Italian National Agency for New Technologies,
Energy and Sustainable Economic Development

ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development)

Battery Value Chain Research Group @ ENEA

Bologna 27 Giugno 2019

Margherita Moreno / DTE-PCU-SPCT

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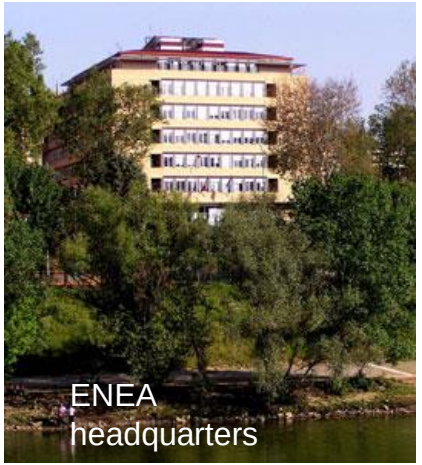
Activities focused on Energy Efficiency, Renewable Energy Sources, Nuclear Energy, Climate and the Environment, Safety and Health, New Technologies, Electric System Research.

ENEA's strengths and purposes:

- multidisciplinary competences and great expertise in managing complex research projects;
- basic, mission-oriented, and industrial research exploiting wide-ranging expertise as well as experimental facilities, specialized laboratories, advanced equipment;
- develops new technologies and advanced applications;
- provides public and private bodies with high-tech services, scientific and technological consulting , studies, measurements, tests and assessments;
- dissemination and transfer of research results
- training and information to broadening sector expertise and public knowledge


ENEA headquarters

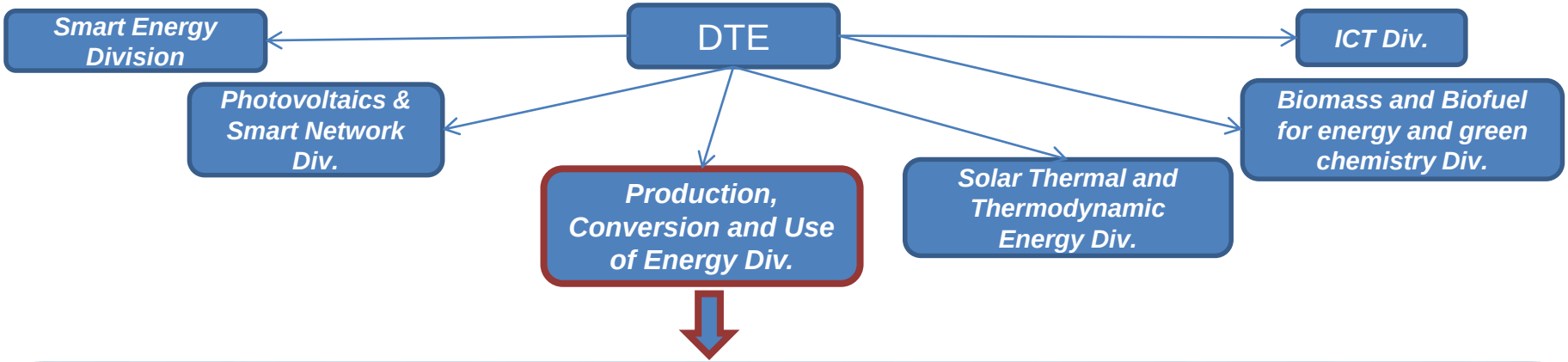
ENEA Organization

- 4 Departments: **Energy Technologies**, Energy Efficiency, Environment and Sustainability and Fusion and Nuclear Safety
- 9 Research Centers
- 5 Research Laboratories
- a network of territorial offices providing information and consultancy services
- an ENEA-EU Liaison Office in Brussels
- ENEA headquarters in Rome

The 2nd major Italian R.O., around 2700 staff employees with a large share (50%) of graduated people


Casaccia Research Center view

ENEA - Energy Technologies Dep. (DTE) organization



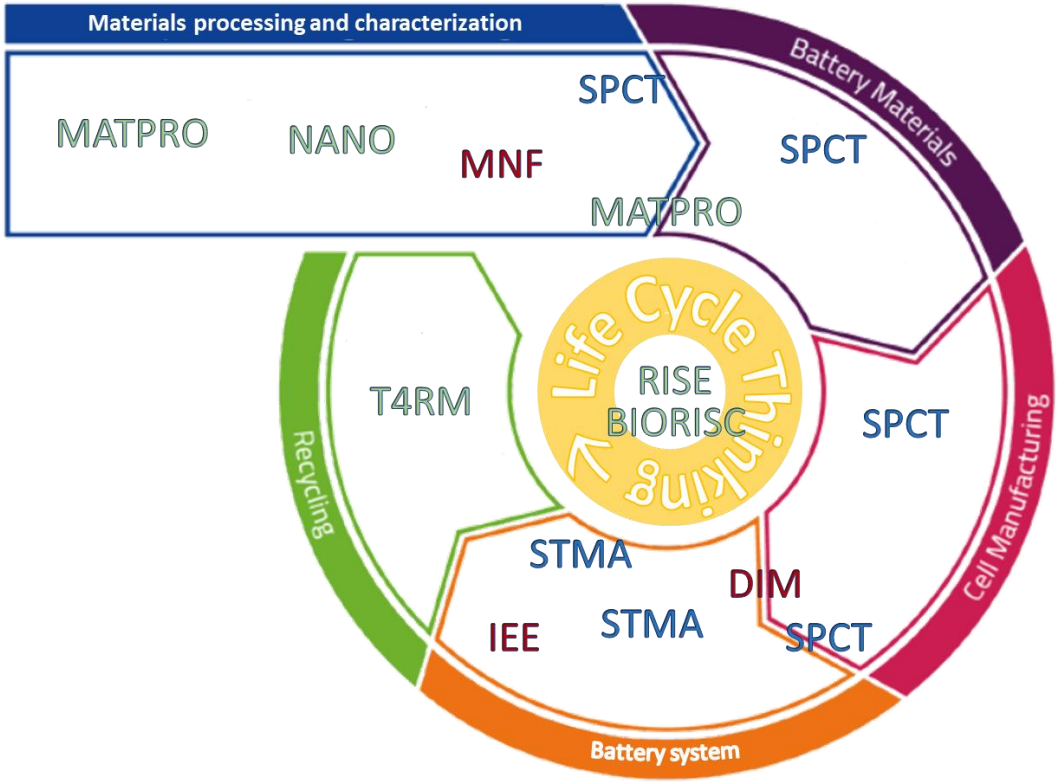
The heart of the activities on new electrochemical storage systems and their characterization in both stationary and electric mobility applications have been conducted for many years within DTE, consisting of big national and European projects @:

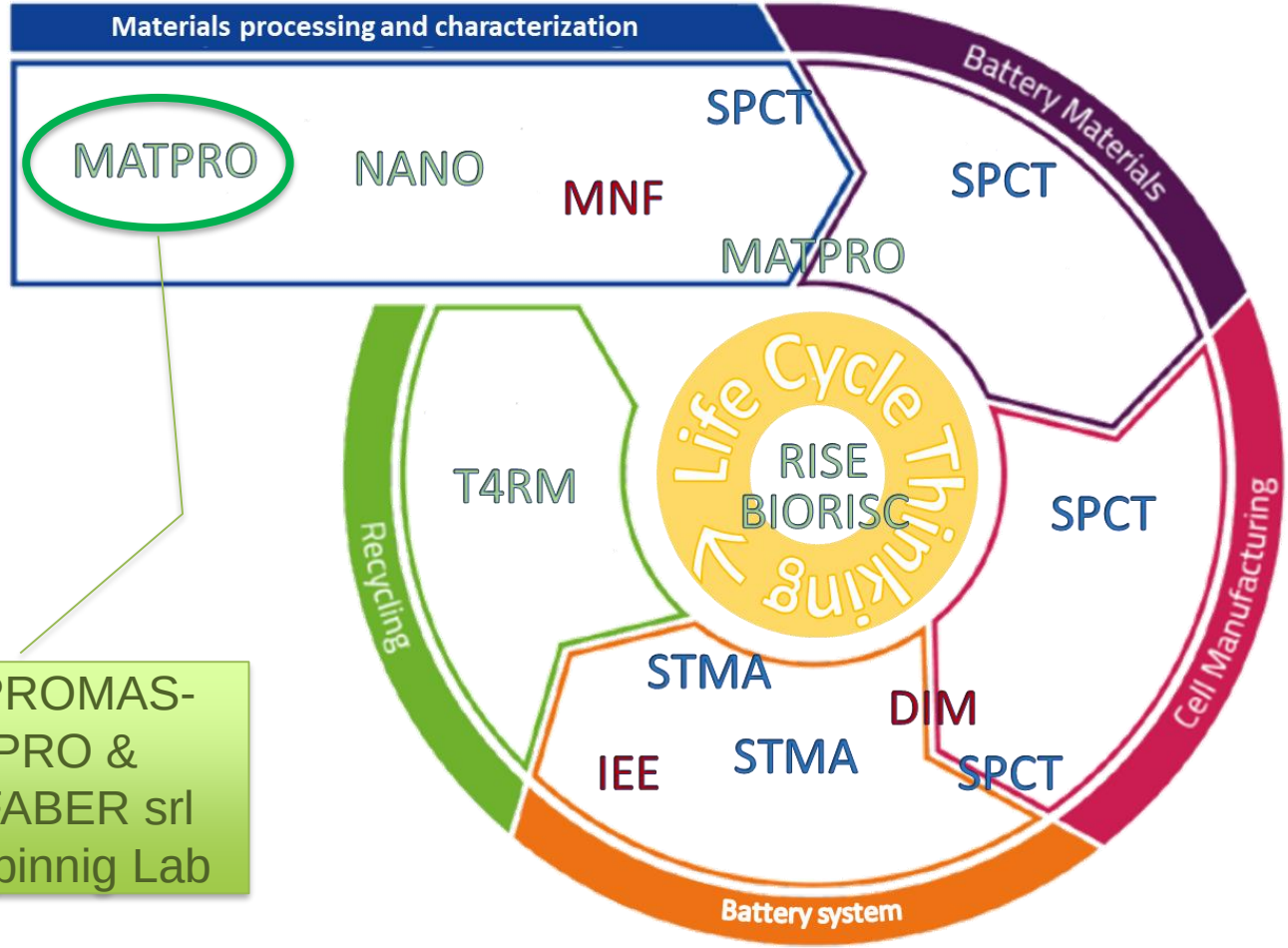
- **SPCT** – Development of Chemical Processes and Thermofluidodynamic Laboratory
  - Electrochemical storage systems and materials development (mailto: pierpaolo.prosini@enea.it/ margherita.moreno@enea.it): ~25 researchers and technicians involved.
  - Thermal management group (mailto: francesco.dannibale@enea.it / carla.menale@enea.it)
- **STMA** - Low-Enviromental-Impact Vehicles (Electric, Hybrid, Innovative Engines) (mailto: antonino.genovese@enea.it / francesco.vellucci@enea.it): ~25 researchers and technicians involved.

ENEA Research overall battery value chain

ENEA Battery Value Chain inter-lab group:

10 laboratories of 3 different departments are involved each positioned in a proper chain segment.





SSPT-PROMAS-MATPRO & NANOFABER srl Electrospinnig Lab

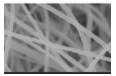
Electrospinning & SEM @ NANOFABER srl & SSPT-PROMAS-MATPRO

Expertise

- Fabrication of fibrous (aligned and random) non-woven sheets, both on planar sheet (about A3 format) and drum collectors, of multiple polymer solutions.
- Engineering of hybrid multiphase micro- and nano-polymer fibers loaded with nanoscale materials (e.g. ZnO and other oxides, plasmonic particles, etc.), including coaxial microfibers from electrospinning two different polymer solutions.
- Scalability studies of electrospinning for roll-to-roll scale up and large scale manufacturing
- Industrial statistics and six-sigma quality control (regression models, DOE, factorial design, SPC, ARIMA, etc.)for product development and process control using MINITAB.
- Multiscale mechanical experimental characterization (also in SEM)
- Microstructural characterization (SEM, AFM, LOM, TEM)

Equipment

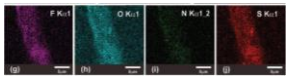
- **Industrial-grade electrospinning *** for pilot scale production, with coaxial nozzle (upgradable with possibility to heat up the nozzle up to 120°C and add a third syringe)

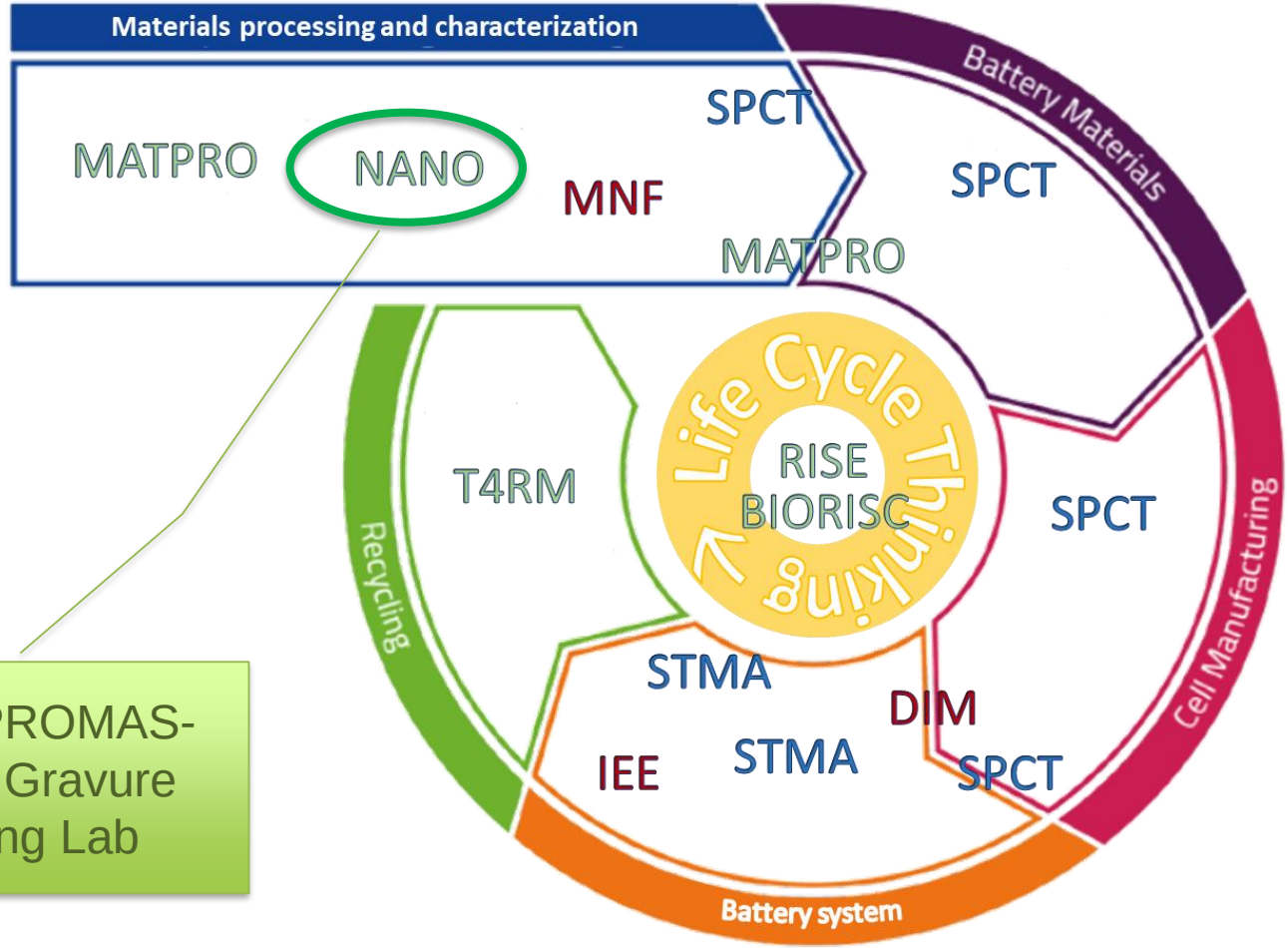


- **Clean room** (class B) setting with controlled temperature and humidity
- **Viscosimeter**

- **Sheet cutting:** Cutter plotter for tool free cutting from bitmaps * and die cutter of standard shapes (e.g. disks)
- **Mechanical characterization:** tensile testing (from 2 N to 100.000N), SEM-monitored testing (microtensile stage and nanoindenter)*
- **Microstructural characterization:** SEM (field emission gun microscope with EDS and nanoindenter) with electrical feedthroughs, optical microscopes, AFM (Nanosurf), TEM (200KV)

* By or with NANOFABER srl (www.nanofaber.com – ENEA spin-off)





SSPT-PROMAS-NANO Gravure printing Lab

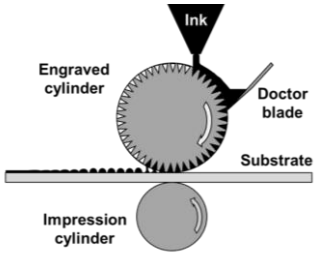
Gravure printing Lab @ SSPT-PROMAS-NANO

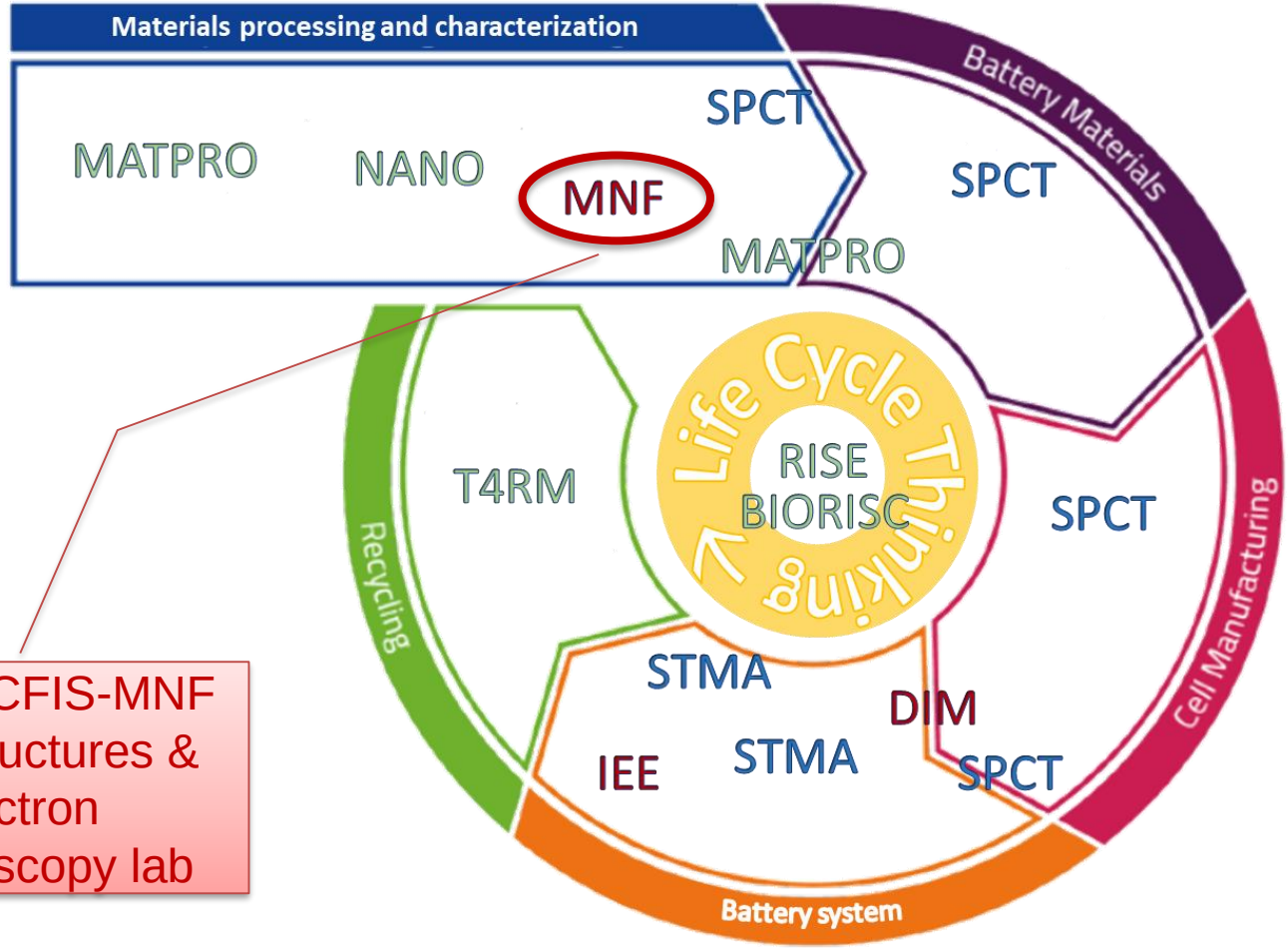
Experties

- Development of functional thin film for different purposes by gravure printing
- Study and testing of pre-printing treatments of substrates
- Ink formulation of functional materials suitable for gravure printing
- Optimization of printing parameters
- Study and testing for the functionalization of inks and printed layers
- Study and testing of post-processing on the printed layers

Equipment

- Gravure Printing machines
- Corona treatment
- Viscosimeter
- Optical profilometer
- Uv visible spectrofotometer
- SEM
- Contact angle
- XRD





FSN-TECFIS-MNF
Nanostructures & electron spectroscopy lab

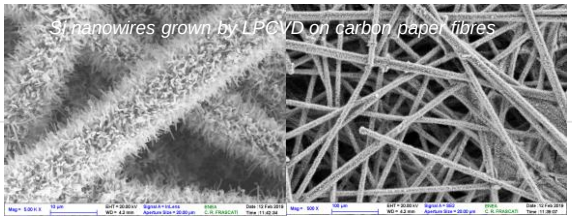
Nanostructures & electron spectroscopy @ FSN-TECFIS-MNF

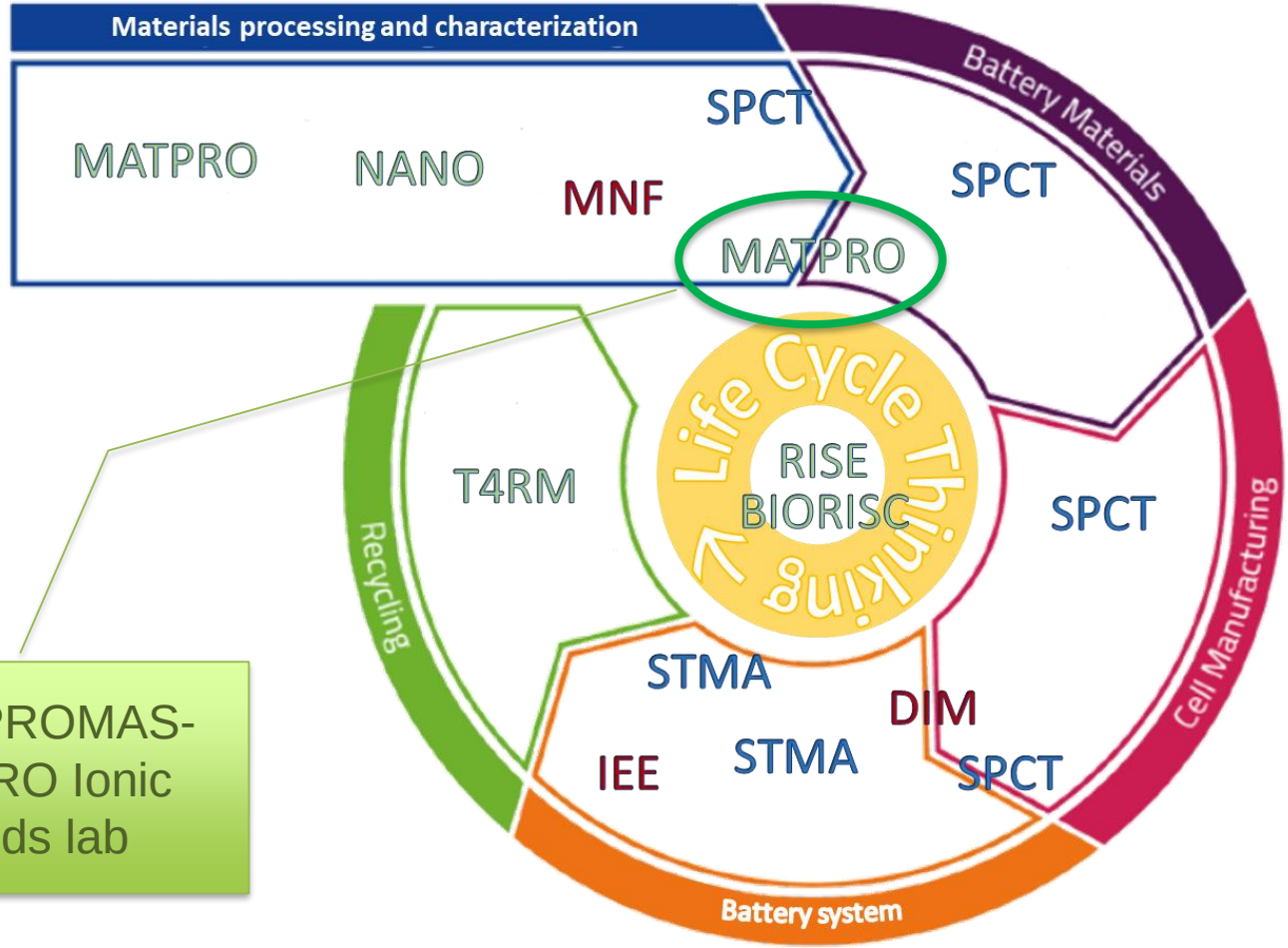
Expertise

- **Electronic properties of materials** for energy and fusion applications. XPS investigation of **superconducting materials** & materials for **thermal neutron detectors**
- **Nanostructured films synthesis .** Si nanowires for nanostructured anodes in lithium batteries for **energy storage**
- **Characterization by XRD, SEM, TEM .**
- **Optical spectroscopy.**

Equipment

- **Chemical-physical characterization**: X-Ray Photoelectron Spectroscopy (XPS) - interfaces, chemical bonds; inverse photoemission spectroscopy (IPES) - gap, conduction band; Auger spectroscopy (XAES).
- **Dedicated system** for the synthesis of Si nanostructures by Chemical Vapour Deposition (CVD).
- **Multi-purpose UHV system for materials synthesis:** CVD, Metal-organic-CVD, Laser–assisted CVD, Physical Vapour Deposition (PVD).





SSPT-PROMAS-MATPRO Ionic Liquids lab

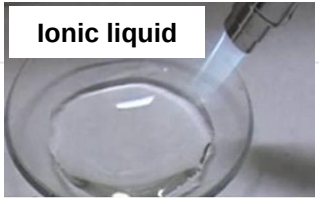
Ionic Liquids Lab @ SSPT-PROMAS-MATPRO

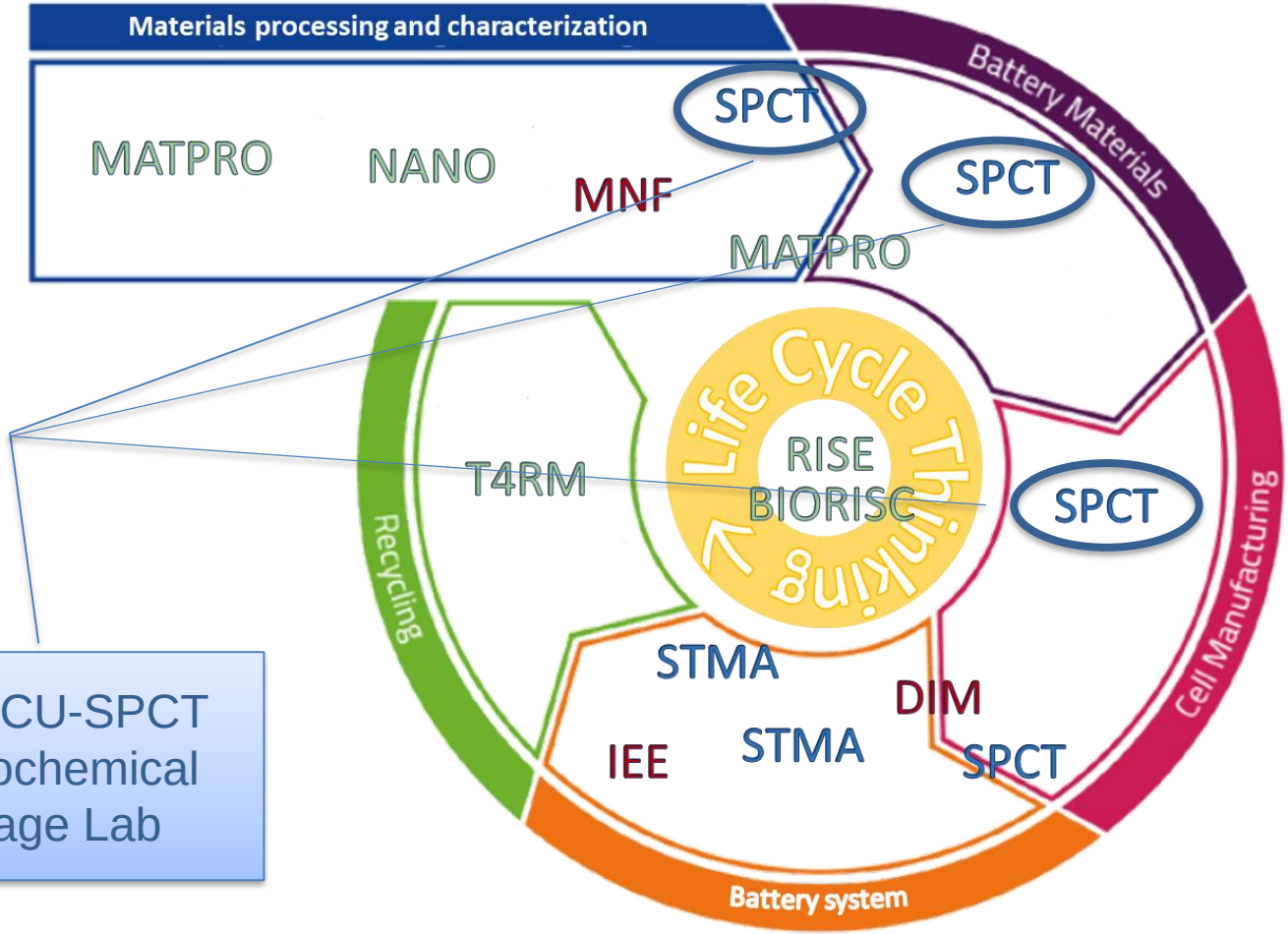
Expertise

- Design, synthesis, purification of ionic liquids as electrolyte components for safer lithium/sodium battery systems
- Formulation of ionic liquid-based, lithium/sodium conducting electrolytes
- Research and development on lithium/sodium conducting, solid polymer electrolyte membranes
- Quality control of the developed electrolytes
- Physicochemical qualification of the developed electrolytes
- Compatibility with electrode materials & validation of the electrochemical performance

Equipment

- Chemical lab, Glove-box, Electrochemical workstation
- Quality control: UV-Vis spectrophotometer, X-ray Fluorescence, FT-IR spectrometer
- Physicochemical investigation: combined TGA/DTA analyzer, thermo-balance equipped with a mass spectrometer
- Electrochemical investigation: Frequency Response Analyzer, Galvanostat/Potentiostat, Battery Cycler





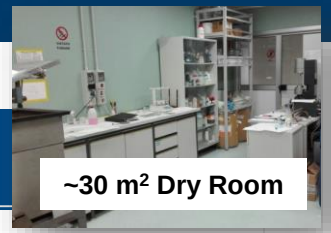
DTE-PCU-SPCT
Electrochemical
Storage Lab

Electrochemical Storage Lab @ DTE-PCU-SPCT

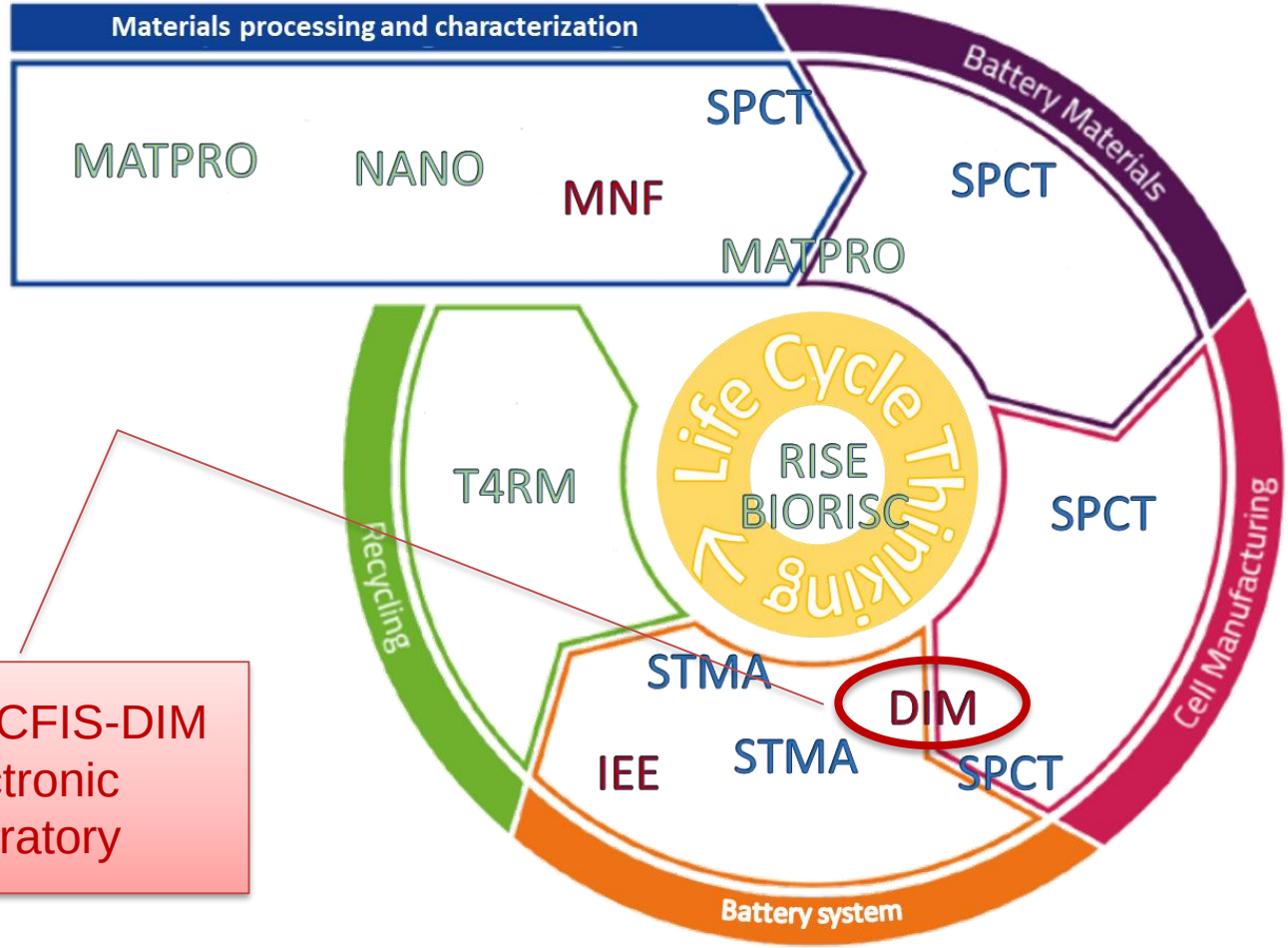
Experties

- Studies on chemistry and physics of energy storage **materials** aimed to: i) improve energy density, ii) better safety, iii) low cost and iv) improve cycle life and durability of batteries.
- Research on new **electrolyte/electrode** materials: polymer electrolytes, ionic liquids as electrolytes or additives; anodic and cathodic materials for **Li-ion** and **post-Li-ion** (such as Na-ion or Li/S); studies on greener and safer solution (e.g. aqueous binders).
- **Development & optimization** of component manufacturing (semi-automatic electrodes production, materials production scale-up) and manufacturing of lab-scale battery prototypes (setting up of new battery configurations)
- **Characterization and testing** of storage systems for mobile and stationary applications

Equipment

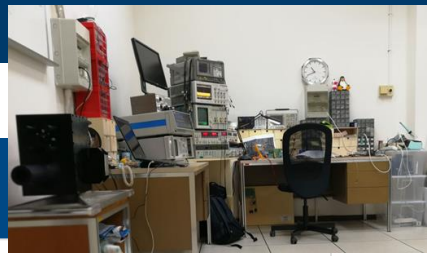


- **Chemical-physical characterization**: SEM, X-ray diffractometer (possibility of *in-situ* mesurements), thermogravimetry (DSC and SDT), impedance spectroscopy, measures of electrochemical stability window and cyclic voltammetry and measures of conductibility, density and reological properties @ different temperatures. Also EDX, BET, UV-Vis, GC.
- **Electrochemical testing** of prototypes and coin cell with battery tester (96 channels @ 40 A & 5 V; 8 channels @ 400 A & 80 V)and climatic chambers



FSN-TECFIS-DIM
Electronic
laboratory

Electronic laboratory @ FSN-TECFIS-DIM

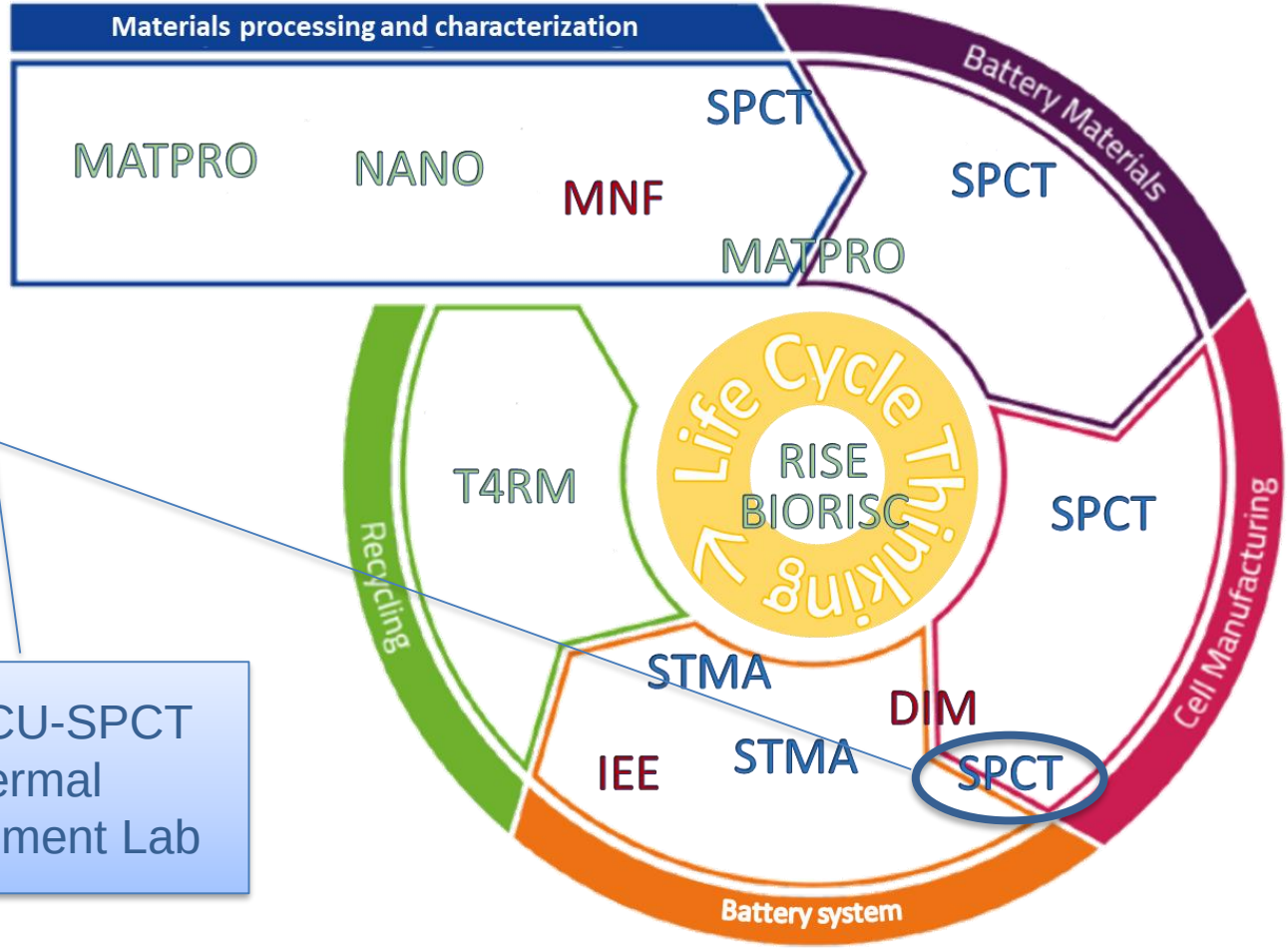


Expertise

- Electronic hardware design (analog, digital and mixed signals)
- Opto-electronic design (optics, LASER sources, detectors, etc.)
- Embedded software development for data acquisition and real time control systems (bare metal, RTOSs, Linux, etc.)
- Model based design, validation and automatic code generation for hardware-in-the loop applications with Matlab, Simulink, ScicosLab, Modelica, LabVIEW; complex, multyi physical simulations with tools like COMSOL , ANSYS and OpenFOAM.
- Rapid development of hardware and software porotypes using internal resources and external companies.
- Complex systems integration (+10 years field experience on experimental nuclear plants).

Equipment

- Analog and digital oscilloscopes up to 1GHz.
- Spectrum analysers up to 22 GHz.
- Dynamic Signal Analysers (HP, Agilent, SRS) up to 100 kHz.
- Analog and digital lock-in amplifier up to 200 MHz.
- EIS measurements with Solartron Schlumberger bridge.
- High accuracy multimeters (HP, Agilent).
- National Instruments real time data acquisition and control systems programmed with Simulink Real Time and LabVIEW.
- High performance workstations for design and simulation.
- Large electronic component magazine.
- Mechanical shop for optic and electronic components.



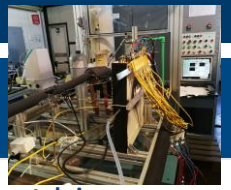
DTE-PCU-SPCT
Thermal
Management Lab

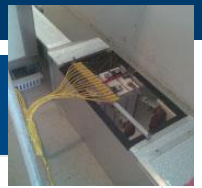
Thermal management Lab @ DTE-PCU-SPCT

Expertise

- Heat and mass transfer in single- and two-phase systems for industrial applications in energy processes, electronics, aerospace, food refrigeration air conditioning, process manufacturing.
- Experimental tests of flow boiling in microchannels.
- Two-Phase Thermal management for terrestrial and space for space applications.
- Use of natural refrigerants with low GWP; in particular: CO_2 for domestic refrigerators, heat pumps and chiller for hot and cold water production and for the climatization and commercial refrigeration.
- Thermal characterization and development of innovative cooling systems for the electrochemical energy storage systems

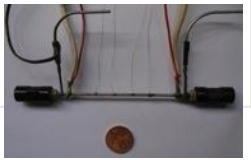
Equipment



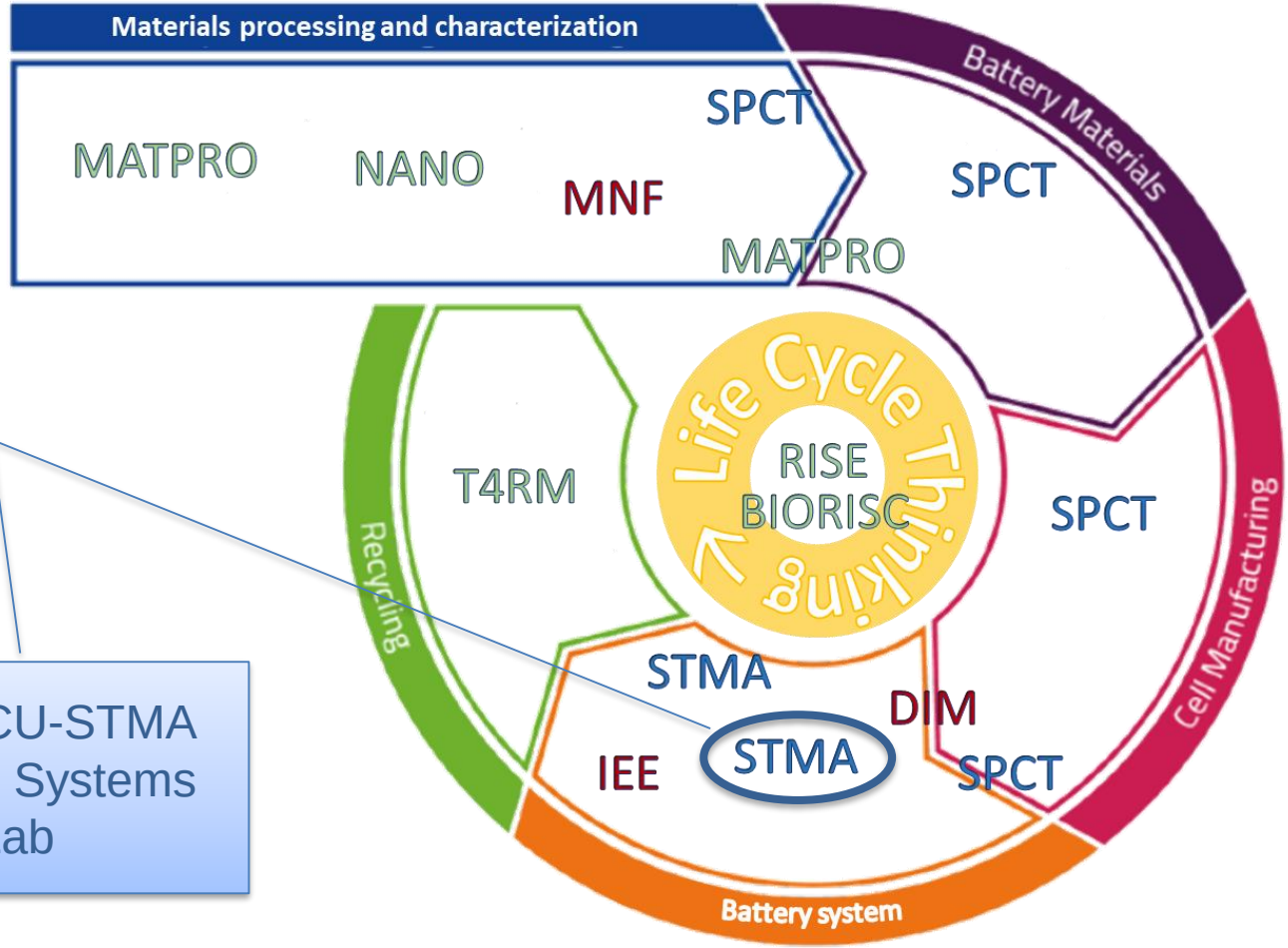


- **Battery thermal management experimental rig:**
  - ***Air cooling***: axial fans, an electric pre-heater to assure the desired inlet air temperature, an anemometer and the test section.
  - ***Liquid cooling*****:** a volumetric gear pump, a Coriolis flow-meter, a pre-heater, a compact heat exchanger to cool down the fluid before the pump and the test section.

- **Climatic chamber** for the pre-industrial development of electrical heat pumps (maximum power: 50 kW_{th})
- **Measurement micro-transducers** (thermocouple, pressure drop transducer, micro-mechanical components) for measuring the experimental parameters during the experiments



- Thermocouple calibration system



DTE-PCU-STMA Storage Systems Lab

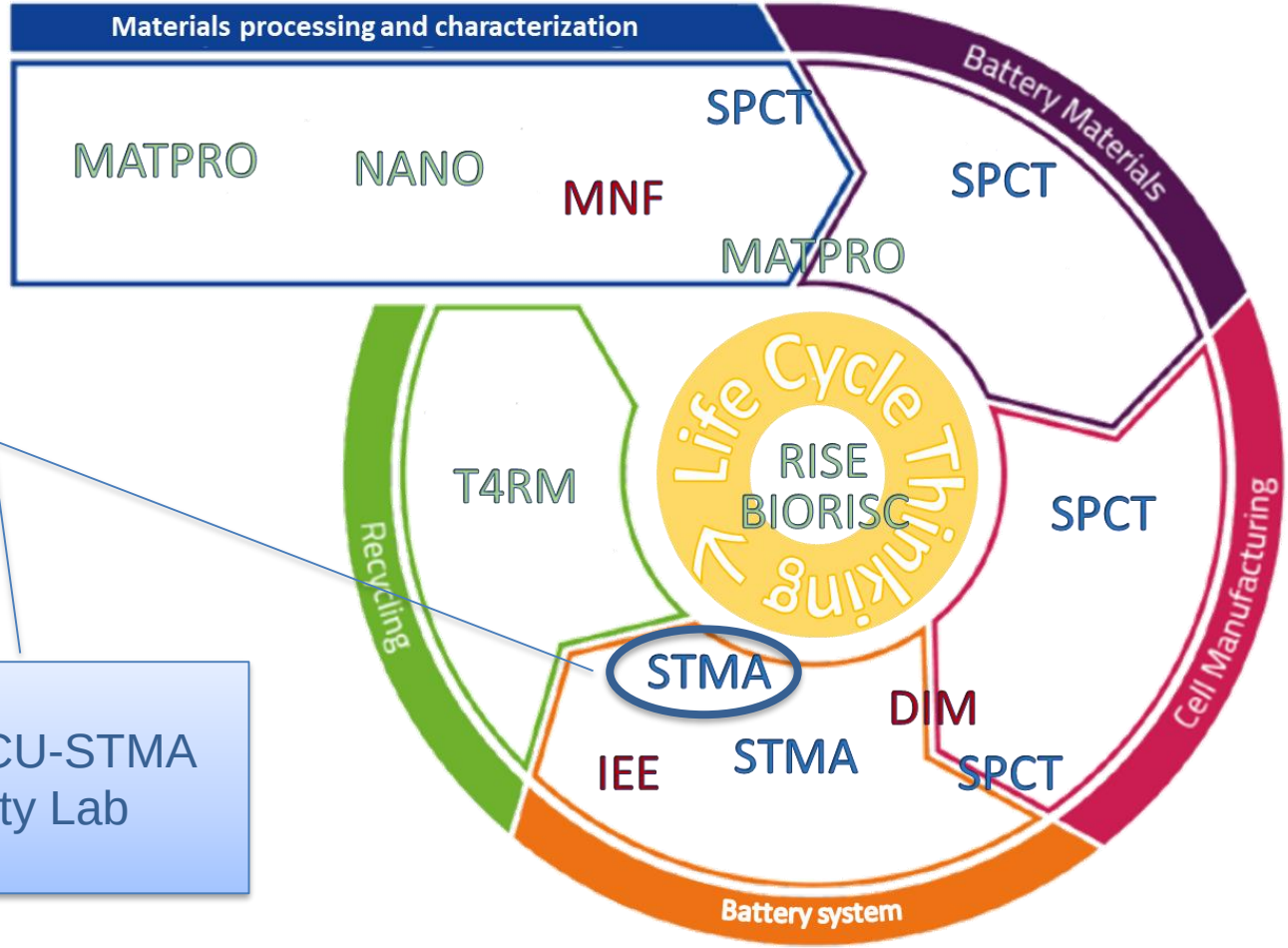
Storage systems Lab @ DTE-PCU-STMA

Experties

- Activities on new technologies for **low environmental impact vehicles** and **storage systems** for automotive and stationary applications
- Series and parallel Hybrid Micro-cars for urban uses
- Electric vehicles for local public transportation purposes
- Innovative Fuel mixtures (Hydro/methane)
- **Electric energy storage systems: Lithium batteries and/or Ultra capacitors**
- Propulsion systems for industrial and off-road applications (overhead cranes, cableways, …)
- Complete vehicles testing on rolling test benches
- Charging systems for EVs

Equipment

- **Electrochemical testing** of battery systems, module, cells. Battery cyclers (1 channel @ 600 A - 800 V 250 kW; 8 channels @ 400 A & 80 V) and climatic chambers



DTE-PCU-STMA
Safety Lab

Safety Lab @ DTE-PCU-STMA

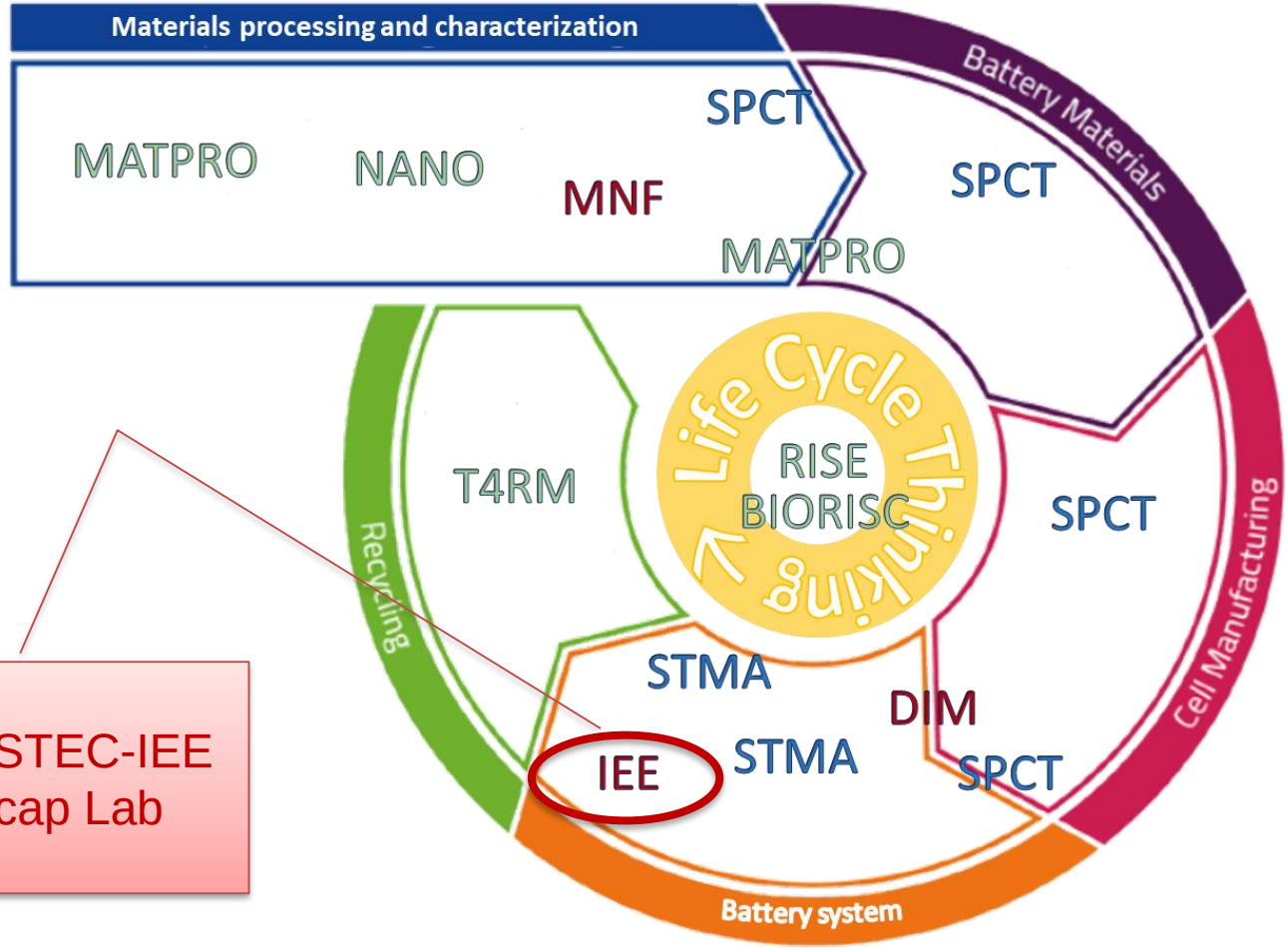
Experties

- Safety regulation in the fields of: H&S at work; Seveso Directive; dangerous good
- Safety review and studies aimed at hazard identification, applyed at electrochemical systems from cradle to grave, chemical processes and new technologies
- Cooperation with the Fire rescue team of Casaccia, in the safe project of abuse testing
- Electrical characterization of batteries made by STMA engineers
- Risk analysis in cooperation with Pisa University
- Fire engineering and ex ante&ex post chemical analisys in cooperation with Roma University and Italian Fire Corp (CNVVF)

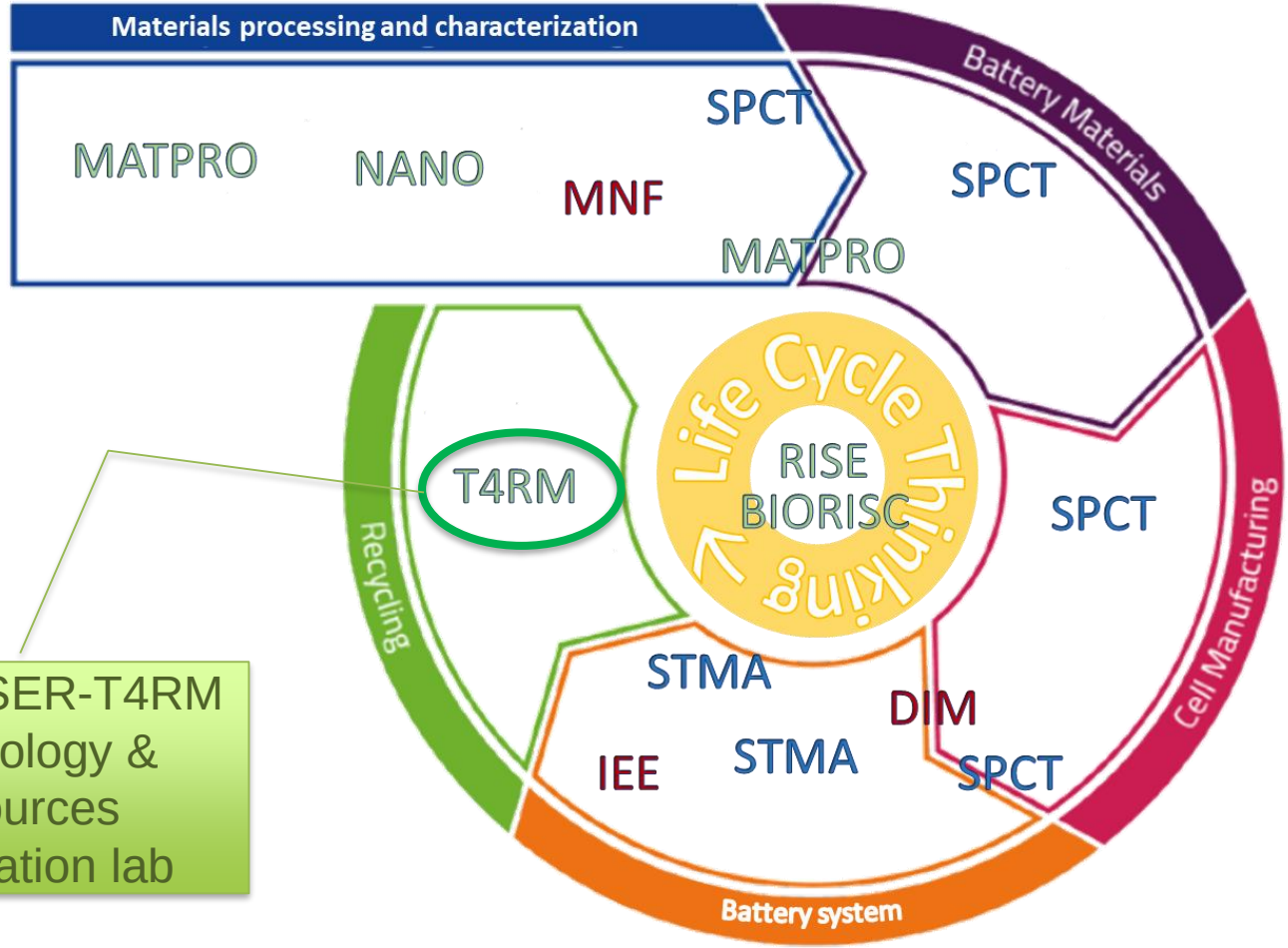
Equipment

- Casaccia FARO Plant aimed at the outside abuse testing (thermal and electric) of electrochemical accumulators (up to 20 kg)
- IR termocamera and videocameras

- CNVVF: Fire engineering equipment, including SBI and Cone calorimeter
- UNIROMA: DSC termal analysis
- UNIROMA: full industrial hygienist evaluation
- UNIPISA: Risk analysis and BMS risk and reliability analysis



FSN-FUSTEC-IEE
Supercap Lab



SSPT-USER-T4RM
Technology & resources valorisation lab

Technology & resources valorisation lab @ SSPT-USER-T4RM

Expertise

Development and implementation of processes for the recovery of raw materials from complex matrices, such as WEEE, fly ash, catalysts, solar panels, batteries and industrial residues:

- Characterization of input and ouptut materials
- Definition and implementation of the unit operations required to separate the elements of interest (e.g. leaching, solvent extraction, precipitation etc.)
- Pilot tests for industrial upscaling of processes and prototypes: through our pilot plants we can check the process operations and their technical and economic efficiency, including risks-benefit analysis.

View of the ROMEO pilot plant

Equipment

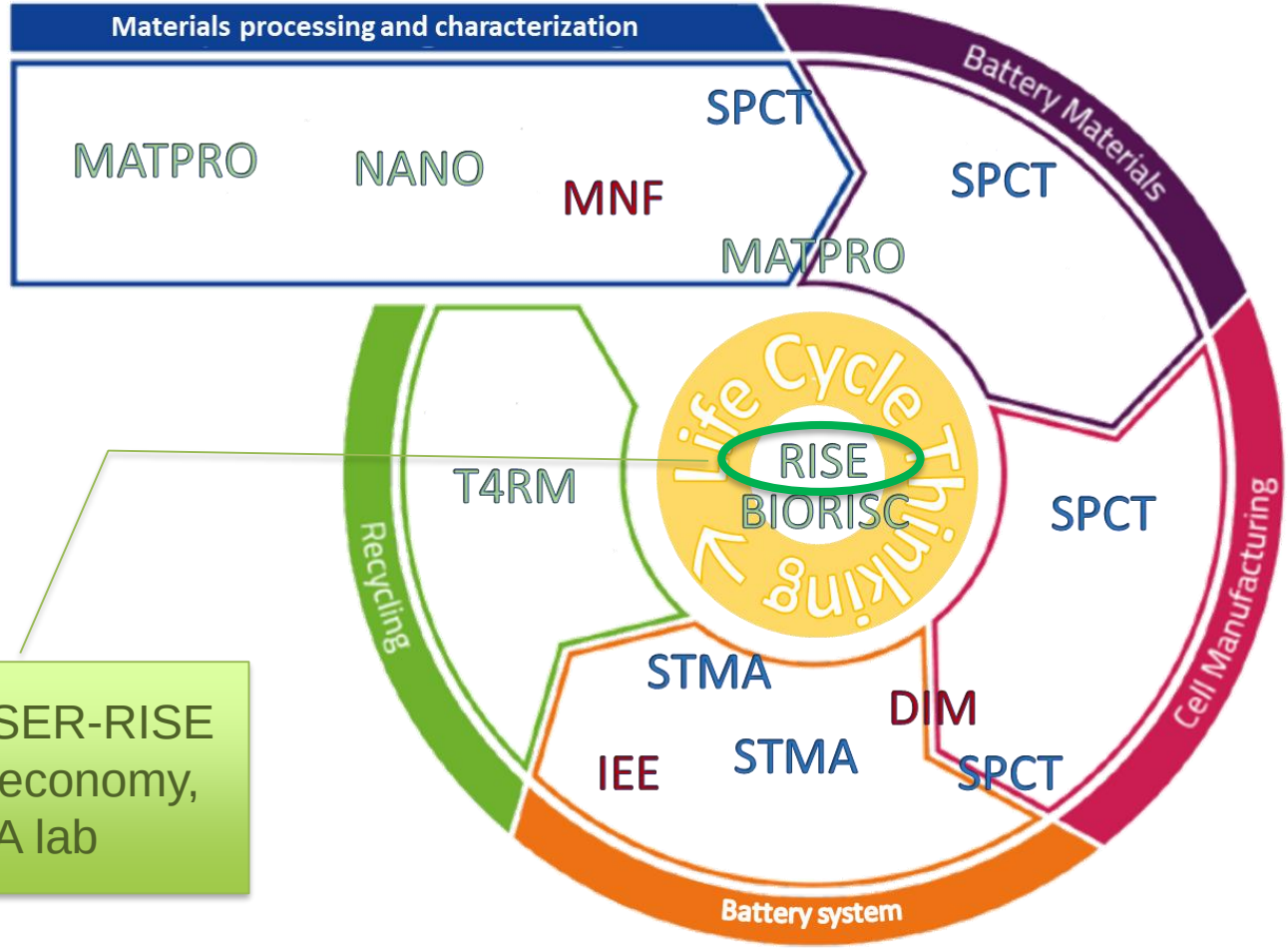
- Atomic absorption spectrophotometer (AAS)
- Microwave Plasma Atomic Emission spectrophotometer (MP-AES)
- Handheld XRF analyzer
- UV-VIS spectrophotometer
- FTIR-ATR spectrophotometer
- Ionic chromatograph (IC)
- Total Organic Carbon (TOC) analyzer
- TGA/DSC analyzer
- Gas chromatograph (GC)
- Microwave mineralizer
- Mills
- High-performance centrifuge
- Lyophilizer
- Muffle furnace

A section of the analytical room

Facilities

ROMEO (Recovery Of MEtals by hydrOmetallurgy) pilot plant

Thanks to its modular structure, the plant can process different types of by-products and/or waste streams, such as printed circuit boards, spent fluorescent lamps and batteries.



SSPT-USER-RISE
circular economy,
LCA lab

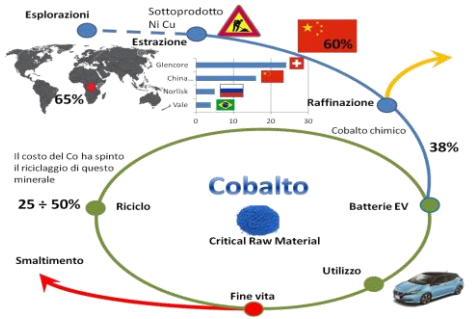
Circular economy & LCA Lab @ SSPT-USER-RISE

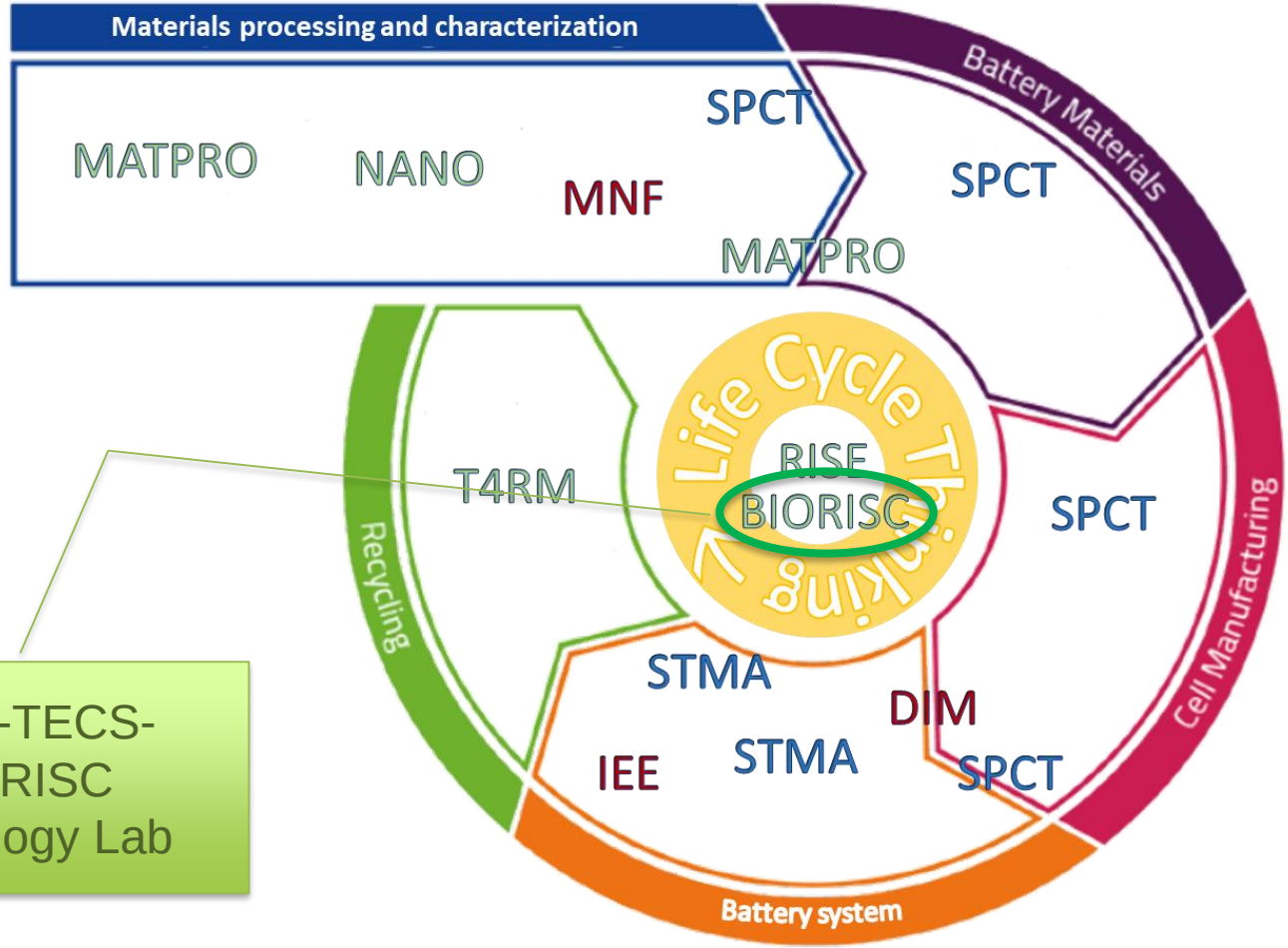
Experties

- Material flow analysis of the electric batteries production and recycling
- Sustainability assessment with life cycle perspective (LCA, LCC & SLCA) of electric batteries production
- Green mining feasibility assessment in the battery industry in order to implement circular economy principles
- Value chain analysis of the battery production, use and end of life management
- Market scenario analysis of the raw materials supply chain for the battery industry
- Special focus on Critical Raw Material (CRM) used in the electric batteries production

Equipment

- Software for Life Cycle Assessment, Life Cycle Costing & Social Life Cycle Assessment
- Life Cycle Assessment databases
- Tool (platform) for Industrial Symbiosis implementation
- Management of networks for Circular Economy implementation at national and international level (ICESP, ECESP, SUN)





SSPT-TECS-BIORISC Toxicology Lab

Toxicology Lab @ SSPT-TECS-BIORISC

Expertise

- Molecular dynamic simulation of interactions of biomolecules with organic and inorganic substrates
- Toxicity and genotoxicity testing on in vitro cell cultures and in vivo rodent models
- Identification and characterization of molecular mechanisms of toxicity
- Human biomonitoring in occupational settings
- Environmental epidemiology
- Implementation of hazard characterization data into risk assessment models

Equipment

- Cell culture laboratories
- Authorized rodent animal house
- Ionizing and non-ionizing radiation exposure systems
- Molecular biology and analytical cytology instrumentation
- Searchable Italian Database of disease-specific mortality rates at municipal level

ENEA-BatVC-InterLab contacts

For any discussion or proposal please contacts:

Electrospinning & SEM @ SSPT-PROMAS-MATPRO	antonio.rinaldi@enea.it
Gravure printing Lab @ SSPT-PROMAS-NANO	maria.montanino@enea.it
Nanostructures & electron spectroscopy @ FSN-TECFIS-MNF	flaminia.rondino@enea.it
Electrochemical Storage Lab @ DTE-PCU-SPCT	margherita.moreno@enea.it
Ionic Liquids Lab @ SSPT-PROMAS-MATPRO	gianni.appetecchi@enea.it
Electronic laboratory @ FSN-TECFIS-DIM	simone.mannori@enea.it
Thermal management Lab @ DTE-PCU-SPCT	carla.menale@enea.it
Storage systems Lab @ DTE-PCU-STMA	francesco.vellucci@enea.it
Safety Lab @ DTE-PCU-STMA	cinzia.dibari@enea.it
Supercap Lab @ FSN-FUSTEC-IEE	alessandro.lampasi@enea.it
Technology & resources valorisation lab @ SSPT-USER-T4RM	danilo.fontana@enea.it
Circular economy & LCA Lab @ SSPT-USER-RISE	cristian.chiavetta@enea.it
Toxicology Lab @ SSPT-TECS-BIORISC	francesca.pacchierotti@enea.it

ENEA-BatVC-InterLab funded projects

Some examples of fundend projects: (not exaustive)

IPCEI -Battery

MARS-EV

Battery 2030+

ENEA: advisory board member

Helios

GREEN Lion

ETIP Batteries Europe

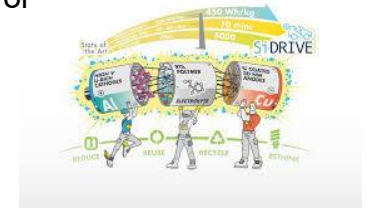
NEXTOWER

ICARUS

EIT Raw Materials SSIC 2017-18
Sustainability Support and Information Centre

EIT Raw Materials AVAR
Added Value Alumina Refining

ECO COM'BAT: Ecological Composites for High-Efficient Li-Ion Batteries



What's next in the agenda…

Next european calls coming soon:

LC-BAT-8-2020: Next-generation batteries for stationary energy storage

Specific Challenge: Stationary applications such as utility grids and industrial sites require storage applications that have the ability to combine high power and heavy use, going through multiple deep cycles per day, with a long lifetime and maximum safety. In addition, future battery systems should have optimal sustainability throughout the entire supply chain, including the substitution of critical raw materials, second-life, and recycling. Current generation Li-ion batteries, despite their success in e-mobility, may not be the ultimate solution for stationary storage; in addition, the growth of Li-Ion battery market is not enough to meet the demand for stationary and e-mobility applications. Interest in next-generation Li-ion and non-Li-ion batteries (for example molten salt, metal-air, lithium-sulphur, sodium, flow batteries, solid state, new ion-based systems) for these applications is growing, but many fundamental and technological obstacles remain to be overcome. This challenge is in line with the identified priorities in the context of the SET-Plan.

344 See https://ec.europa.eu/transport/sites/transport/files/3rd-mobility-pack/com20180293-annex2_en.pdf.

345 See Manifesto for a long-term research initiative to create the batteries of our future: http://battery2030.eu/

346 See https://setis.ec.europa.eu/

347 See https://ec.europa.eu/transport/sites/transport/files/swd20170223-transportresearchandinnovationtomobilitypackage.pdf

Scope: The objective is to develop and validate or demonstrate innovative next-generation battery technologies for stationary energy storage that have a low cost, high safety, high depth of discharge, and high cycle life and efficiency. Development must include the integration of sensors and/or battery management electronics in the cell, and the potential for upscaling the battery systems. The battery systems should have optimal sustainability throughout the entire supply chain, including the substitution of critical raw materials. A key issue is the design of an efficient production process with minimal environmental impacts across the whole life-cycle, including recycling. Solutions must be validated or demonstrated in a relevant environment. Since cost is the most important driver for grid scale electricity storage, targets for key performance indicators such as capital cost, storage cost and end-of-life cost should be set. "Balance of plant" components should be included in cost estimates.

The activities are expected to bring the technology from TRL 3 to TRL 5 (please see part G of the General Annexes).

The Commission considers that proposals requesting a contribution from the EU of between EUR 6 and 8 million would allow this specific challenge to be addressed appropriately. Nonetheless, this does not preclude submission and selection of proposals requesting other amounts.

Expected Impact: Project results are expected to contribute to:

- Assure best possible performance and lifecycle for the next-generation battery technologies for stationary energy storage at lowest cost, in particular by putting the energy storage cost on the path to fall below 0.05 €/kWh/cycle by 2030;
- Reduce the pressure on limited natural resources due to longer battery lifespan, improved recyclability and the use of more abundant and less harmful materials;
- Speeding up development and subsequent deployment of batteries for energy storage applications.

Type of Action: Research and Innovation action

The conditions related to this topic are provided at the end of this call and in the General Annexes.

What's next in the agenda…

services and/or products. This challenge is in line with the identified priorities in the context of the SET-Plan [348].

LC-BAT-9-2020: Hybridisation of battery systems for stationary energy storage

Specific Challenge: Advanced batteries are expected to play a major role in electricity grid management in systems with a high share of renewable electricity. The need for simultaneously providing multiple services (e.g. artificial inertia, frequency regulation, renewables balancing, load levelling, backup power and longer-term energy storage) requires compromises between power needs and energy needs. Hybrid battery systems can provide the ability to optimise power/energy performances by the combination of different technologies. Such hybrid systems would reach better business cases by mixing the contribution to different

Scope: The objective is to develop and demonstrate optimised innovative battery storage systems based on hybridisation. The resulting storage system can be engineered either by the twinning of distinct systems, or internal hybridisation of cells and control systems. Focus should be on cell and stack design, on advanced battery management systems and on high-level, hybrid storage control systems. The hybrid storage systems may for example be optimised for one or more of the following applications:

- Stand-alone provision of services to the interconnected pan-European grid
- Provision of services to island grids
- Provision of services in weak distribution grids
- Provision of services in private grids such as industrial parks
- Provision of load levelling for EV charging service stations.

The activities are expected to bring the technologies from TRL 4 to TRL 6 (please see part G of the General Annexes). The battery systems should have optimal sustainability throughout the entire supply chain, including the substitution of critical raw materials. The systems should be demonstrated in a relevant environment and at a scale that allows future business cases to be developed.

The Commission considers that proposals requesting a contribution from the EU of EUR 3 to 4 million would allow this specific challenge to be addressed appropriately. Nonetheless, this does not preclude submission and selection of proposals requesting other amounts.

Expected Impact: Increased competitiveness of electrical energy storage by balancing power needs with energy needs, providing a more efficient system with a longer and better performing lifespan, and by optimising balance-of-plant and installation costs. Project results should put the energy storage cost on the path to fall below 0.05 €/kWh/cycle by 2030.

Type of Action: Research and Innovation action

The conditions related to this topic are provided at the end of this call and in the General Annexes.

Opening date(s), deadline(s), indicative budget(s):[349]

Topics (Type of Action)	Budgets (EUR million)		Deadlines
	2019	2020	
Opening: 03 Dec 2019			
LC-BAT-8-2020 (RIA)		20.00 [350]	21 Apr 2020
LC-BAT-9-2020 (RIA)		10.00 [351]	
Overall indicative budget		30.00	

What's next in the agenda…

UPCOMING CALLS

1) Materials Acceleration Platform 20 M Euro for one project
2) Sensors 10 M Euro for several 2-4 M Euro projects
3) Self-healing 10 M Euro for several 2-4 M Euro projects
4) CSA 2 M Euro for administration for three years
5) **M-ERA NET 5M Euro from the commission and at least 10 M Euro from member states - A COMPLEMENTARY PROJECT**

Competences in materials, characterisation, modeling at different length-scales, sensors, AI, machine learning, polymer chemistry, recyling, BMS, how to adapt batteries in an application, etc…

BATTERY 2030+

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Thank to organizers and thank you all for the attention!