

# *Advanced Function Approach* for analyzing multivariable system

Naum Feygenson

BongKyoung Park

Corporate R&D Center/Technology Planning Group,

SAMSUNG SDI Co. LTD;

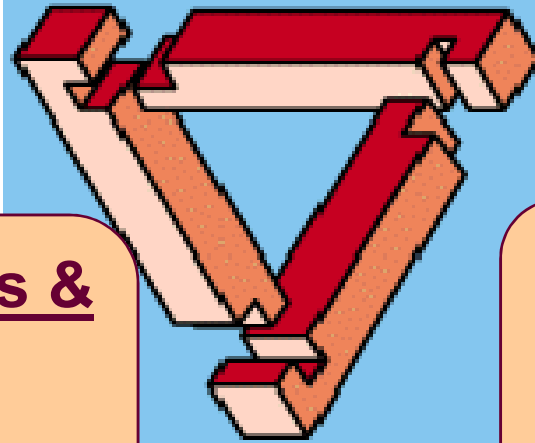
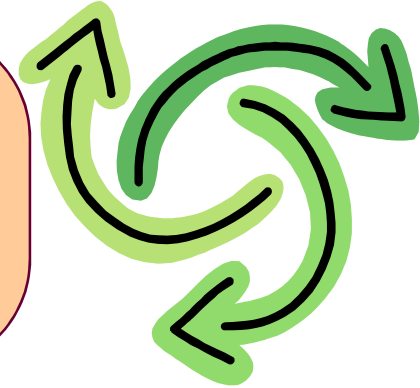
Suwon, South Korea

## 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

### Trifurcated problem formulation:

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

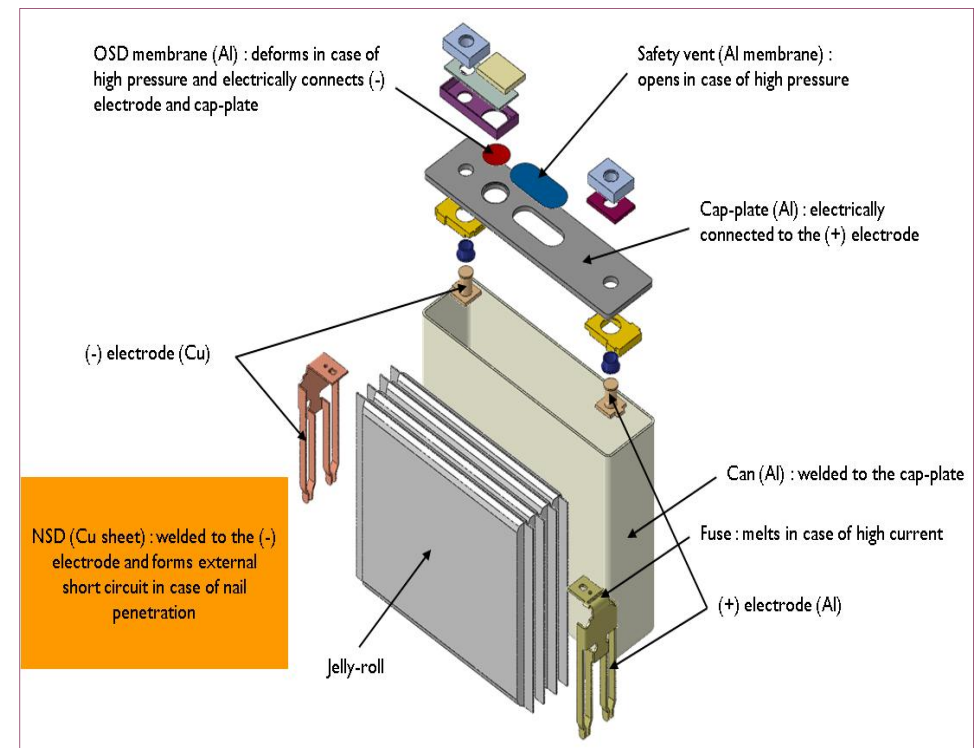


## Case Study: Li Ion Battery (LIB) – brief description

LIB are very popular types of battery for many applications



LIB have safety features integrated in to the cell itself



## Nail Penetration Test at glance

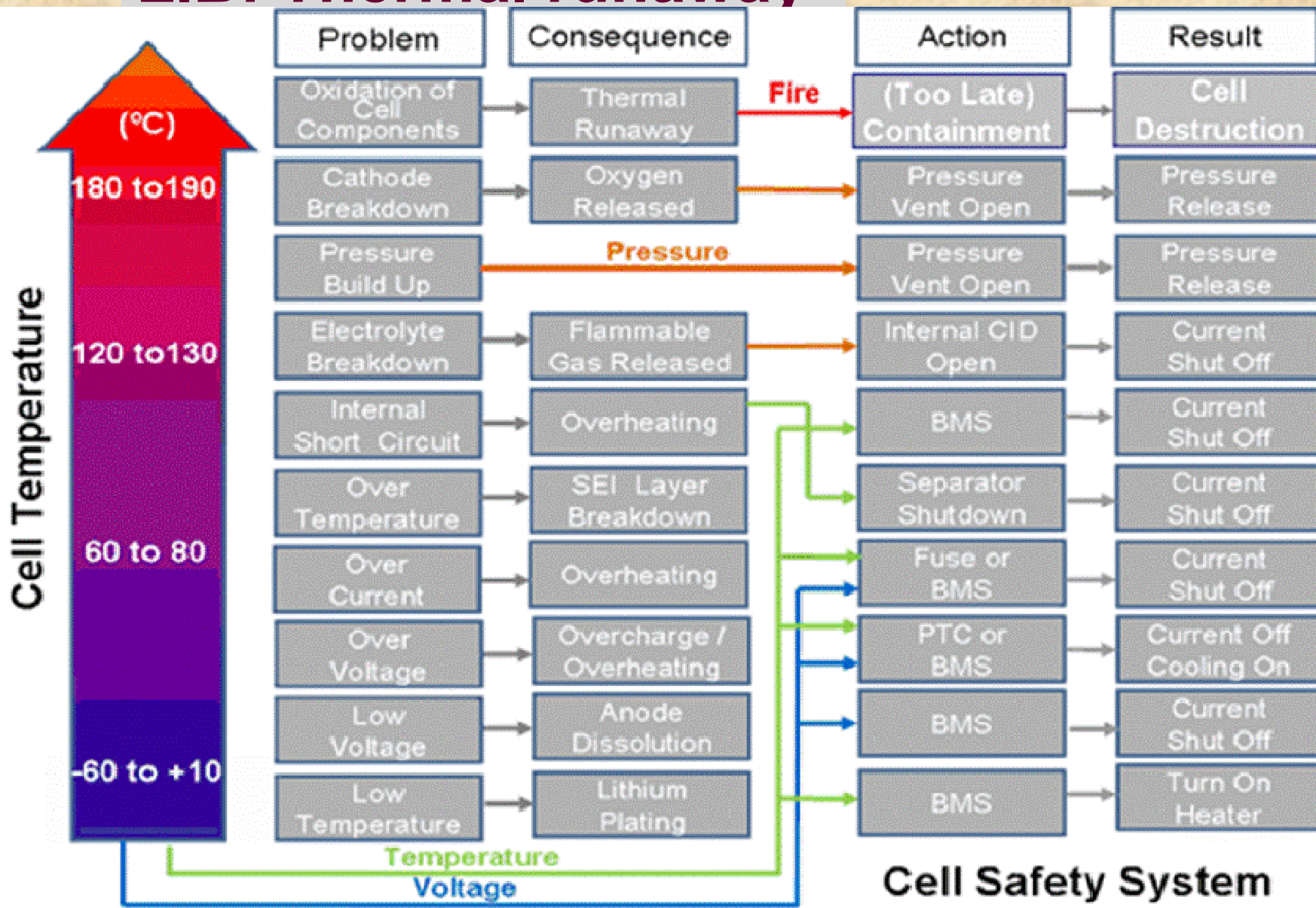


**Illustration video fragments:**

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

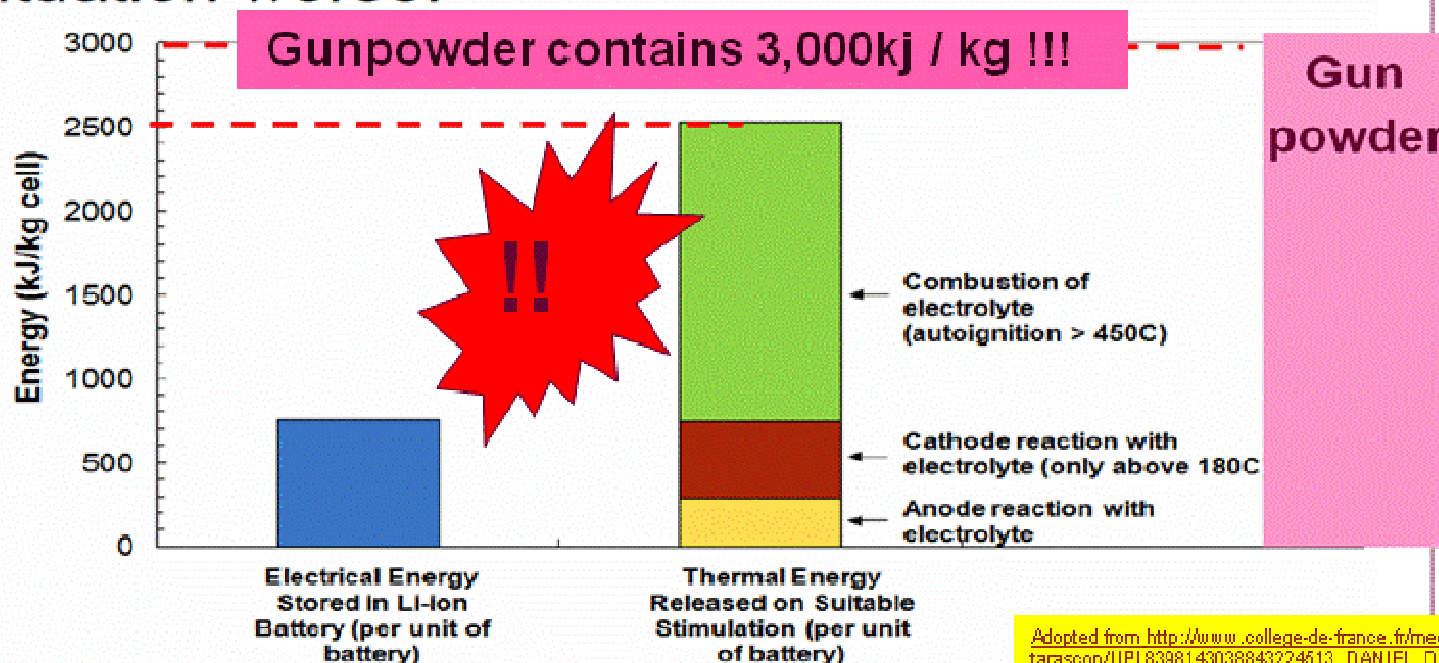
<http://www.youtube.com/watch?v=2xtmBJ9X8Y8>

# LIB: Thermal runaway



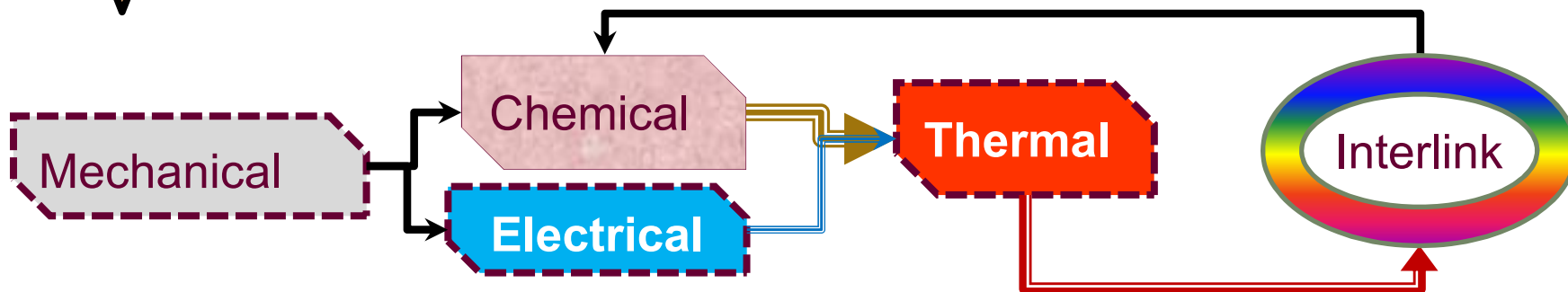
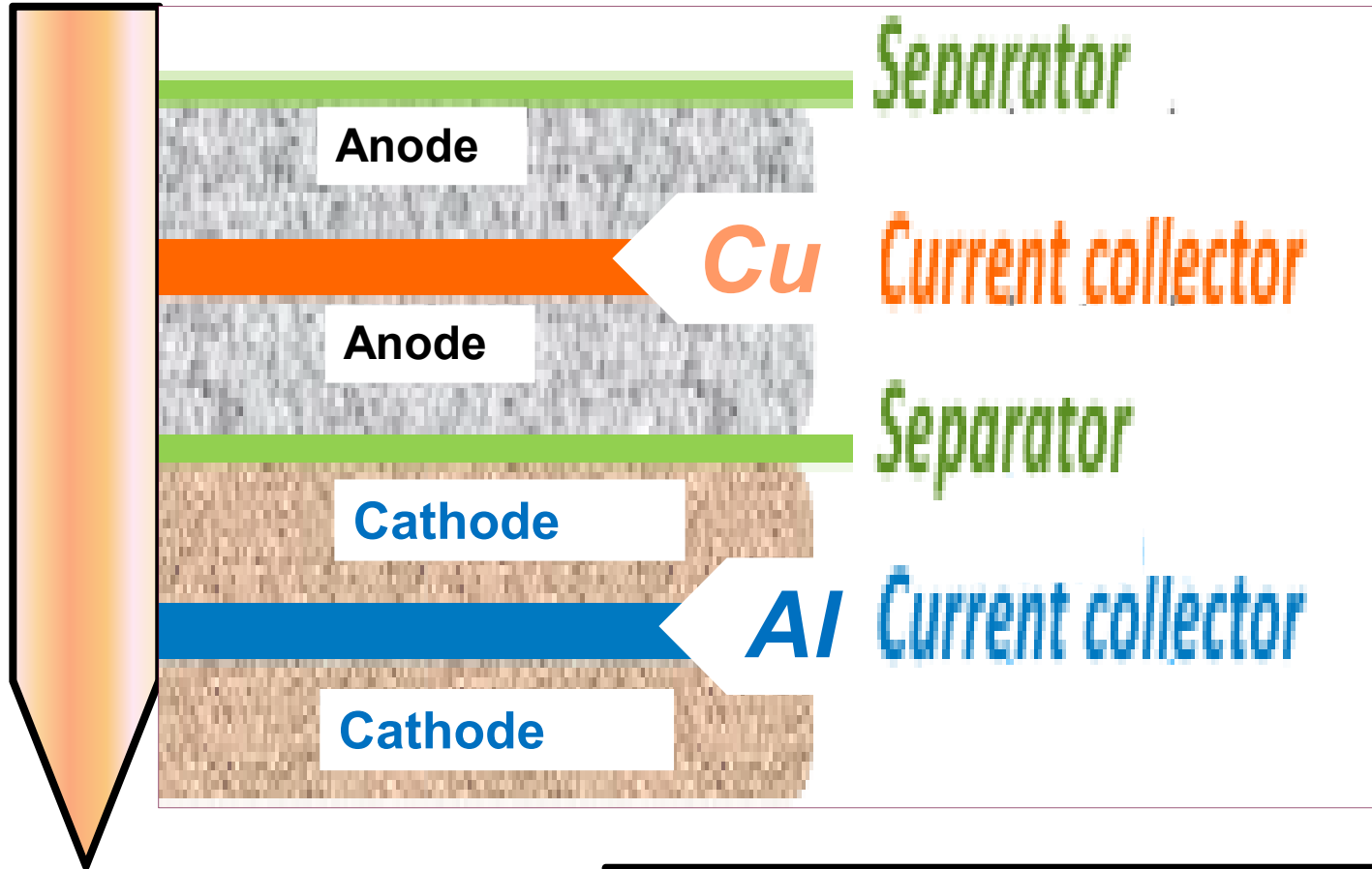
## Why battery safety problem need new approach?

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

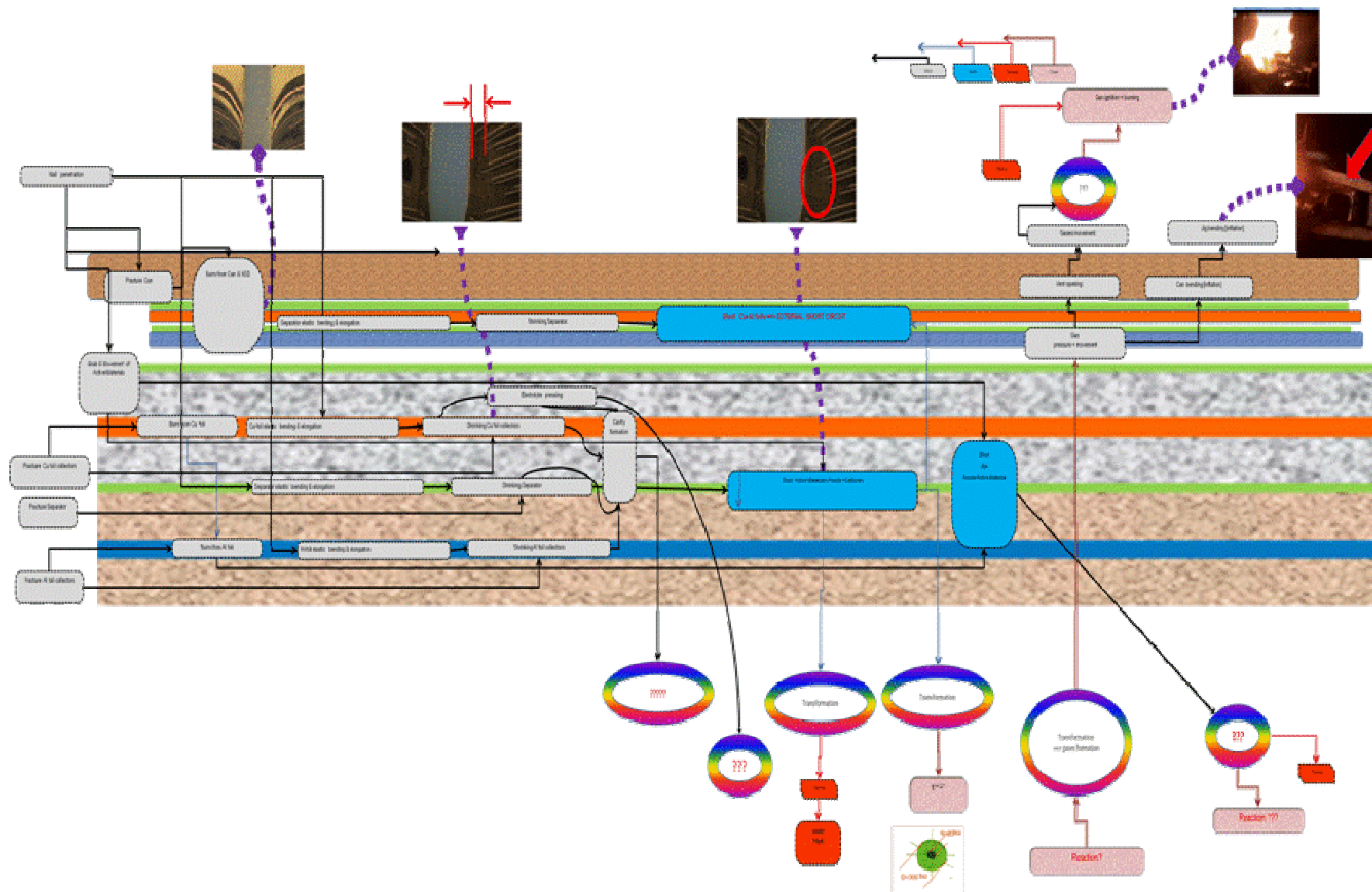


**Thermal runaway ~ explosive process**

# Notation

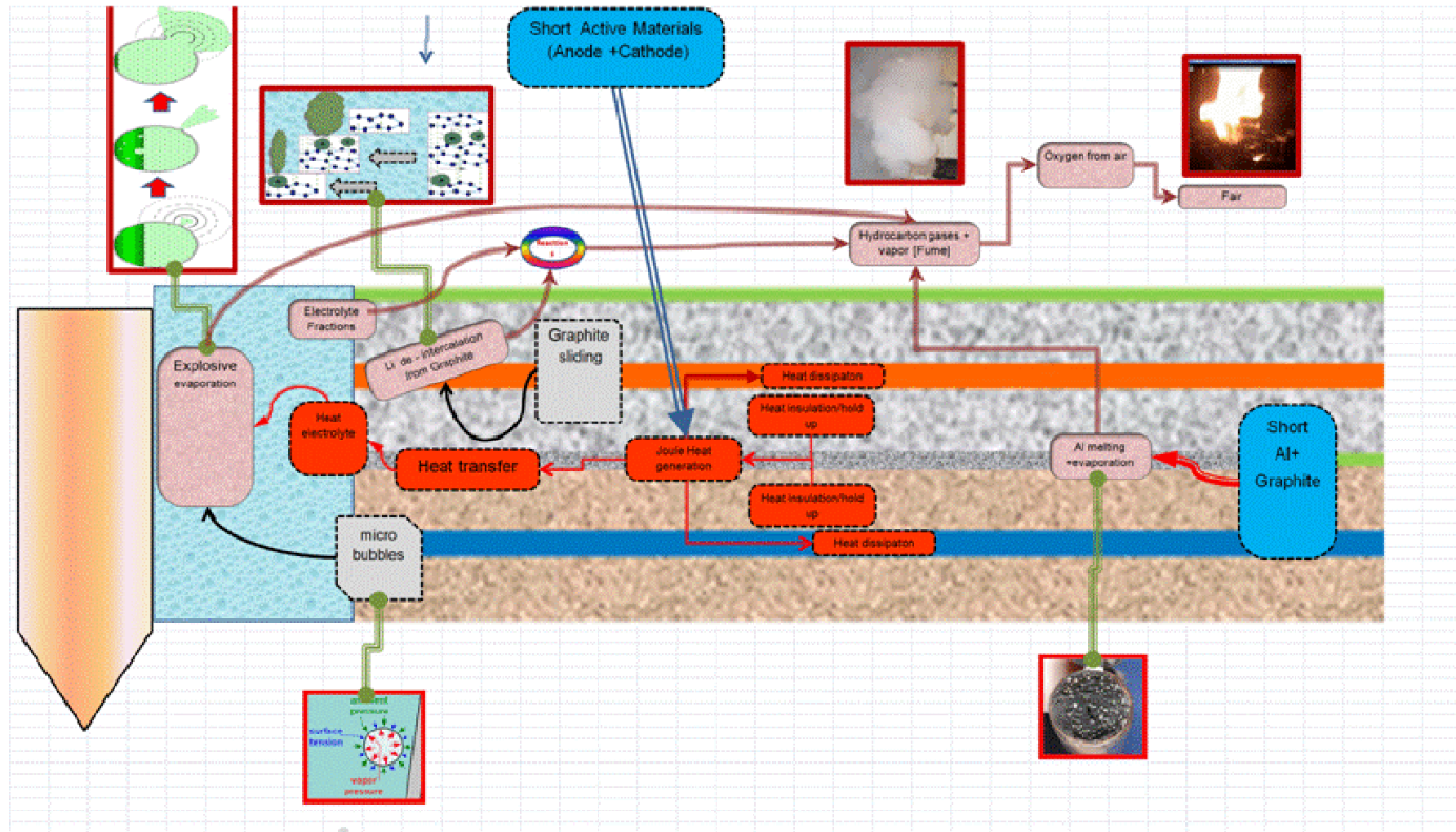


# Mechanical & electrical processes and interlinks(fragment\_1)





# Thermal & chemical processes and interlinks (fragment\_2)

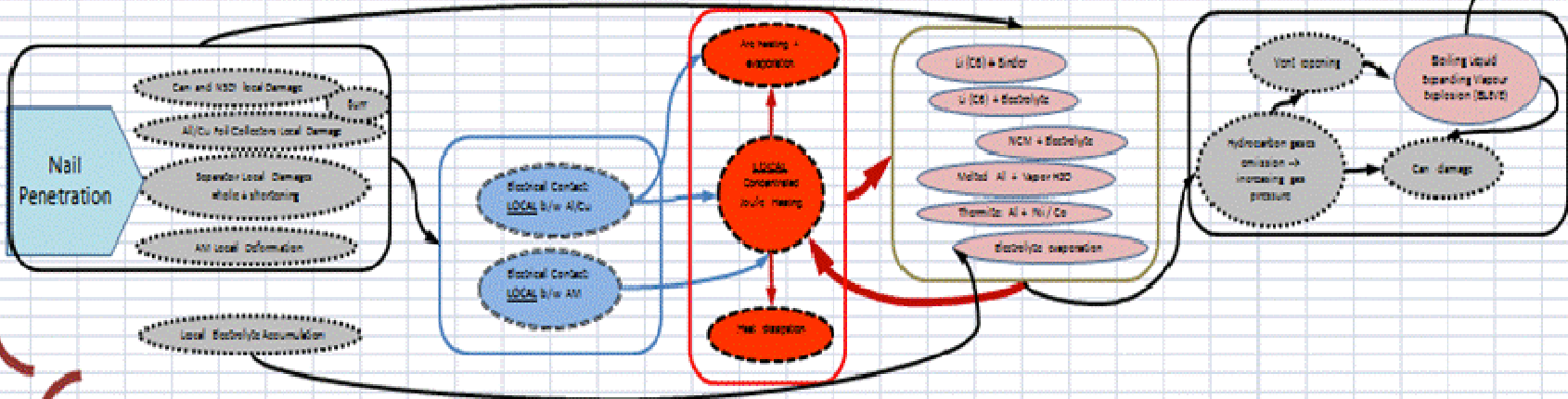


AM - Active Material  
 b/w - between  
 AM - Active Material  
 cu - for example

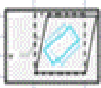


AM pedal

Key process



Key problems



**HOW TO PREVENT:**  
 X Can damage & deformation - cu, add amount?  
 X Dramatic damage in jelly rolls - cu, hard separator?  
 X Local Electrolyte Accumulation - cu,

**HOW TO CHANGE:**  
 X Al/Cu foil deformation - cu, without burn formation?  
 X AM local deformation - cu, without shearing forces?  
 X location of accumulated electrolyte - cu, avoids from future heat source?

**HOW TO CORRECT:**  
 X Damage of AM - BUT NO new electrical contacts?  
 X Separator damaged + AM locally deformed - BUT after that anyway NO local contact b/w AM?

**HOW TO PREVENT:**  
 X Separator damaged after nail penetration - BUT after that separator anyway prevent local contact b/w AM?  
 X AM contacted - BUT after that (if allowed) anyway prevent local current electrical conductance b/w AM - cu, only on conductivity?

**HOW TO CHANGE:**  
 X AM contacted - BUT no local electrical current b/w AM - cu, only on conductivity or contact not local?

**HOW TO CORRECT:**  
 X Electrical current across contacted AM - BUT BUT no local heat emission - cu, superconductivity or low current density?

**HOW TO PREVENT:**  
 X LOCAL heat concentration via for example, to decompose heat sources?

**HOW TO CHANGE:**  
 X Local distribution of appearing heat

**HOW TO CORRECT:**  
 X dissipate locally concentrated heat? or, absorb and/or increase dissipation by way of contacted AM?

**HOW TO PREVENT:**  
 X All harmful chemical reactions - cu, change composition, concentration or prevent thermo-activation of this reactions?  
 X exclude "harmful" component -

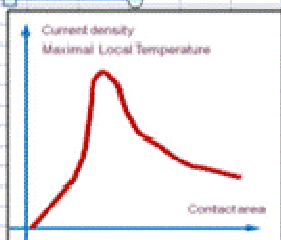
**HOW TO CHANGE:**  
 X decrease harmful over heating and/or harmful gas emission in existing reactions?  
 X Mediate another "bypass" chemical reactions - without harmful effects?

**HOW TO CORRECT:**  
 X dissipate over heat from chemical reactions?  
 X introduce cooling / refrigerant / heat-absorbing substances?  
 X remove emitted gas from can?

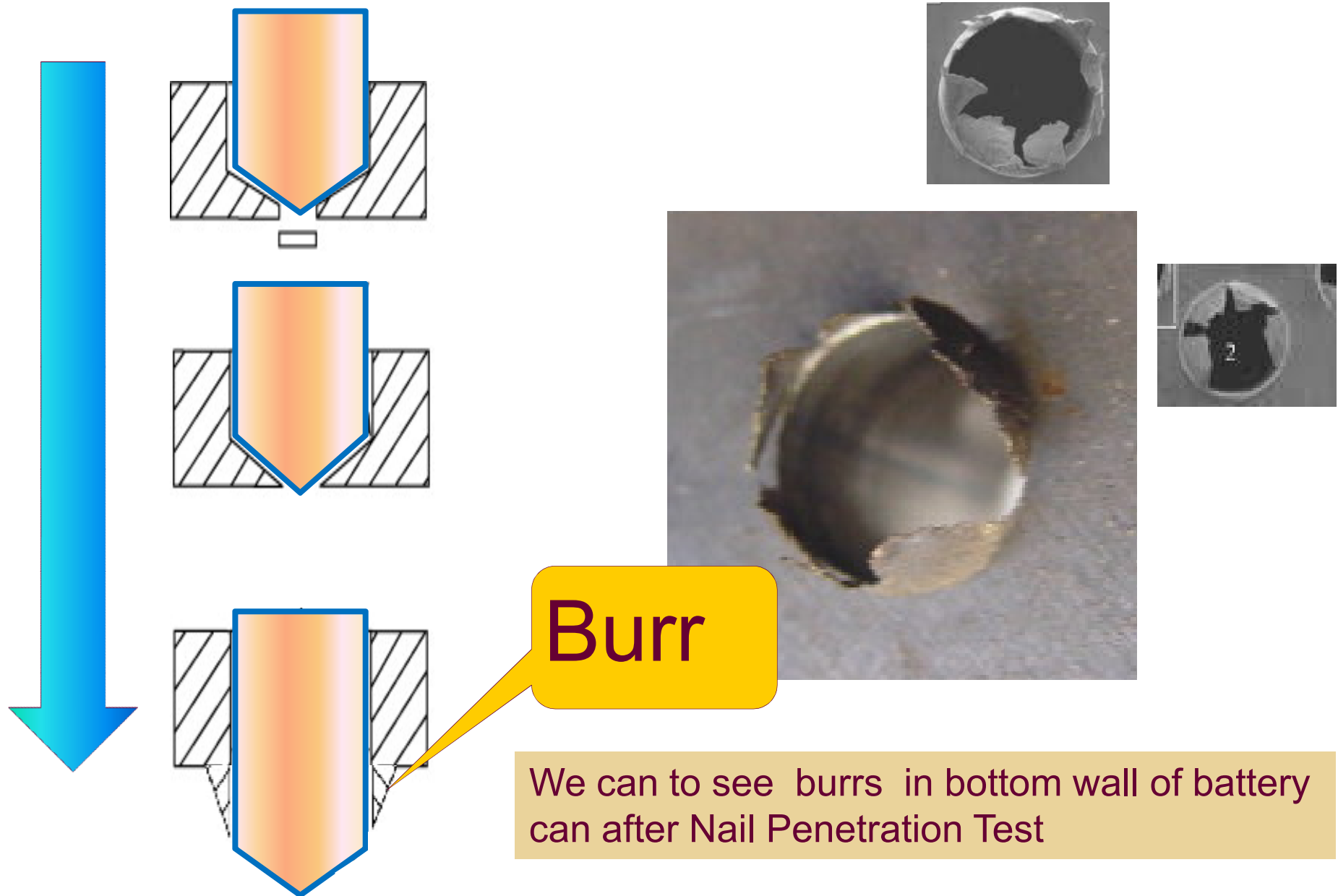
**HOW TO PREVENT:**  
 X severe effect?  
 X?

**HOW TO CHANGE:**  
 X?

**HOW TO CORRECT:**  
 X ???



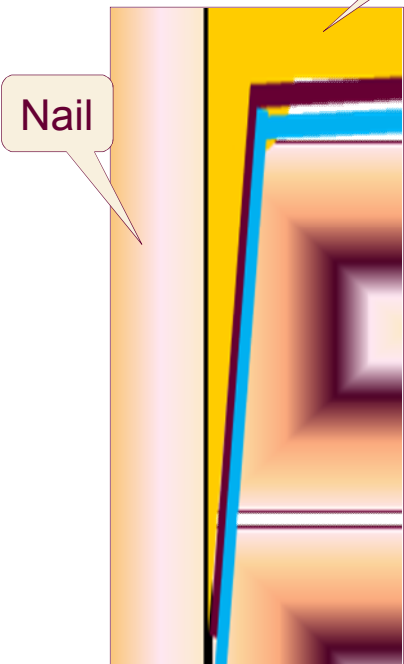
# 11 Example 1: Schematic burr formation



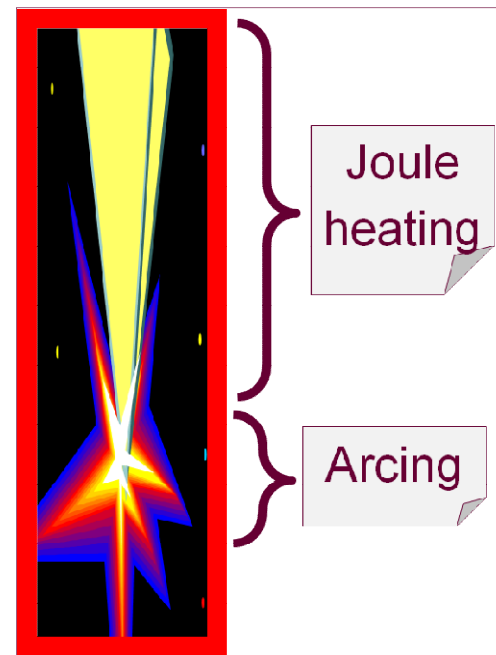
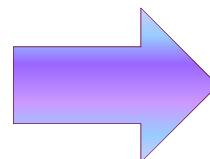
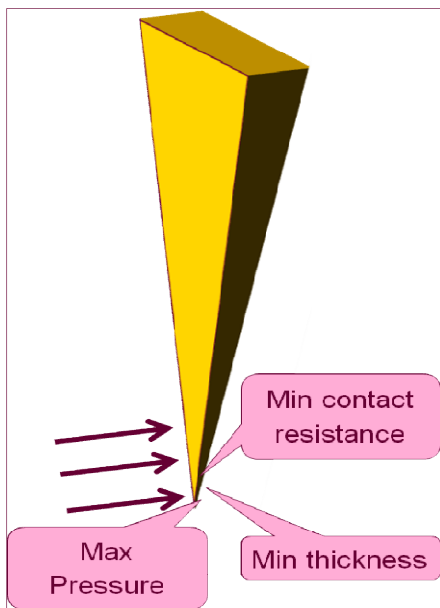
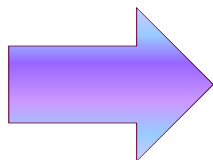
# Example 1: Burrs + electric current is possible reason of arc initiation



Can



Nail



## Example 1: Burr + Arcing. Conditions and harmful effects

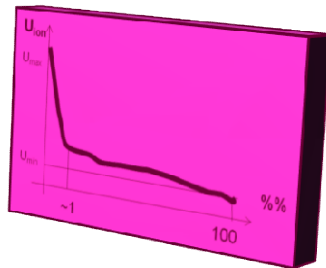
### Conditions

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

Joule + Arc: Effective heat generation

Plasma activation of exothermic reactions

Local metal evaporation

Cu: solid → vapor expands 67,000

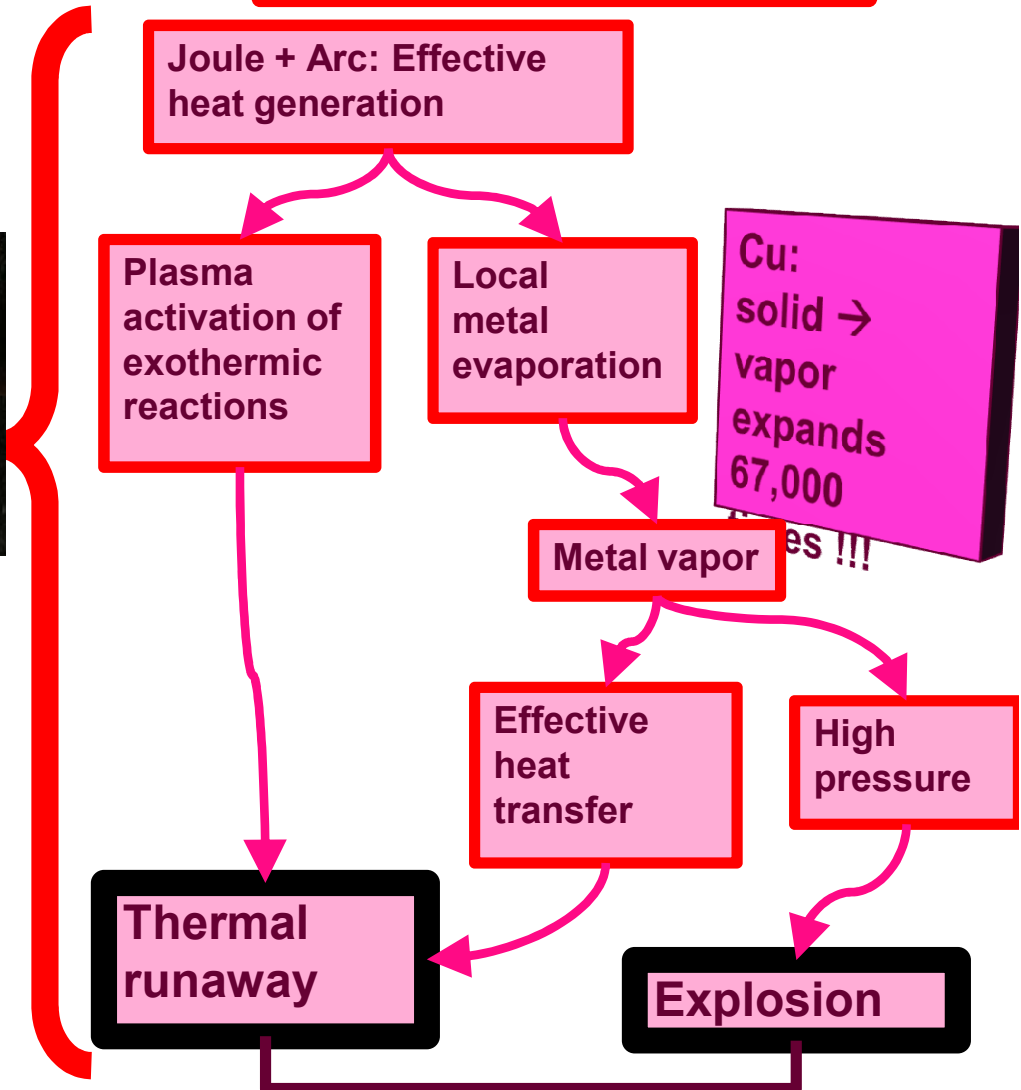
Metal vapor

Effective heat transfer

High pressure

Thermal runaway

Explosion



## 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 →

External overheating →

Gas overpressure jet →

Explosion of vessel →

Fireball out vessel →

← Can / vent

← Internal overheating

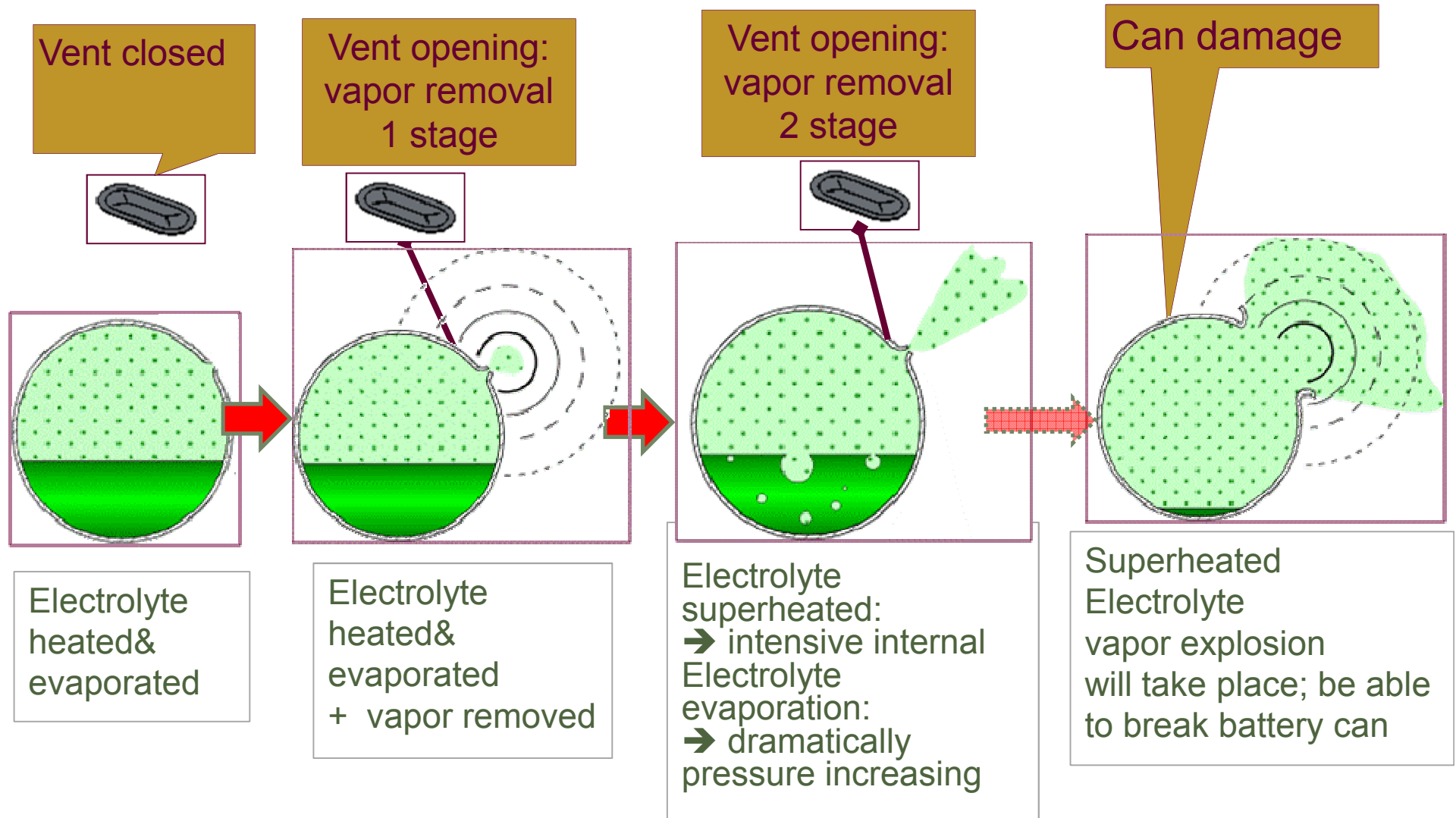
← Vapor steam jet

← Can rupture

← 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**