ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES, ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT

Battery materials research ENEA - highlights

MOTUS-E - 13/05/202

Sicurezza energetica e competitività. Le aziende dello storage incontrano le Istituzioni

Antonio Rinaldi - ACEL Head

Laboratory of Electrochemical Storrage Techlogies and Devices (ACEL)
Division of Technologies and Vectors for Decarbonization (DEC)
Dept of Energy Technologies and Renewable Sources (TERIN)

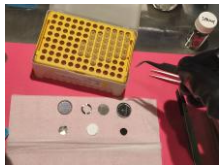
MINISTERO DELL'AMBIENTE E DELLA SICUREZZA ENERGETICA

IPCEI BATTERIES

RdS RICERCA DI SISTEMA

About us

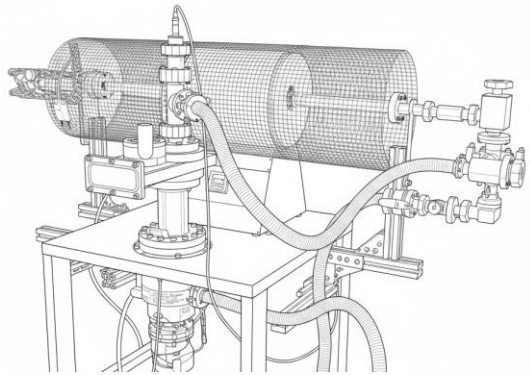
Casaccia Research Center

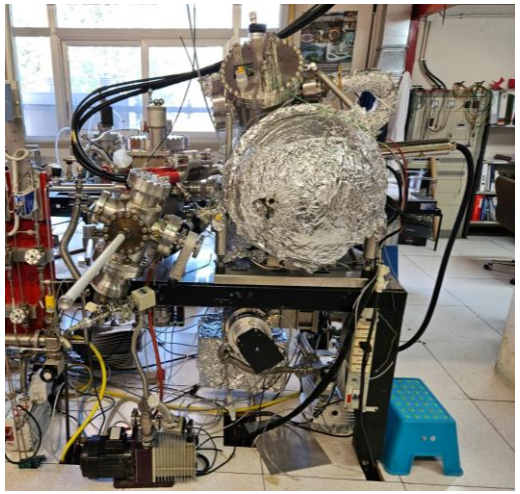


- **Chemistry facility**
- **Dry room 30m^2**
- **Microscopy facility**
- **Thermal analysis facility**
- **X ray diffraction & tomography**
- **Electrochemical testing facility (EIS, CV, cycle life,...)**
- **Mechanical and stress test facility**
- **Rheology and slurry optimization**
- **ICP**
- **Pilot line (small scale)**

About us

Frascati Research Center



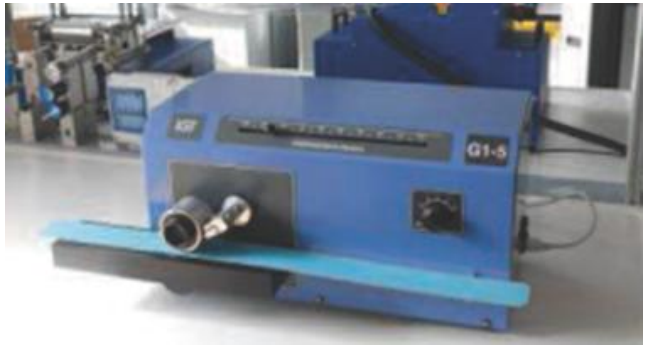


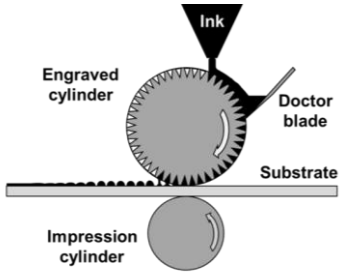
- **Chemistry facility**
- **Glove Box**
- **CVD**
- **FT-IR**
- **XPS**

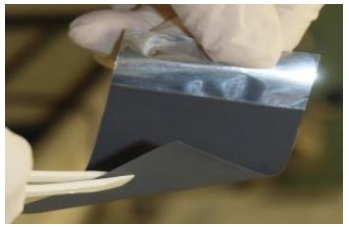
About us

Portici Research Center

- **Manufacturing**
- **Gravure Printing**







About us

Some European and National Projects & initiatives

RdS RICERCA DI SISTEMA

MASE

IPCEI BATTERIES

MIMIT

ORANGEES Organics for Green Electrochemical Energy Storage

BATTERY 2030+

BATMASS

NEST NETWORK FOR ENERGY SUSTAINABLE TRANSITION

ENSA

EERA European Energy Research Alliance

BEPA Batteries European Partnership Association

Batteries +Europe

EURAMET

SET-PLAN

ENEA

PTR 25-27 · Progetto 1.2 — Vision & WP Structure

17.7 M€ — Total Budget

TRL 3–6 — Maturity Range

47+ — Partners & Co-beneficiaries

30+ — University partners

A diversified storage portfolio for 2050

WP1 — Advanced Materials

Li-ion · Na-ion · Zn/Al/Ca-ion
Metal-air · Redox flow
Electrodes, electrolytes, synthesis
Flagship coordinated line on Na-ion (ENEA+CNR+RSE)

WP2 — Innovative Systems

Aging models & 2nd-life batteries
Physics-informed Digital Twins
ML-based BMS & diagnostics
Hybrid VRFB+LiB prototype (5-10 kW)

WP3 — Sustainability & Manufacturability

Life Cycle Assessment / LCA-LCC
Critical Raw Materials analysis
Italian battery value chain mapping
→ Aligned with EU Battery Regulation
Advanced characterization techniques
Net-Zero Scenarios → Aligned with EU Green Deal

WP4 — Thermal Storage (0–900 °C)

Sensible · Latent · Thermochemical
ATES (underground thermal)
CO_2 transcritical cold storage
CSP, District Heating, industrial waste heat

WP5 — Management & Dissemination

Coordinated by CNR
Management Board (MB)
Management Hubs: ENEA · CNR · RSE
KPI tracking, open-access publications
Dissemination Events (Nanoinnovation, ICSET, Sector fairs, WS)

Italy's National Storage Ecosystem – Research Network & Coordination

PTR 25-27
Project 1.2

Consiglio Nazionale delle Ricerche

ENEA

RSE Ricerca Sistema Energetico

Università di Pisa · Politecnico di Torino · Politecnico Milano 1863 · Università degli Studi di Palermo · Università degli Studi Milano Bicocca · Università degli Studi di Padova · Università degli Studi di Messina · Tor Vergata · Sapienza Università di Roma · INSTM · Alma Mater Studiorum Università di Bologna · Università di Catania · Università di Foggia · Roma Tre · Università del Salento · Università degli Studi di Napoli Federico II · Università degli Studi Mediterranea di Reggio Calabria · Università degli Studi di Cassino e del Lazio Meridionale · Università degli Studi di Perugia · Università degli Studi di Bari Aldo Moro · Università degli Studi di Camerino · Università di Pavia · Università degli Studi di Brescia · Università degli Studi del Sannio

National stakeholders:

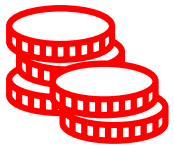
>50 industries

universities and research organizations

consultancy, service, associations and agencies

International Links:

Our Activities



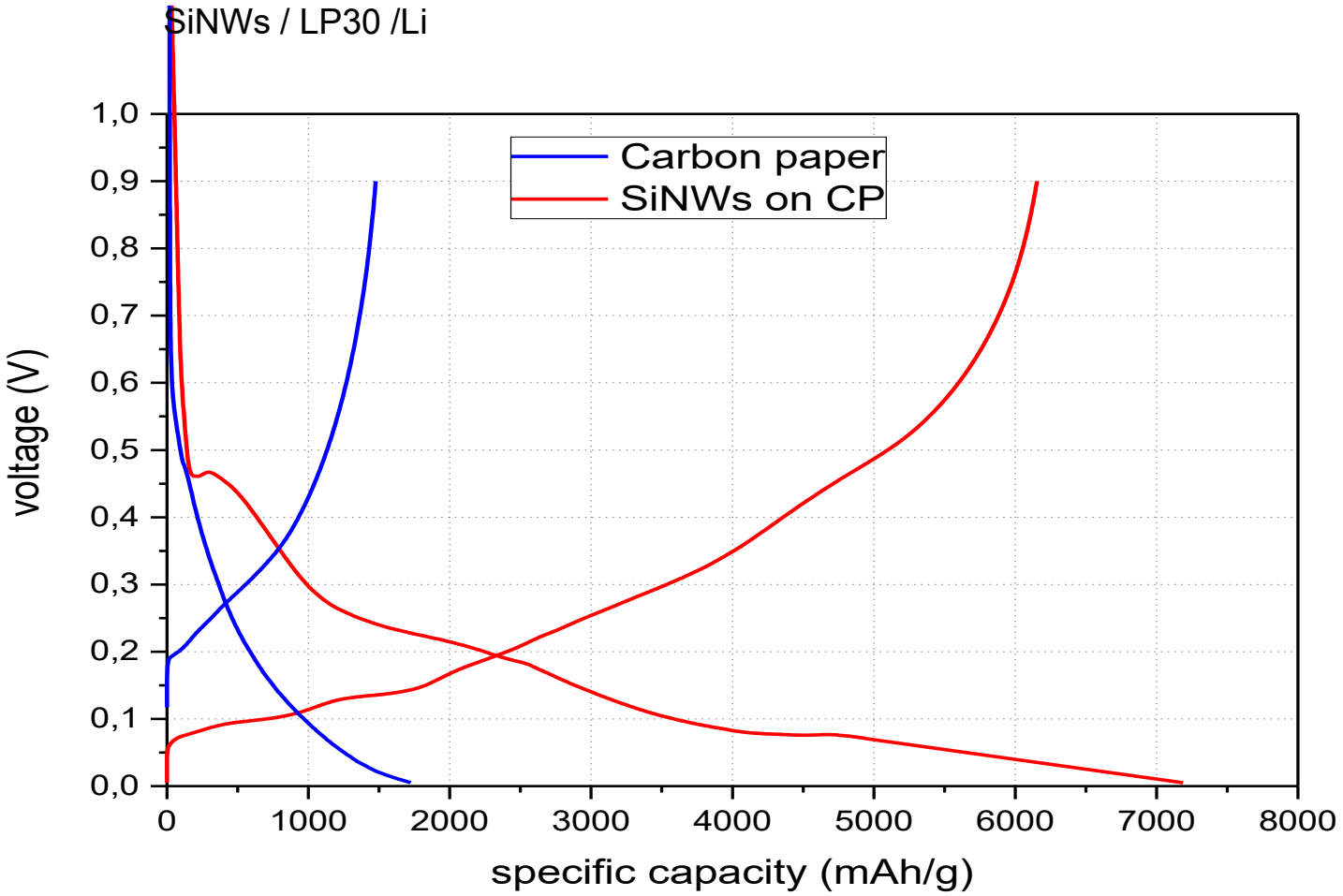
Lower cost: cheaper, more available and recyclable materials
e.g. Ca- and Na- ion batteries, Cathode materials with low content of CRM

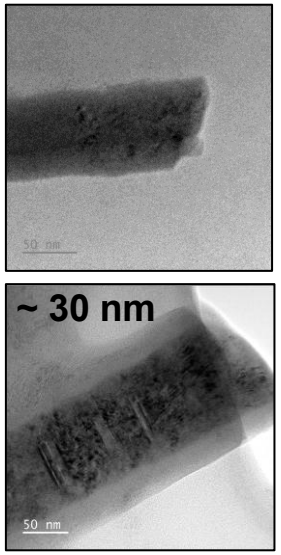
Higher sustainability: non-toxic components, green processes, new chemistries, design for recycling
e.g. aqueous based binders Innovative separators, Regeneration of electrode materials from spent batteries

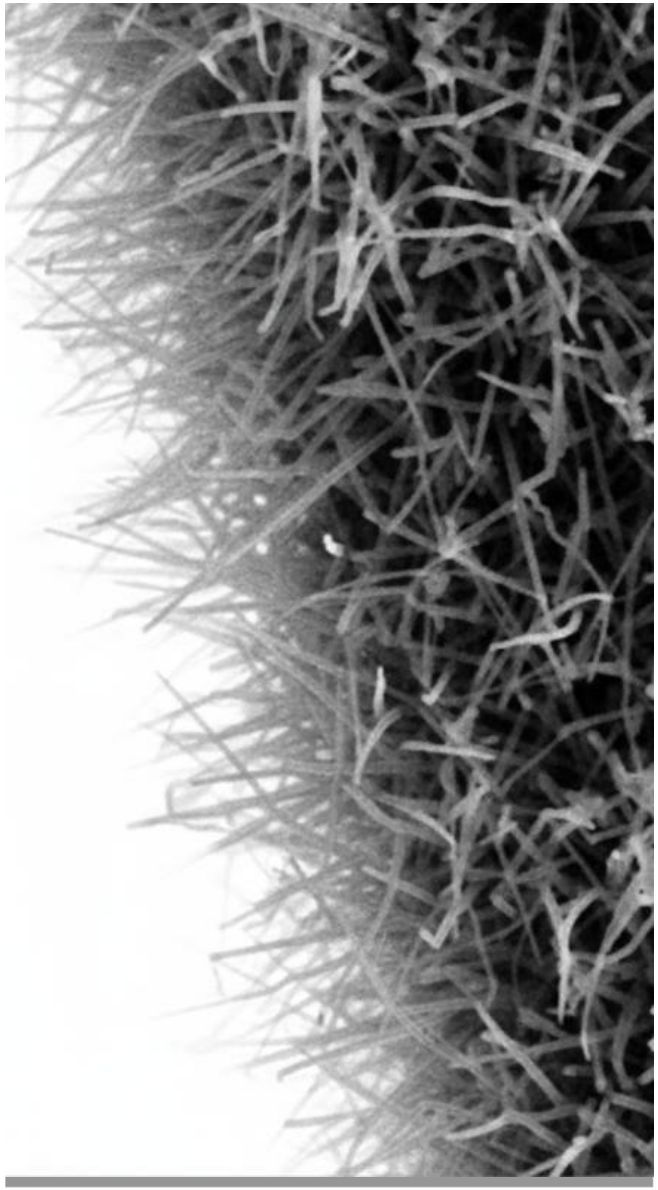
Higher performance: new advanced materials increasing energy, power and durability
e. g. Advanced Li-Ion batteries, Li metal batteries, Optimized scaled-up synthesis and cell manufacturing

Higher safety level: avoid liquid organic electrolytes, artificial SEI for lithium metal protection, smart sensors.
e. g. Ionic Liquids, Solid State Batteries, new sensors @cell level

Energy Density: Silicon Nanowires Anodes

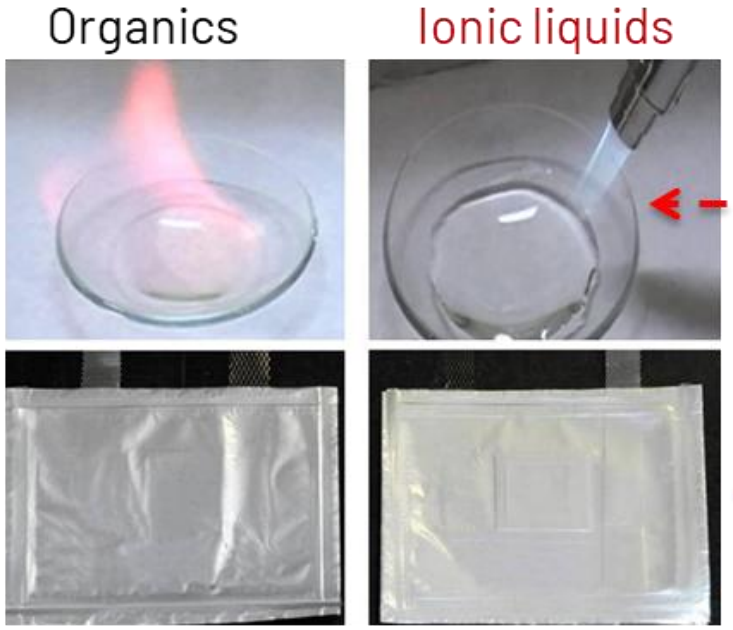






Safety: Innovative Electrolyte Systems

Ionic liquids technologies (patented)



Molten salts at room temperature or below

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No volatility, no flammability

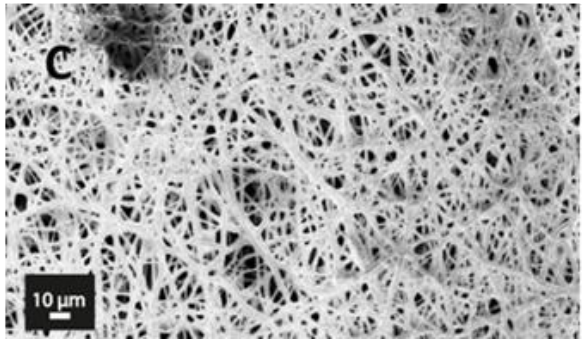
↓

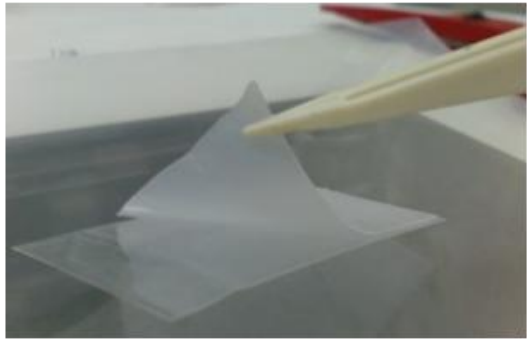
Alternative solvents proposed for replacing organics in lithium battery electrolytes

↓

Enhanced safety/reliability of devices

A





Confinement in proper, electro-spun polymer hosts

↓

Solid-state, polymer electrolytes

B

G.B. Appetecchi, Safer electrolyte components for rechargeable lithium batteries, in *Electrochemical Storage Materials: From Crystallography to Manufacturing Technology*, D.C. Meyer, T. Leisegang, M. Zschornak, H. Stöcker, eds., De Gruyter Publishing, 2019, ISBN 978-3-11-049137-1.

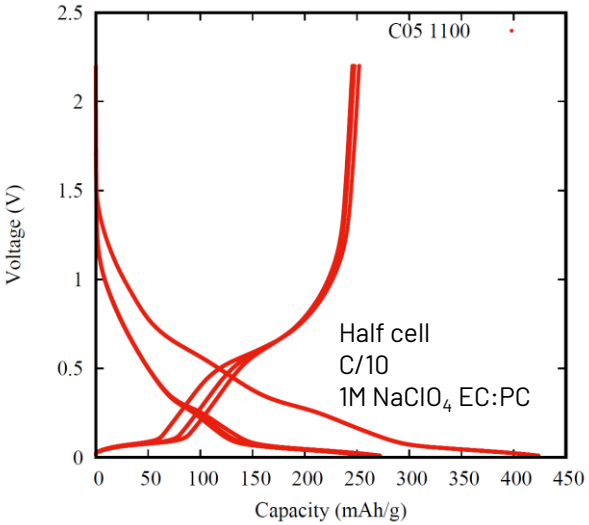
Beyond Li: Na-ion Batteries

Hard Carbon Anodes

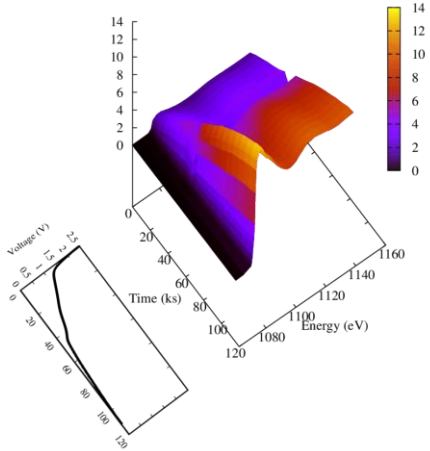
Synthetic route
1. Digestion
2. Temperature

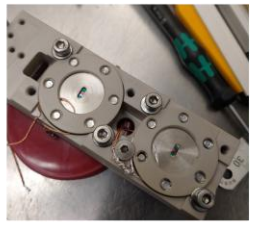
ATOMIC STRUCTURE AND MICROSTRUCTURE (<2 nm)

Electrode prepared by casting on Al
85% AM, 10% carbon black, 5% CMC

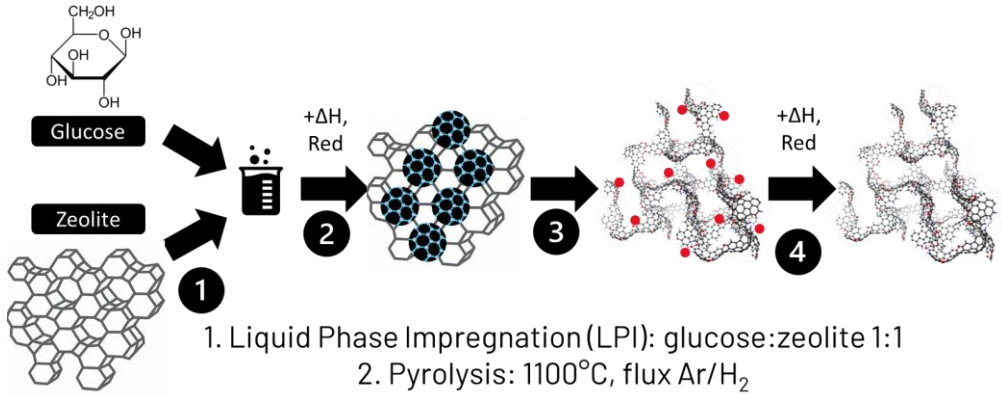


X-ray Absorption at Na K-edge of HC upon cycling





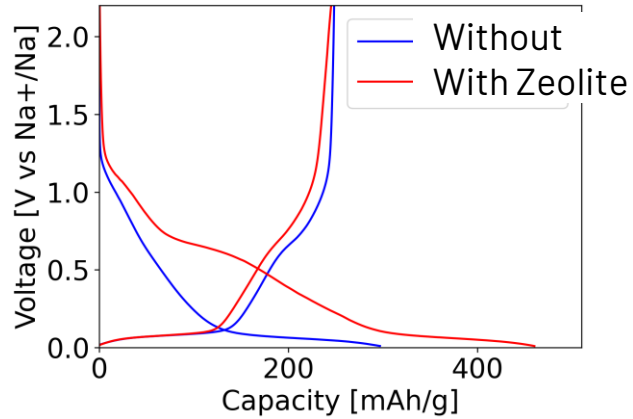
Zeolite Templated Carbon



1. Liquid Phase Impregnation (LPI): glucose:zeolite 1:1
2. Pyrolysis: 1100°C, flux Ar/H_2
3. Template removal: NaOH 2M, HCl 1M at 80°C
4. Reduction: 600°C, 6h, flux Ar/H_2

Objective: To standardize the structural and electrochemical properties of hard carbons derived from different organic precursors, such as biological waste materials.

Carbon anode | $NaClO_4$ 1M in PC |Metal Na



Beyond Li: Na-ion Batteries

Layered Transition Metals Oxides Cathodes

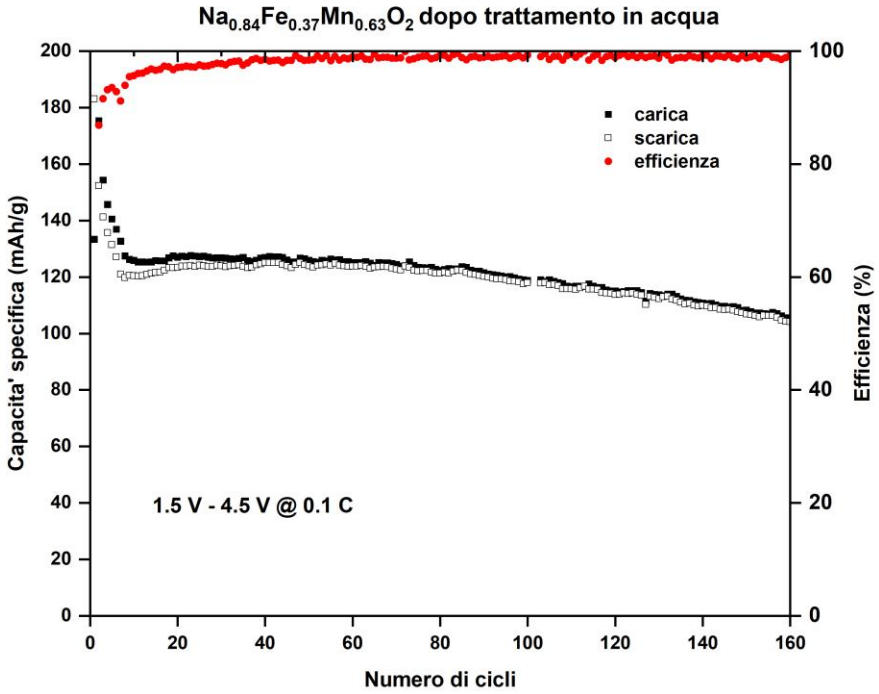
Low-CRM Cathode Materials
($Na_xFe_yMn_{1-y}O_2$)

PROs

- Easy and scalable synthesis
- High sodium storage capacity
- Suitable for high-energy sodium-ion batteries
- ***Compatible with established lithium-ion battery manufacturing processes***

CONs

- High content of critical raw materials (CRMs: Li, Co, Ni)
- Sensitivity to water (H_2O reactivity)



Next Steps

- Optimizing cathode composition to maximize electrochemical performance after water exposure
- Development of water-based formulations for large-scale cathode electrode manufacturing

Beyond Li: Na-ion Batteries

Cathode Active Materials: scaling - up

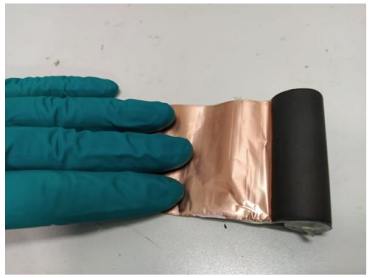
New Pilot-scale Facility

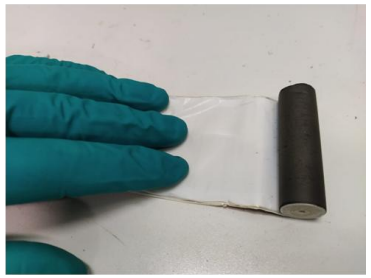
• Production by Flame-Spray for large batch of nanopowders and nanostructured powder production

Sustainability: Direct Recycling

Regeneration of Electrode Materials from spent Li-ion batteries

Graphite



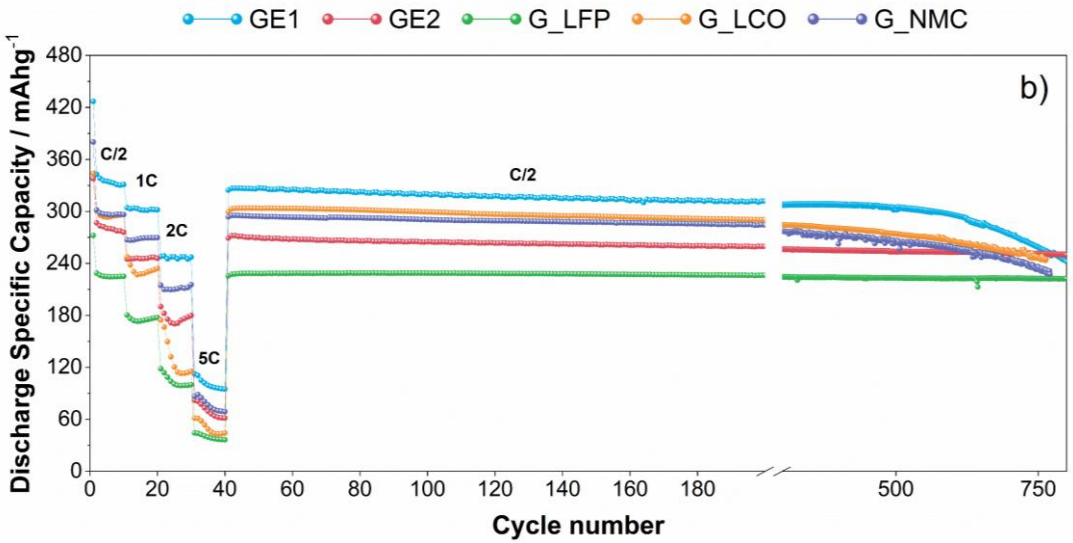


	Samples name	Battery Chemistry	Cell format	Recovery Route	Post-processing treatments
HML	GE1	$LiNi_{1-a-b}Mn_aCo_bO_2$	Cylindrical 18650	Black Mass leaching with 1.5M H_2SO_4 and 1 vol.% H_2O_2 (30% solution) at 70 °C	Filtration + washing with H_2SO_4 and water (70 °C)
HML	GE2	$LiNi_{1-a-b}Mn_aCo_bO_2$	Cylindrical 18650	Black Mass leaching with 1.5M H_2SO_4 and 2.5 vol.% H_2O_2 (30% solution) at 70 °C	Filtration + washing with H_2SO_4 and water (70 °C)
DPR	G_LFP	$LiFePO_4$	Prismatic	Anode detachment with DI water	Filtration + drying 12h@80 °C + sieving
DPR	G_LCO	$LiCoO_2$	Cylindrical 18650	washing with DMC + Scratching + drying 12h@ 60 °C + grinding	n/a
DPR	G_NMC	$LiNi_{1-a-b}Mn_aCo_bO_2$	Pouch	washing with DMC + Scratching + drying 12h@ 60 °C + grinding	n/a

Engitec Technologies S.p.A.

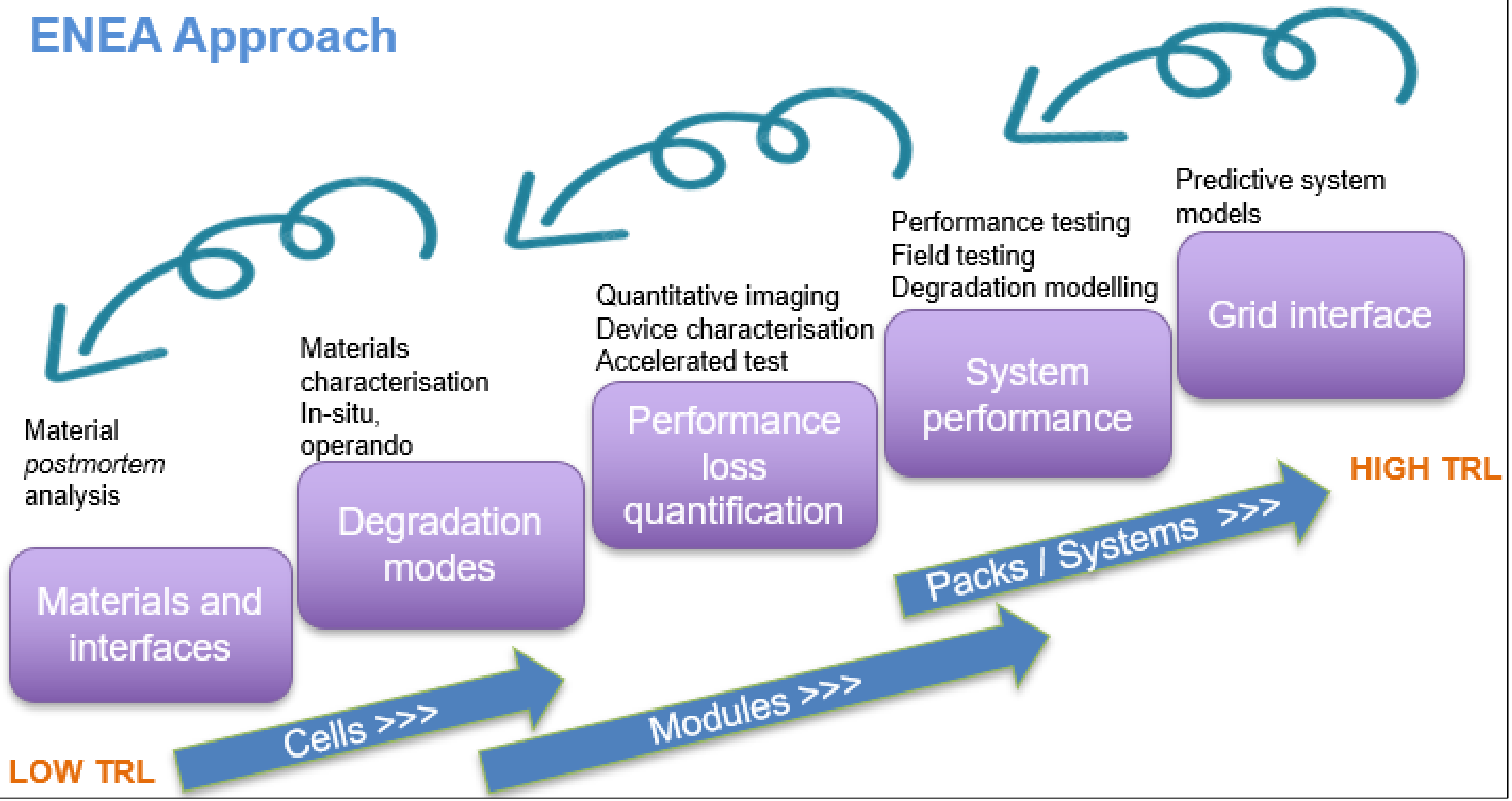
Galvanostatic Cycling, 0.01-2V,

Li|100µl $LiPF_6$ EC:DMC| Graphite



Cancelliere et al, Journal of Power Sources, 658 (2025), 238320

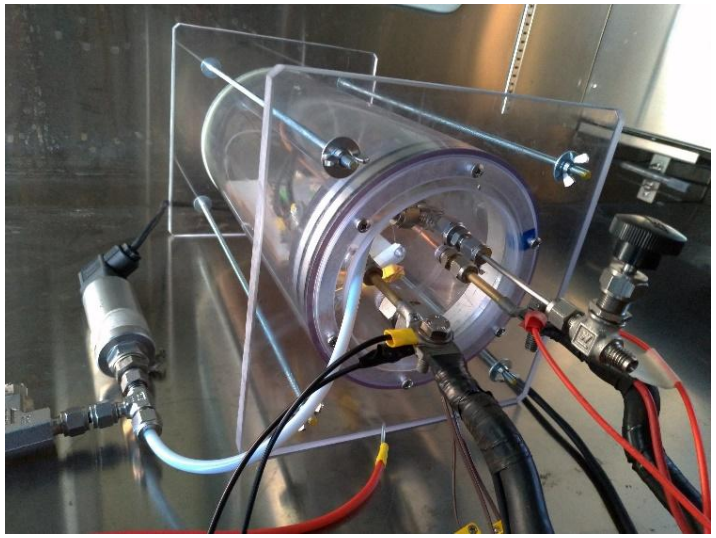
ENEA Approach



Battery Testing Hall - Cyclers

Abuse testing

Vessel for electric abuse testing



Cell venting during overcharge

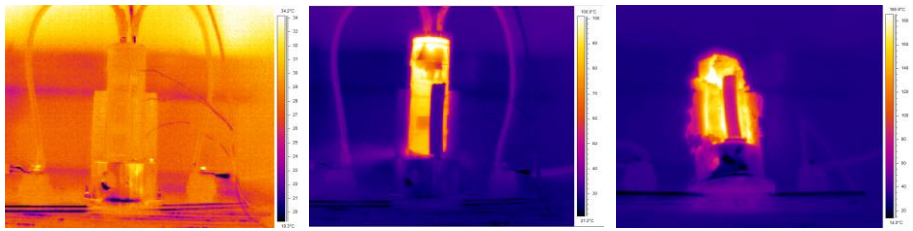
FARO plant

Remote or portable cycler

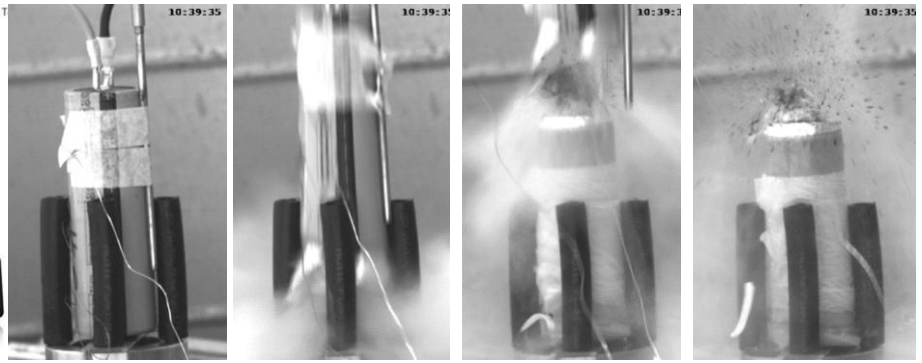
Infrared thermal camera

High speed camera

Site, equipment, and know-how for abuse testing



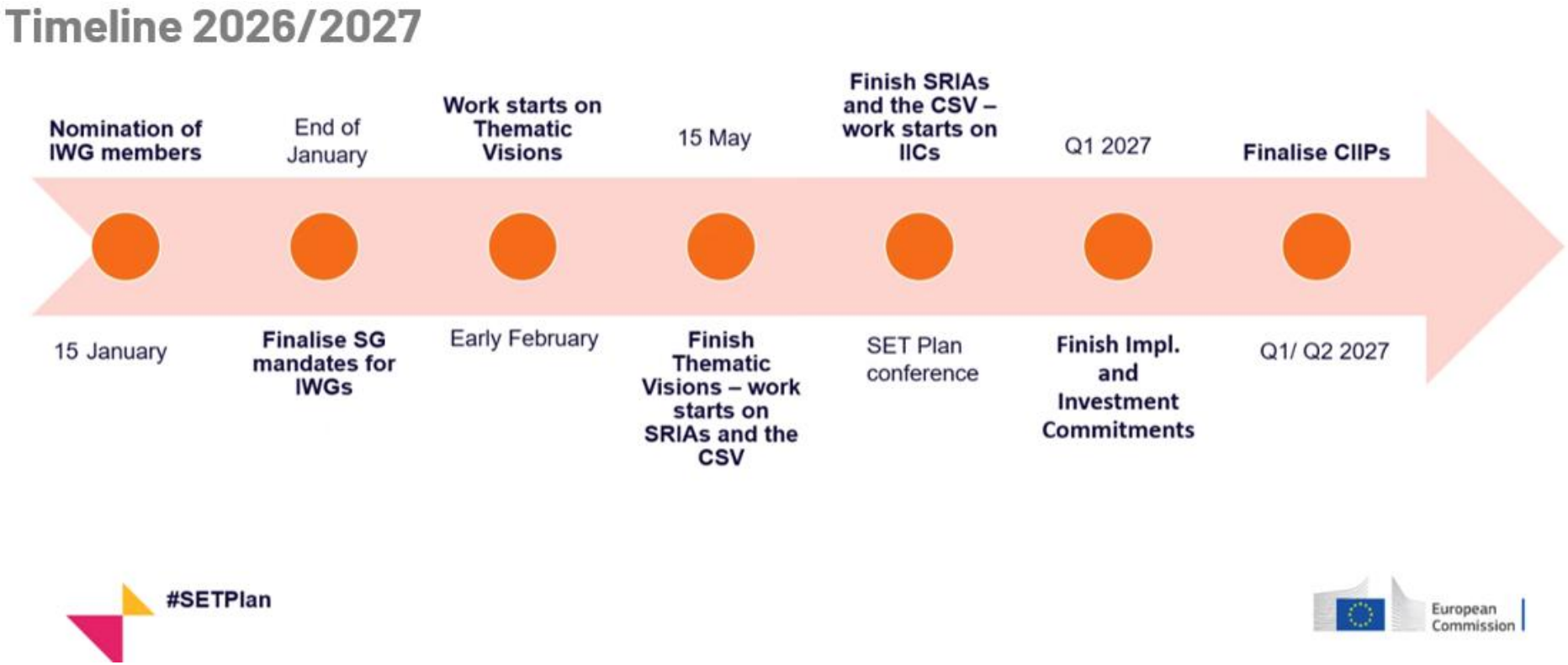
Thermal images explosion



Frame explosion

Strategic Energy Technology Plan (SET Plan)

- European coordination of energy research
- Development of net-zero technologies (hydrogen, **batteries**, CCS, renewables)
- Alignment of public and private investments
- Strengthening EU technological leadership



Informal national group on batteries

Promoting the active participation of stakeholders (research institutions, universities, and Italian companies across the entire battery value chain) with the aim of strengthening Italy's position in the European innovation landscape, enhancing scientific expertise and industrial capabilities

Informal national group on batteries key figures

5 agencies/associations

4 consulting firms

17 universities/research bodies

41 industries

A COORDINATED ITALIAN APPROACH TO ENERGY STORAGE

From sustainable materials to system scenarios for Europe's 2050 transition

EU & ITALY CONTEXT

- EU Green Deal Fit for 55
- Battery Regulation
- Net Zero Industry Act
- Italian PNIEC targets
- Climate neutrality by 2050

NEED FOR A DIVERSIFIED STORAGE PORTFOLIO

Flexible, sustainable, competitive, secure

1. SUSTAINABLE MATERIALS

Innovative and greener materials as the starting point

- Organic and hybrid compounds
- Waste-derived and abundant resources
- Sustainability by design

2. ELECTROCHEMICAL STORAGE

Beyond lithium portfolio for next-generation batteries

- Sodium-ion (flagship coordinated line ENEA – CNR – RSE)
- Beyond Li chemistries: solid-state, Li–S, Li–air, multivalent, flow batteries
- Enhanced performance, safety, durability

3. SMART DIAGNOSTICS & DIGITAL TWINS

Data-driven understanding and predictive capability

- Operando / in situ diagnostics
- State-of-health and degradation prediction
- Digital twins for design, control and optimization

4. THERMAL STORAGE

Long-duration flexibility and sector coupling

- Medium / high temperature TES
- Industrial decarbonization
- Coupling with renewables and district heating

5. SCENARIOS & SUSTAINABILITY

Quantifying impact and guiding the path to 2050

- Techno-economic analysis
- Life Cycle Assessment and circularity
- System scenarios 2030–2050 to support policy and investment

6. IMPACT: SUPPORTING EUROPE'S 2050 GOALS

- High RES integration
- Grid flexibility and resilience
- Industrial competitiveness
- Climate neutrality and sustainability

RICERCA DI SISTEMA

National, mission-oriented R&D framework for the energy system

PUBLICLY FUNDED
Long-term strategic research

MISSION ORIENTED
Addressing national and European priorities

COORDINATED ECOSYSTEM
ENEA – CNR – RSE
Universities – Industry

BRIDGING THE GAP
From research to technology & system deployment

CONTINUITY, COORDINATION, IMPACT

Key strengths of the Italian model

A STRONG NATIONAL ECOSYSTEM

ENEA · CNR · RSE

30+ Universities involved

Industrial partners

TOGETHER, BUILDING THE STORAGE ECOSYSTEM
ITALY NEEDS – EUROPE NEEDS
Technology innovation. System integration. Sustainable transition.

Thanks for your attention