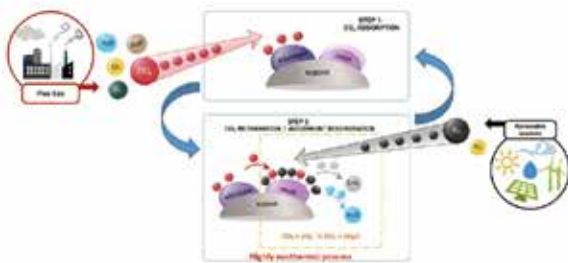
Methanation and production of Met-OH and derivatives.

Pyrolysis and gasification of biomasses and wastes. Catalytic pyrolysis of biomass.

Materials in CaL+CLC.
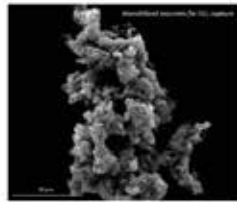
Immobilized enzymes for CO_2 capture.

Porous materials/hybrids for gas capture/storage.

Novel catalytic materials.

Lithium polymer batteries.

Post-lithium batteries.

Hybrid Energy Grid with hydrogen production, storage and reuse.

Dynamic numerical simulation of the energy mix.

Characterization of non-fossil gas fuels (H_2, CH_4, NH_3, Syngas).

Use of biomass fuels.

Hydrogen PEM Fuel Cell.
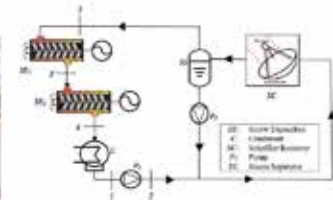
Micro-Cogeneration from renewable sources.

DECARBONIZATION AND ENERGY TRANSITION

During the energy transition period, fossil fuels will continue to represent a significant portion of the energy mix. In this context, the use of fossil fuels is addressed with the aim of increasing the efficiency of energy conversion processes by reducing climate-altering emissions.

Oxycombustion and CLC.

New combustion technologies.

CO_2 capture by fine powders.

Solar thermochemical splitting.

Integrated Carbon Capture and Utilization.

Alternative engines.

CFD modeling of 330 kW Micro Gas Turbine burner.

Furnace for 1 MW turbo gas burners.

Micro emulsions in optical engines.

Efficiency and impact of combustion.

Materials for O_2, CO_2, VOC detection.

SOLUTIONS FOR SUSTAINABLE MOBILITY

The mobility of people and goods is an important element for socio-economic and environmental development on a local, national, European and global scale, The evolution of the transport and mobility system to ensure the balance between the needs of individuals, the environment and the productive economic system requires effective methods and methodologies for its implementation.

INTEGRATION OF SYSTEMS FOR MOBILITY

- Distributed electronic systems over vehicle network, for a global optimized control.

- Human-machine interface systems for calibration and diagnostics.

- Vehicle sensorization to detect the surrounding environment (e.g. LIDAR).

- Automation of actuations.
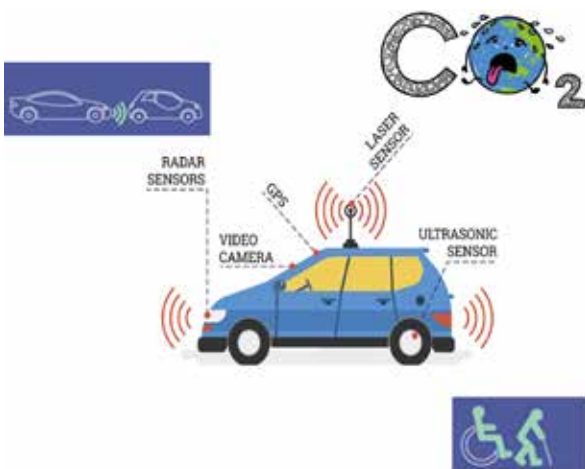
Evaluation of the sonic environment and its perception by smartphone.
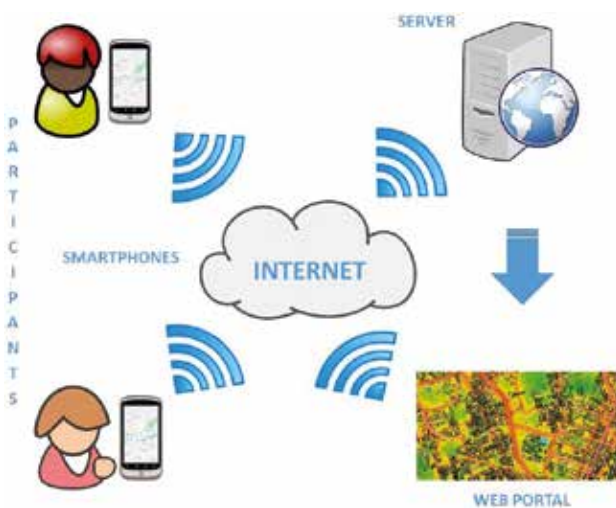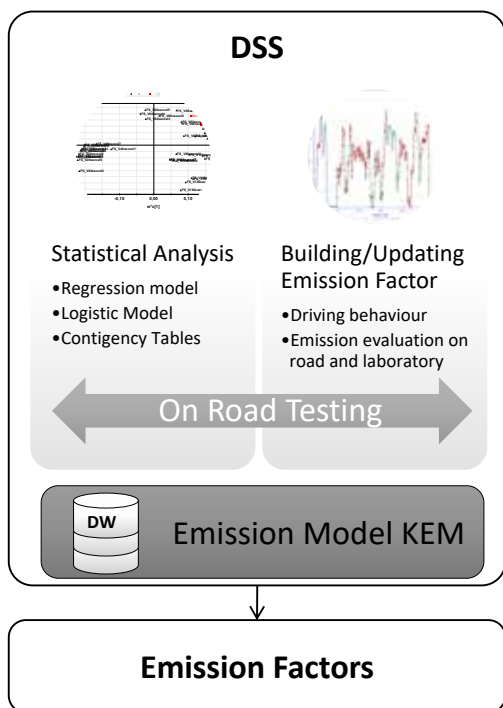

VEHICLES EMISSIONS

For mobility management and regulatory policies of road transport, STEMS deals with indicators for specific emissions of CO, NMVOC, NOx, PM and CO_2 from vehicles (buses, cars and motorcycles), pollutants linked to the UNECE Convention on long-range transboundary air pollution (CLRTAP) and on air quality in urban centers.
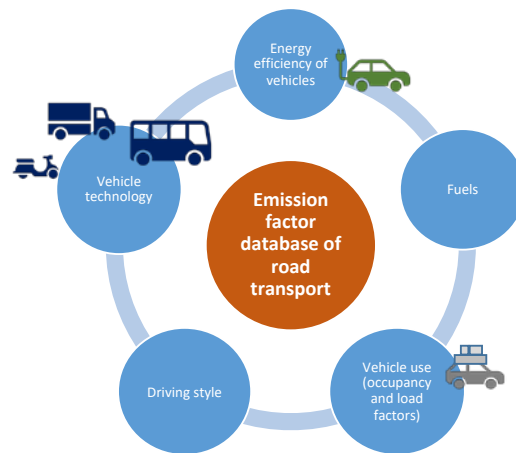

- There is constant work to update a national database of emissions according to:

  - vehicle technology;

  - the energy efficiency of the vehicle;

  - the fuels used;

  - the use of vehicles (occupancy and load factors);

  - the driving characteristics (speed and driving style).

- Integrated modeling and statistical analysis of emission factors. Correlation between different traffic situations and geolocation of emission data to identify routes with minimum environmental impact in terms of consumption and emissions.

- Physical data analysis using multivariate statistical models and partial regression models. Logistic models and multiple multi-factor contingency tables for the assessment of the environmental impacts of any transportation modes in the broader scenario of an LCA.

SOLUTIONS FOR SUSTAINABLE MOBILITY

DSS

Statistical Analysis
- Regression model
- Logistic Model
- Contigency Tables

Building/Updating Emission Factor
- Driving behaviour
- Emission evaluation on road and laboratory

On Road Testing

DW Emission Model KEM

Emission Factors

MAAS-MOBILITY AS A SERVICE

- User-centered integration of multi-modal public and private transport services and management of the journey through a single digital channel accessible via smartphone or other digital tools, taking advantage of the various transport modes and involving operators with even conflicting interests: from conventional passenger transport operators, to taxi and NCC services, to car and light vehicles sharing services, and in the near future, services based on self-driving cars.
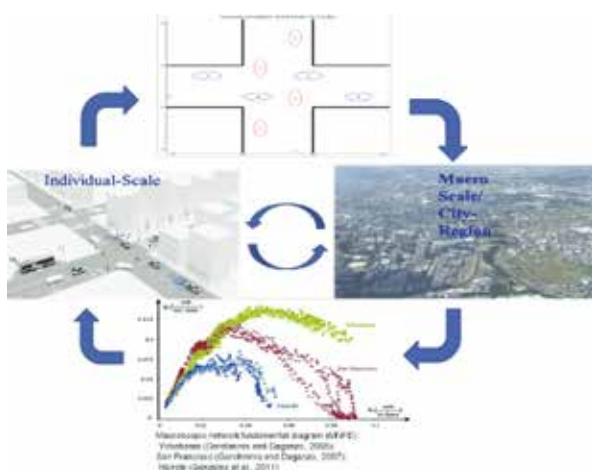
MULTIMODAL URBAN MOBILITY

- Development of multiscale methodologies for the analysis of critical conditions in urban transport network (congestions/accidents), combining: data mining techniques, equation free methods, complex networks, multiagent systems.

- Development of decision support systems that also include self-driving vehicles.

- Development of multi agents-based microscopic models that include different types of interactions between autonomous cars and vulnerable vehicles (pedestrians/bicycles/scooters) with a focus on the analysis of self-organized emergent behavior in shared urban spaces, road crossings and intersections.

SOLUTIONS FOR SUSTAINABLE MOBILITY IN AGRICULTURAL SYSTEMS

- Precision monitoring (by in-field or proximal sensors) and remote sensing of soil degradation (i.e. soil compaction, erosion).

- Investigation and development of solutions to support the mobility in the agricultural systems in order to promote sustainable use of soil and water, with advanced data analysis, modelling and implementation of DSS.

- Investigation on soil compaction induced by agricultural traffic and its effects on plant growing and hydrological and soil erosion processes.

# DEVELOPMENT OF SUSTAINABLE TECHNOLOGIES FOR THE CIRCULAR ECONOMY

To make the economy sustainable, there is a need for processes and technologies that encourage the transition toward the circular economy, with measures to reduce waste, reduce the consumption of resources, and encourage their recovery and reuse. The research activity on these issues is transversal to various production sectors according to the paradigms of the "performance economy", the recovery of critical resources, the intelligent recycling of materials, etc.

ENHANCEMENT OF RESIDUAL MATERIALS

- Characterization of gaseous fuels derived from waste and biomass (Syngas, Biogas).

- Detailed characterization of complex carbon-based products of thermoconversion processes (bio-oil, biomass components, tar, char ...).

- Restructuring of carbon particulate matter with thermal annealing by furnace and laser heating. Valorization of carbonaceous by-products emitted from combustion/pyrolysis systems.

- Pyrolysis and gasification processes in fluidized bed reactors for the valorisation of waste and residual biomass.

- Pre-treatment and fractionation (upgrading) of complex carbon-based matrix (biomasses, solid fuels, end-of-life materials, wastes ...).
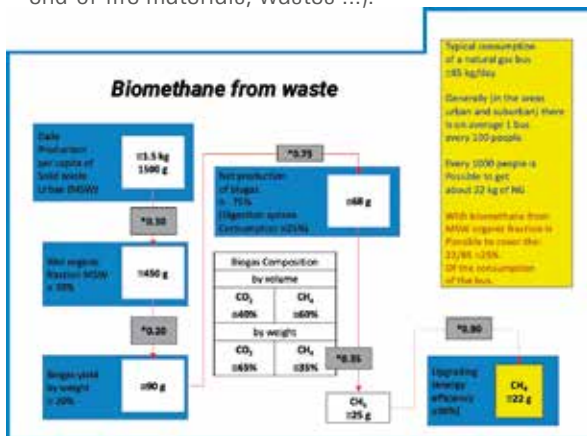

- Study of the environmental sustainability characteristics of agricultural and productive machines and processes, through the development and testing of product and process innovations in the agricultural and ICT fields.
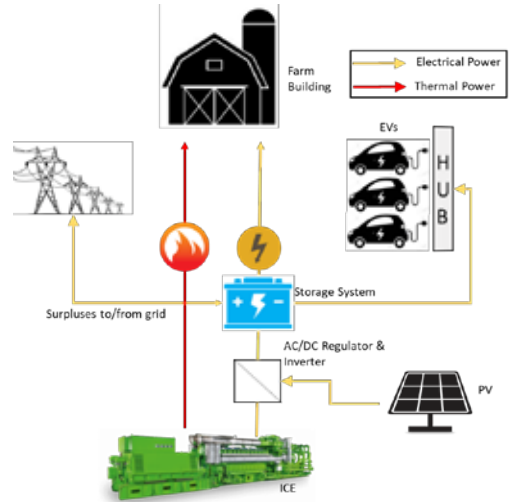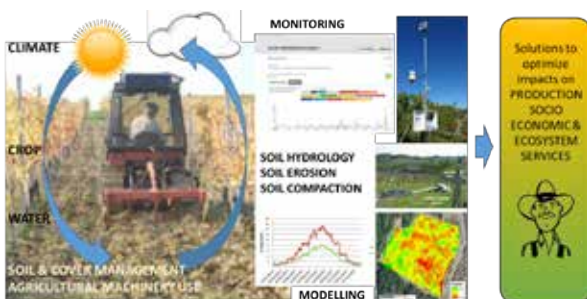
- Numerical techniques for:
  - the optimal exploitation of renewable resources;
  - the production of energy in response to energy loads belonging to agro-industrial plants and/or residential homes.

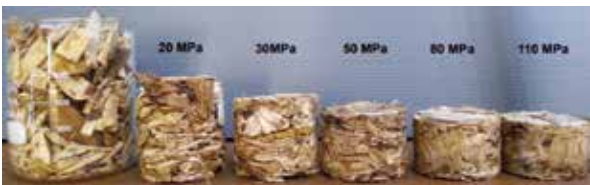- Agrometeorology, management of natural resources (soil and water).
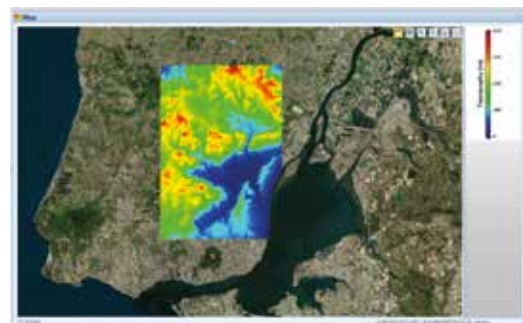
- Environmental impacts of the various cultivation and processing techniques, surveys of environmental parameters with consolidated and innovative methodologies.
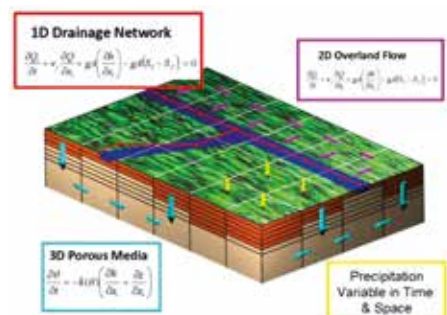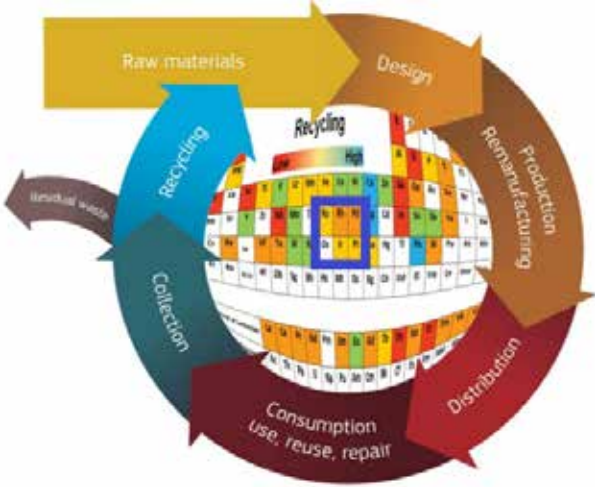
DEVELOPMENT OF SUSTAINABLE TECHNOLOGIES FOR THE CIRCULAR ECONOMY

- Development and technical-economic analysis of processes for the valorization of residual biomass and industrial waste.
- LCA-Life Cycle Assessment for a product/process to assess the environmental impact (LCIA-Life Cycle Impact Assessment) of the product/process in terms of emissions in water, air, soil.
- Improving agro-food waste treatment technologies focused on ammonia and GHG reduction.
- Agronomical valorization of agro-food waste.
- Optimization of biomass densification process and characterization of densified products.

- Biodegradability, good antimicrobial and mechanical properties recently introduced in the biomedical sector as biodegradable patches.
- Biorefinery of lignocellulosic wastes.
- Biomass enzymatic depolymerization:
  - saccharification;
  - lignin valorization.

FOR THE CIRCULAR ECONOMY

- Agricultural waste as precursor for green synthesis of oxides with several shapes and dimension.
- Thermal treatment of shives and short fibres for obtaining biochar.
- Addition of biochar to several polymer matrix: composites with enhanced mechanical, wear, electric and flame retardant properties.

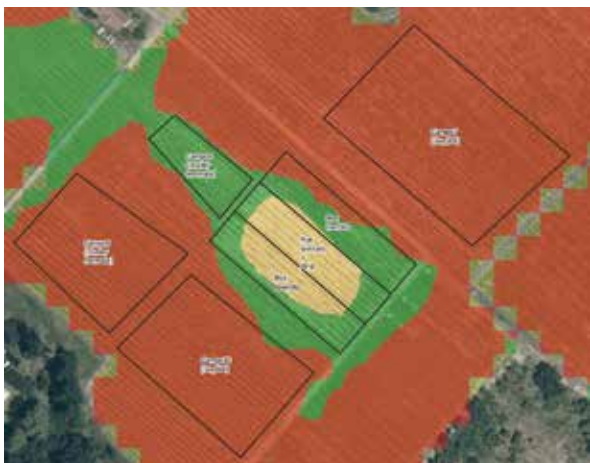*Breweries' Spent Grains*   *Coffee Silverskin*

DIGITAL TRANSITION IN ENERGY, TRANSPORT AND AGRICULTURE

The development of technologies for the collection, communication, processing and certification of large amounts of data (Big Data) is imposing a radical transformation in the modes of production, distribution and use of every tangible or intangible asset, the energy, transport and agriculture sectors are anything but extraneous. The research activities developed in this theme cover all the steps mentioned also through the development and application of advanced methods of Artificial Intelligence at the base of digital platforms.

DIGITAL TRANSITION IN AGRICULTURE

- Development of tools to support the management of agricultural systems that promote the sustainable use of soil and water resources through:

  - precision monitoring (via field and vehicle sensors) and remote;

  - creation of open decision support systems, capable of integrating heterogeneous sensors and capable of generating work programmes of machines' clusters, optimising both machine work cycles and crop and soil treatments in a perspective that prevents human error. The aim is "no human in the loop";

  - development of automated systems for agriculture.

CORYL ROBOT: for the automated harvesting of hazelnuts.

STEMS is DIH (Digital Innovation Hub) for Agricultural Robotics, thanks to the European Union initiatives born from the Agrobofood project

MECHATRONICS, REMOTE SENSING AND AI FOR AGRICULTURE, ENERGY AND TRANSPORT

- development and adaptation of advanced sensors for reactive systems according to soft-sensing principles.

- Design of innovative sensors and actuators.

- Distributed systems for measuring, collecting, organizing and storing data in big-data infrastructures.

- Data mining techniques to identify critical macroscopic variables to be used for data driven model construction.

- AI methods for identification of interactions between vehicles (autonomous and non-automatic)/ pedestrians/micro-mobility in shared spaces.

SCORPION: Precision spraying robot safe and autonomous, integrated in a robotic platform and aimed at use in vineyards with a steep slope for precision agriculture.


Elaboration with artificial intelligence methods of data from the monitoring of agro-environmental parameters, for the recognition of critical alert thresholds of erosive phenomena of agroforestry soils.

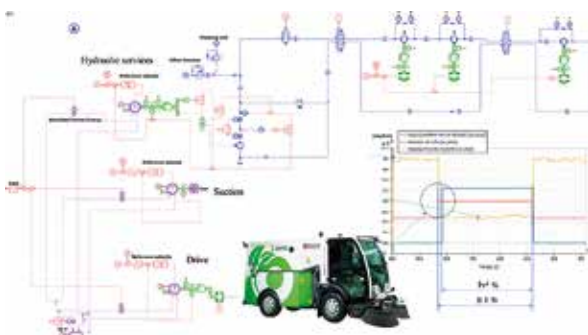# DIGITAL TRANSITION IN ENERGY, TRANSPORT AND AGRICULTURE
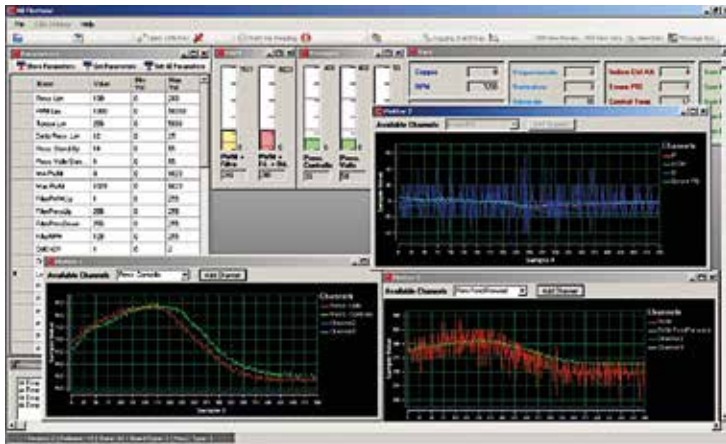
Development of complete systems for humanmachine interaction, both in local and remote diagnostics on vehicle network, calibration, interaction with remote servers for the management of machines in the field/ site).

Integrated methods of artificial intelligence, analysis and data processing, and data mining for the development of data driven models for the creation of integrated digital platforms for urban mobility management.
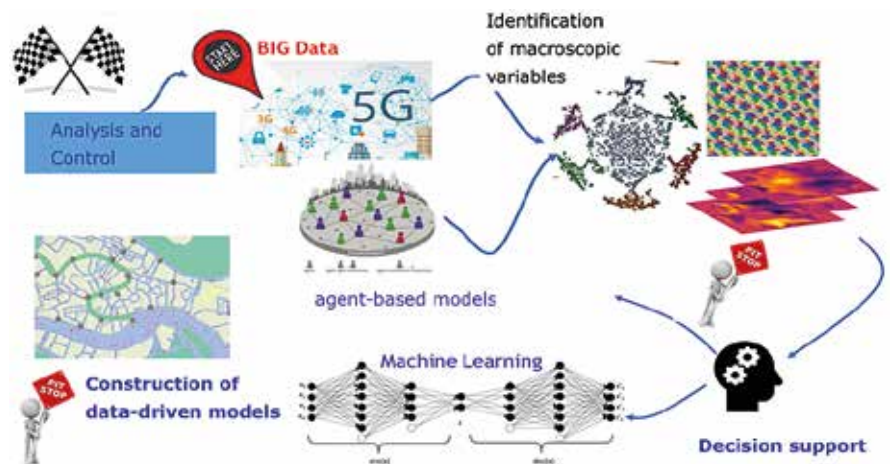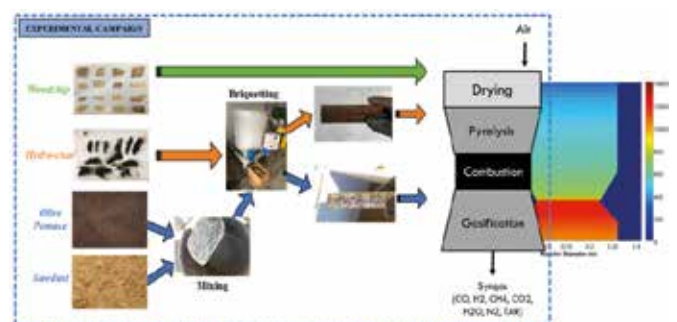

MODELLING AND DIGITAL TWIN

- Tools to support the management and optimization of energy and mechanical systems through:

  - CFD analysis and virtual simulations of mechanical processes and energy systems;

  - artificial Neural Networks and development of machine learning models.

Multimodal analysis of the process of exploitation of biomass of animal and plant origin for the production of non-fossil fuels.

Multi-physics models for the prediction of operating machines and agriculture machines electrified and their subsystems, fuelled by sustainable energy sources and carriers.

CFD simulation of multi-phase and non-Newtonian flows.

SUSTAINABLE PROPULSION FOR TRANSPORT, OFF ROAD AND OPERATING MACHINES

The research carried out in this area covers all the aspects connected to the transition of propulsion technologies towards the full environmental neutrality: "Powertrain technologies", "Enviromental impact of the vehicles, vessels and off-road machines" and "Sustainable energy carriers for propulsion systems". The activities are articulated both in the experimental analysis of innovative concepts, and in the development of computational methodologies to model and simulate reliable and predictive digital twins.

POWERTRAIN TECHNOLOGIES

- Modeling, optimization and virtual prototyping in a (co-) simulative environment of multi-domain hydraulic/mechanical/electrical architectures, for the conversion/transmission of power for operating machines, on-road/off-road vehicles and boats.

- Experimentation and optimization of power transmissions for on-road/rail/off-road applications.

- Energy analysis and optimization of innovative powertrains for on-road vehicles (HEV, PHEV, BEV, ...).

- Design and implementation of control/actuation systems for powertrain testing.

- Model-based control algorithms for complex propulsion systems.


Powertrains development labs.

COMBUSTION-BASED POWERTRAINS

- Characterization of combustion parameters of carbon-neutral energy carriers (H_2, bio-methane).

- Analysis of combustion and pollutants formation processes in internal combustion engines.

- Design, construction, experimentation and optimization of very high efficiency combustion systems for innovative engines.

- Innovative methods of modeling and simulation of advanced combustion systems.
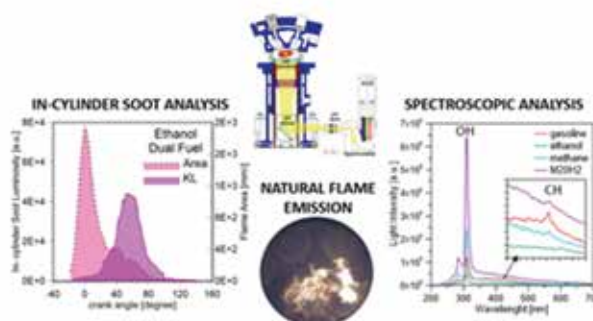
Combustion diagnostics.
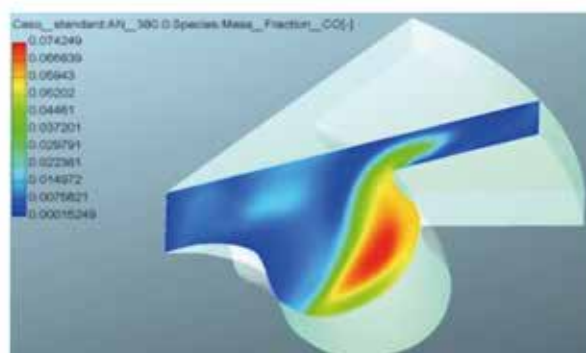
Engines models and simulators.

SUSTAINABLE PROPULSION FOR TRANSPORT, OFF ROAD AND OPERATING MACHINES

ELECTRIC-BASED POWERTRAINS

- Thermo-electric models of electrochemical components (batteries, super-capacitors) and electrical and electromechanical components.

- Experimental characterization of electrical energy storage systems and electric motors.

- Optimization of the energy management of storage systems.

- Analysis and energy optimization of electric vehicles (PHEV, BEV, FCHV).

Simulation of powertrain architectures.

ENVIROMENTAL IMPACT OF THE VEHICLES, VESSELS AND OFF-ROAD MACHINES

- Characterization of emissions and climaltering impact of the engines.

- Emission impact models of propulsion systems.

- Characterization and modelling of "non-exhaust" particulate emissions of vehicles (brakes, tyres, asphalt, etc.).

- Emission impact linked to atmospheric transformations of primary emissions.

- Analysis and energy optimization of electric propulsion systems (PHEV, BEV, FCHV).


Electric motor test bench.


Vehicle testing laboratory.

On road vehicle testing.

SUSTAINABLE ENERGY CARRIERS FOR PROPULSION SYSTEMS

- Analysis and optimization of the interaction between energy carrier and propulsion system.

- Experimentation and characterization of sustainable and innovative fuels.

- Optimization of fuel formulation for advanced propulsion systems.
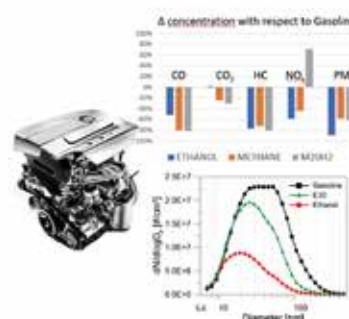

Impact of fuels on emissions.
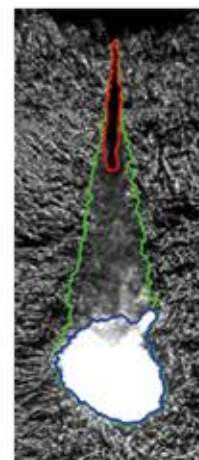
Diagnostics of reactive sprays.

INNOVATIVE CATALYTIC PROCESSES AND ADVANCED MATERIALS

Design, development and testing of heterogeneous catalysts and sorbents for energy and environmental applications at nano-scale level suitably tuning the properties through morphological, physico-chemical functional characterization. Development of multifunctional materials obtained by chemical reaction and/or preparation of hybrid compounds for different applications. Study of wear phenomena of thermally and mechanically stressed materials.

APPLICATIONS

- Power to Gas (methanation).
- Thermochemical cycles: Chemical looping combustion/reforming, H_2O/CO_2 thermochemical splitting).
- Purification of natural gas and bio-gas.
- Upgrading and purification of H_2-rich streams.
- Exhaust after-treatment for diesel/gasoline engines.
- DeNO$_X$, DeSO$_X$, VOC abatement, Hg/H_2S removal.
- Steam/Dry/Tri-reforming.
- Poisoning tolerance and Regeneration.
- Upgrading of by-products and wastes.
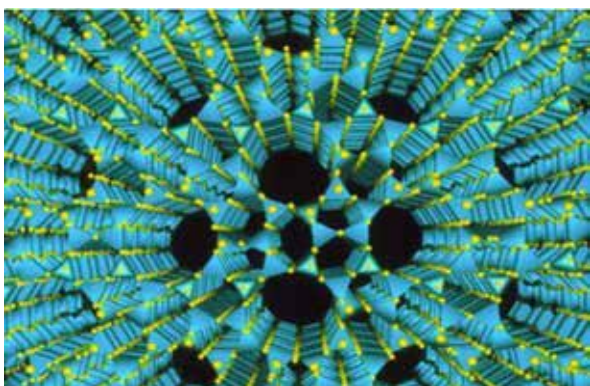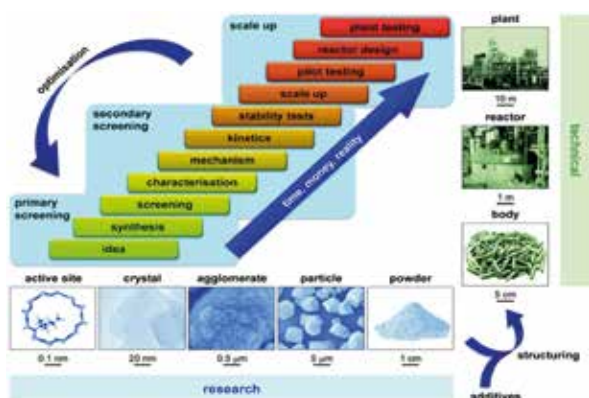
- Catalysts for deoxygenation and upgrade of oil produced by fast pyrolysis of biomasses and plastic waste in fluidized bed reactor.
- Catalyst for hot-gas cleaning of syngas produced by gasification process.

- Thermal management strategies for catalytic reactors (micro-combustors, diesel and gasoline particulate filters) using CFD modeling.

INNOVATIVE CATALYTIC PROCESSES AND ADVANCED MATERIALS

- Green and blue fluorescent Carbon Quantum Dots (CQDs) as by-products of combustion and pyrolysis processes.Optimization of operating conditions in combustion/pyrolysis reactors for the synthesis of blue and green fluorescent CQDs.

- CQDs production from residual biomasses by catalytic fluidized bed processes.
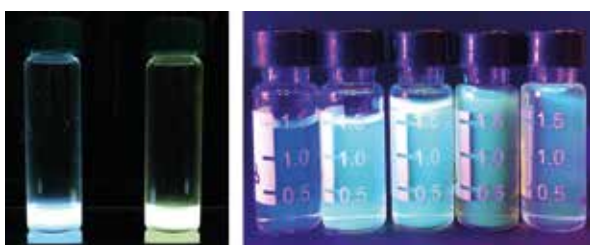
- Sustainable methods for machining superalloys for aeronautic, aerospace and automotive applications.

- Mechanical and microstructural analysis of materials produced by sustainable Additive Manufacturing processes.

- Wear and friction properties of materials for mechanical applications.
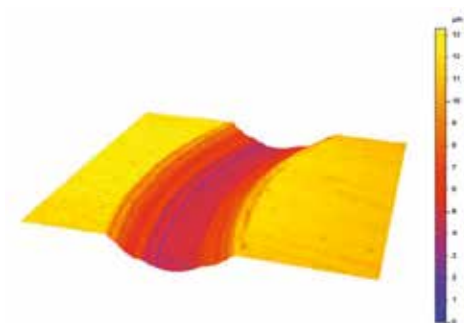
- One-pot synthesis of hybrid water-stable electrically conductive metal-organic framework (MOF)/graphene-like layer (GL) composites.

- High temperature gas-phase synthesis of metallic oxides and carboneous nanomaterials for sensing and elettronic applications.

- Processing of nanoparticles suspensions (organic, inorganic and mixed phases) as thin films.

- Functionalization, purification and characterization of complex carbon-based materials and of surface functionalities of carbonaceous solids.

- Sol-gel synthesis of nano-structured semiconductor oxides for gas sensing and as filler in polymer matrix for energy harvesting applications.
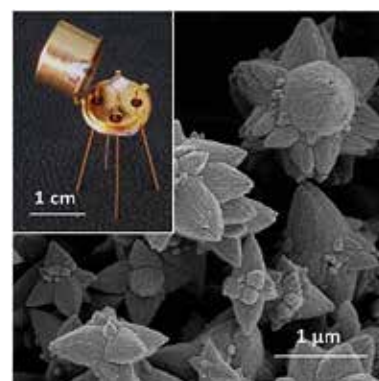
- Thermochemical processes for the production of carbonaceous materials having desired microstructural properties.

- Production of Graphene Related Materials (GRM) through wet chemical approaches.

- Nanocomposite materials for biomedical applications with enhanced mechanical and osseointegration properties.
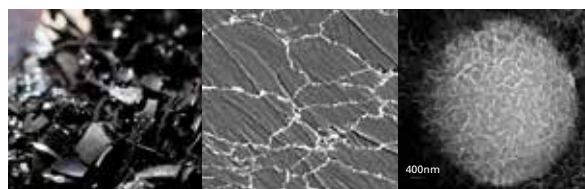

- Photocatalitic composite materials for the production of energy, chemicals and for metal recovery.

- Response to fire of composites and bio-composites including the effects of flame retardants.

- Computational fluid dynamics (CFD) modeling of Phase Change Materials (PCF) for thermal energy storage technologies.

SAFETY OF INDUSTRIAL PROCESSES, PLANTS AND MACHINES

The research activities carried out in the present area deal with various aspects of safety: "Process safety", "Functional Safety" e "Risk Assessment". These analyses, other than to mobility solutions, are applicable to urban and land planning of industrial areas, through the development of complex systems modelling and accidental risk analysis, and the arrangement of prevention and mitigation measures.

RISK ASSESSMENT OF EXPLOSIONS AND FIRES

- Characterization of flammability and the explosion behavior of gases/vapors, powders and hybrid systems (powder-gas/vapour) under process conditions.

- Unsteady flame propagation during gas explosions: flame front acceleration, deflagration-to-detonation transition, explosion of reacting mixtures.

- CFD simulation of explosions and fires.

- Suppression of fires with Ultra Fine Water Mist.

- Thermo-kinetic characterization of the ageing behavior of energetic materials (explosives, propellants and pyrotechnics) and development of models to predict their *shelf life*.

- Development of models, based on cellular automata, for the analysis, control and real-time prediction of forest fires propagation.
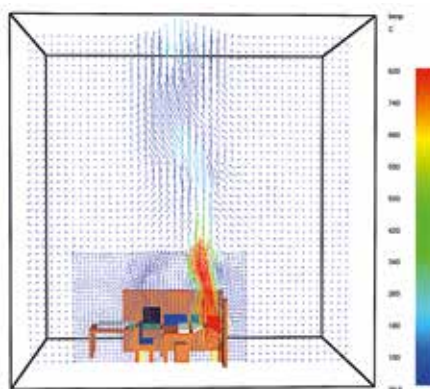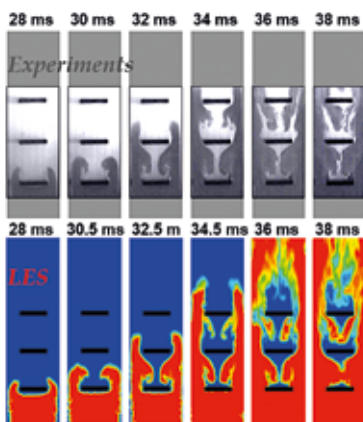


SAFETY OF INDUSTRIAL CHEMICAL PROCESSES

- Development of predictive mathematical models for the analysis, prevention and mitigation of risks associated with industrial chemical processes - explosions, fires and release of toxic substances - occurring in industrial sites.

SAFETY OF INDUSTRIAL PROCESSES, PLANTS AND MACHINES

CONTROL SYSTEMS AND STRATEGIES

- System analysis, system verification/validation, according to international *functional safety* standards.

- Model-based development of control algorithms at functional level, according to safety standards and good-design guidelines, combined with automatic generation of the final embedded control code.
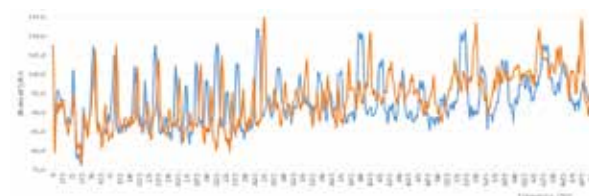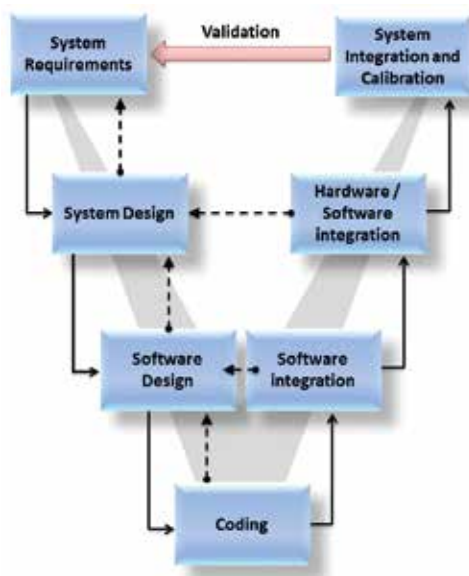
ACOUSTIC AND VIBRATIONAL EMISSIONS

- Improve aspects related to the comfort of the workplaces of operators, measure noise and vibration of machinery, vehicles or their components, in order to optimize their performance.

- *Product Sound Quality* for the reduction of the noise emission levels and the characterization of the sound features more related to the human perception, using the psychoacoustics descriptors.

- Identification of the sound power spectrum emitted by noise sources, to characterize the noise emission areas from a complex source or the transmission sound path, in 1D and 3D.

IMPLEMENTATION OF SAFETY STANDARDS

- Technology transfer, consulting, training, machinery testing and safety analysis, according to international and national health and safety standards, aimed to raise the product performances at market level.

PROCEDURES FOR THE DEVELOPMENT OF REGULATIONS AND NEW CERTIFICATION STRATEGIES

The activities are aimed at industry, CE, international and National Ministries for the development of procedures, laws and standards. Support to manufacturers in mandatory and voluntary evaluation of the performances, safety and comfort and usability for development, type approval, certification and testing under customer specification of off-road vehicles and their components.

LABORATORY APPOINTED FOR THE OFFICIAL TESTING IN ACCORDANCE WITH OECD/OCSE CODES FOR PERFORMANCE AND SAFETY (ROPS AND FOPS) TEST FITTED ON AGRICULTURAL AND FORESTRY TRACTORS

- ROPS certification under OECD Code 4, Code 6, Code 7, Code 8, e Code 9, ISO 5700, ISO 12003-1, ISO 12003-2, AS 1636.1, ASAE S383.1, ANSI/ASAE S478:2000, SAE J1040, SAE J1194, SAE J2194, CSA B352.0, B352.1, B352.2, OSHA 1928.51, OSHA 1928.52, OSHA 1928.53.

- FOPS certification under OECD Code 10 ISO 27850, ISO 8083, SAE J167.

- OPS certification under ISO 8084.

- Verification test for the operator's safety of earthmoving machines under ISO-3471 / ISO-3449 / ISO-6055 / ISO-12117 / ISO-10262 / ISO-6683 / EN-13531 / EN-15059 / UNI-11023.
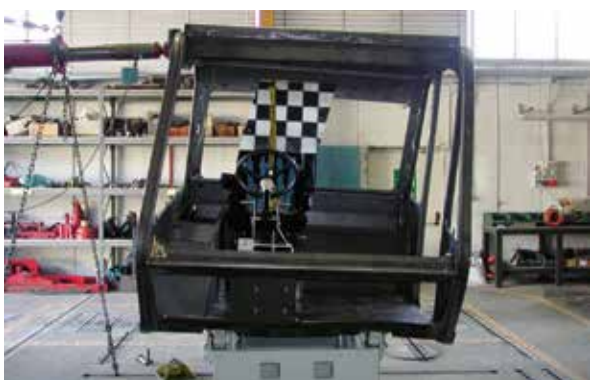
- Testing track 1 km long with asphalt, concrete, turf and clay surfaces, dynamometric brake for engine up to 300 kW, portable data acquisition systems, 10 ha of arable land for field testing.

- Artificial test track (ISO 5008 standard) for the simulation of the irregularities of typical surfaces on which the vehicle off-road test is advanced at different speeds. Rig useful for vibration levels measurement on the machines and their subsystems.

PROCEDURES FOR THE DEVELOPMENT OF REGULATIONS AND NEW CERTIFICATION STRATEGIES

- Hydraulic test bench for the evaluation of seat vibration for agricultural and earth moving machinery.

- Certification, maintenance over time of the safety requirements of agricultural machines through periodic surveillance activities and drafting and periodic review of the technical documentation according to ENAMA specifications based on the relevant technical standards.

- Directive 2000/14/EC "Noise emission in the environment by equipment for use outdoors" - experience in testing procedures, qualification of the acoustic environment, determination of the measured and guaranteed sound power levels.

PARTICIPATION IN TECHNICAL COMMITTEES AND WORK GROUPS

- Member in technical tables of UNI standardization commission for acoustics and vibration for regulatory development.

- CUNA (Commissione Tecnica di Unificazione nell'Autoveicolo), for the unification and publication of voluntary standards to be used by lawmakers to support binding legislation.

- Annual CUNA inter-laboratory exercises with cars and motorcycles on chassis dynamometers.

- Definition of sampling procedures and limits for unregulated pollutant emissions (VOC, PAH and PM).

FUEL EFFICIENCY AND VEHICLE EMISSIONS TESTING FACILITIES

- Real Driving Emissions (RDE) tests. Vehicles (light and heavy-duty) are instrumented with Portable Emission Measurement Systems (PEMS) and tests are realized on-road according to the procedures described in the EU Regulations 2018/1832 (RDE LD PACK4) e UE 2018/932 (RDE HD).

- Chassis dynamometer tests:
  - WLTP (Worldwide harmonized Light vehicles Test Procedure) for cars and vans;
  - WMTC (World Motorcycle Test Cycle) for 2 wheelers, Regulation EU 168/2013.

National Research Council

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Institute of Science and Technologies
for Sustainable Energy and Mobility

Headquarter	Via Guglielmo Marconi, 4 - 80125 Napoli (NA) Italy Telephone +39 081 7177 111 - Fax +39 081 2396 097
Other Locations	c/o Department of Chemical, Materials and Production Engineering University of Naples Federico II Piazzale Vincenzo Tecchio, 80 - 80125 Napoli (NA) Italy Telephone +39 081 768 2245 - Fax +39 081 768 2262
	Via Canal Bianco, 28 - 44124 Ferrara (FE) Italy Telephone +39 0532 735 611 - Fax +39 0532 735 666
	c/o Turin Research Area Strada delle Cacce, 73 - 10135 Torino (TO) Italy Telephone +39 011 3977 1 - Fax +39 011 3489218

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