



*Transizione energetica, Sostenibilità e Prevenzione Incendi*  
*14, 15 e 16 Novembre 2022*  
*Compendio polifunzionale dei Vigili del Fuoco*

**I SISTEMI DI ACCUMULO ELETTROCHIMICO DELL'ENERGIA**

# **Caratteristiche generali delle batterie Li-ione**

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**14 Novembre 2022**



**SAPIENZA**  
UNIVERSITÀ DI ROMA

# INDICE

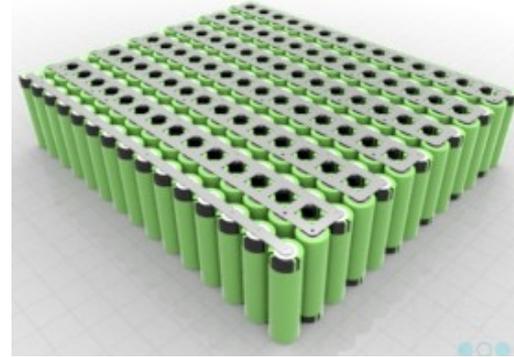
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## Le batterie al litio:

1. Batterie Ricaricabili e non Ricaricabili
2. Proprietà e caratteristiche delle batterie Li-ione
3. Applicazioni delle batterie Li-ione
4. Rischio incendio ed esplosioni: vulnerabilità all'abuso
5. Dispositivi di protezione e controllo cella/batteria
6. Test di abuso

# CELLA/BATTERIA

La **cella** è un dispositivo in grado di convertire energia chimica in energia elettrica, tramite una reazione chimica di ossido-riduzione, che implica il trasferimento di elettroni.

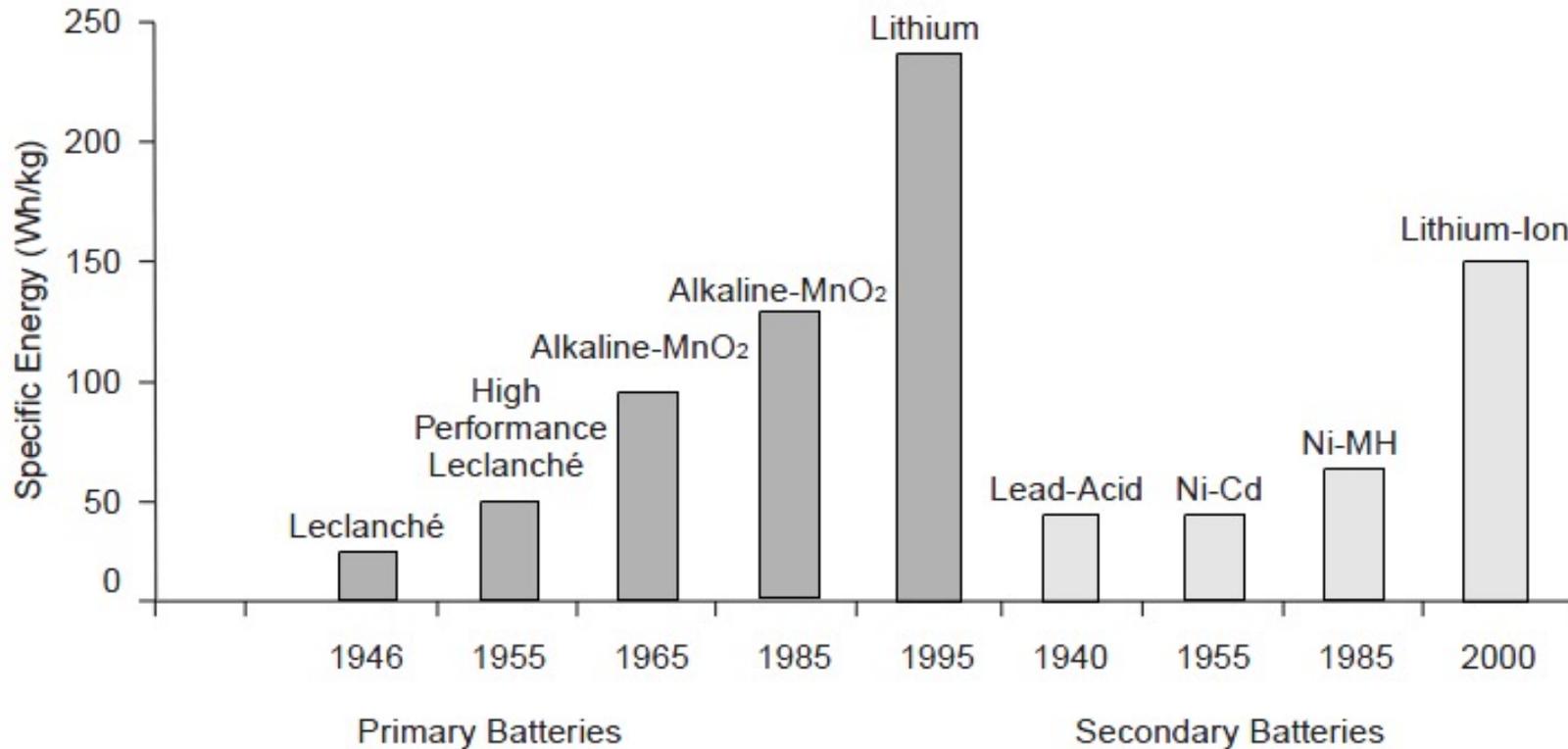


Si parla di **batteria** quando si hanno più celle collegate tra loro in serie o in parallelo.

Esse possono essere di due tipi:

- **batterie primarie (non ricaricabili) (PILE)**
- **batterie secondarie (ricaricabili) (ACCUMULATORI)**

# BATTERIE RICARICABILI E NON



**BATTERIE NON RICARICABILI**

**BATTERIE RICARICABILI**

# CELLE/BATTERIE RICARICABILI

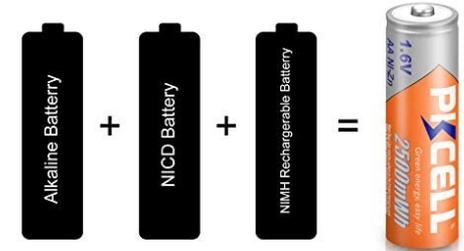


Ni-Cd



Ni-MH

Alkaline + NICD + NIMH = NIZN



- ✓ Higher Voltage- 1.6V
- ✓ Higher Drain Current- 2500mWh
- ✓ More Using Time- 500times at least



Pb acido



Ni-Fe



Li-ione

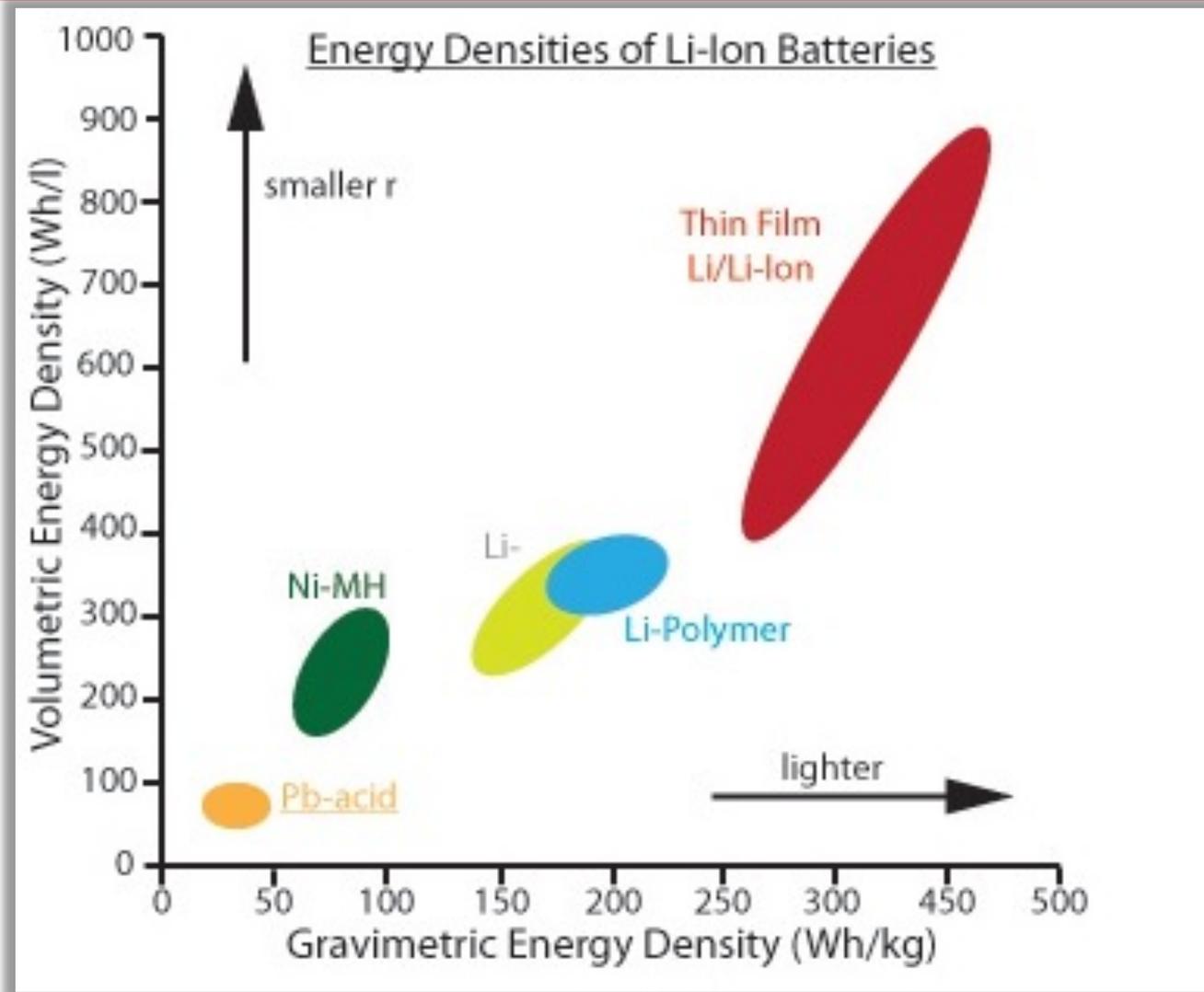
# LE DIVERSE TECNOLOGIE

Energy Storage type	Specific energy (Wh/kg)	Energy density (Wh/L)	Specific power (W/kg)	Life cycle	Energy Efficiency (%)	Production cost (\$/kWh)	Application
<b>Lead battery</b>							Conventional automotive starting, lighting and ignition, large power backup, grid energy storage, BEV's, UPS, IC engine start up
Lead acid	35	100	180	1000	>80	60	
Advance lead acid	45	–	250	1500	–	200	
Valve regulated lead acid (VRLA)	50	–	150+	700+	–	150	
Metal foil lead acid	30	–	900	500+	–	–	
<b>Nickle battery</b>							Ni–Cd – Two way radios, emergency medical equipment, professional video cameras and power devices tools, NiMH – Powering portable low powered devices. Ni – Fe – off – grid power system storage.
Nickle - iron	50–60	60	100–150	2000	75	150–200	
Nickle - zinc	75	140	170–260	300	76	100–200	
Nickle – Cadmium (Ni–Cd)	50–80	300	200	2000	75	200–300	
Nickle-metal hydride (Ni-MH)	70–95	180–220	200–300	<3000	70	200–250	
<b>ZEBRA battery</b>							Suitable for automotive applications: cars, buses and transporters where low maintenance is needed.
Sodium - sulfur	150–240	–	150–230	800+	80	250–450	
Sodium-nickle chloride	90–120	160	155	1200+	80	230–345	
<b>Lithium battery</b>							Light weight and high energy density battery. Can be used for EV's, portable devices like laptop, torch, smartphone, camcorder, digital camera, electronic cigarette, toys
Lithium – iron Sulphide (FeS)	150	–	300	1000+	–	350	
Lithium – iron Phosphate (LiFePO4)	120	220	2000–4500	42,000	–	150	
Lithium – ion Polymer (LiPo)	130–225	200–250	260–450	>1200	495	150	
Lithium-ion	118–250	200–400	200–430	2000	–	2000	
Lithium-titante (LiTiO/NiMnO <sub>2</sub> )	80–100	–	4000	18,000	–	–	
<b>Metal air battery</b>							
Aluminium – air	220	–	60	–	–	–	
Zin – air	460	1400	80–140	200	60	90–120	
Zin - refillable	460	–	–	–	–	–	
Lithium - air	1800	–	–	–	–	–	

# CONFRONTO TRA LE DIVERSE TECNOLOGIE

Advantage of... .....On		Lead acid	Nickel cadmium	Nickel metal hydride	Lithium-ion	
					Cylindrical - prismatic	Pouch
Lead acid			<ul style="list-style-type: none"> <li>• Energy density</li> <li>• Operating temperature</li> <li>• Self discharge rate</li> <li>• Reliability</li> </ul>	<ul style="list-style-type: none"> <li>• Gravimetric energy density</li> <li>• Volumetric energy density</li> <li>• Self discharge rate</li> </ul>	<ul style="list-style-type: none"> <li>• Gravimetric energy density</li> <li>• Volumetric energy density</li> <li>• Voltage output</li> <li>• Self discharge rate</li> </ul>	<ul style="list-style-type: none"> <li>• Gravimetric energy density</li> <li>• Volumetric energy density</li> <li>• Voltage output</li> <li>• Design characteristics</li> </ul>
Nickel cadmium		<ul style="list-style-type: none"> <li>• Higher cyclability</li> <li>• Voltage output</li> <li>• Price</li> </ul>		<ul style="list-style-type: none"> <li>• Gravimetric energy density</li> <li>• Volumetric energy density</li> </ul>	<ul style="list-style-type: none"> <li>• Gravimetric energy density</li> <li>• Volumetric energy density</li> <li>• Voltage output</li> <li>• Self discharge rate</li> </ul>	<ul style="list-style-type: none"> <li>• Gravimetric energy density</li> <li>• Volumetric energy density</li> <li>• Voltage output</li> <li>• Design characteristics</li> </ul>
Nickel metal hydride		<ul style="list-style-type: none"> <li>• Higher cyclability</li> <li>• Voltage output</li> <li>• Price</li> </ul>	<ul style="list-style-type: none"> <li>• Operating temperature</li> <li>• Higher cyclability</li> <li>• Self discharge rate</li> <li>• Price</li> </ul>		<ul style="list-style-type: none"> <li>• Energy density</li> <li>• Operating temperature</li> <li>• Higher cyclability</li> <li>• Voltage output</li> <li>• Self discharge rate</li> </ul>	<ul style="list-style-type: none"> <li>• Gravimetric energy density</li> <li>• Volumetric energy density</li> <li>• Operating temperature</li> <li>• Design characteristics</li> <li>• Self discharge rate</li> </ul>
Lithium-ion	Cylindrical - prismatic	<ul style="list-style-type: none"> <li>• Price</li> <li>• Safety</li> <li>• Recyclability</li> </ul>	<ul style="list-style-type: none"> <li>• Operating temperature</li> <li>• Higher cyclability</li> <li>• Price</li> <li>• Safety</li> </ul>	<ul style="list-style-type: none"> <li>• Price</li> <li>• Safety</li> <li>• Discharge rate</li> <li>• Recyclability</li> </ul>		<ul style="list-style-type: none"> <li>• Gravimetric energy density</li> <li>• Volumetric energy density</li> <li>• Safety</li> <li>• Design characteristics</li> </ul>
	Pouch	<ul style="list-style-type: none"> <li>• Price</li> <li>• Safety</li> <li>• Recyclability</li> </ul>	<ul style="list-style-type: none"> <li>• Recyclability</li> <li>• Operating temperature</li> <li>• Higher cyclability</li> <li>• Price</li> </ul>	<ul style="list-style-type: none"> <li>• Volumetric energy density</li> <li>• Higher cyclability</li> <li>• Price</li> </ul>	<ul style="list-style-type: none"> <li>• Operating temperature</li> <li>• Higher cyclability</li> <li>• Price</li> </ul>	
Absolute advantages		<ul style="list-style-type: none"> <li>• Higher Cyclability</li> <li>• Price</li> </ul>	<ul style="list-style-type: none"> <li>• Operating temperature</li> <li>• Price</li> </ul>	<ul style="list-style-type: none"> <li>• Volumetric energy density</li> </ul>	<ul style="list-style-type: none"> <li>• Gravimetric energy density</li> <li>• Volumetric energy density</li> <li>• Voltage output</li> <li>• Self discharge rate</li> </ul>	<ul style="list-style-type: none"> <li>• Energy density</li> <li>• Design characteristics</li> <li>• Voltage output</li> <li>• Self discharge rate</li> </ul>

# PROPRIETA' DELLE BATTERIE LI-IONE



# BATTERIE LI-IONE: COSA SONO?



Le celle sono costituite da una vasta gamma di forme e dimensioni a seconda dell'impiego.

Anche i materiali delle diverse componenti variano a seconda dell'utilizzo.

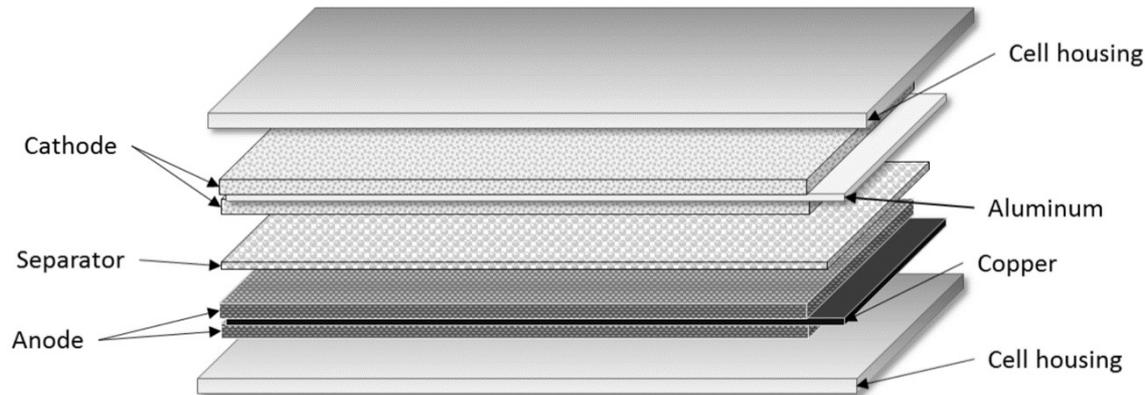
# COMPONENTI DELLE CELLE LI-IONE

**Anodo:** collettore di corrente in rame ricoperto di grafite.

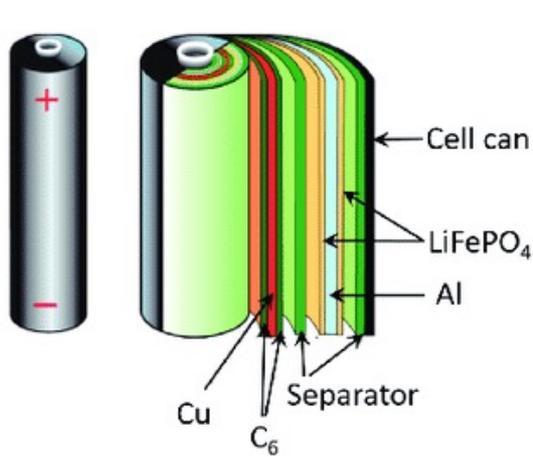
**Catodo:** collettore di corrente in alluminio ricoperto di ossidi di metalli di transizione.

**Membrana:** fogli di polietilene (PE) o polipropilene (PP) porosi.

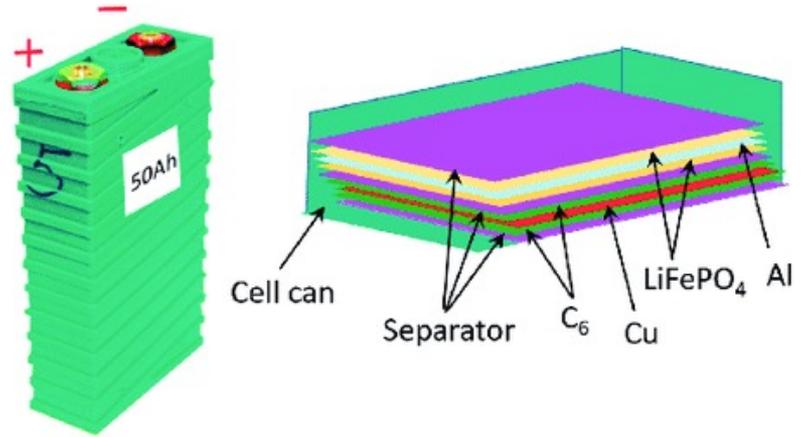
Funge da strato di isolamento elettrico fra gli elettrodi permettendo comunque il passaggio degli ioni durante la carica e scarica.



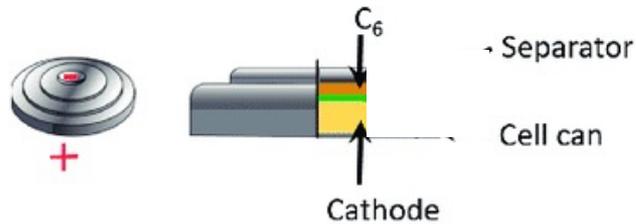
# GEOMETRIE DELLE CELLE LI-IONE



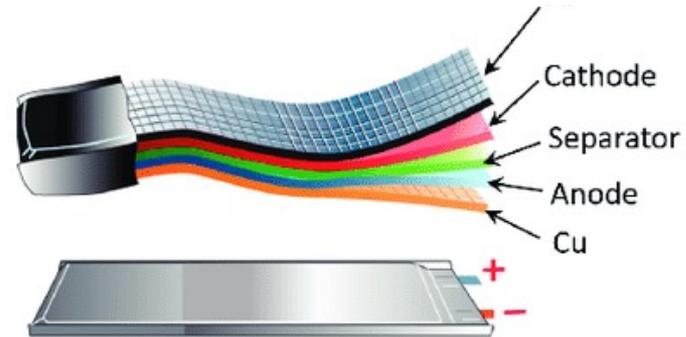
Cilindriche



Prismatiche



A bottone



A bustina  
(Pouch)

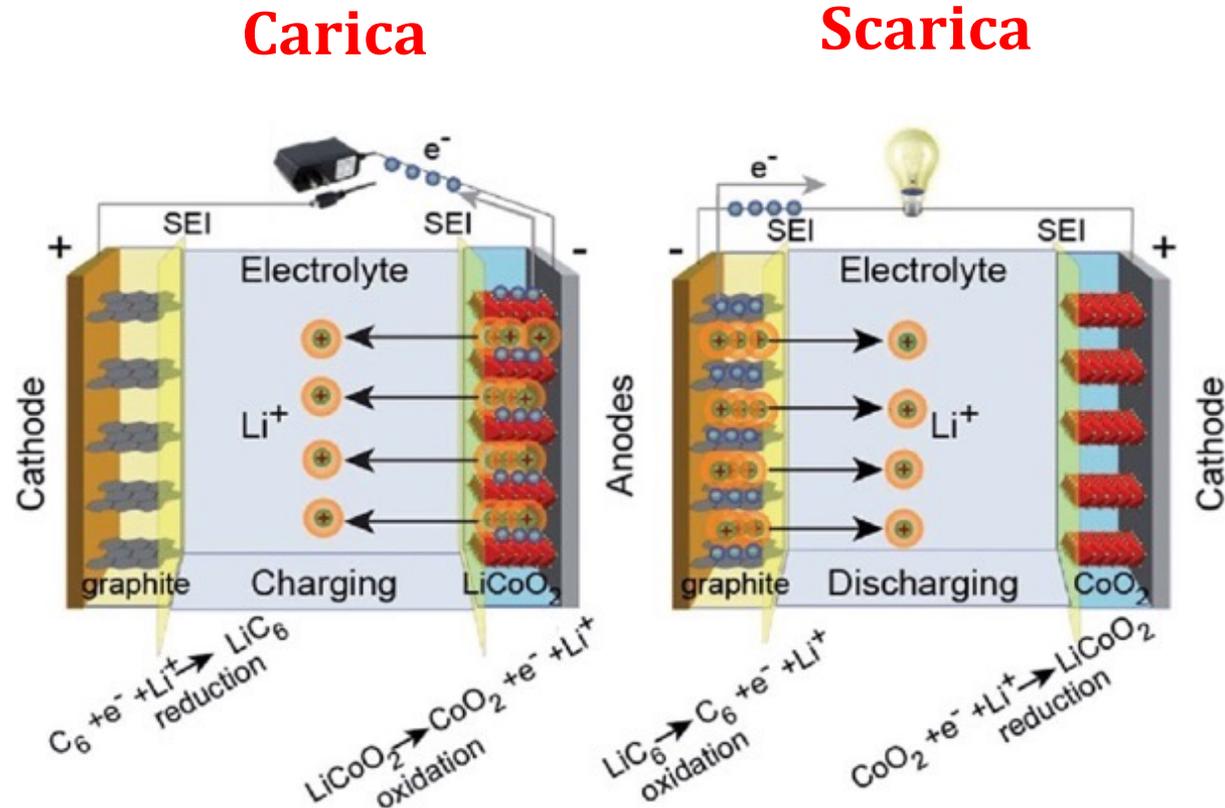
# MECCANISMO DI CARICA-SCARICA

## Carica

Movimento degli ioni di litio verso l'anodo, dove si intercalano nel materiale.

## Scarica

Movimento degli ioni di litio verso il catodo, dove si intercalano nel materiale.



# ELETTROLITA

E' costituito da un sale di litio (esafluorofosfato di litio,  $LiPF_6$ ) e un solvente organico

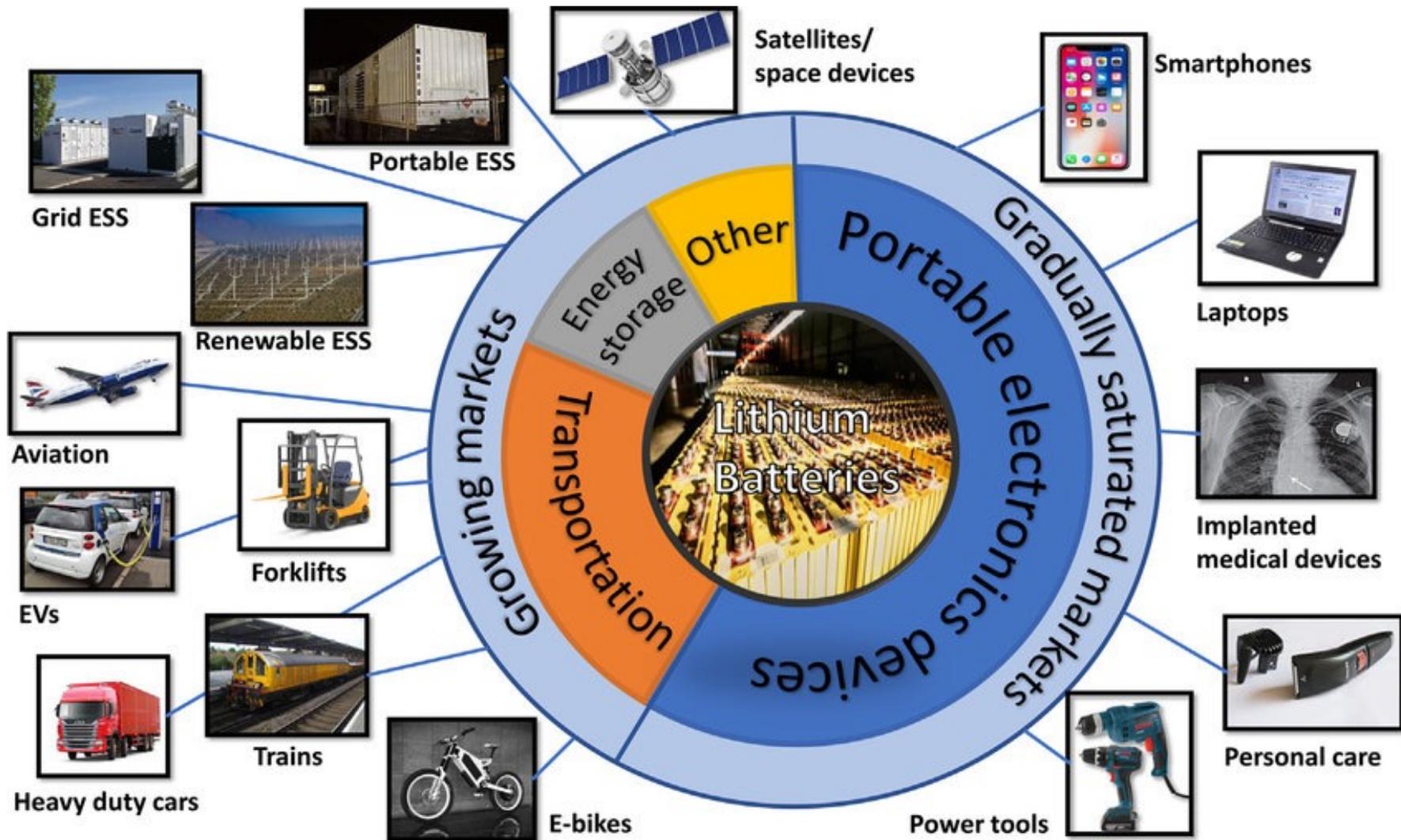
**Table 1. Measured flash points, auto-ignition temperatures, and heats of combustion of some typical lithium-ion cell organic electrolyte components**

Electrolyte Component	CAS Registry Number	Molecular Formula	Melting Point <sup>25</sup>	Boiling Point <sup>25</sup>	Vapor pressure (torr) <sup>26</sup>	Flash Point <sup>26</sup>	Auto-Ignition Temperature <sup>26</sup>	Heat of Combustion <sup>27</sup>
Propylene Carbonate (PC)	108-32-7	C <sub>4</sub> H <sub>6</sub> O <sub>3</sub>	-49°C -56°F	242°C 468°F	0.13 at 20°C	135°C 275°F	455°C 851°F	-20.1 kJ/ml -4.8 kcal/ml
Ethylene Carbonate (EC)	96-49-1	C <sub>3</sub> H <sub>4</sub> O <sub>3</sub>	36°C 98°F	248°C 478°F	0.02 at 36°C	145°C 293°F	465°C 869°F	-17.2 kJ/ml -4.1 kcal/ml
Di-Methyl Carbonate (DMC)	616-38-6	C <sub>3</sub> H <sub>6</sub> O <sub>3</sub>	2°C 36°F	91°C 195°F	18 at 21°C	18°C 64°F	458°C 856°F	-15.9 kJ/ml -3.8 kcal/ml
Diethyl Carbonate (DEC)	105-58-8	C <sub>5</sub> H <sub>10</sub> O <sub>3</sub>	-43°C 45°F	126°C 259°F	10 at 24°C	25°C 77°F	445°C 833°F	-20.9 kJ/ml -5.0 kcal/ml
Ethyl methyl carbonate (EMC)	623-53-0	C <sub>4</sub> H <sub>8</sub> O <sub>3</sub>	-14°C 6.8°F	107°C 225°F	27 at 25°C	25°C 77°F	440°C 824°F	None available

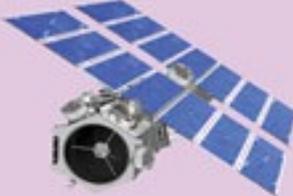
# TIPOLOGIE DI BATTERIE Li-ione

Name	Abb.	Cobalt content	Market share	Properties and applications
Lithium Cobalt Oxide	LCO	60%	21%	High capacity. Mobile phones, tablets, laptops, cameras
Lithium Manganese Oxide	LMO	no Co	8%	Safest; lower capacity than LCO but specific power and long life. Power tools, e-bikes, EVs, medical devices.
Lithium Iron Phosphate	LFP	no Co	36%	
Lithium Nickel Manganese Cobalt Oxide	NMC	10-30%	26%	
Lithium Nickel Cobalt Aluminium Oxide	NCA	10-15%	9%	High capacity; gaining importance in electric powertrain and grid storage; industrial applications, medical devices

# APPLICAZIONI DELLE BATTERIE LI-IONE



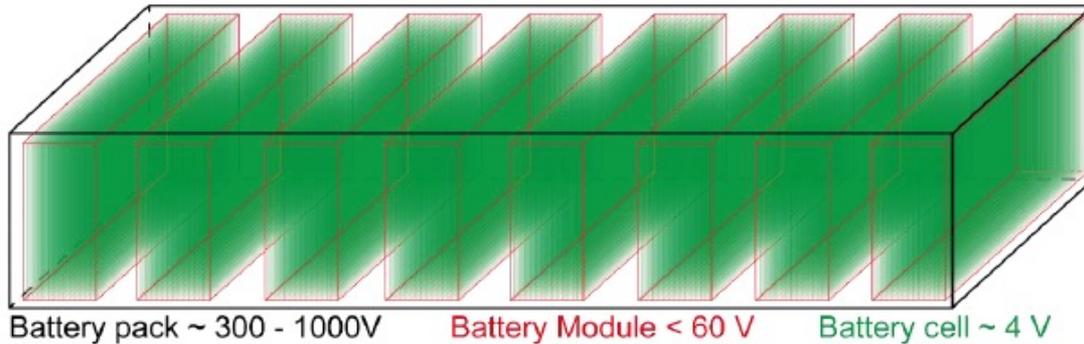
# APPLICAZIONI DELLE BATTERIE LI-IONE

<p><b>Consumer Electronics</b></p>  <p>Smart Phone      Portable PC      Mobile Phone</p> <p>Small LIB with energies &lt;100 Whr</p> <ul style="list-style-type: none"><li>• High energy density = increase run time</li><li>• Light weight = increase portability</li><li>• High power density = faster processor power etc.</li></ul>	<p><b>Aerospace Applications</b></p>  <p><b>Energy density:</b> 260-310 Whr.L<sup>-1</sup>, <b>Cycle life:</b> Satellites for Geo-Synchronous earth orbit: 12000-24000 cycles at 60% DOD over a 15 year period, For satellites at Low-earth orbit: 5,000 cycles at 25% DOD over seven years</p> <p>Long-life, high energy densities and lightweight and the prime requirements for aerospace applications</p>
<p><b>Electric Vehicles</b></p>  <p><b>Power density:</b> 660-600 W.L<sup>-1</sup> <b>Energy density-C/3</b> <b>Discharge rate:</b> 230-300 Whr.L<sup>-1</sup> <b>Life:</b> 10 years, <b>Cycle life:</b> 1000 to 80%DOD <b>Normal recharge time:</b> to 6 hrs, <b>High rate charge:</b> 40-80% SOC in 15 mins</p> <ul style="list-style-type: none"><li>• High energy density = Long distance driving</li><li>• High power density = Excellent driving performance, significant fuel efficiency</li></ul>	<p><b>Stationary Energy Storage</b></p>  <p><b>Capacity:</b> 2KWh, <b>Energy density:</b> 240 Whr.L<sup>-1</sup> <b>Specific energy:</b> 120 Wh.kg<sup>-1</sup> <b>Energy efficiency:</b> 90%, <b>Cycle life:</b> 3500 cycles</p> <p>Longer battery lifetime and lower cost are the prime requirements as weight/volume of LIBs are not constrained in immobile applications</p>

# APPLICAZIONE: VEICOLI ELETTRICI

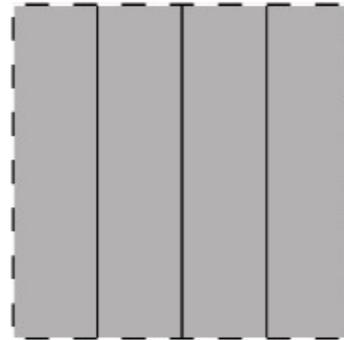
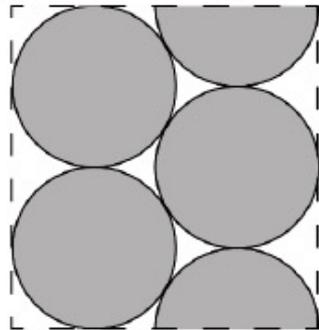
Passenger cars: BEV	Battery Pack		Battery Cell	
	Energy Cap. [kWh]	Configuration	Type	Chemistry [Anode/Cathode]
Nissan Leaf (2015)	30 [71]	Floor [72]	Pouch [71]	C/LMO-NCA [71]
Renault Zoe (2017)	41 [54]	Floor [54]	Pouch [71]	C/NMC [71]
Volkswagen e-Golf (2016)	36 [71]	Floor / T-shape [59]	Prismatic [71]	C/LMO-NCA-NMC [71]
BMW i3 (2017)	33 [71]	Floor [73]	Prismatic [71]	C/LMO-NCA-NMC [71]
Tesla Model S (2012)	60-100 [71]	Skateboard [53] [74]	Cylindrical [71]	C/NCA [71]
Mitsubishi Outlander (2015)	12 [75]	Floor [65]	Prismatic [75]+ [76]	C/LFP [75]
Volkswagen Passat GTE (2015)	9.9 [77]	Rear [69]	Prismatic [59]	-/-
Volvo XC60 (2017)	10.4 [78]	Linear [64]	Pouch [79]	NMC [79]
Volkswagen Golf GTE (2015)	8.7 [80]	Rear [81]	Prismatic [59]	C/LMO-NCA-NMC [82]
Kia Niro (2017)	1.56 [83]	Rear [70]	Pouch [84]	-/-
Chevrolet Volt (2016)	18.4 [85]	T-shape [63]	Pouch [84] + [85]	C/LMO-NMC [85]

# VEICOLI ELETTRICI: celle-moduli-pacco batteria



General construction of a battery pack.

**Packing principle for cylindrical cells**

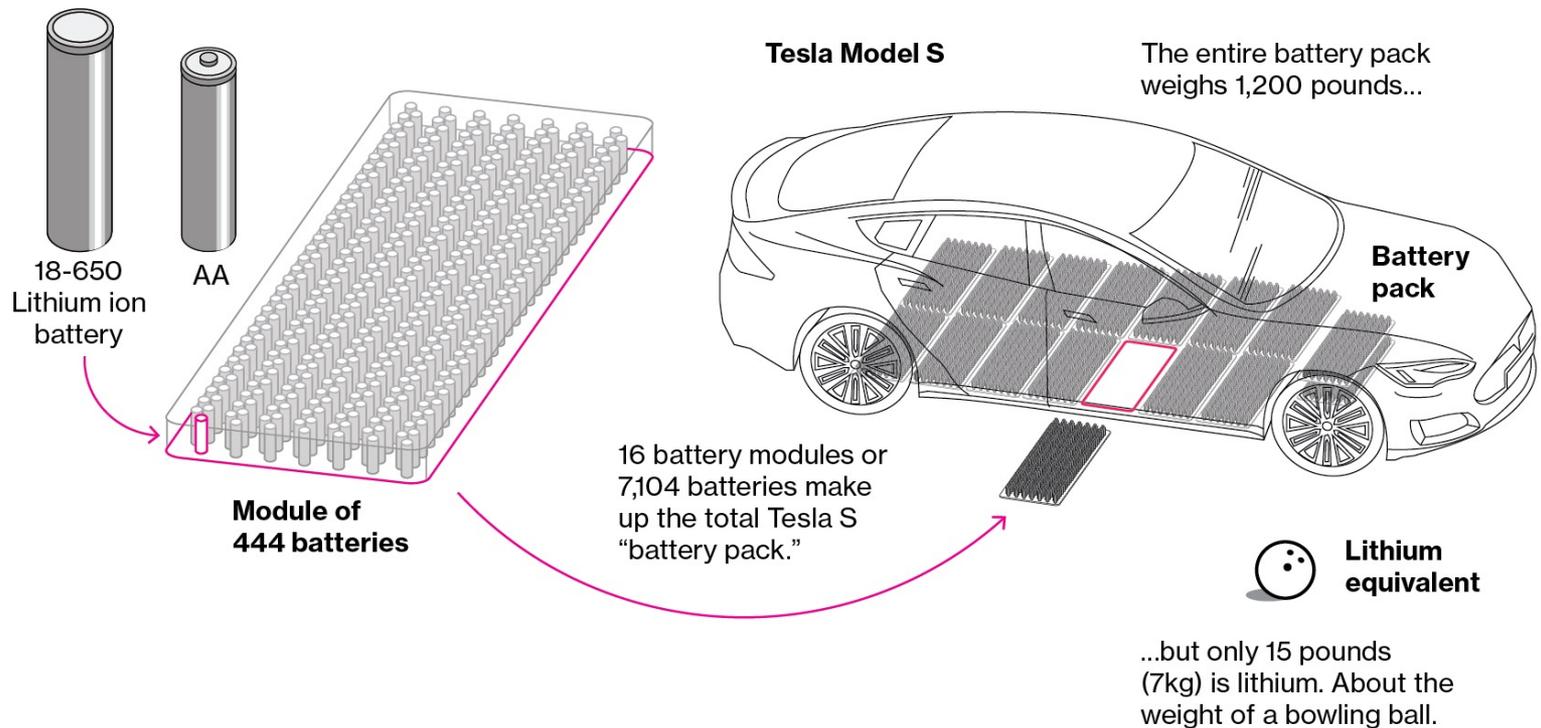


**Packing principle for prismatic/pouch cells**

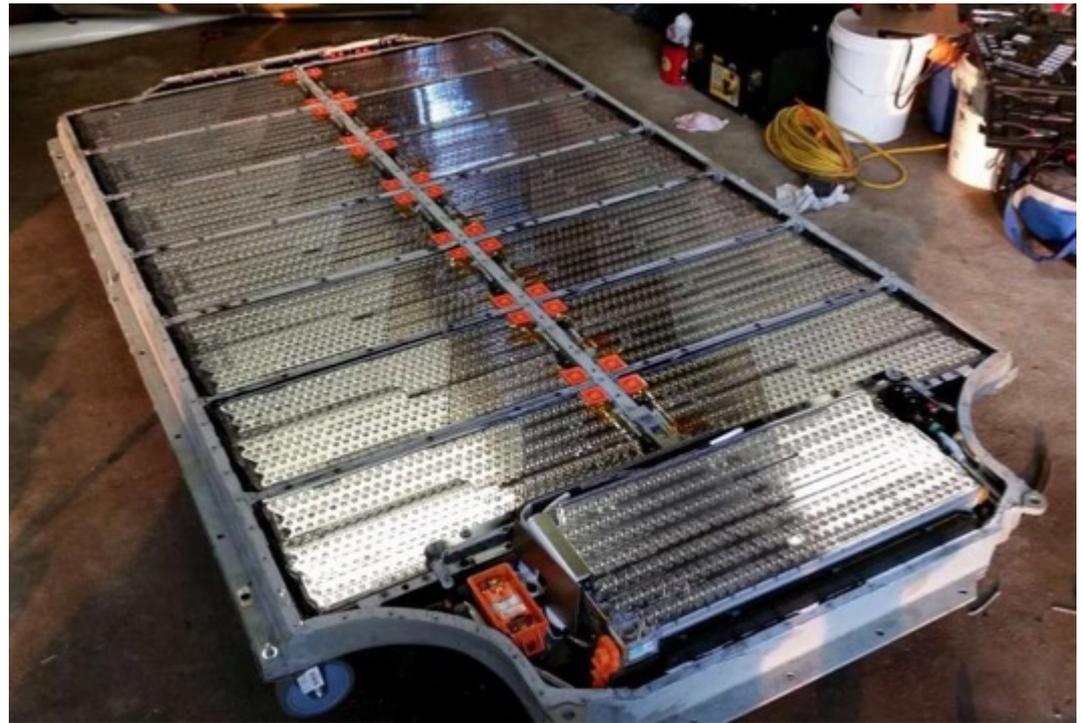
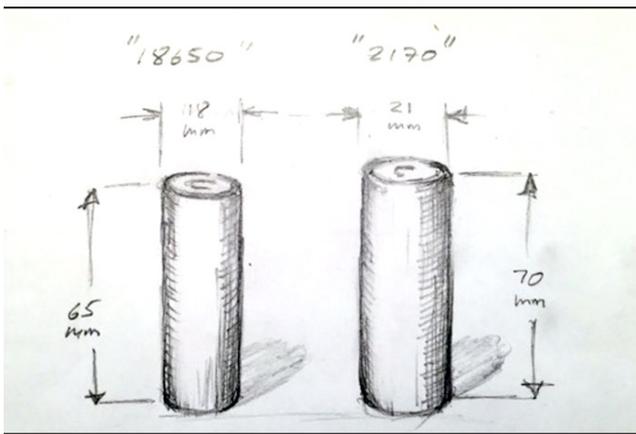
La geometria della cella influenza la densità della batteria e la dissipazione del calore.

# TESLA

La batteria della Tesla Model S 85 rappresenta il 30% del suo peso totale



# TESLA: soluzione sul pianale



# Installazione del pacco batteria

Un approccio comune consiste nell'installare il pacco batteria all'interno di scomparti rigidi e rinforzati o in aree meno soggette ad essere colpite in condizioni di incidente

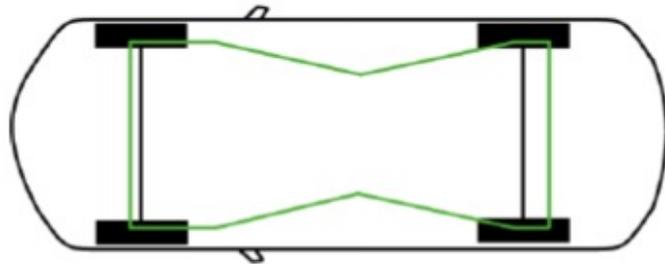


Figure 14 "Safe-zone" based on [48]

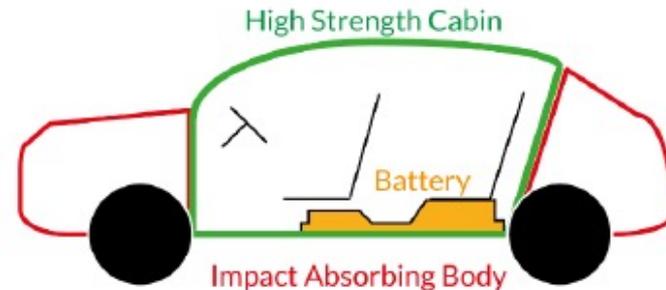


Figure 15 Battery layout for a Nissan Leaf [49]

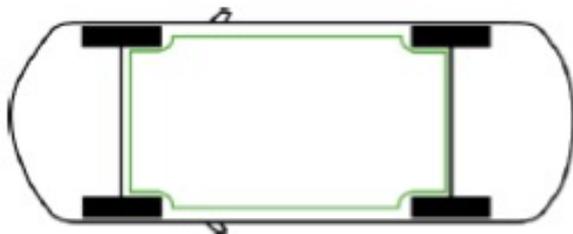


Figure 16 The "Floor" solution

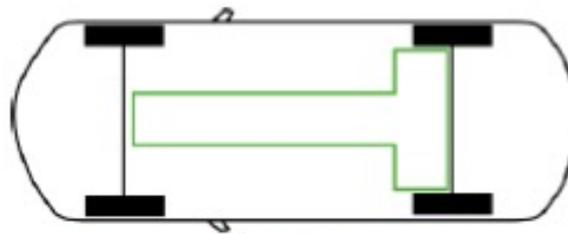


Figure 17 The "T" solution

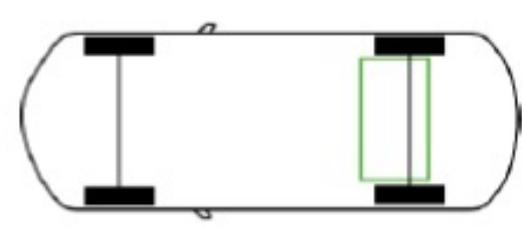


Figure 18 The "Rear" solution

# AUTOBUS

Table 13 Selected electric bus models currently operating in Europe and their characteristics.

Buses: BEV or PHEV	Battery Pack		Battery Cell	
	Energy Capacity [kWh]	Configuration	Type	Anode/Cathode
Volvo 7900	76 [95] 150 - 250 [96]	Roof (rear) [89]	-	-/LFP
BYD K9	216-345 [97]	Roof (rear) + rear and front [88]	Prismatic [98]	-/LFP [99]
Solaris Urbino	80-240 [91]	Roof (front) [91]	Pouch [100]	LTO/- [101]
VDL Citea	60-250 [90]	Roof (front) [90]	Prismatic [90] + [102] or Pouch [90] + [103]	LTO/ or -/LFP [90]
Optare Versa	92-138 [104]	Rear [92]	Cylindrical [105] + [106]	-/Lithium Iron Magnesium Phosphate [92]
Proterra Catalyst	94 -440 (35 ft.) [107] 94 -660 (40 ft.) [87]	Floor [94]	-	-



Citaro Hybrid - Mercedes

Table 12 Battery packs in electric buses

BYD K9	A+C+E [88]
Volvo 7900	C [89]
VDL Citea	B [90]
Solaris Urbino	B [91]
Optare Versa	D+E [92]
Proterra Catalyst	F [93][94]

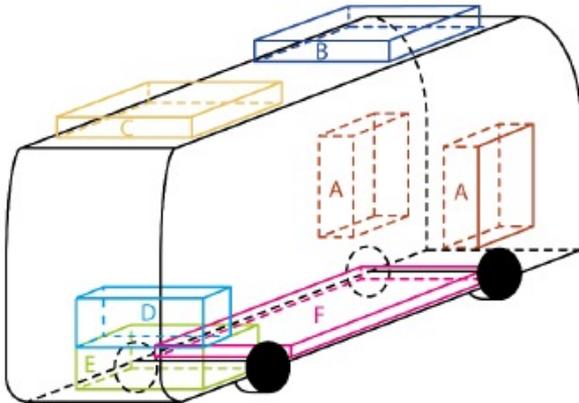


Figure 37 Position of the battery packs on selected buses

# Energy Storage System (ESS)



## OPERATION AND USE OF AN ENERGY STORAGE SYSTEM (ESS)

### BATTERY MODULES

Energy storage

### BATTERY MANAGEMENT SYSTEM

Optimizes the management of battery modules

### FIRE SUPPRESSION SYSTEM

### HEATING, VENTILATION AND AIR-CONDITIONING SYSTEM

Battery

### HEATING, VENTILATION AND AIR-CONDITIONING SYSTEM

### CONTROL UNIT

Manages the charge and discharge cycles of the batteries according to grid needs

### INVERTERS

Convert direct current (DC) into alternating current (AC), and vice versa

### Power Conversion System (PCS)

### TRANSFORMERS

Convert the low voltage battery output to the medium or high voltage required by grid

An ESS can be combined with renewable energy resources to store surplus energy

Un pacco batterie per ESS può avere una capacità energetica fino a MWh

# PROPRIETÀ DELLE BATTERIE Li-ione

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## Vantaggi

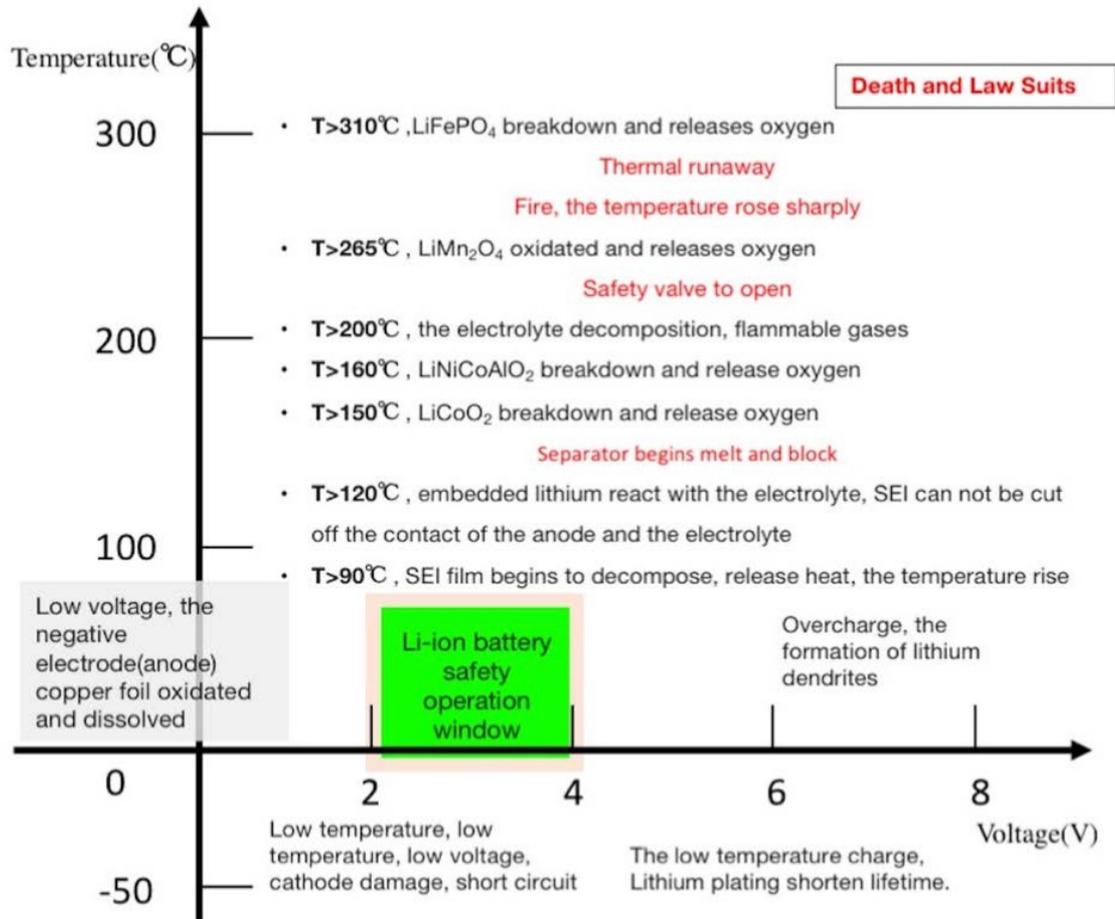
1. Alta densità di carica
2. Alta tensione (3 - 4,2 V)
2. Bassa autoscarica
3. Lunga durata di un ciclo
4. Elevato numeri di cicli

## Svantaggi

1. Degrado progressivo in caso di non utilizzo per lunghi periodi
2. Problemi di stoccaggio per lunghi periodi (sovraccarico)
3. Guasto catastrofico in dispositivi che richiedono alta potenza
4. Componenti infiammabili
5. Emissioni tossiche per l'uomo e per l'ambiente

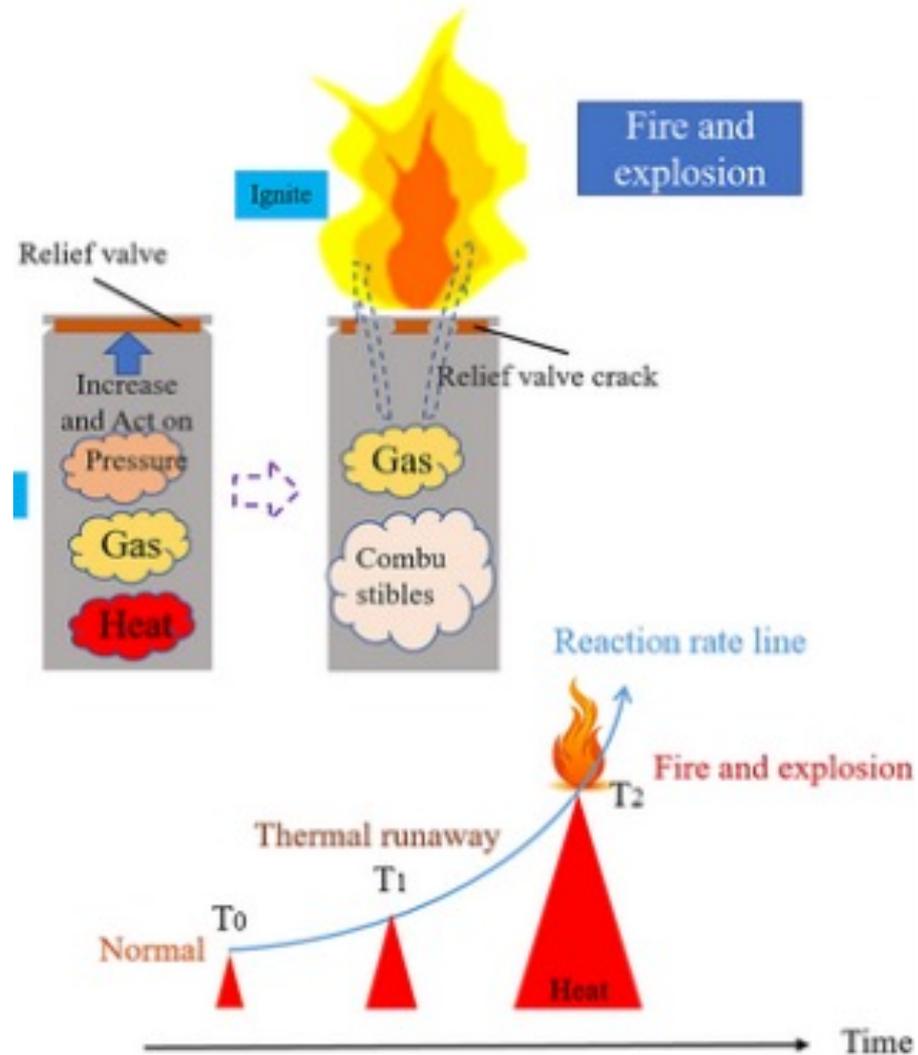
# FINESTRA OPERATIVA

“Finestra operativa” ovvero un campo Temperatura-Tensione di corretto funzionamento, al di fuori del quale una cella può essere irreversibilmente danneggiata a causa di reazioni chimiche indesiderate.



# THERMAL RUNAWAY

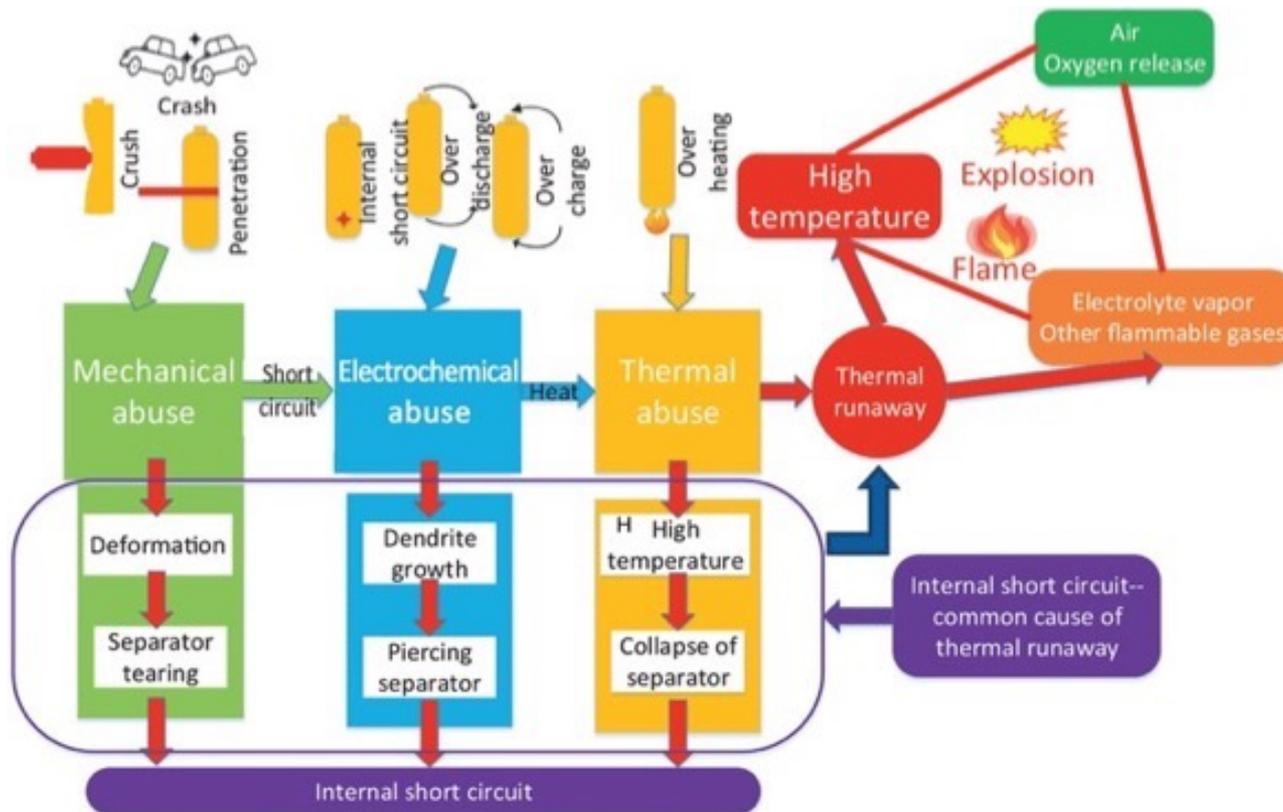
- ✓ Il *thermal runaway* implica:
- ✓ un rapido aumento della temperatura delle celle della batteria
- ✓ accompagnata dal rilascio di gas infiammabili, i quali possono essere facilmente innescati, causando un incendio.
- ✓ Se non opportunamente rilasciati i gas determinano l'esplosione della cella.



# CONDIZIONI DI ABUSO

Le condizioni di abuso sono raggruppabili in tre classi:

- ✓ **Abuso elettrico** (overvoltage, undervoltage e cortocircuito esterno)
- ✓ **Abuso termico** (esposizione a fiamma, a calore; calore generato non correttamente rimosso)
- ✓ **Abuso meccanico** (foratura, piegamento, ecc.)



# DISPOSITIVI DI PROTEZIONE E CONTROLLO

## A livello di Cella

- Scelta dei Materiali
- **CID** (Current Interruption Device)
- **Venting** (Disco di rottura)
- PTC (Positive Temperature Coefficient expansion device)
- Circuito protettivo

## A livello di Batteria

- Progettazione (per migliorare lo scambio termico)
- BMS (Battery Management System)
- PCM (Phase Changing Materials) per mantenere la T nei range di normale funzionamento

*Una batteria è un insieme di celle collegate tra loro in serie e/o in parallelo. Oltre alle celle contiene l'elettronica di «bordo» (collegamenti, BMS, ecc.), sistemi di raffreddamento e controllo temperatura (ventole, PCM, ecc.), il contenitore esterno.*

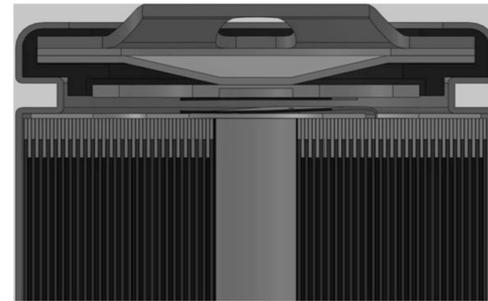
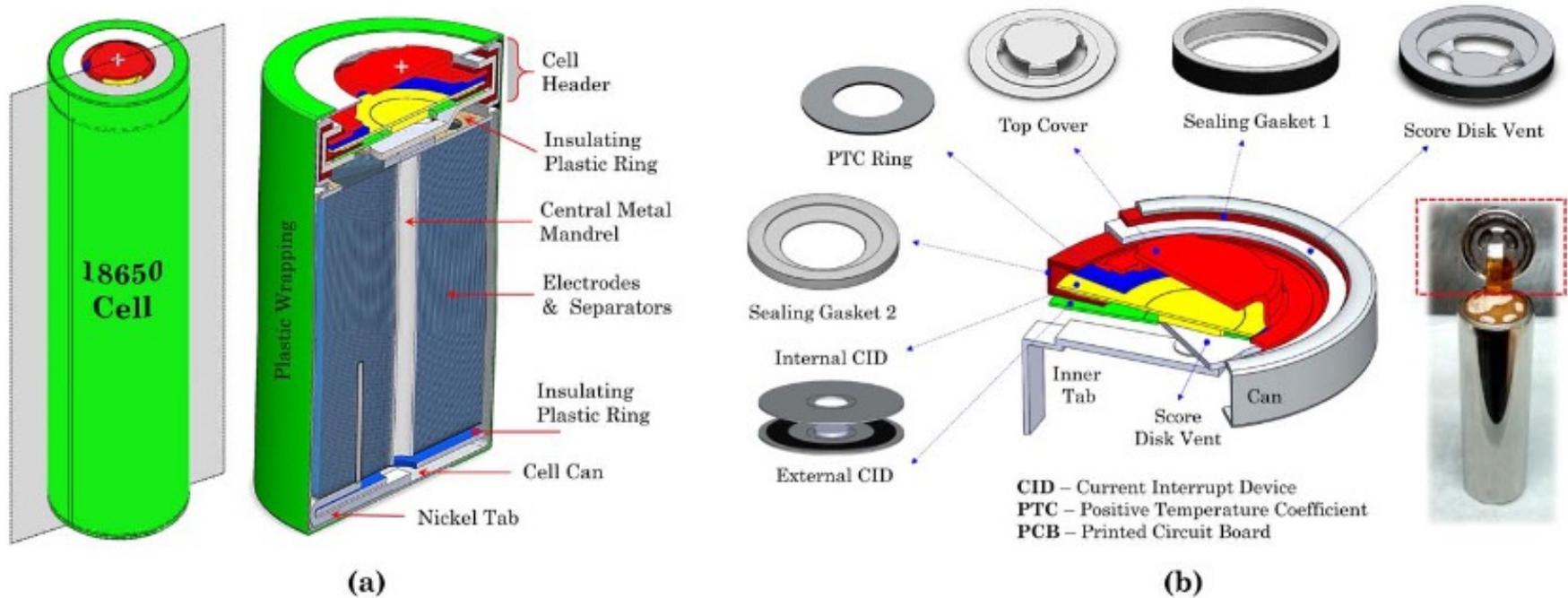


Fig. 5.11 Cross-sectional diagram of 18,650 cell showing CID and PTC

# DISPOSITIVI DI PROTEZIONE: CELLE CILINDRICHE



**Figure 1.** Schematic of a conventional cylindrical 18650 Li-ion cell with a spiral wound cell design. (a) Cross-section of the cell along the axial direction. (b) Cell header design showing the internal protective devices.

# DISPOSITIVI DI PROTEZIONE: CELLE CILINDRICHE

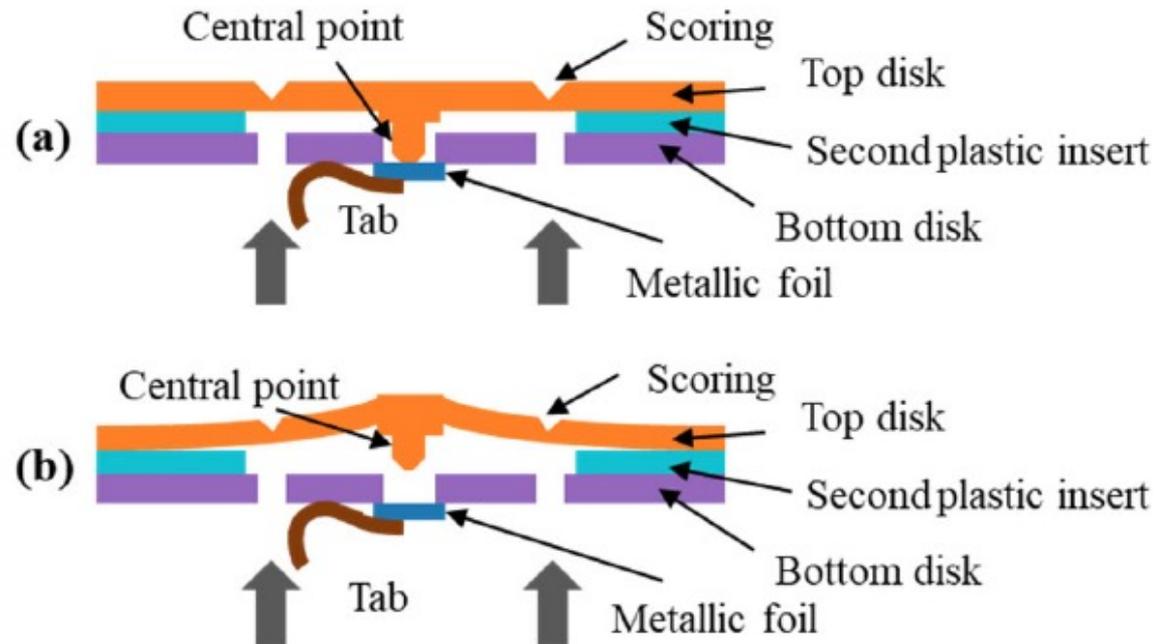
**TABLE 3.** Summary of protection devices in 18650 cells.

Protection devices	Activation conditions	Advantages	Disadvantages	Safety improvement
<b>CID</b>	Internal pressure over 1.0 ~ 1.2 MPa	Effective for the single cell	Irreversible protection device; difficult to control the connection strength;	Middle
<b>Top vent</b>	Internal pressure over 2.2 ~ 2.3 MPa, or 2.58 MPa	Protect battery case from rupturing	May fail to protect the cells in series or/and parallel configures	High
<b>PTC</b>	PTC temperature over 100 °C	Compact size; lightweight; resettable.	Increases cell resistance and energy loss.	Low
<b>Bottom vent</b>	Internal pressure over 2.47 MPa	Prevent sidewall rupture;	Increases the risk of electrolyte leakage.	Middle
<b>Protection circuit</b>	Overcharge, over-discharge, overcurrent, and short circuit	Active full-time protection; works for both the single cell-level or pack-level	Increases cost and manufacturing complexity.	High

# CID - Current Interruption Device

Il CID è costituito da un **disco superiore**, un **inserto in materiale plastico**, un **disco inferiore** ed un **foglio metallico**.

Durante il normale impiego il dispositivo permette il passaggio della corrente, mentre a seguito di un aumento di pressione interna il CID si attiva isolando elettricamente uno degli elettrodi, prevenendo il passaggio di corrente



**FIGURE 6.** CID structure before and after being triggered.

# VENTING

TOP

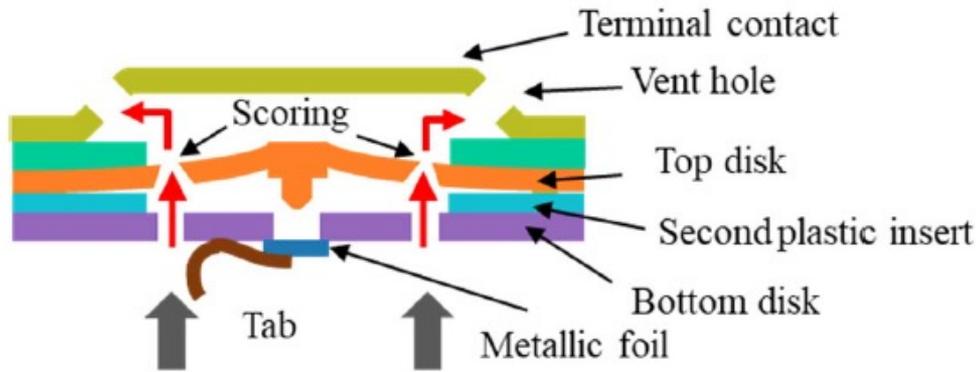


FIGURE 8. Gas releasing pathway during venting.

BOTTOM

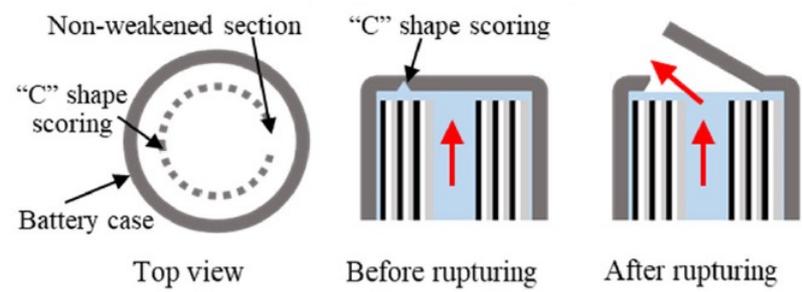


FIGURE 13. Before and after rupturing of the bottom vent.

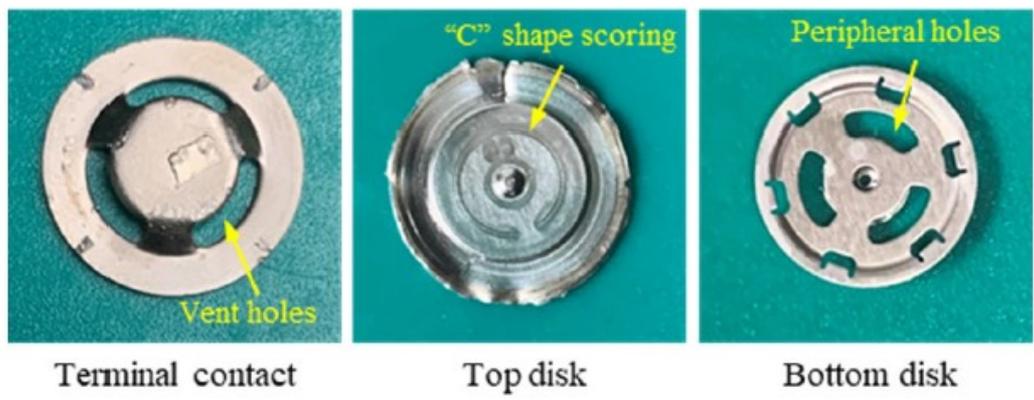
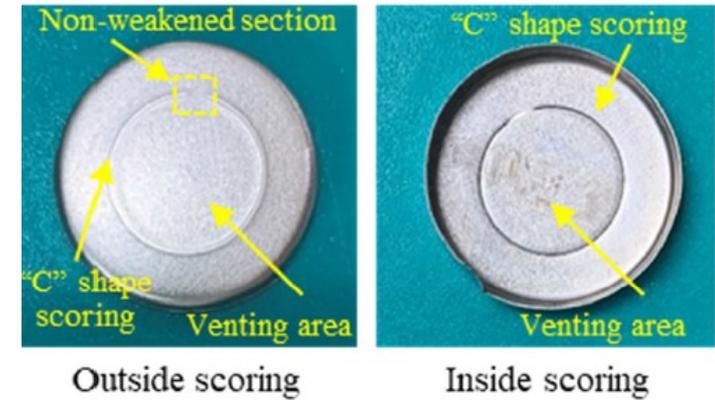


FIGURE 7. Components of the top vent in the protected Samsung 30Q battery.



Bottom vent in the Sony VTC5D battery.



# PTC - Positive Temperature Coefficient

- Il PTC è costituito da una struttura a tre strati di forma anulare: **uno strato polimerico conduttivo fra due strati metallici**.
- A temperature  $>100^{\circ}\text{C}$  il polimero si espande aumentando la distanza fra i due strati metallici.
- In questo modo aumenta la resistenza e la corrente che attraversa della cella viene significativamente ridotta.

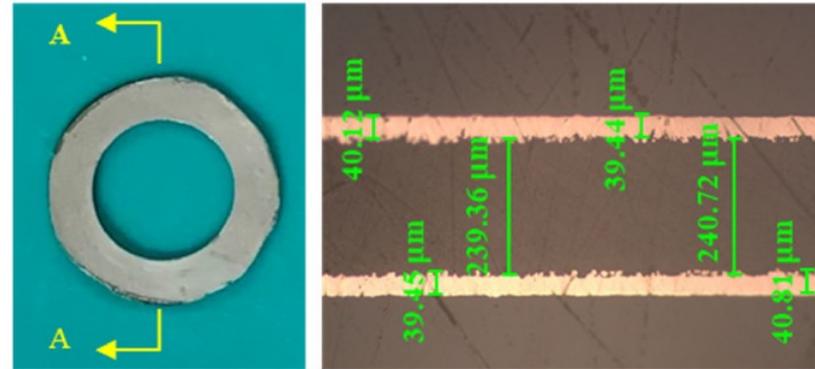


FIGURE 9. The PTC in the Samsung 26F battery.

# Circuito di protezione

- Le celle con un circuito protezione sono considerate celle intelligenti che hanno un **controllore** e degli **interruttori**.
- Il circuito permette una protezione attiva costante nel tempo contro sovraccarichi, sotto scariche, sovracorrenti e cortocircuiti.

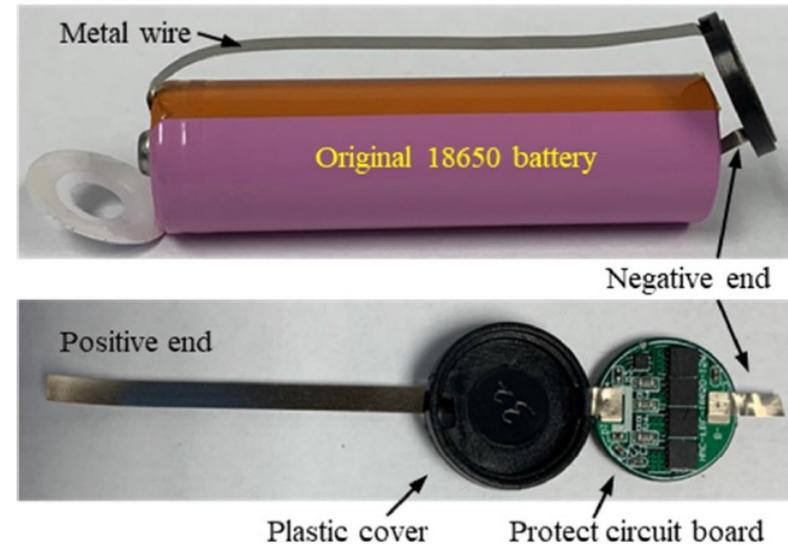


FIGURE 14. Protection circuit in the protected Samsung 30Q battery.

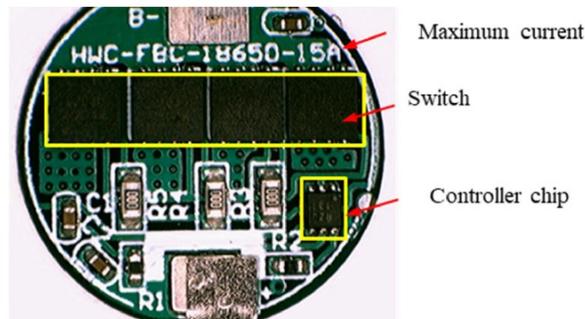


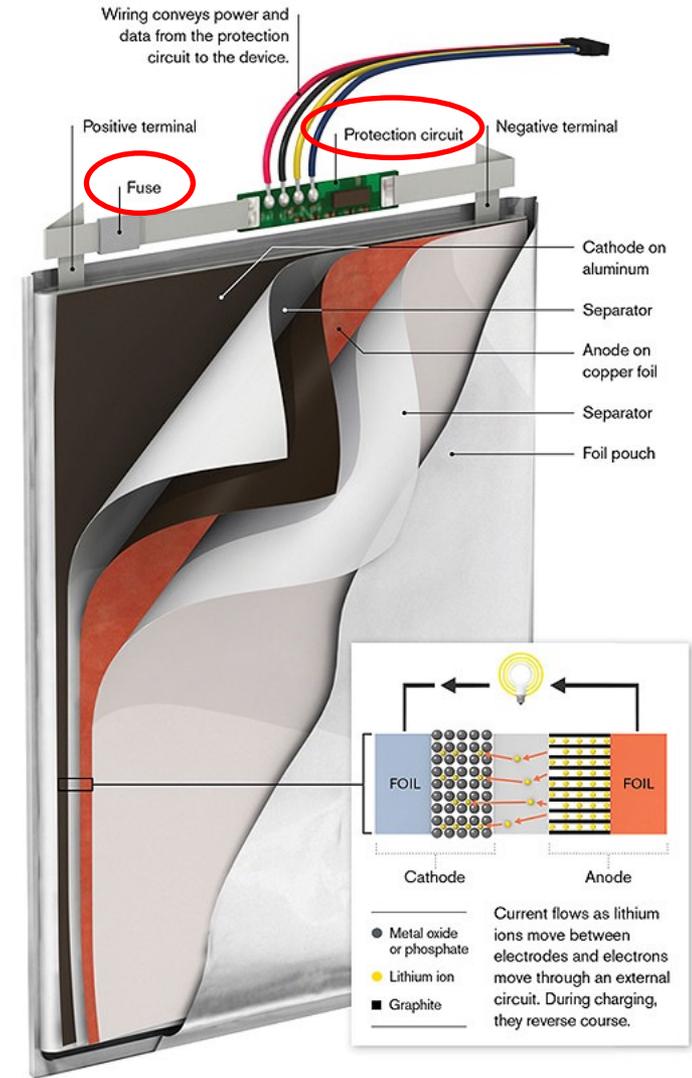
FIGURE 15. Enlarged view of the protection circuit board.

# CELLE A BUSTINA (POUCH)

Le celle a bustina, a causa del limitato spazio non presentano sistemi di protezione installati all'interno ma solo all'esterno della cella. I dispositivi presenti sono:

- un fusibile;
- un circuito di protezione fra il terminale positivo e quello negativo.

Non essendoci sistemi di venting, a seguito di aumenti di pressione interna la cella si rigonfia fino a che l'involucro esterno in alluminio si rompe.



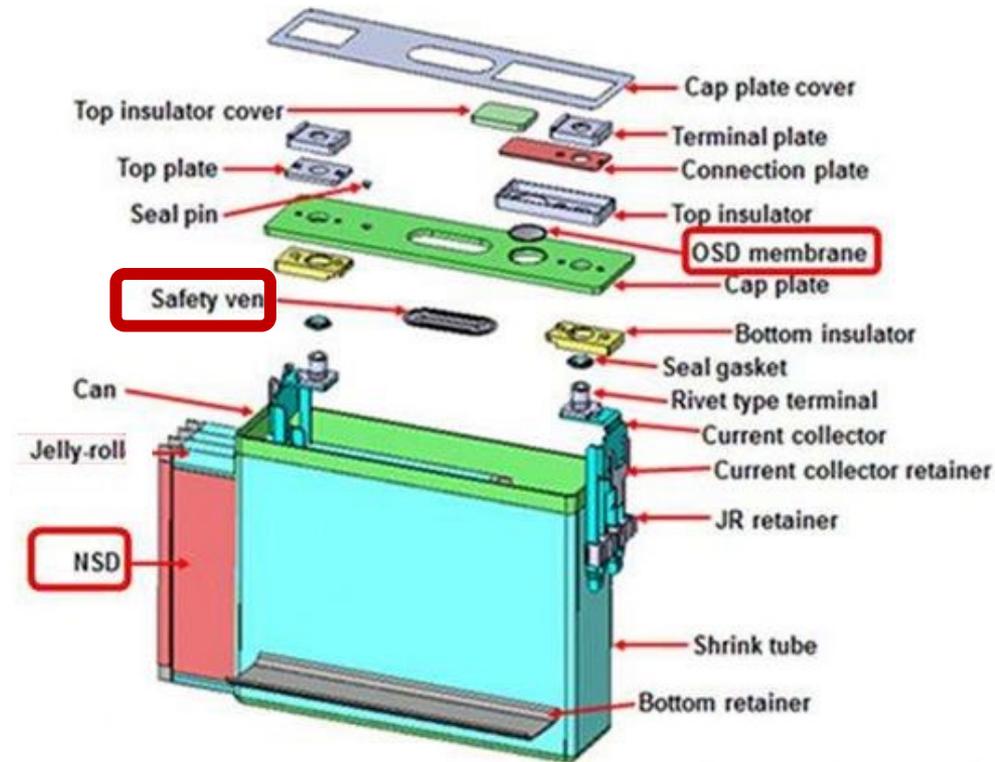
# CELLE PRISMATICHE

I componenti principali di una cella prismatica includono:

- coperchio superiore
- piastra positiva
- piastra negativa
- laminato o avvolgimento composto da diaframma
- parti isolanti

Dispositivi di sicurezza :

- venting,
- il dispositivo di sicurezza per forature (NSD)
- il dispositivo di protezione da sovraccarico (OSD).



<https://ceramixenergy.com/brief-introduction-of-prismatic-lithium-battery-cell/>



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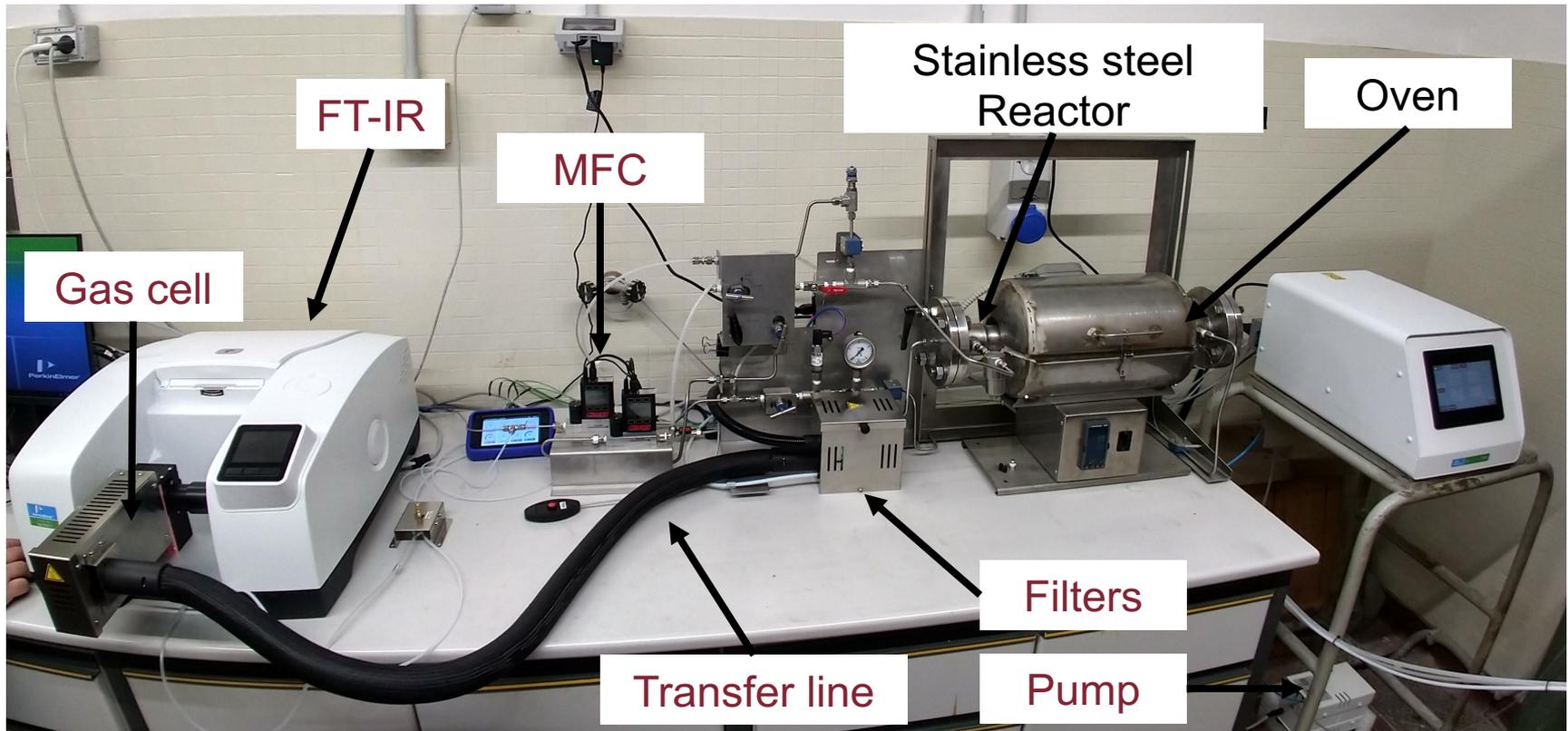
# PREVENZIONE DEI RISCHI: BMS

- ✓ Il funzionamento in carica e scarica delle batterie Litio-ione è controllato da un sistema elettronico intelligente: il **BMS (Battery Management System)**.
- ✓ Il BMS generalmente ha anche funzioni di prevenzione e protezione dei rischi, quando integrato per le funzioni di controllo, allarme e intervento.
- ✓ In casi più semplici, il BMS è sostituito da un Battery Protection Circuit.
- ✓ I dispositivi di più semplice permettono la protezione da sovraccarica, da sovrascarica, da corrente massima e da cortocircuito.



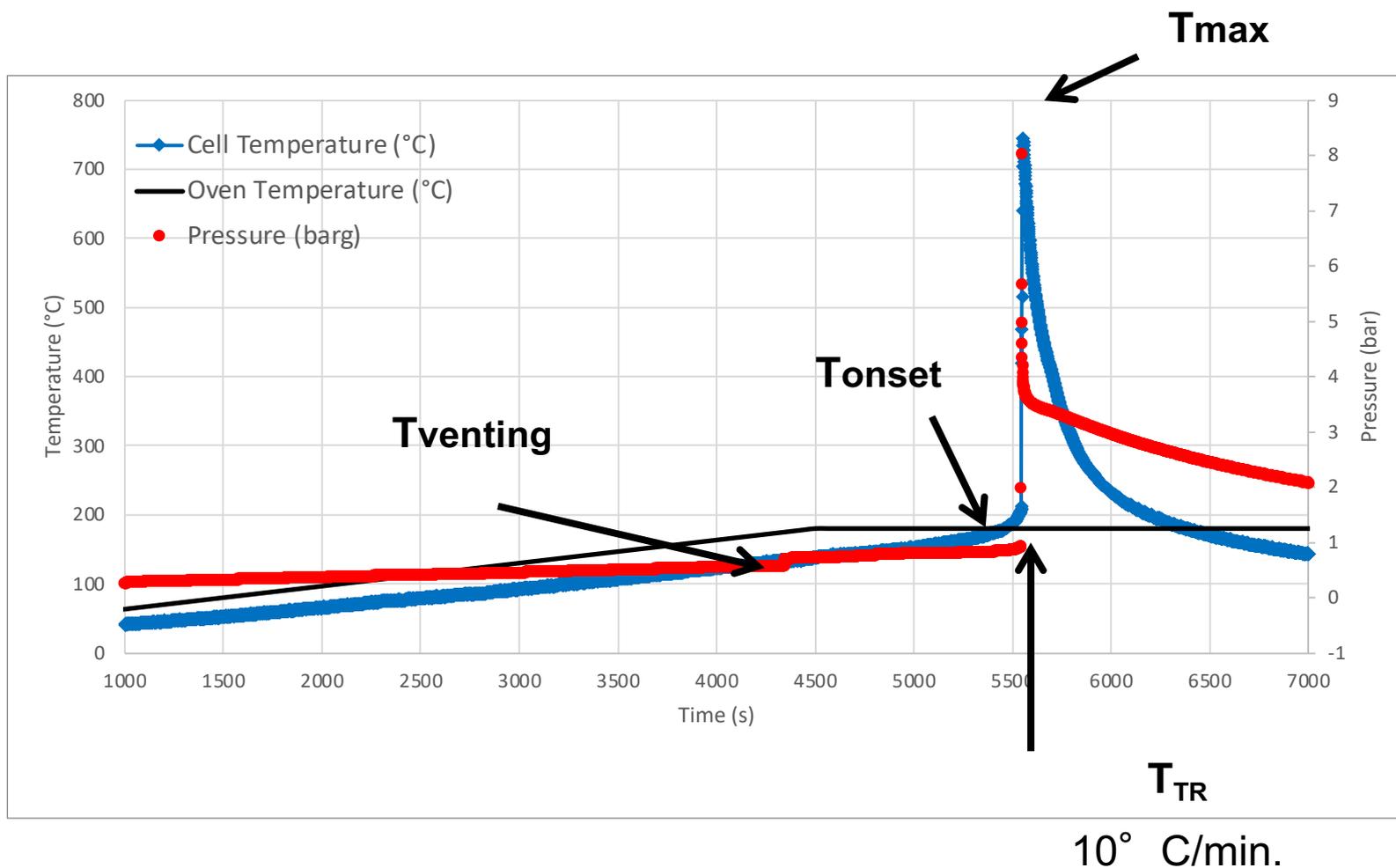
# TEST DI ABUSO

# APPARATO SPERIMENTALE IN LAB



# ABUSO TEERMICO: TEMPERATURA E PRESSIONE

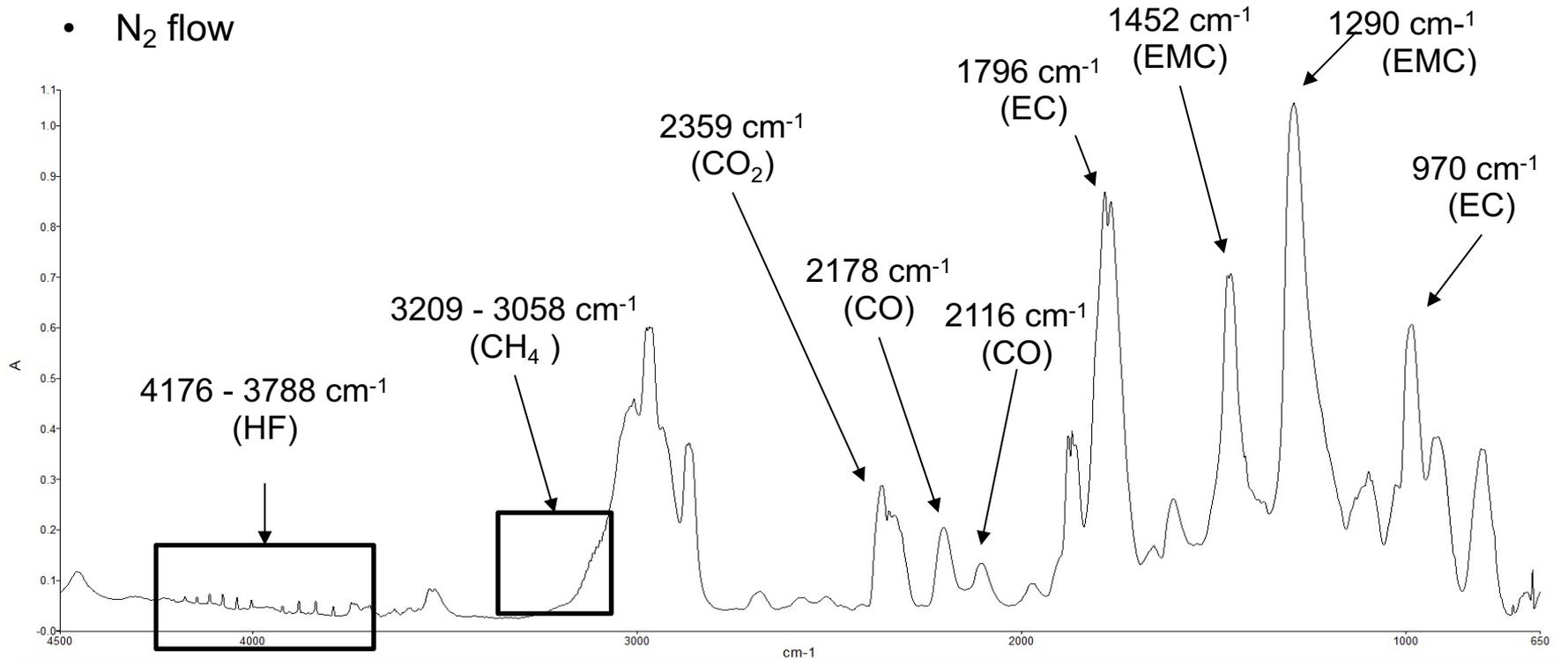
- N<sub>2</sub> flow, 2 C/min



# EMISSIONI DI GAS: Venting

## Emissioni di HF e elettrolita

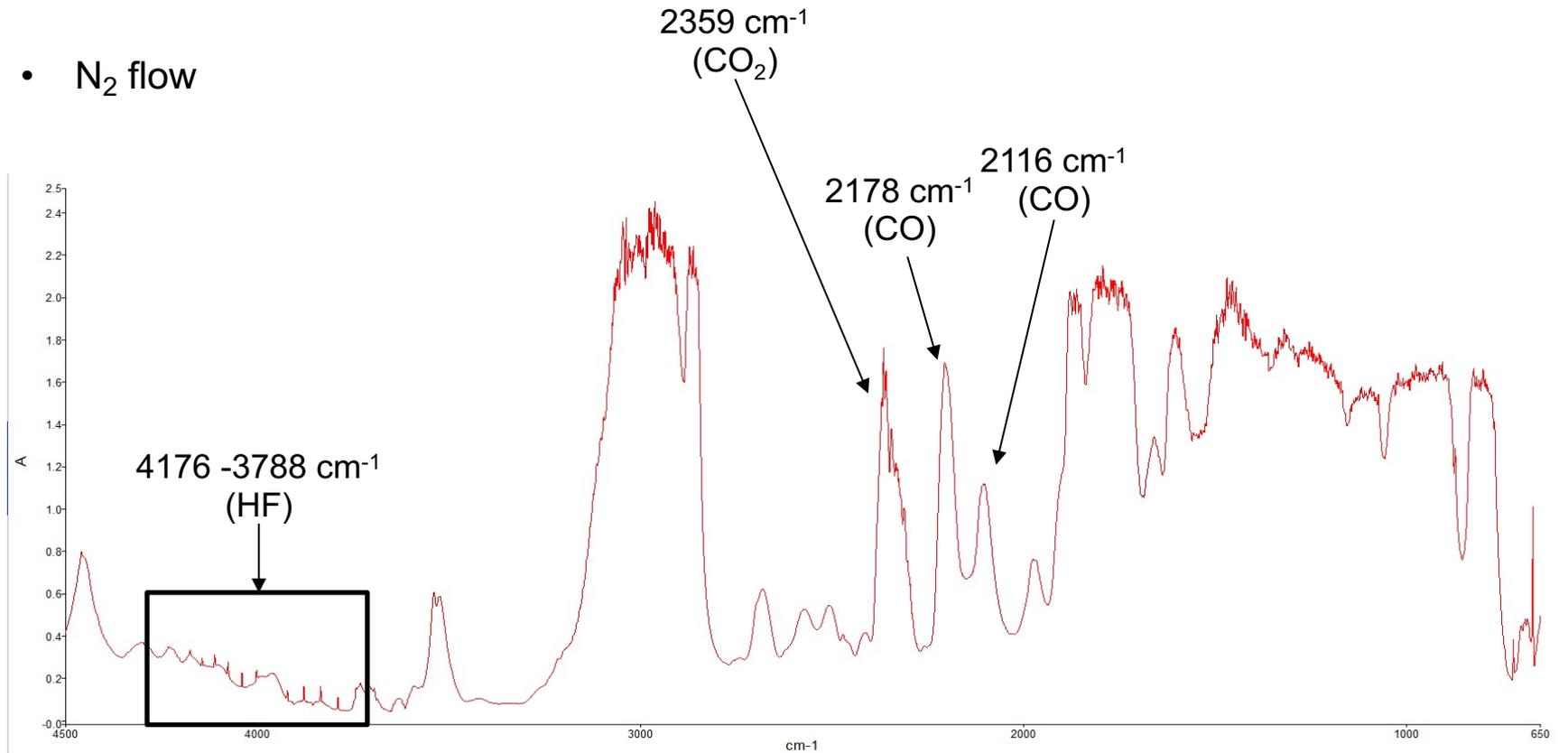
- N<sub>2</sub> flow



# EMISSIONI DI GAS :Thermal runaway

Emissioni di HF, CO, CO<sub>2</sub>

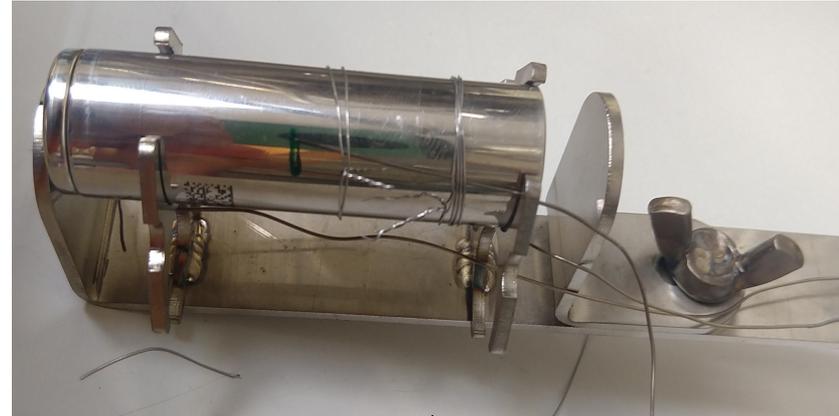
- N<sub>2</sub> flow



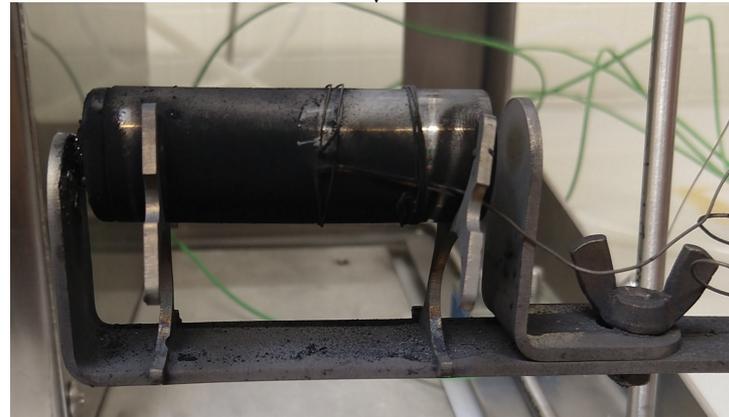
- Concentrazioni di HF (400-500 ppm) superiori all' IDLH (30 ppm)



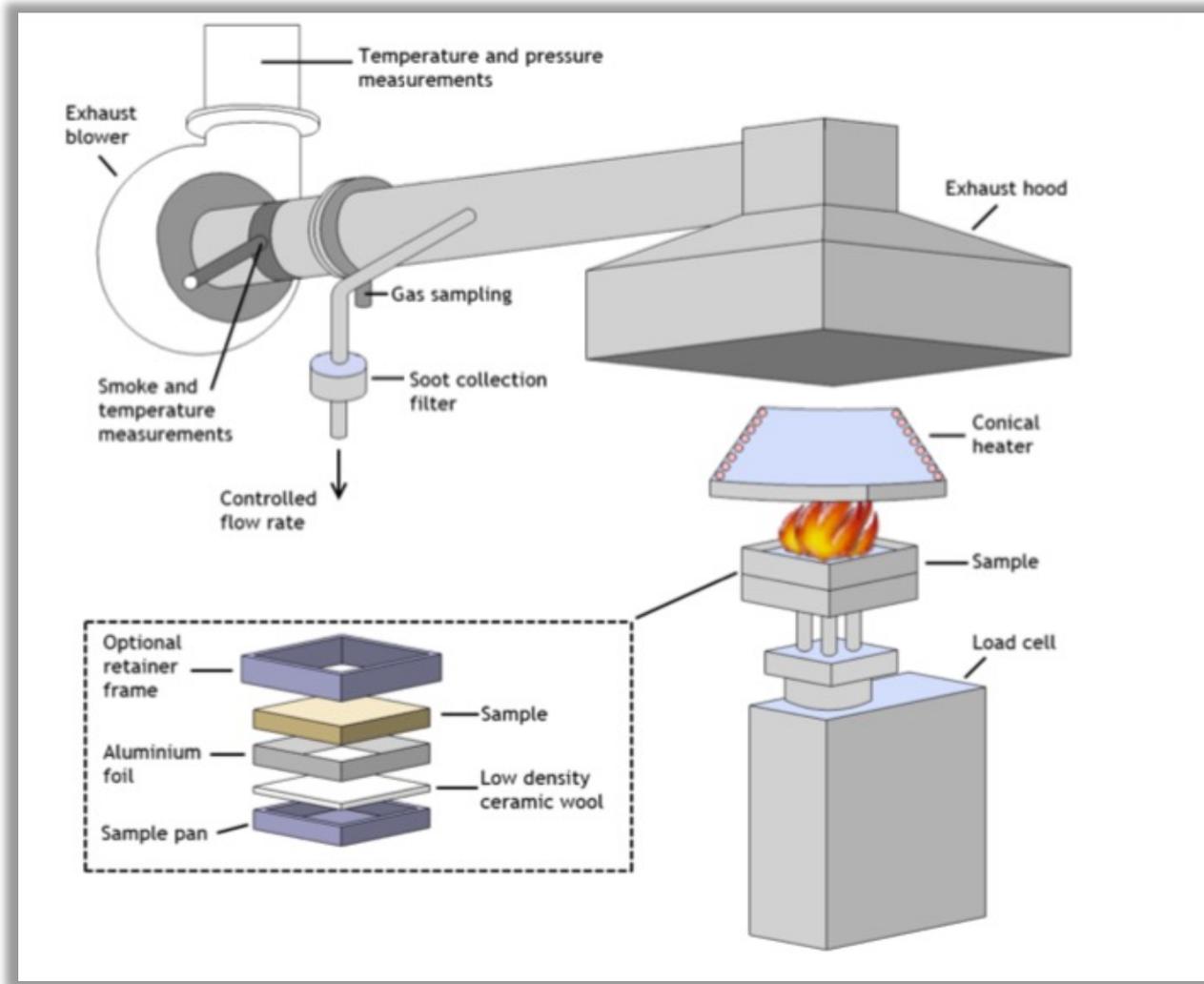
# PRIMA DEL TEST



# DOPO IL TEST



# CALORIMETRO A CONO



Laboratori di Capannelle

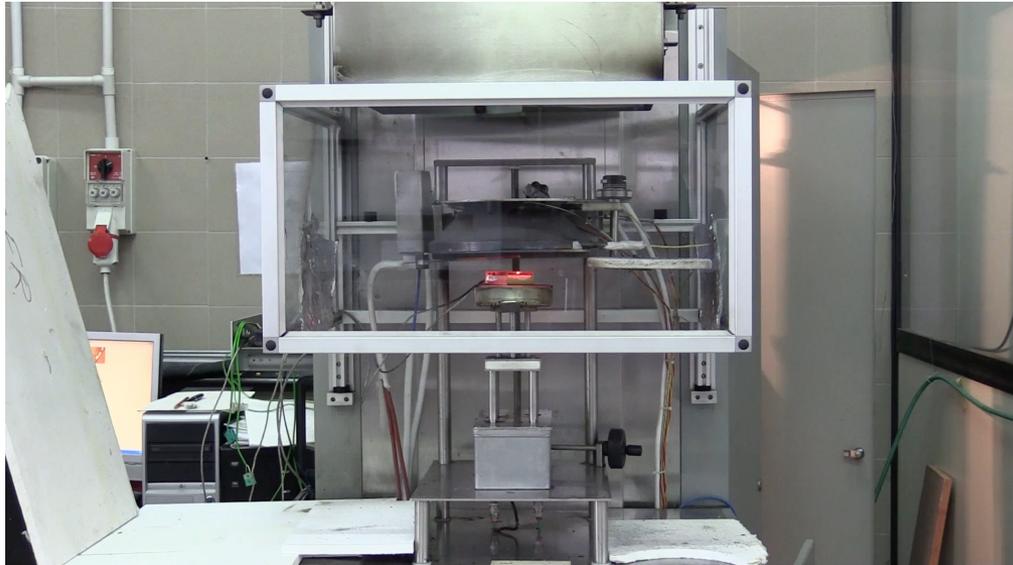
prof. Paola Russo



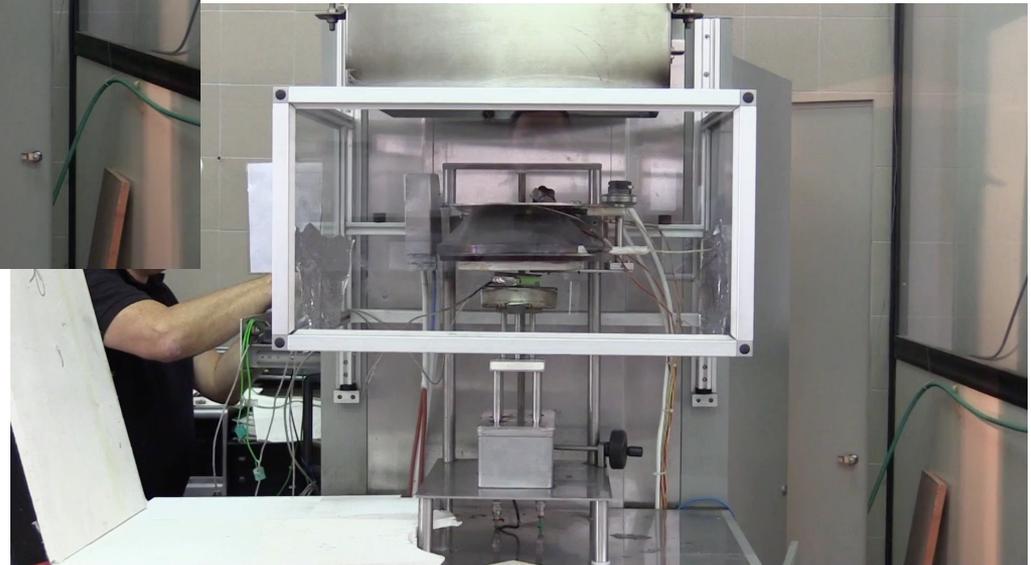
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# CALORIMETRO A CONO: CELLE CILINDRICHE

100% SoC, 50 kW/m<sup>2</sup>



100% SoC, 35 kW/m<sup>2</sup>

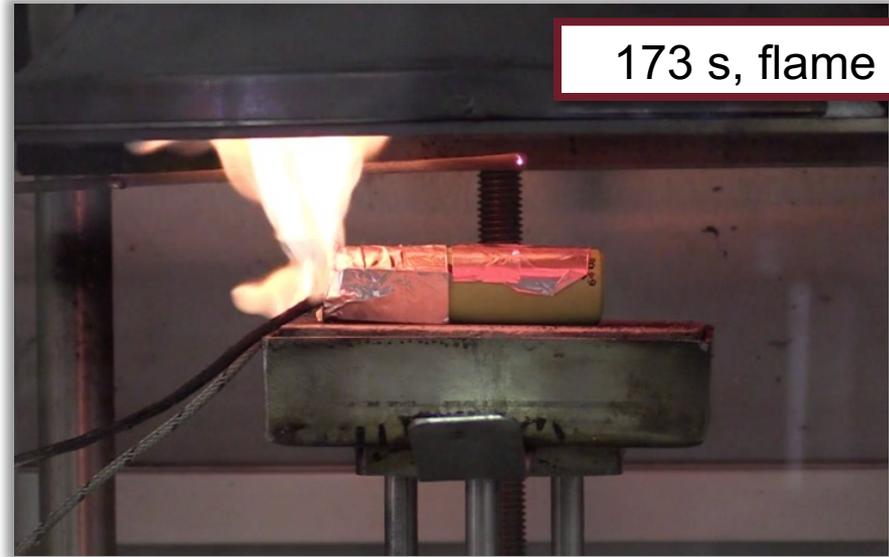


# 100% SoC, 50 kW/m<sup>2</sup>

171 s, venting



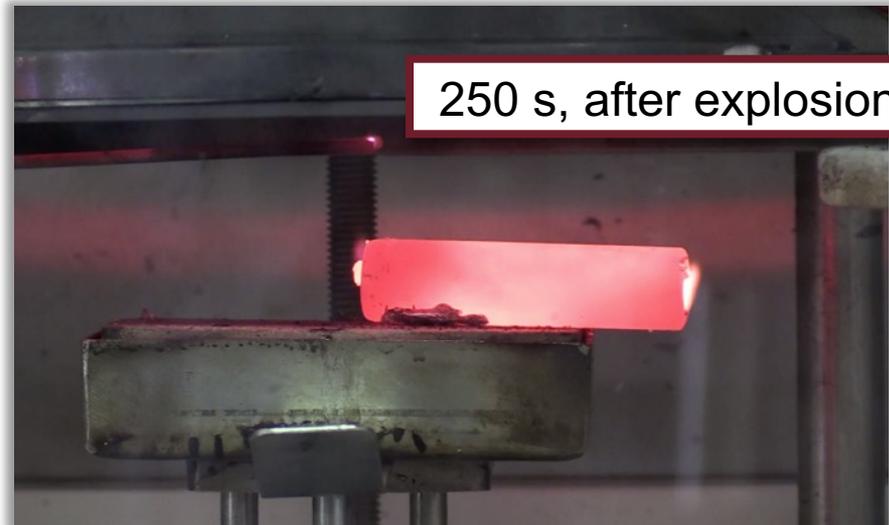
173 s, flame



226 s, explosion

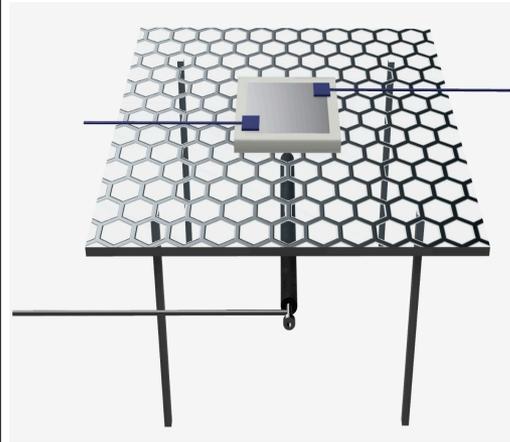


250 s, after explosion

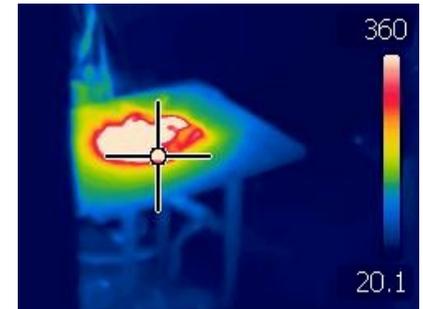


# ESPOSIZIONE A FIAMMA: CELLE POUCH

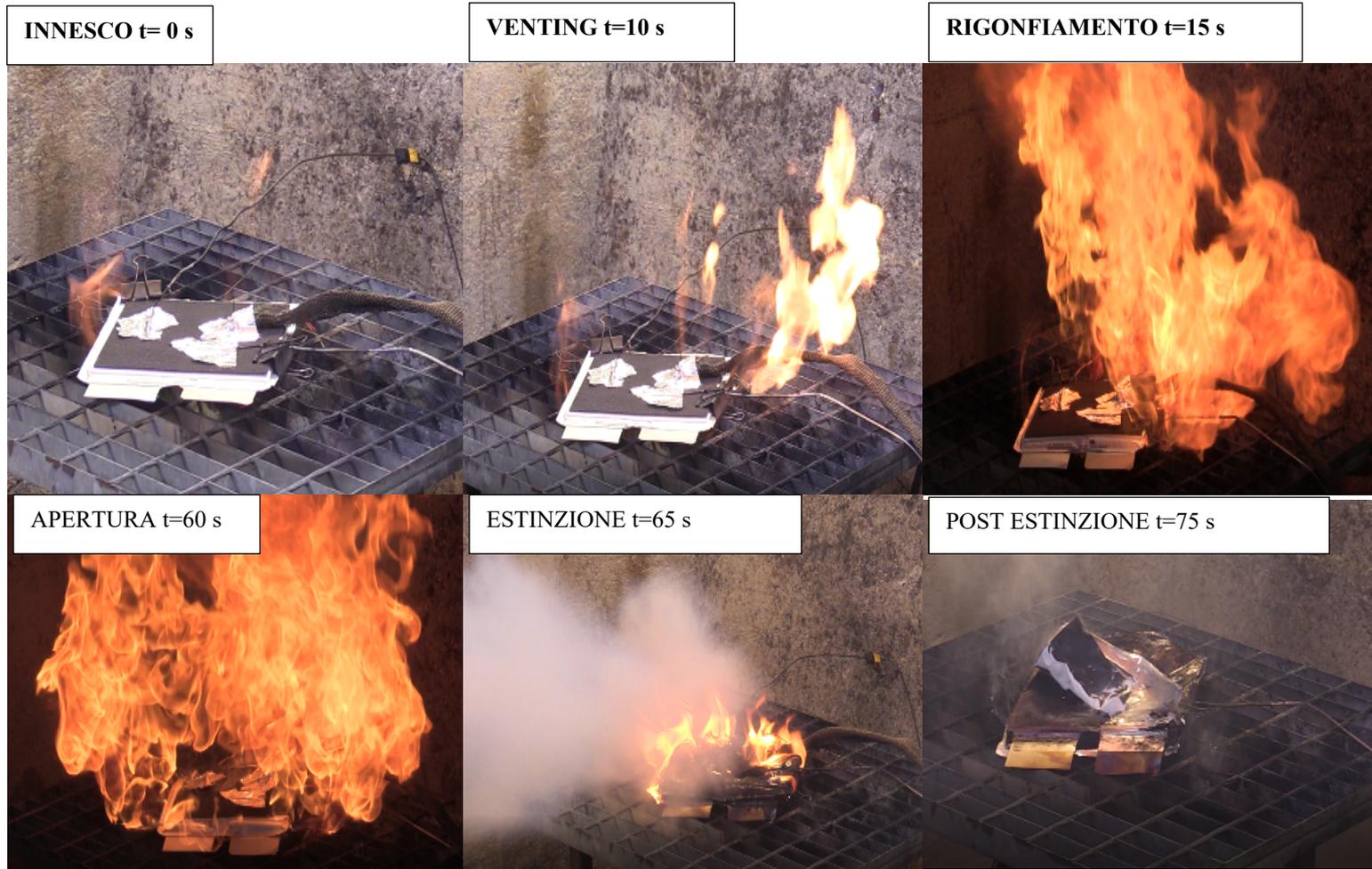
**Kokam Superior  
Lithium Polymer  
Battery (SLPB)**



Water mist    CO<sub>2</sub>    F500



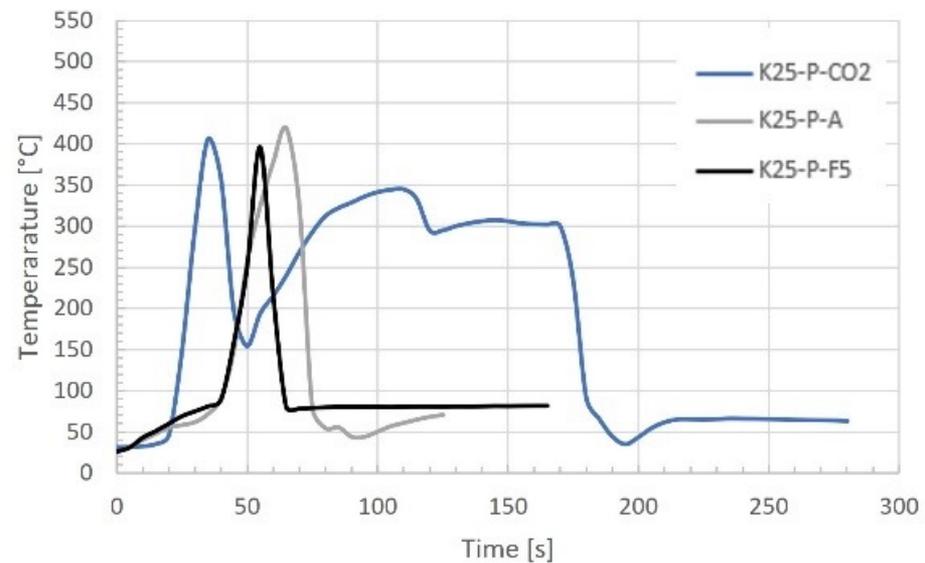
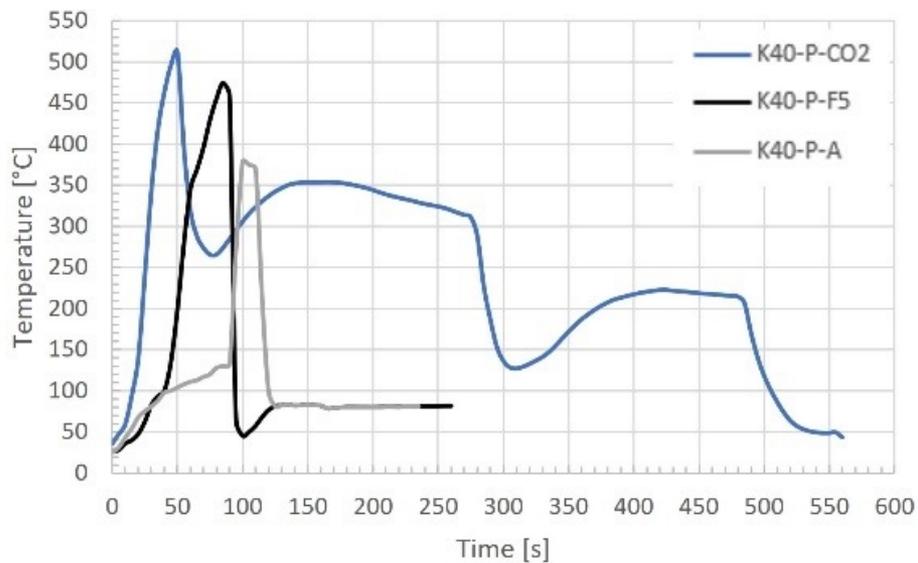
# ESPOSIZIONE A FIAMMA: CELLE POUCH



**Fig. 1.** K40-P-CO<sub>2</sub> test: (a) ignition, 0s; (b) venting, 10s; (c) swelling, 15s; (d) catastrophic rupture, 60s; (e) extinction, 65s; (f) post extinction, 75s.

# TEST DI ESTINZIONE

nome video	nome termocoppie	data	celle	innesco	estinguente	II estinguente	III estinguente
MVI_0043	27.05.21 10-06-48	27/05/2021	Kokam40	fiamma propano	F500		
MVI_0032	/	20/05/2021	Kokam40	fiamma propano	Water mist		
MVI_0049	27.05.21 12-06-14	27/05/2021	Kokam40	fiamma propano	CO2	CO2	Water mist
MVI_0027	/	20/05/2021	Kokam25	fiamma propano	F500		
MVI_0045	27.05.21 10-48-51	27/05/2021	Kokam25	fiamma propano	Water mist		
MVI_0050	27.05.2021 12-21-00	27/05/2021	Kokam25	fiamma propano	CO2	CO2	Water mist
MVI_0053	27.05.2021 17-42-41	27/05/2021	Kokam25	fiamma propano	Water mist		

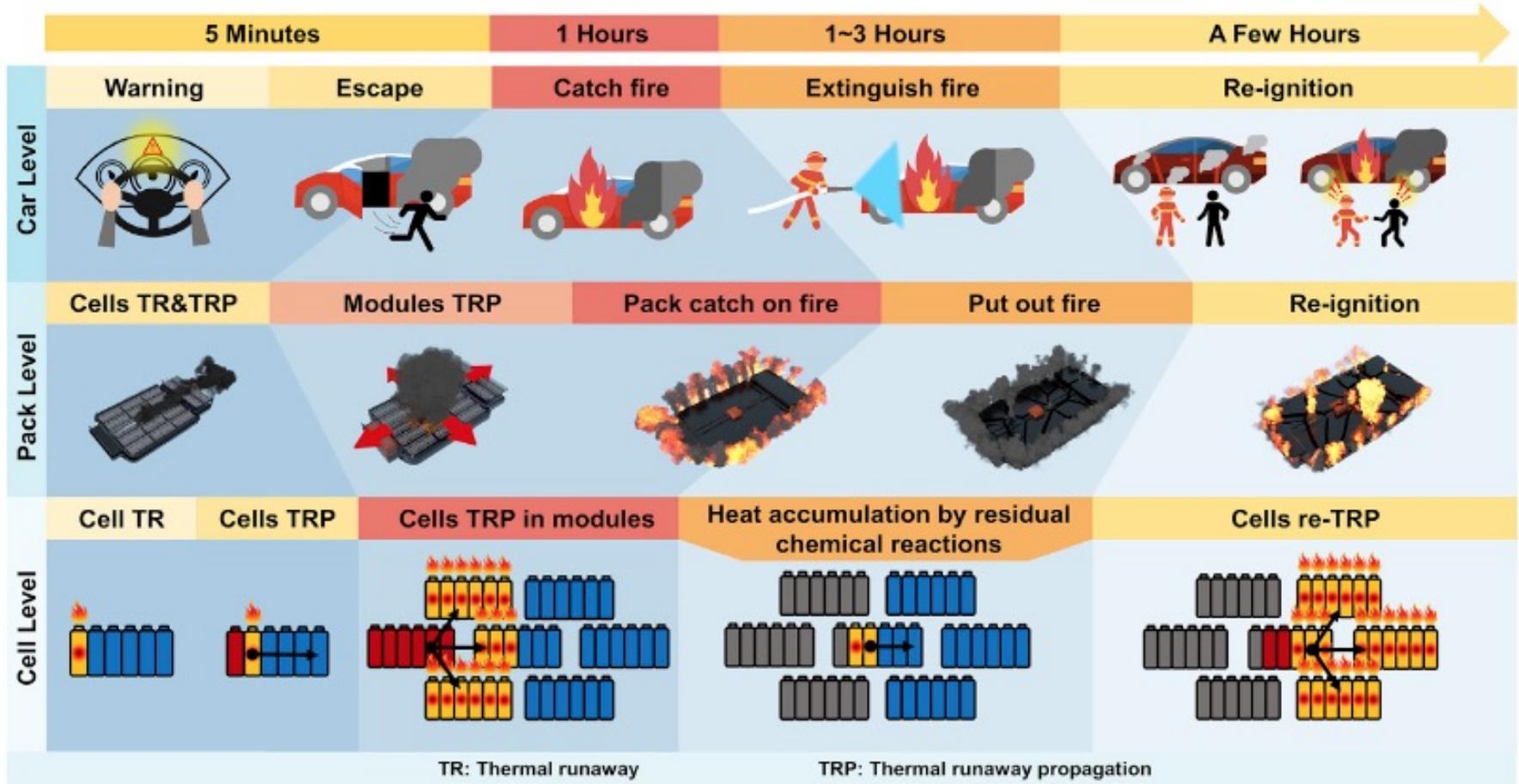


# TIPOLOGIA DI ESTINGUENTI

Company	Country	Date	Battery Chemistry	Water	CO <sub>2</sub>	Foam	Chemical/Dry Powder	Nitrogen	Sand	Halon*	Whatever Suitable	
Yuka energy	China	2011	Pack	LCO		x	x	x		x		
Makita	USA	2013	Pack	NCO	x		x					
Enertech	Korea	2017	Pack	NMC	x		x		x			
Samsung	Korea	2011	Cell	NMC	x		x					
Samsung	Korea	2016	Cell	NMO	x	x	x		x			
Saft	France	2009	Pack	LCO	x	x				x		
Bipower	USA	2017	Pack	LCO	x	x						
LG Chem	Korea	2013	Cell	NMC							x	
Motorola	USA	2017	Pack	LCO	x	x	x					
Ideal	USA	2010	Cell	LCO		x	x					
SDPT	China	2016		LCO	x	x						
Bren-Tronics	USA	2013	Pack	LCO	x	x	x					
Advance Energy	USA	2011		LCO							x	
Leo Energy	Singapore	2014		NMC	x		x					
IDX	Japan	2016	Pack	LMO	x	x	x		x			
Panasonic	USA	2015		NMC	x	x	x					
<b>Total</b>					<b>12</b>	<b>10</b>	<b>9</b>	<b>12</b>	<b>2</b>	<b>2</b>	<b>1</b>	<b>2</b>

\* Note that Halon-based products deplete the ozone layer and are prohibited.

# RISCHIO di RE-INNESCO



# RISCHIO di INNESCO RITARDATO e RE-INNESCO

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- Per i veicoli elettrici non c'è solo la minaccia di un incendio subito dopo un incidente, ma anche il rischio di un evento ritardato.
- Ciò potrebbe verificarsi durante la movimentazione post-incidente, comprese le attività di traino e di officina.
- Inoltre, esiste un rischio di riaccensione per periodi di tempo significativi dopo la prima estinzione.
- La riaccensione potrebbe non portare necessariamente a problemi quando sono presenti i primi soccorritori, poiché sono addestrati ad affrontare tali situazioni.
- Tuttavia, rappresenta una grande preoccupazione per coloro che devono gestire veicoli elettrici danneggiati.

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Grazie per l'attenzione!

Domande?

[paola.russo@uniroma1.it](mailto:paola.russo@uniroma1.it)

