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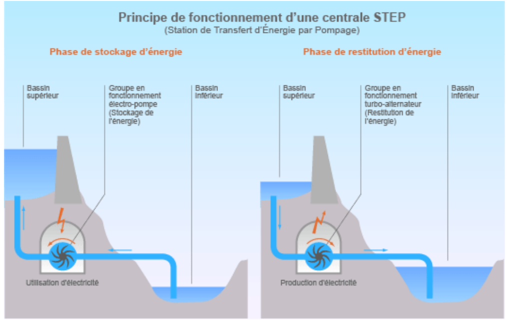
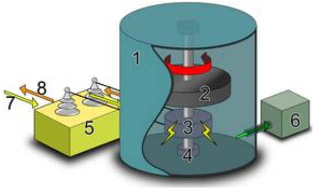
Hazards, tests and what is to be expected in the future on battery technology, including battery storage systems

Different type of energy storage means

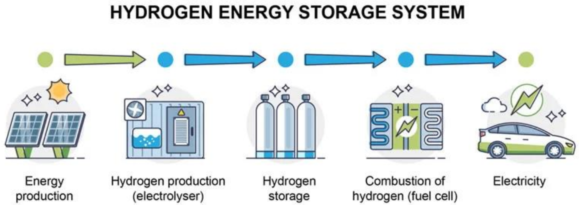
Pumped Hydro Storage (Dam)



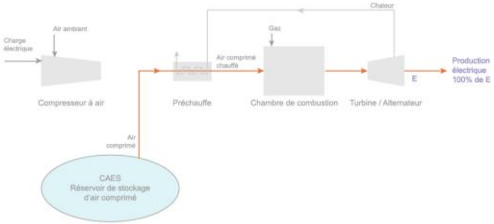
Flywheel



H_2 storage



CAES: Compressed Air Energy Storage



Batterie

SNG : Substitute (ou Synthetic) Natural Gas

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Battery technologies

Nickel-Metal Hydride
(UN 3496)

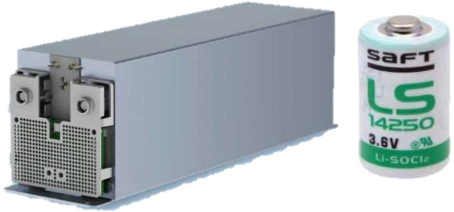
Acid-Lead
(UN 2794)

Sodium-Nickel Chloride(UN 3292)

Supercapacitor
(UN 3499)

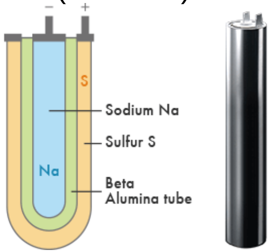
Lithium-ion
(UN 3480)

Lithium-metal
(UN 3090)



Na-ion
(UN 3551)

Sodium-Sulfur
(UN 3292)



Battery technologies

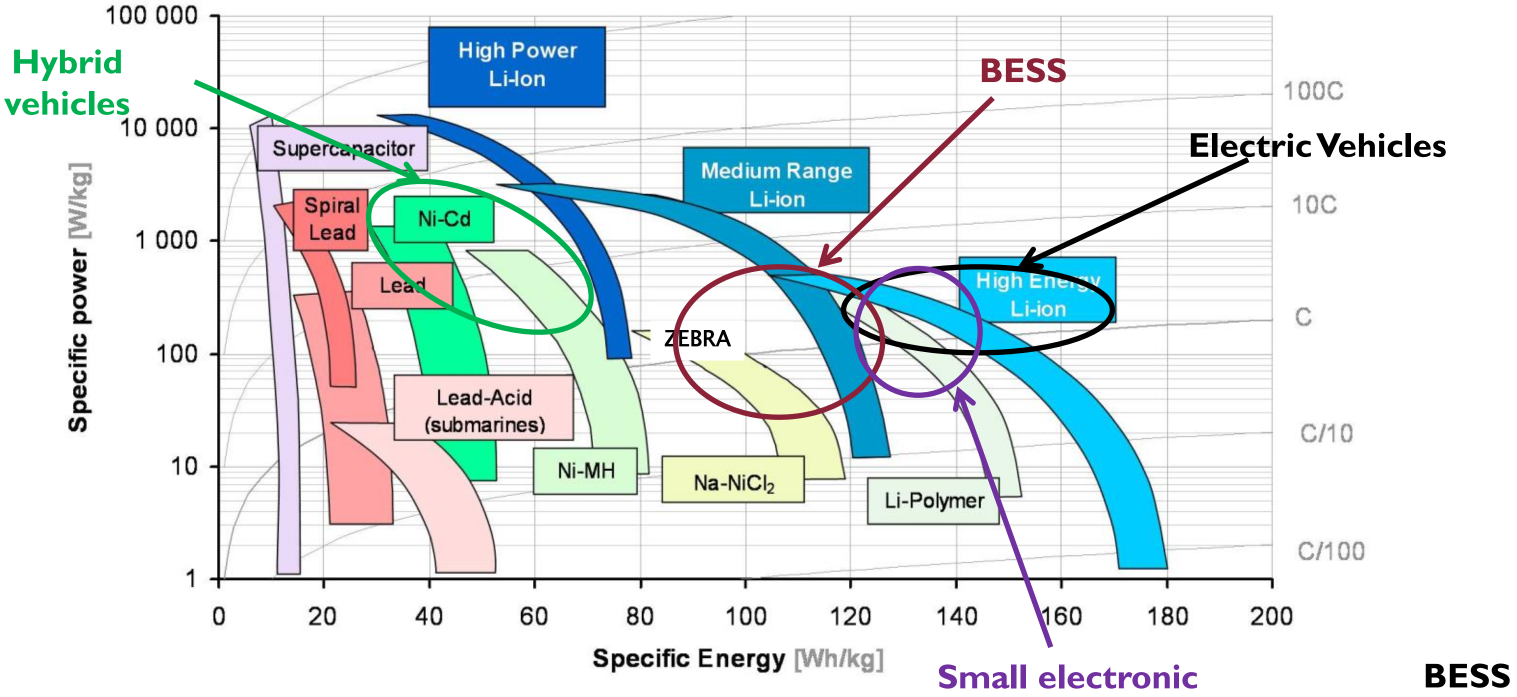


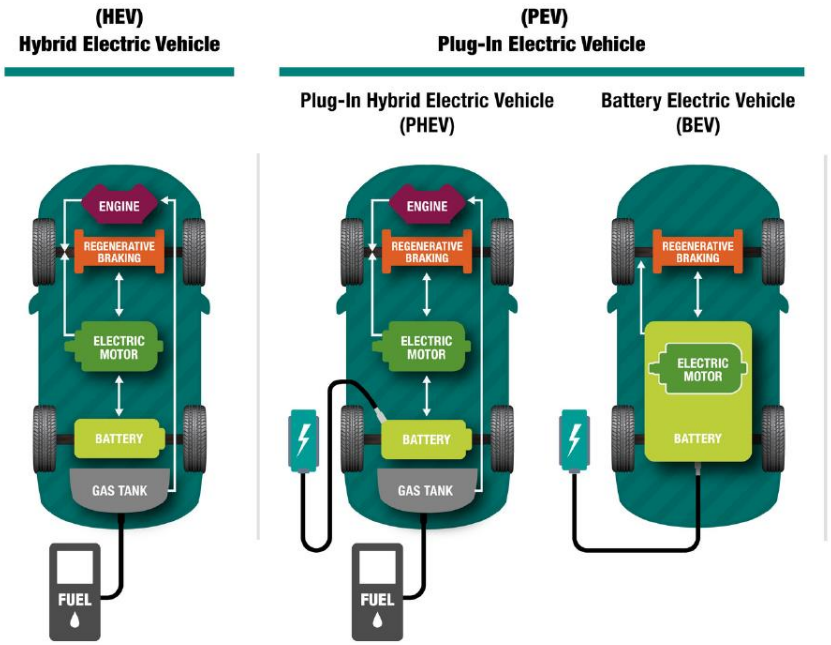
Diagramme de Ragone

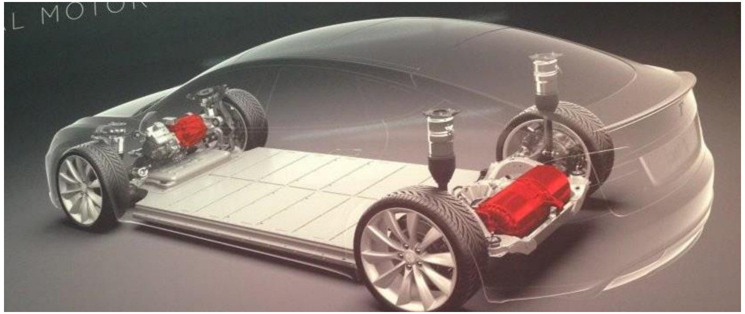
Li-ion batteries for which application ?

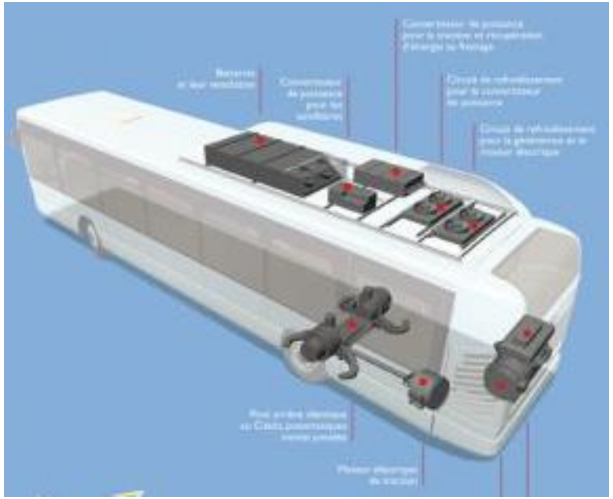
Small electronic
(UN 3481-3091)

Li-ion batteries for which application ?

Electric Vehicles (UN 3556, 3557, 3558)

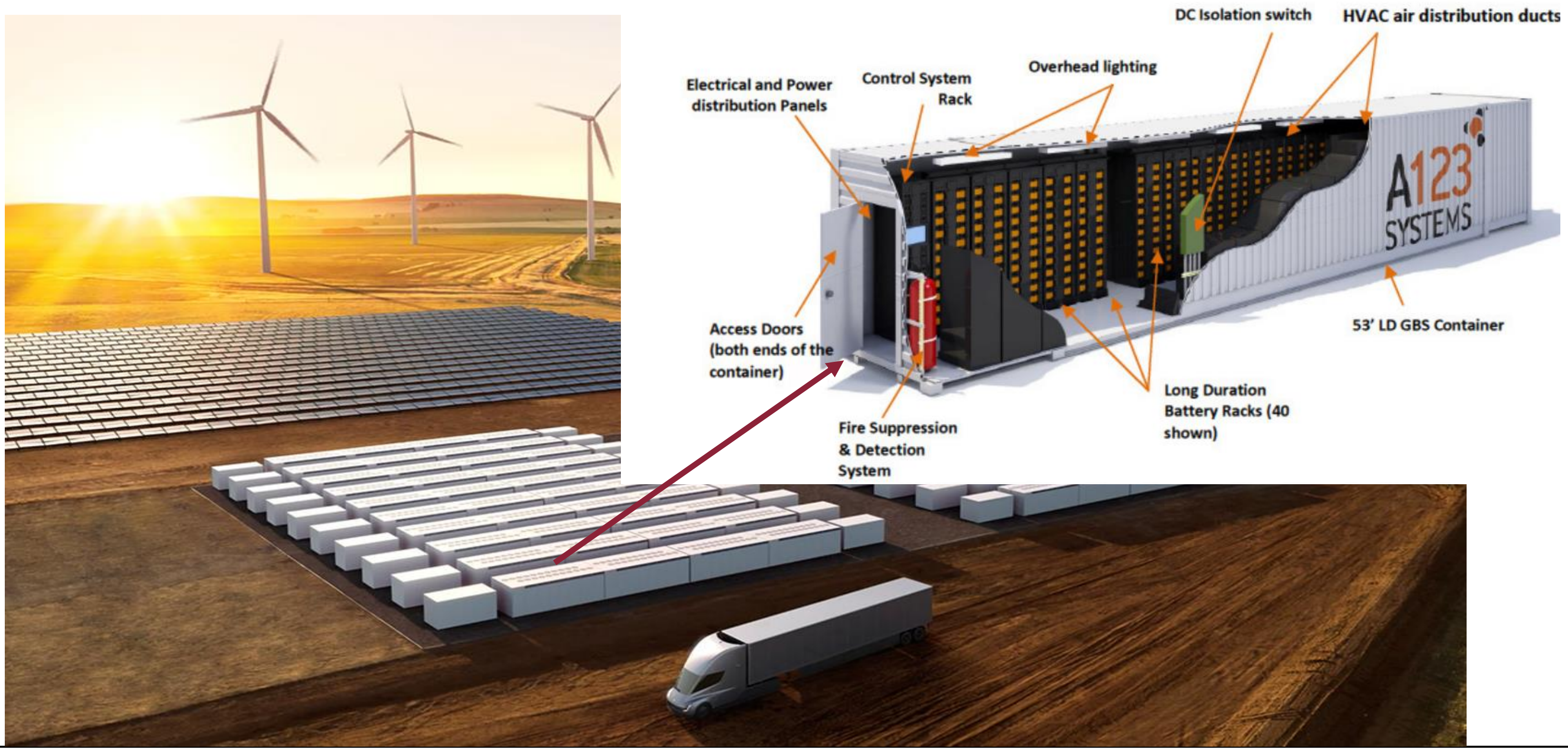






Li-ion batteries for which application ?

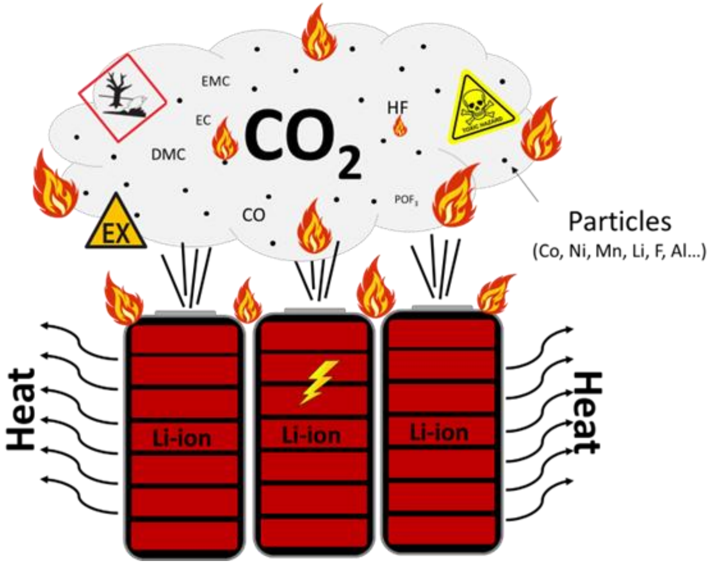
Stationary Storage (UN 3536 *"LITHIUM BATTERIES INSTALLED IN CARGO TRANSPORT UNIT"*)



Why are we here today ?

- Li-ion Batteries are generally safe but can produce dangerous reaction when expose to external abuse :
  - Misused
  - Expose to high temperature
  - Short circuit
  - Drop/crush

- Reaction can be extremely violent and produce specific effects



Why are we here today ?

Why are we here today ?

Why are we here today ?

(Houston 27/07/2017)

RID

Rail

UN model regulation

Aviation

ICAO

Nautic

ADN & code IMDG

Felicity Ace, 2022

Road

ADR

(Jackson 2008)

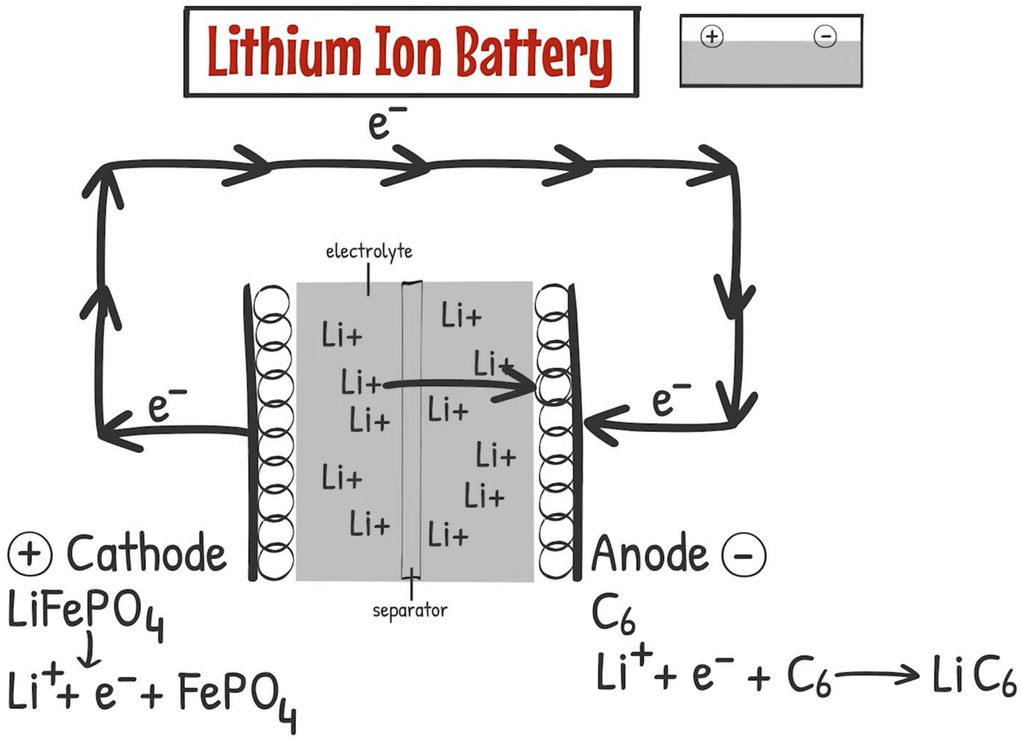
Why are we here today ?

Batteries burn, explode after big rig overturns in San Pedro (youtube.com)

Why are we here today ?

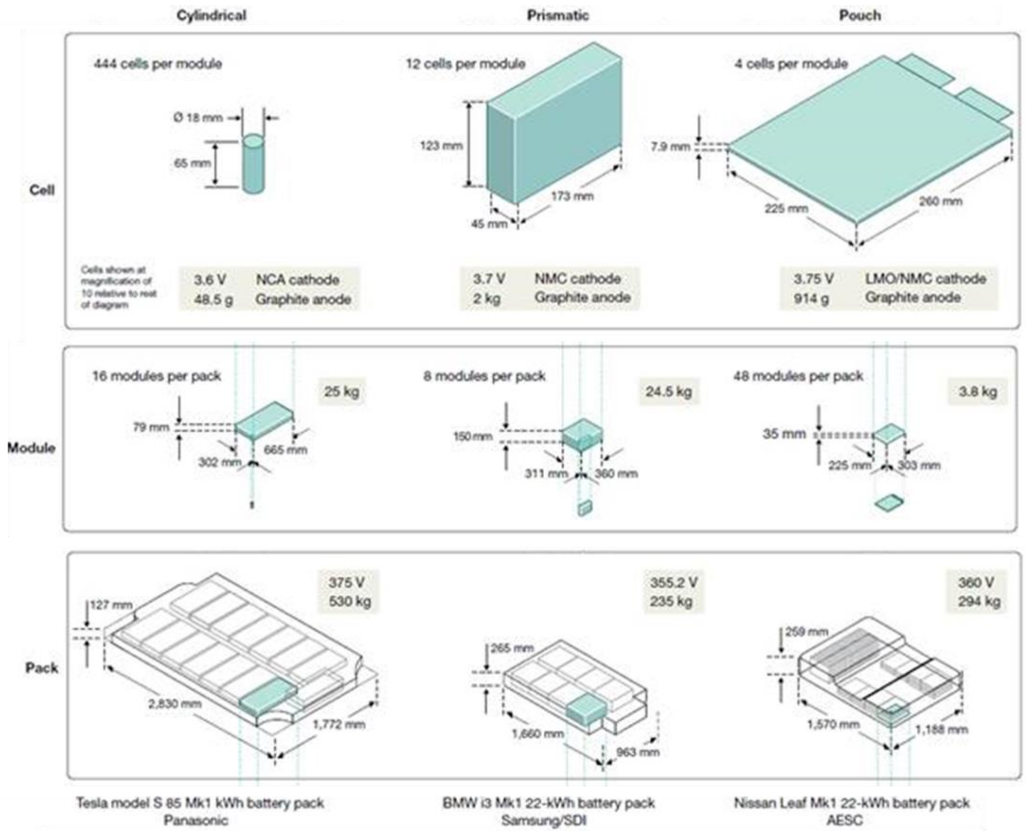
Des batteries au lithium prennent feu dans le port de Montréal

How does a Li-ion battery works ?

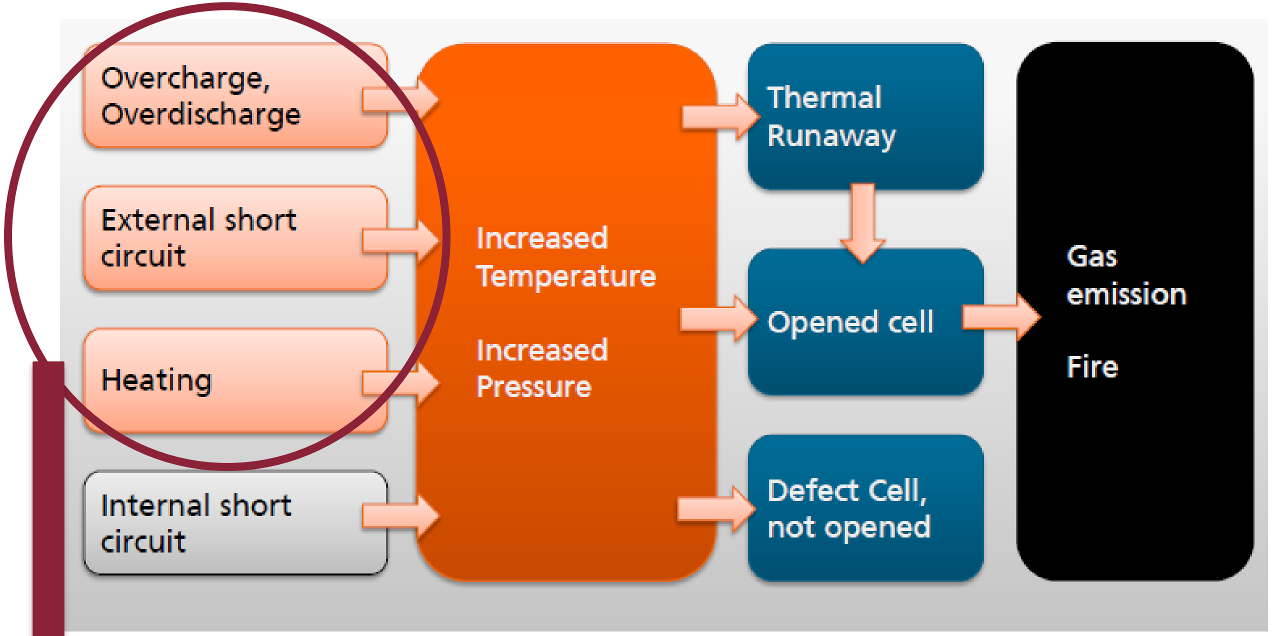


GEOMETRY OF ELECTROCHEMICAL CELLS

- Cells
- Cluster
- Modules
- Pack



LIB thermal runaway phenomenon



Current transport regulation make sure that cell safe limit is not exceeded during normal transport condition through 38.3 tests

UN 38.3 test series

<table>
<tr><th colspan="11">Rechargeable cells and batteries</th></tr>
<tr><th colspan="2"></th><th>T.1</th><th>T.2</th><th>T.3</th><th>T.4</th><th>T.5</th><th>T.6</th><th>T.7[a]</th><th>T.8</th><th>Sum[d]</th></tr>
<tr><td rowspan="4">Cells not transported separately from a battery</td><td>first cycle, 50 % charged state</td><td></td><td></td><td></td><td></td><td></td><td>5</td><td></td><td></td><td rowspan="4">30</td></tr>
<tr><td>25th cycle, 50 % charged state</td><td></td><td></td><td></td><td></td><td></td><td>5</td><td></td><td></td></tr>
<tr><td>first cycle, fully discharged state</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>10</td></tr>
<tr><td>25th cycle, fully discharged state</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>10</td></tr>
<tr><td rowspan="6">Cells</td><td>first cycle, fully charged state</td><td colspan="5">5</td><td></td><td></td><td></td><td rowspan="6">40</td></tr>
<tr><td>25th cycle, fully charged state</td><td colspan="5">5</td><td></td><td></td><td></td></tr>
<tr><td>first cycle, 50 % charged state</td><td></td><td></td><td></td><td></td><td></td><td>5</td><td></td><td></td></tr>
<tr><td>25th cycle, 50 % charged state</td><td></td><td></td><td></td><td></td><td></td><td>5</td><td></td><td></td></tr>
<tr><td>first cycle, fully discharged state</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>10</td></tr>
<tr><td>25th cycle, fully discharged state</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>10</td></tr>
<tr><td rowspan="7">Single cell batteries[b]</td><td>first cycle, fully charged state</td><td colspan="5">5</td><td></td><td>4</td><td></td><td rowspan="7">48</td></tr>
<tr><td>25th cycle, fully charged state</td><td colspan="5">5</td><td></td><td></td><td></td></tr>
<tr><td>first cycle, 50 % charged state</td><td></td><td></td><td></td><td></td><td></td><td>5</td><td></td><td></td></tr>
<tr><td>25th cycle, 50 % charged state</td><td></td><td></td><td></td><td></td><td></td><td>5</td><td></td><td></td></tr>
<tr><td>25th cycle, fully charged state</td><td></td><td></td><td></td><td></td><td></td><td></td><td>4</td><td></td></tr>
<tr><td>first cycle, fully discharged state</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>10</td></tr>
<tr><td>25th cycle, fully discharged state</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>10</td></tr>
<tr><td rowspan="2">Small batteries</td><td>first cycle, fully charged state</td><td colspan="5">4</td><td></td><td>4</td><td></td><td rowspan="2">16</td></tr>
<tr><td>25th cycle, fully charged state</td><td colspan="5">4</td><td></td><td>4</td><td></td></tr>
<tr><td rowspan="2">Large batteries</td><td>first cycle, fully charged state</td><td colspan="5">2</td><td></td><td>2</td><td></td><td rowspan="2">8</td></tr>
<tr><td>25th cycle, fully charged state</td><td colspan="5">2</td><td></td><td>2</td><td></td></tr>
<tr><td>Batteries assembled with tested batteries ≤ 6 200 Wh or ≤500 g Li</td><td>fully charged state</td><td></td><td></td><td colspan="4">1</td><td>1</td><td></td><td>2</td></tr>
<tr><td>Batteries assembled with tested batteries > 6 200 Wh or or >500 g Li[c]</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
</table>

Test Series	Content
T.1	Altitude Simulation
T.2	Thermal Test
T.3	Vibration
T.4	Shock
T.5	External Short Circuit
T.6	Impact/Crush Test
T.7	Overcharge
T.8	Forced Discharge

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Test on LIBs

T1 : Altitude simulation

- <u>Test conditions</u> : storage at a pressure of 11.6 kPa or less for at least six hours at ambient température

- <u>Test criteria</u> : Cells and batteries meet this requirement if there is
  - no leakage,
  - no venting,
  - no disassembly,
  - no rupture,
  - no fire,
  - the open circuit voltage of the cell after testing is not less than 90 % of its initial voltage.

T2 : Thermal test

- Test conditions : six hours at 72 ± 2 °C, followed by six hours at - 40 ± 2 °C. Max 30 minutes between test temperature extremes. Repeated 10 times.
- Test criteria : Cells and batteries meet this requirement if there is
    - no leakage,
    - no venting,
    - no disassembly,
    - no rupture,
    - no fire,
    - the OCV of the cell after testing is not less than 90 % of its initial voltage.

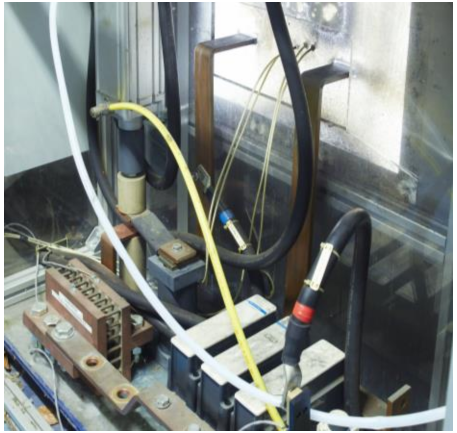
Overheat & Thermal runaway of a group of 6 Na-ion cells

T3-4 : vibration and shock test

- Test conditions (vibration) : Cells and batteries are firmly secured to the platform. The vibration shall be a sinusoidal waveform with a logarithmic sweep between 7 Hz and 200 Hz and back to 7 Hz traversed in 15 minutes. Repeated 12 times.
- Test conditions (shock) : Each cell shall be subjected to a half-sine shock of peak acceleration of 150 g_n and pulse duration of 6 milliseconds.

- Test criteria : Cells and batteries meet this requirement if there is
  - no leakage,
  - no venting,
  - no disassembly,
  - no rupture,
  - no fire,
  - OCV not less than 90 %

T5 : External short circuit test



- Test conditions : The cell at 57 ± 4 °C shall be subjected to short circuit with an external resistance of less than 0.1 ohm.

- Test criteria : Cells meet this requirement if
  - their external temperature inf to 170 °C
  - no disassembly,
  - no rupture
  - no fire.

  } for 6 hours

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T6 : Impact/crush test

- Test conditions : A bar of diameter 15.8 mm, and length at least 6 cm long (or the longest dimension of the cell), is to be placed across the center of the sample. A 9.1 kg ± 0.1kg mass is dropped from a height of 61 ± 2.5 c

- Test criteria : Cells meet this requirement if
  - their external temperature inf to 170 °C
  - no disassembly
  - no fire during

  } for 6 hours

T7-8 : Overcharge and overdischarge test

- <u>Test conditions</u> (overcharge) : The charge current shall be twice the manufacturer's recommended maximum continuous charge current. The minimum voltage of the test shall be as follows:
- <u>Test conditions</u> (overdischarge) : Each cell shall be forced discharged at ambient temperature by connecting it in series with a 12V D.C. power supply at an initial current equal to the maximum discharge current specified by the manufacturer.

- <u>Test criteria</u> : Cells meet this requirement if
  - no disassembly
  - no fire during

  } for 7 days

Overcharge of a pouch cell

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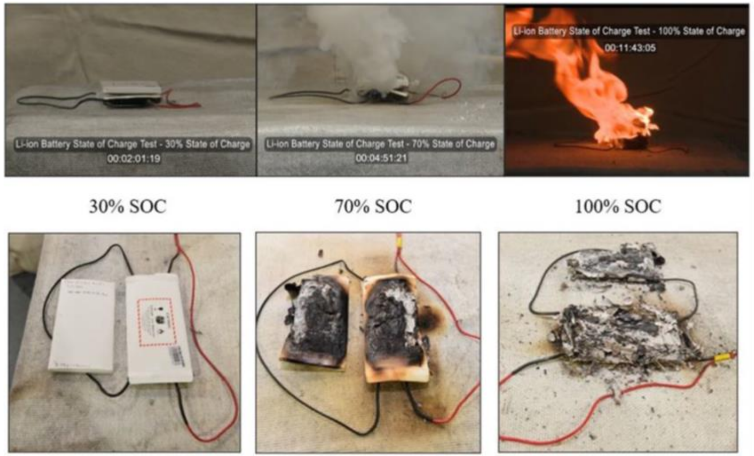
Limits of the current regulation

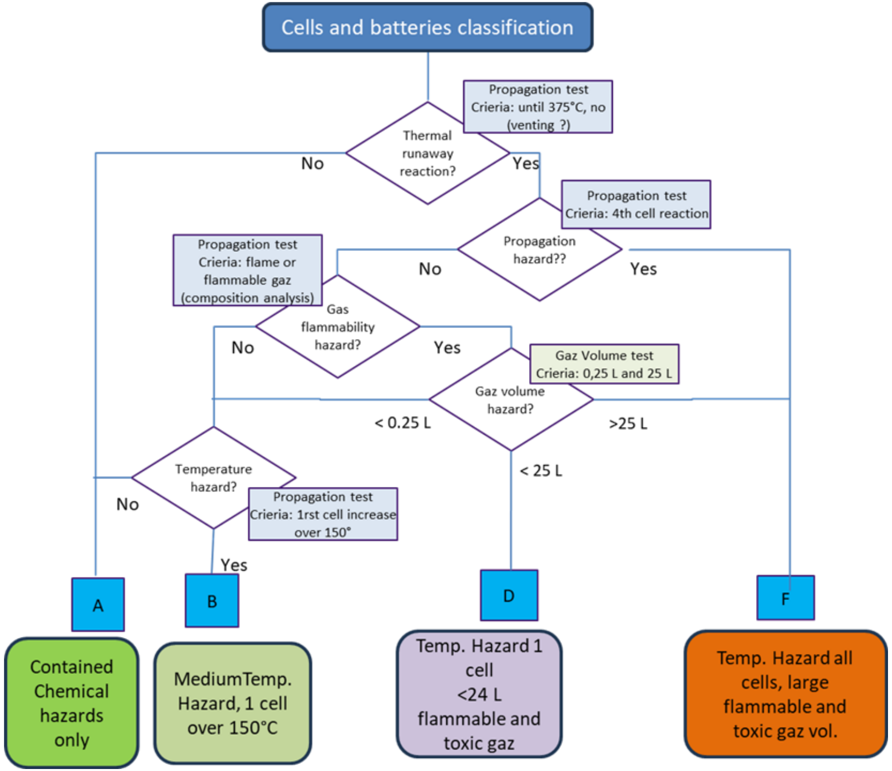
- One size fits all
- State of charge is not taken into account
- Internal short circuit is not really taken into account (except for the quality control obligation)
- Propagation properties are not considered



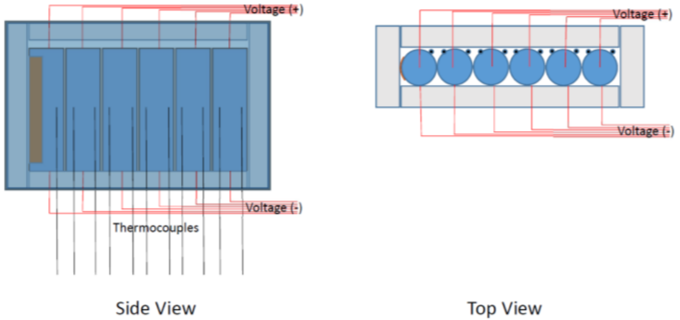
New regulation approach will take this into account as well as other critical hazard (Fire, gas generation)

Propagation of the thermal runaway

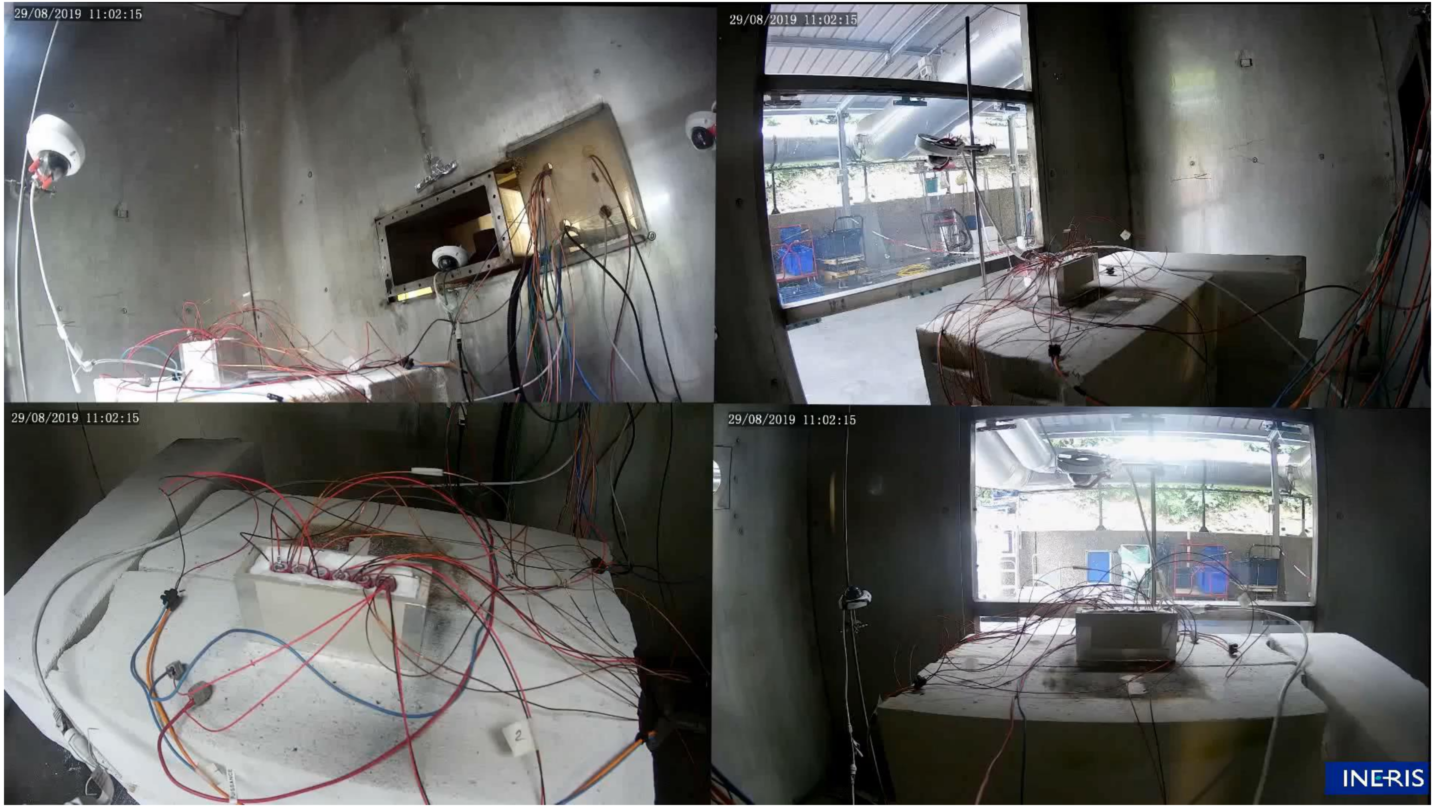
Hazard based classification scheme



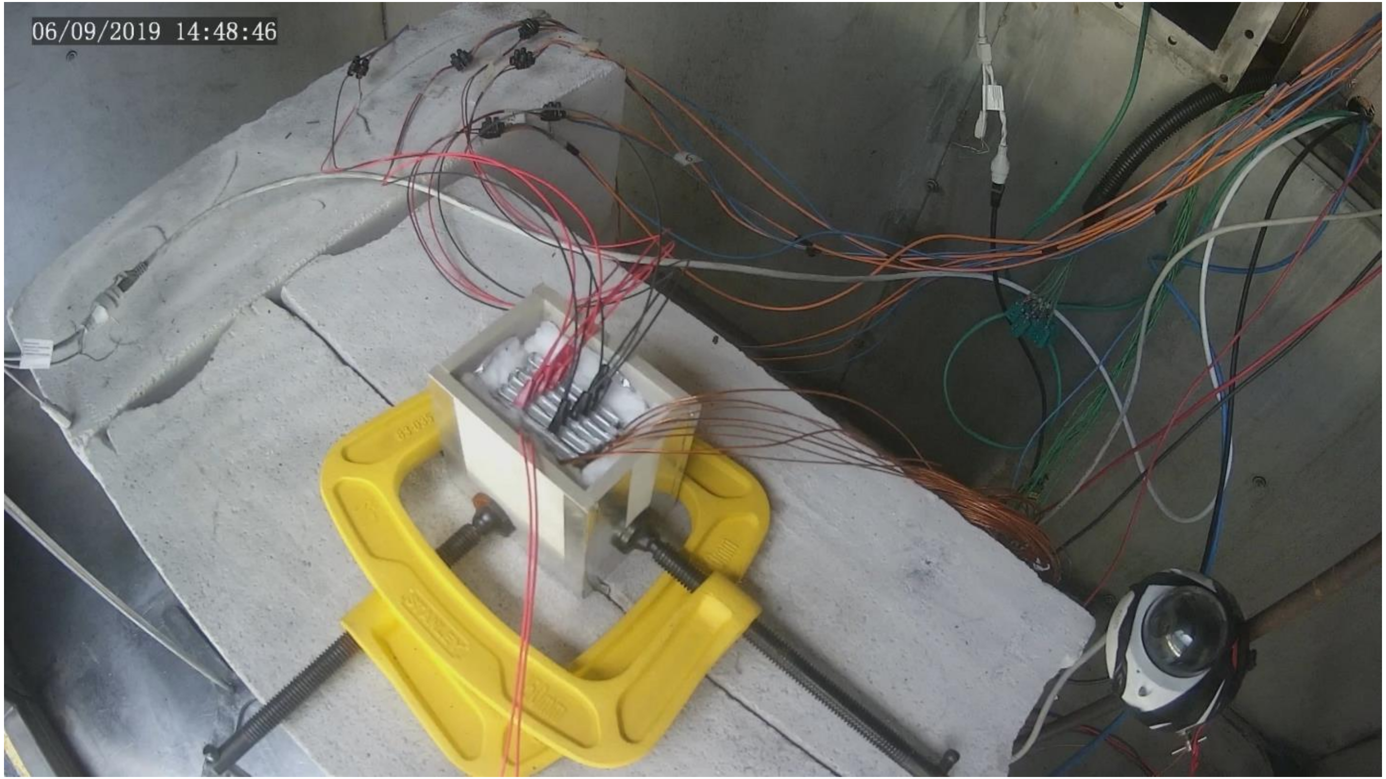
Test set up



Thermal propagation of 6 Li-ion 18650 cells



Thermal propagation of 6 Li-ion pouch cells



Thermal propagation in a pouch cell module

Conclusions

- **Various type of batteries are transported (Ni-Cd, lead-acid, NiMH, Li-ion, Li-metal, Na-ion...)**
- **Li-ion batteries are generally safe**
- **In abusive condition or because of poor quality LIB can produce dangerous reactions**
- **Current UN regulations ensure LIB transport safety through a series of tests**
- **Current regulation is "one size fits all"**
- **Future regulation will discriminate batteries according to they hazard (eg : propagation, fire, flammable gas)**
- **Future regulation will allow to consider State Of Charge in transport condition**

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Thank you for your attention

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