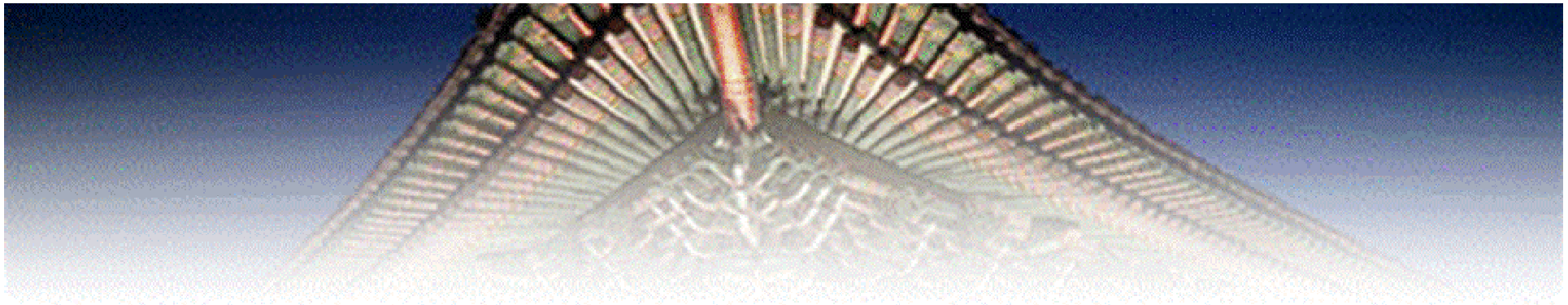

Advanced Function Approach for analyzing multivariable system

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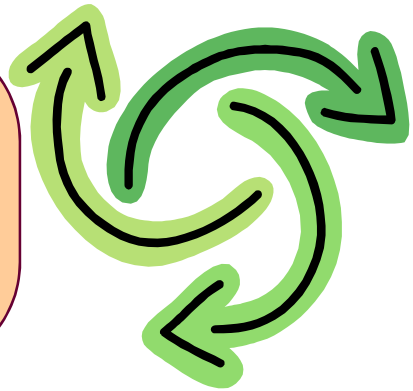
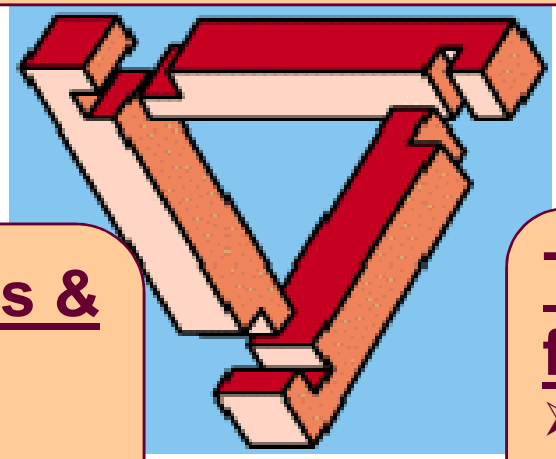
Methodological background

Advanced Function Approach

connected the concepts of :

- space (place of function performance)
- time (time of function performance)
- harmful effects mapping (functional disadvantages)





Combined analysis & synthesis:

- separated analysis by inventive fields (*Me-Th-Ch-EM*)
- following inter-cross-linking in failure scenarios

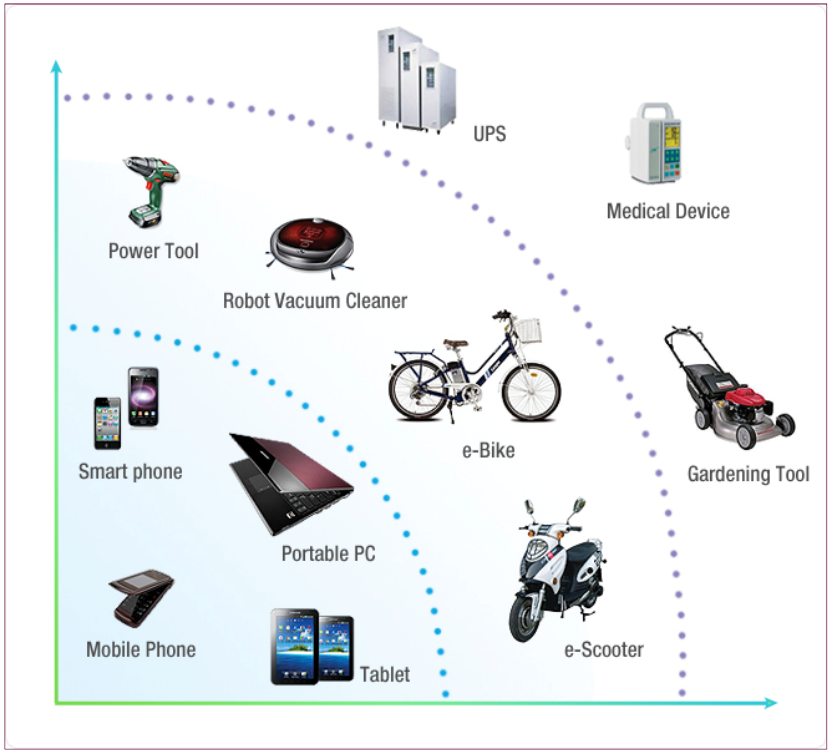
MeThChEM

Trifurcated problem formulation:

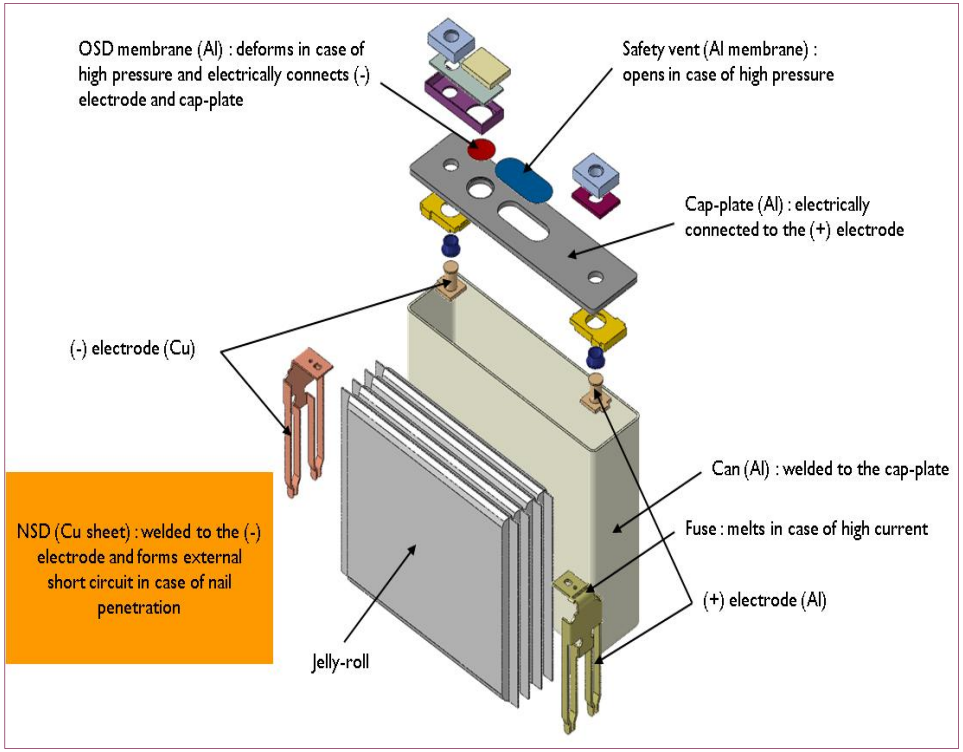
- how to prevent
- how to transform
- how to correct

Case Study: Li Ion Battery (LIB) – brief description

LIB are very popular types of battery for many applications



LIB have safety features integrated in to the cell itself



http://www.samsungsdi.com/battery/rechargeable-battery.jsp

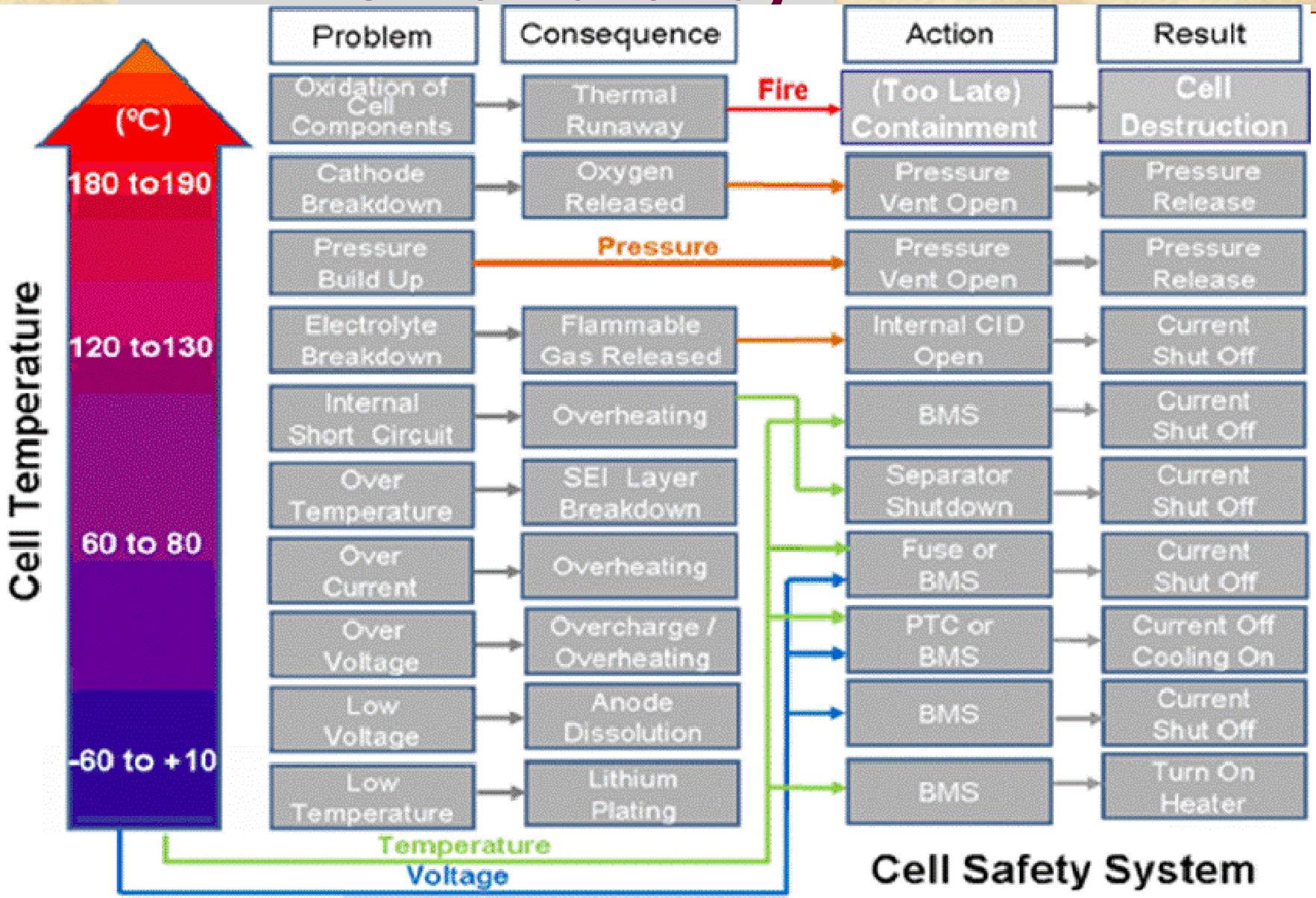
Nail Penetration Test at glance

Illustration video fragments:

http://www.youtube.com/watch?v=f30fBFitkSM

http://www.youtube.com/watch?v=2xtmBJ9X8Y8

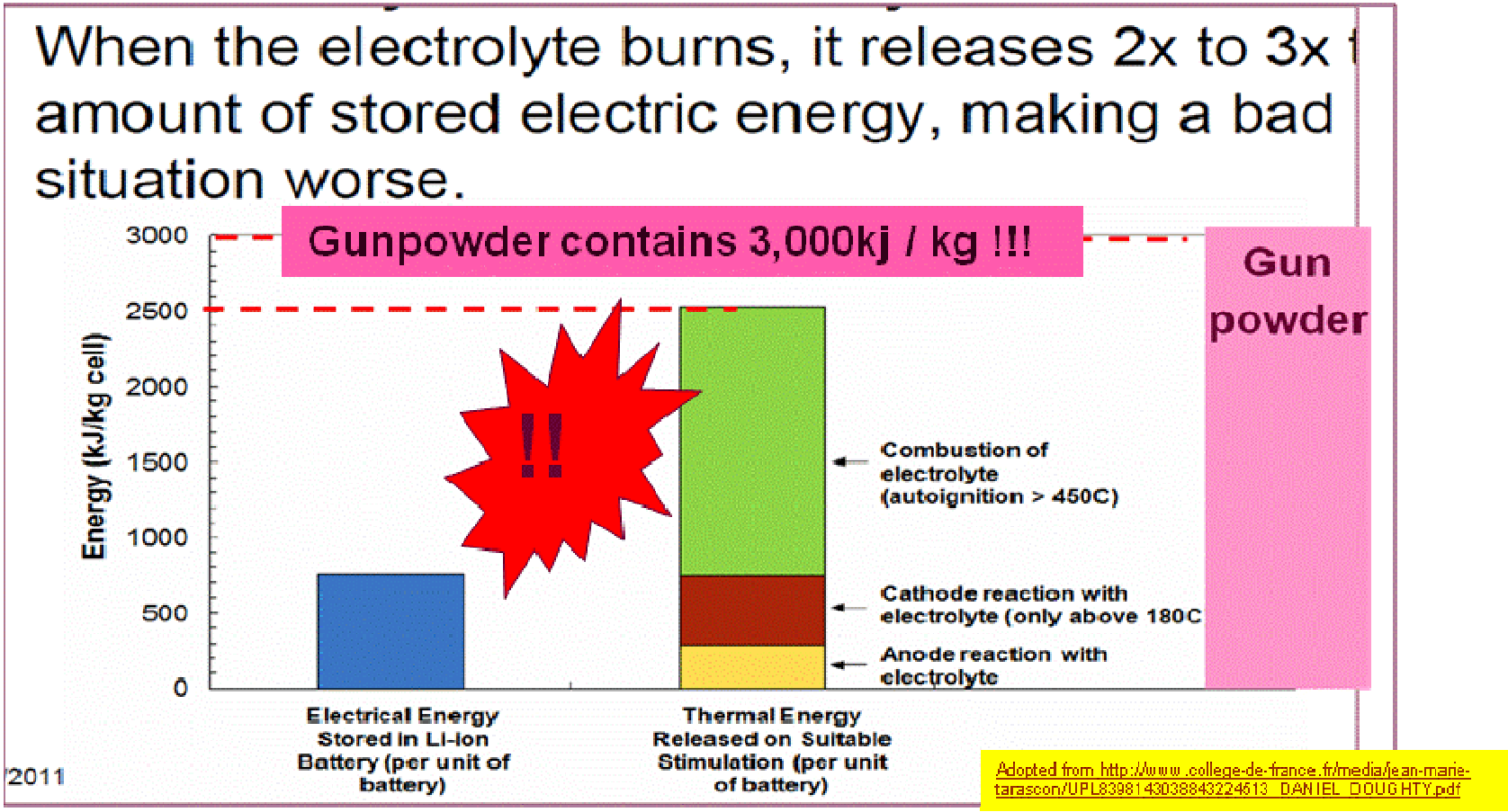
LIB: Thermal runaway



Source: http://www.mpoweruk.com/safety.htm#separators

Why battery safety problem need new approach?

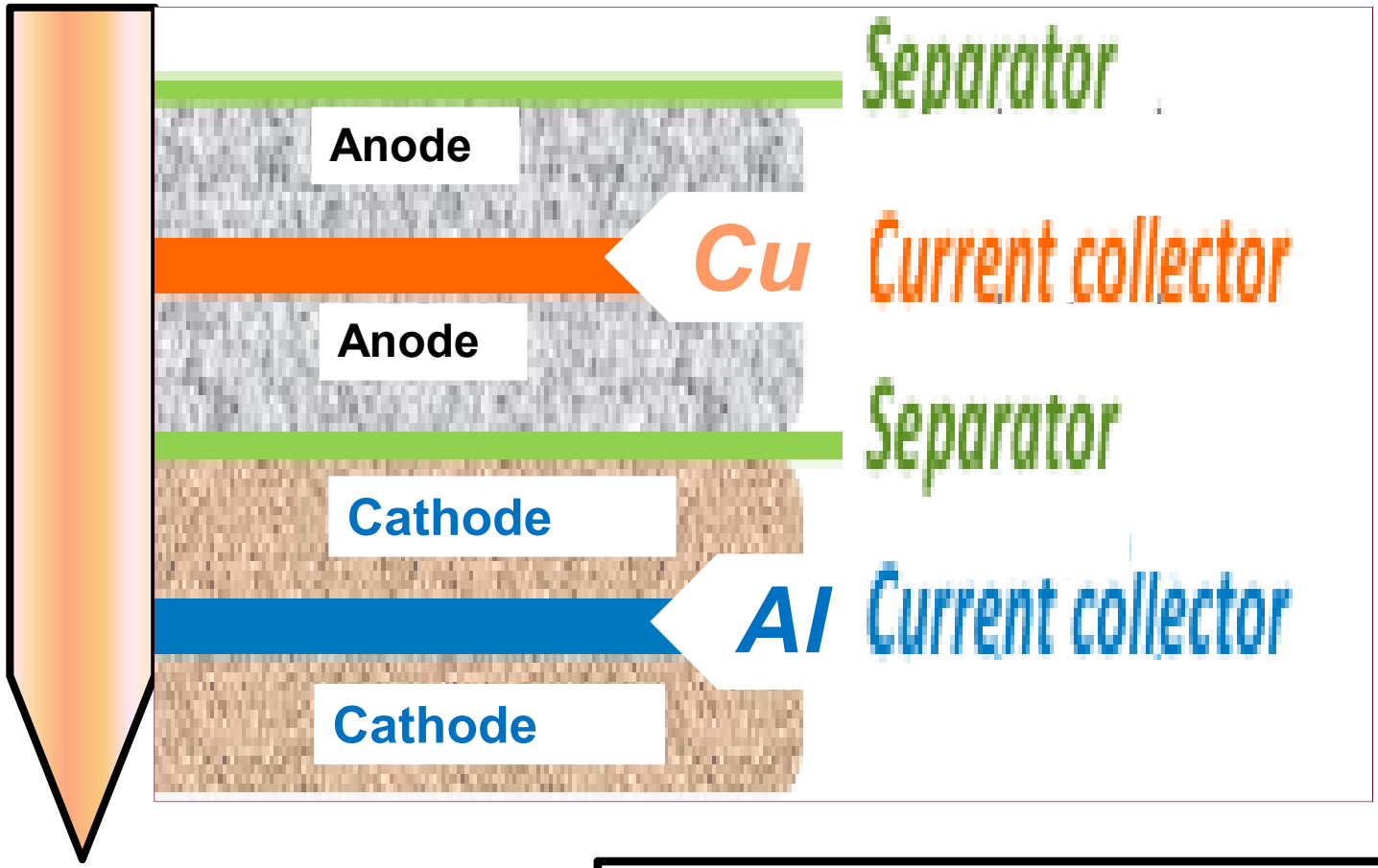
When the electrolyte burns, it releases 2x to 3x t
amount of stored electric energy, making a bad
situation worse.

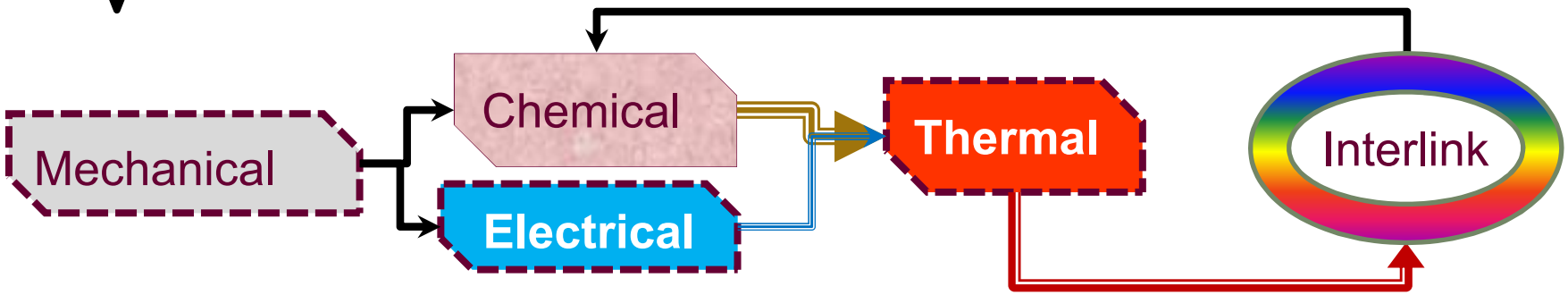


Adopted from http://www.college-de-france.fr/media/jean-marie-tarascon/UPL8398143038843224613_DANIEL_DOUGHTY.pdf

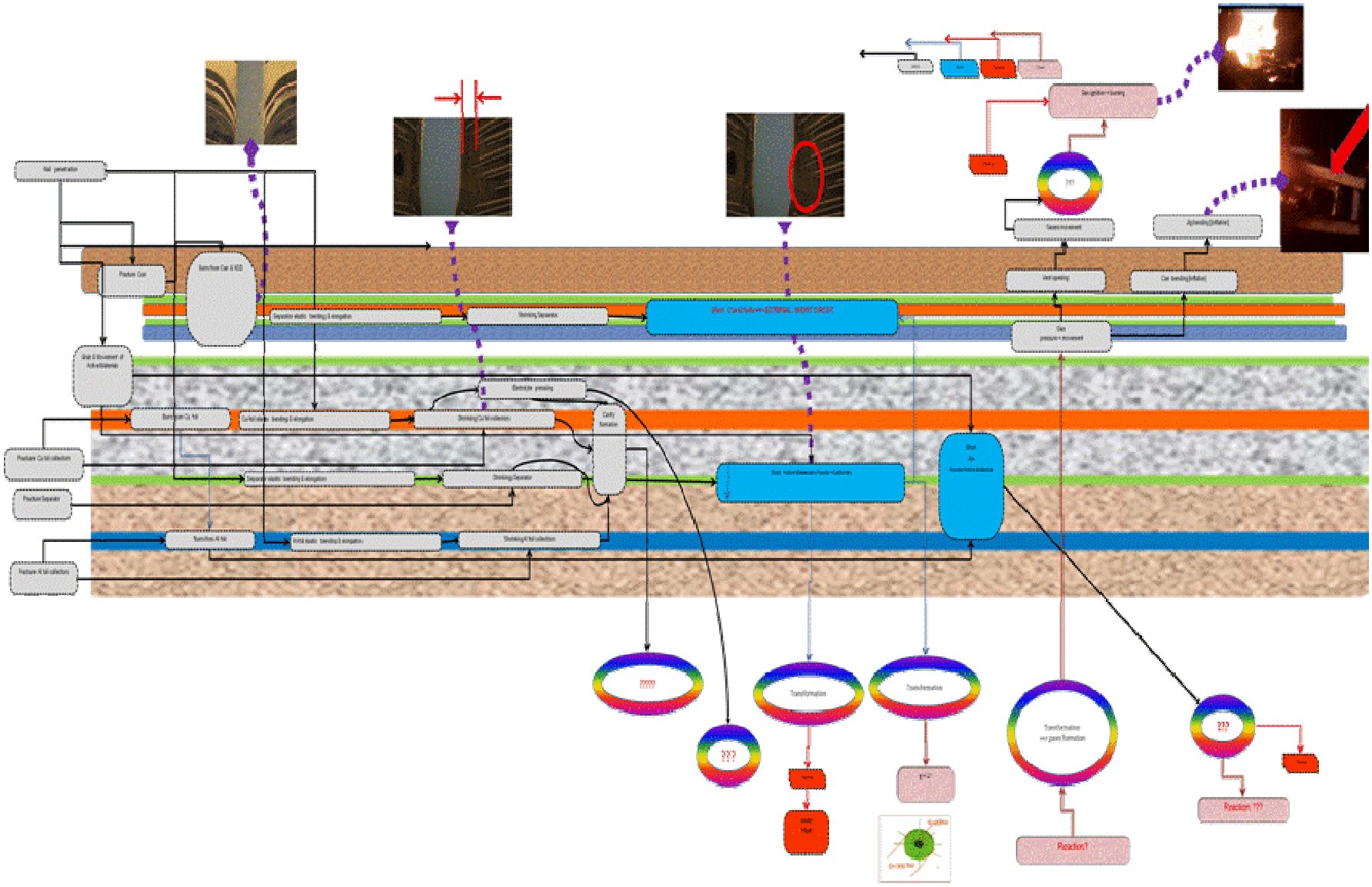
Thermal runaway ~ explosive process

Notation

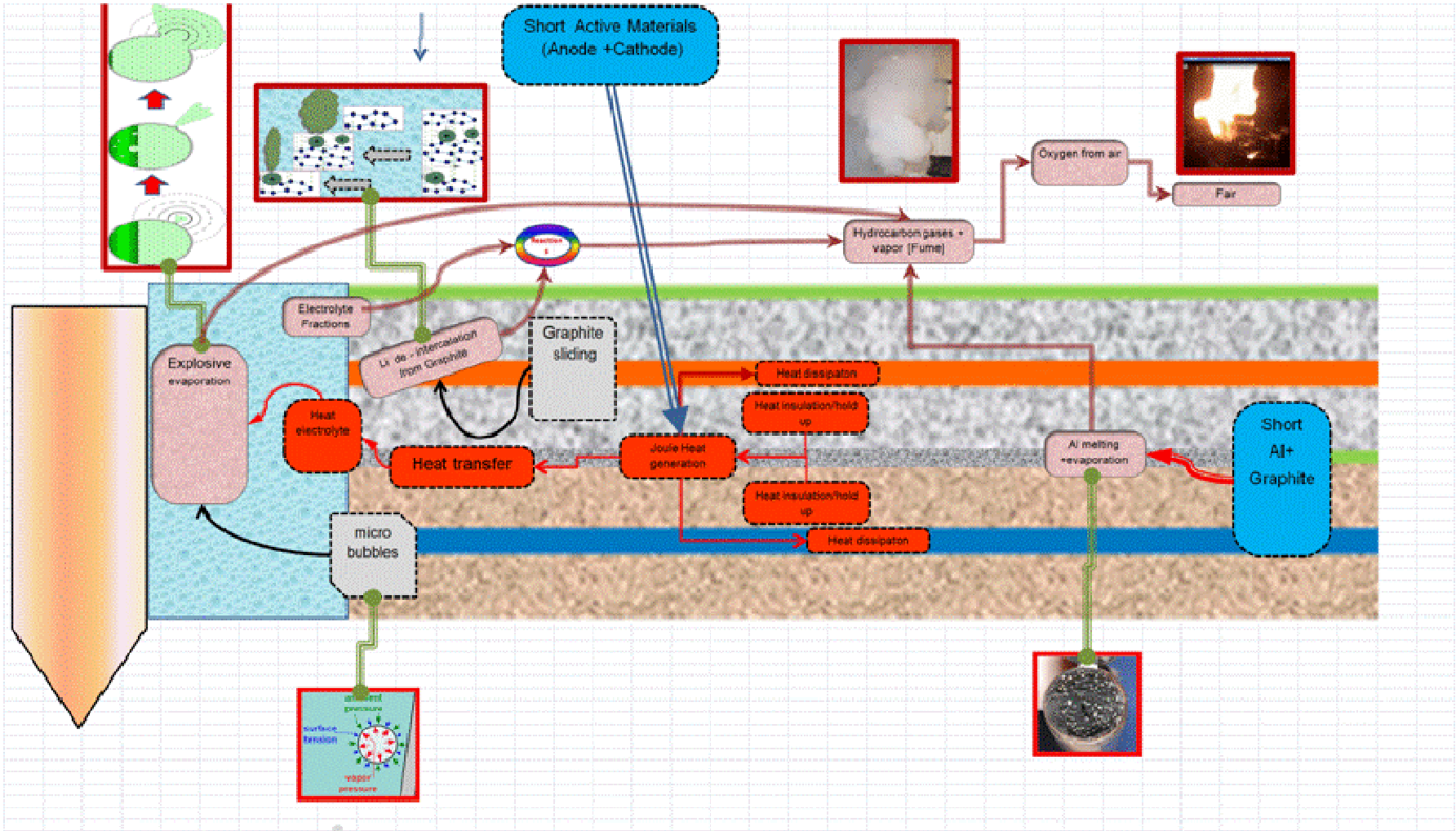

Separator
Anode
Cu
Current collector
Anode
Separator
Cathode
Al
Current collector
Cathode


Mechanical
Chemical
Electrical
Thermal
Interlink

Mechanical & electrical processes and interlinks(fragment_1)

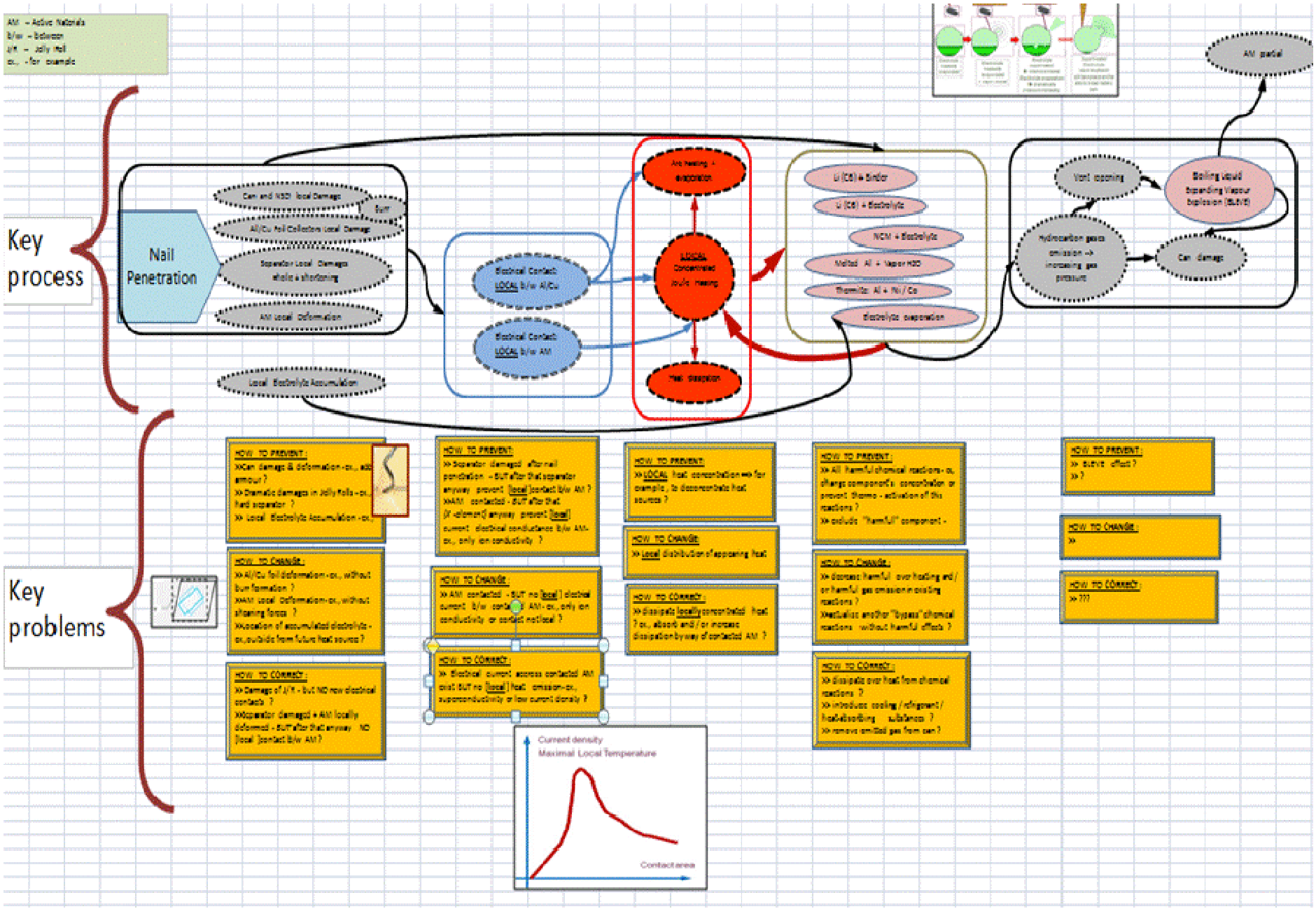


Thermal & chemical processes and interlinks (fragment_2)

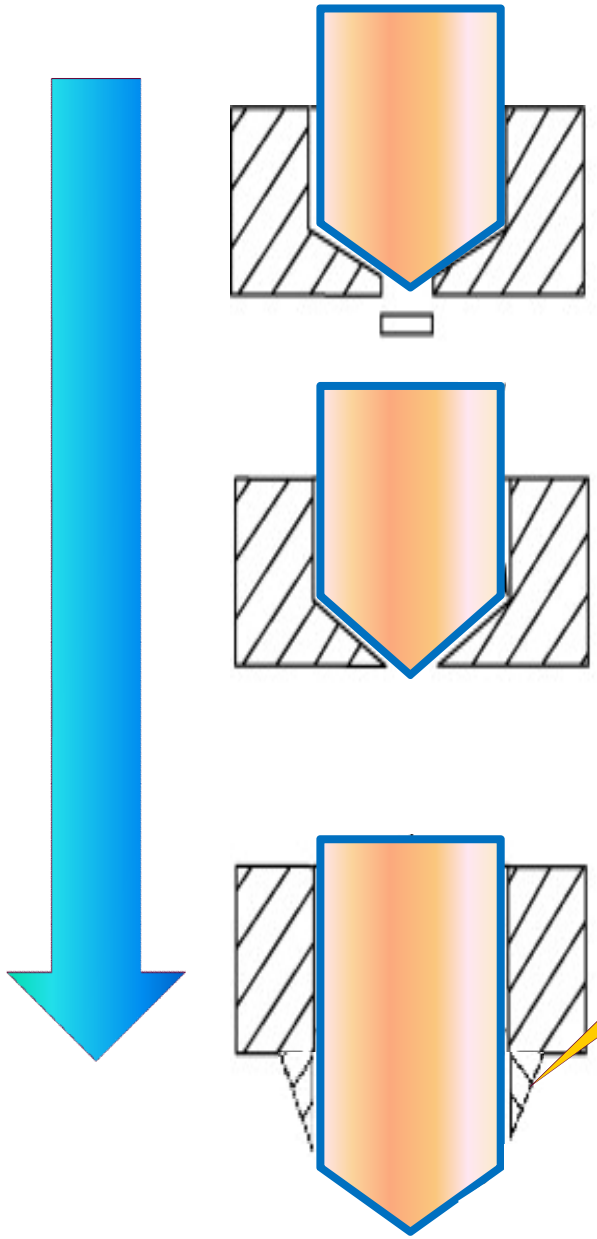


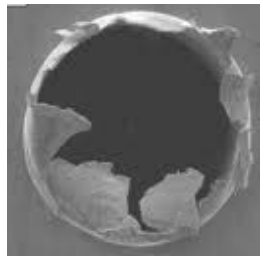
10

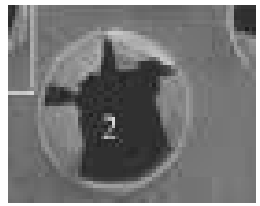
Key processes and problem formulation (fragment)



11 Example 1: Schematic burr formation



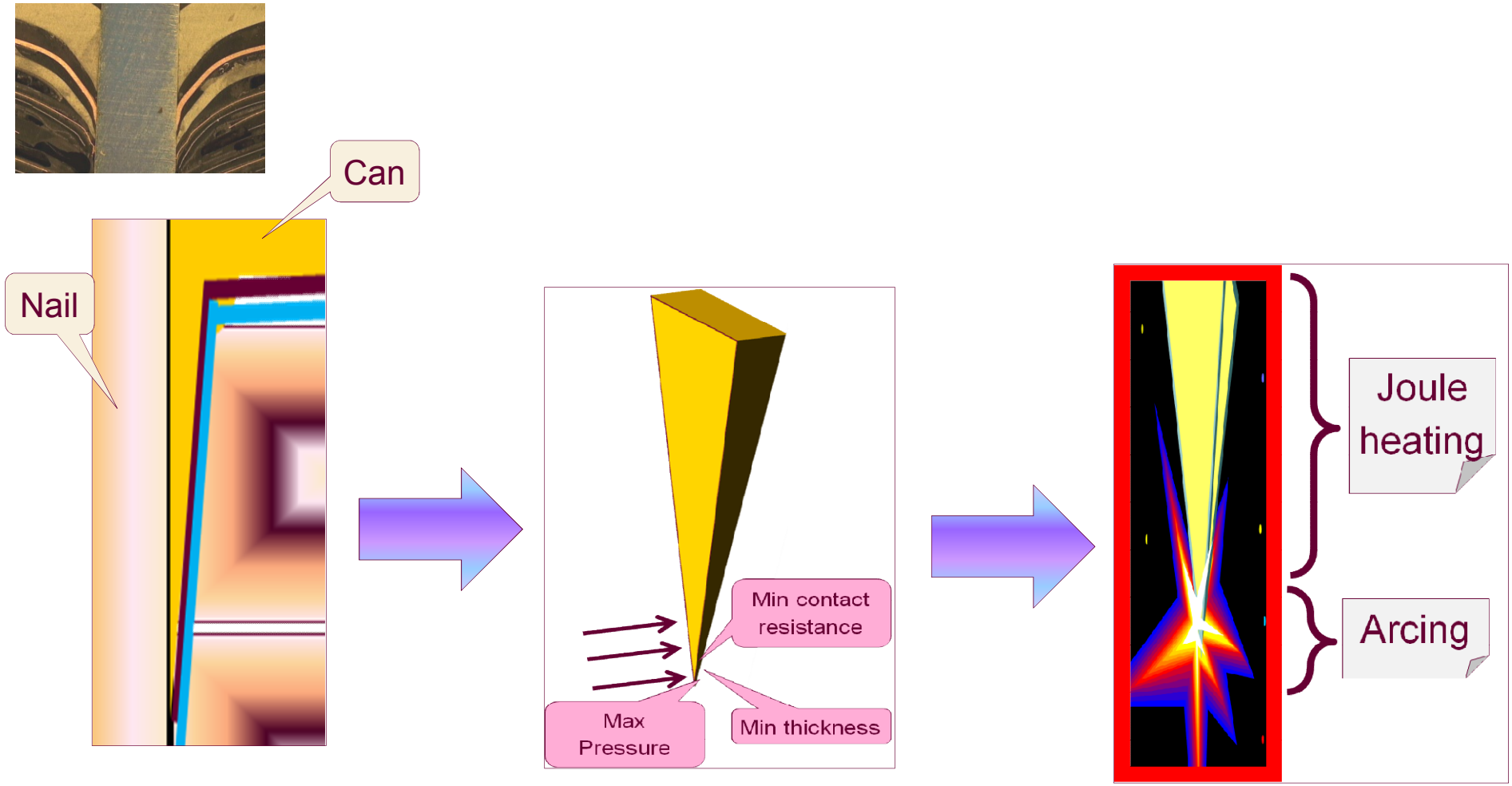




Burr

We can to see burrs in bottom wall of battery can after Nail Penetration Test

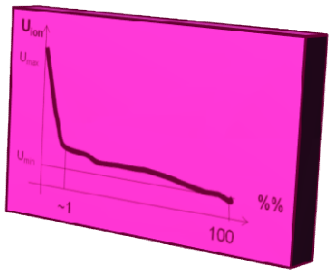
Example 1: Burrs + electric current is possible reason of arc initiation



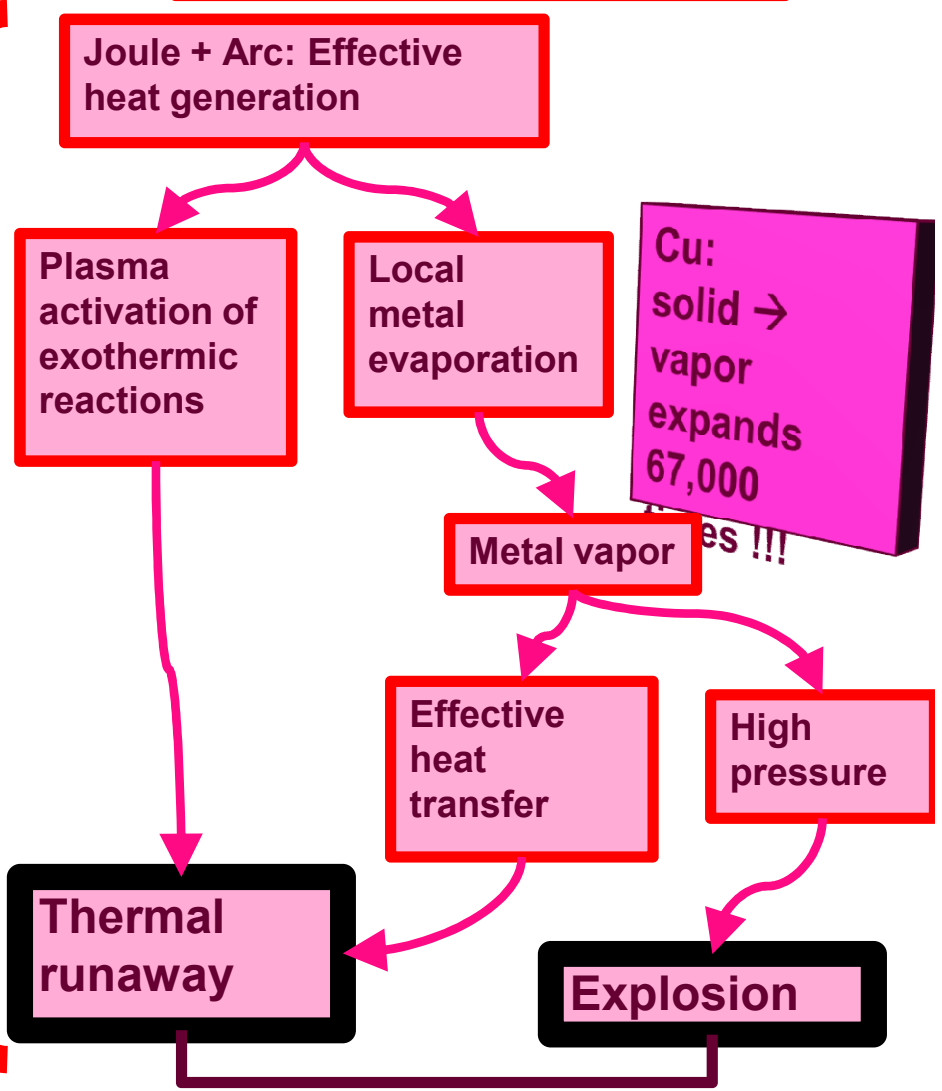
Example 1: Burr + Arcing. Conditions and harmful effects

Conditions

- Burr formation → multiple short-circuit
- Voltage ~3…4 V → as much as necessary for unstable arc
- Electrical current ~ 10…100 A
- Easy ionizing additives → Li; Al



Harmful effects

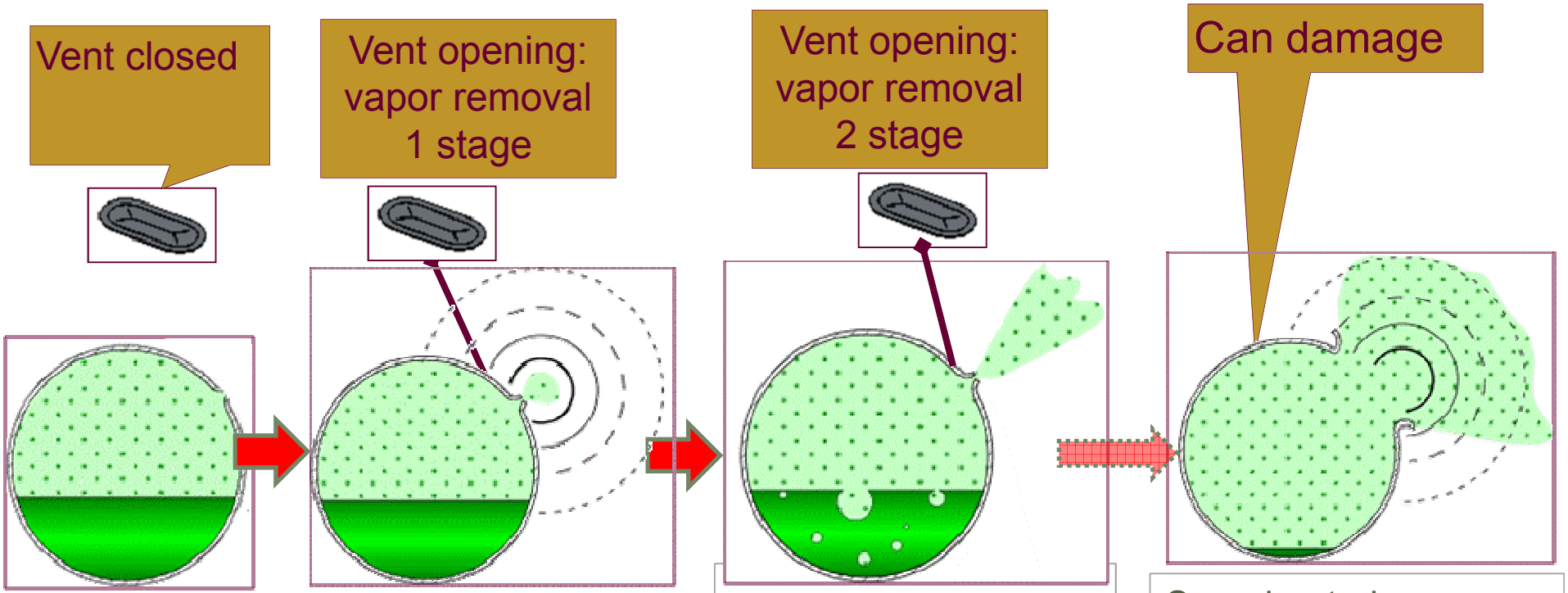


Example 2: Why BLEVE in Li ion battery?

Most important physical processes are similar
in BLEVE *(Boiling Liquid Expanding Vapour Explosion)* **effects**
and in LIB's Nail Penetration Test

Vessel / vent →	←Can / vent
External overheating →	← Internal overheating
Gas overpressure jet →	← Vapor steam jet
Explosion of vessel →	← Can rupture
Fireball out vessel →	← Flame outside LIB

Example 2: *Boiling Liquid Expanding Vapour Explosion (BLEVE)* : illustration for LIB



Brief summary

① New compilative approach based on *Advanced Functional Approach* is developed for complex engineering system application

② We verified proposed approach for Li-ion battery safety problems and showed its usefulness for identification new previously unexplored factors, mechanisms and scenarios of thermal runaway in Li-ion battery

③ Based on the results of analytical procedures ~ 30+ different conceptual solutions have been developed for improving safety of lithium-ion batteries. Concepts have been successfully validated, verified and tested