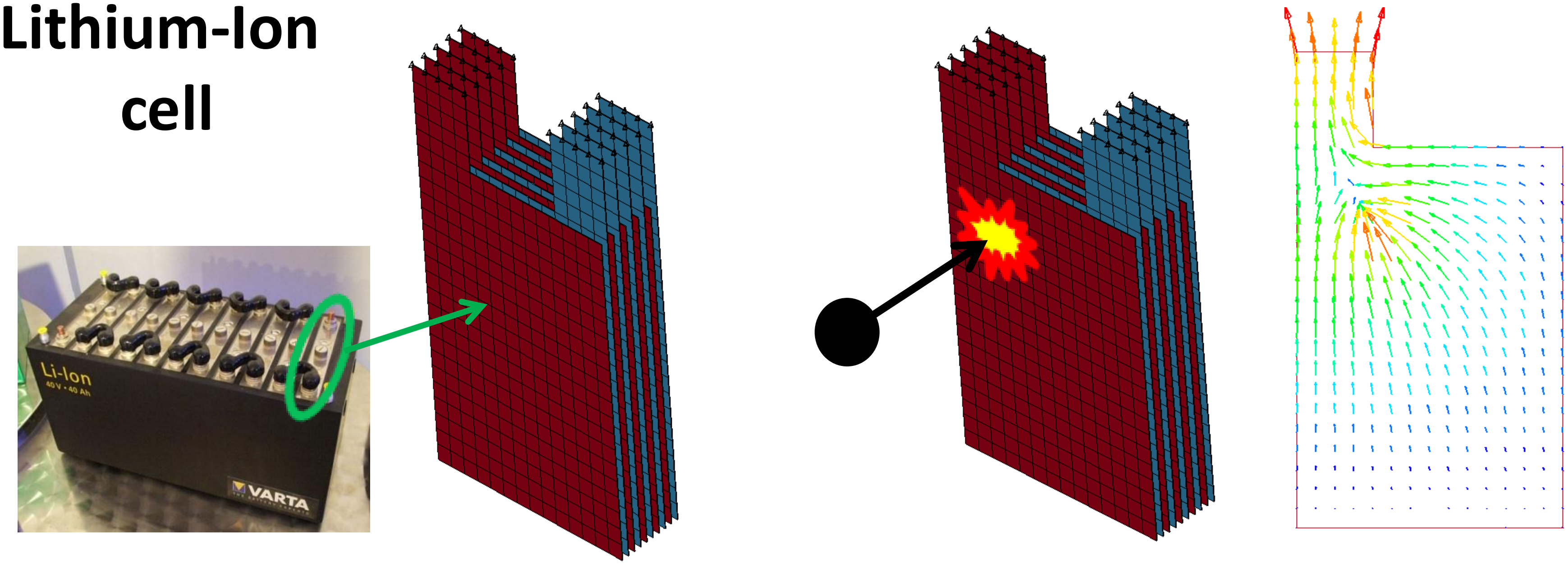
Batteries crash simulation with LS-DYNA

Lithium-Ion cell



In collaboration with
J. Marcicki et al,
Ford Research and Innovation Center, Dearborn, MI

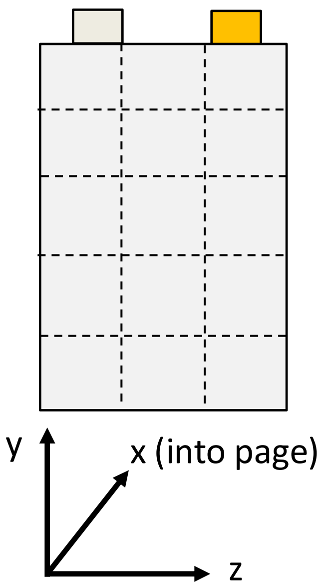
Battery crash simulation (general)

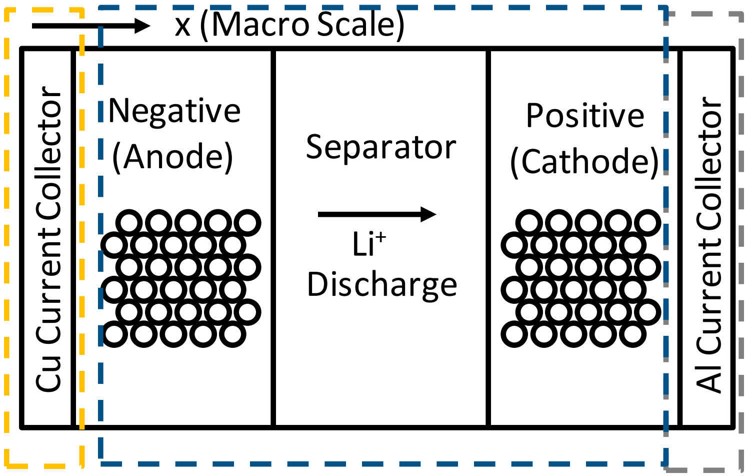
Car crash

- Mechanical
- EM
- Thermal
  - CPM

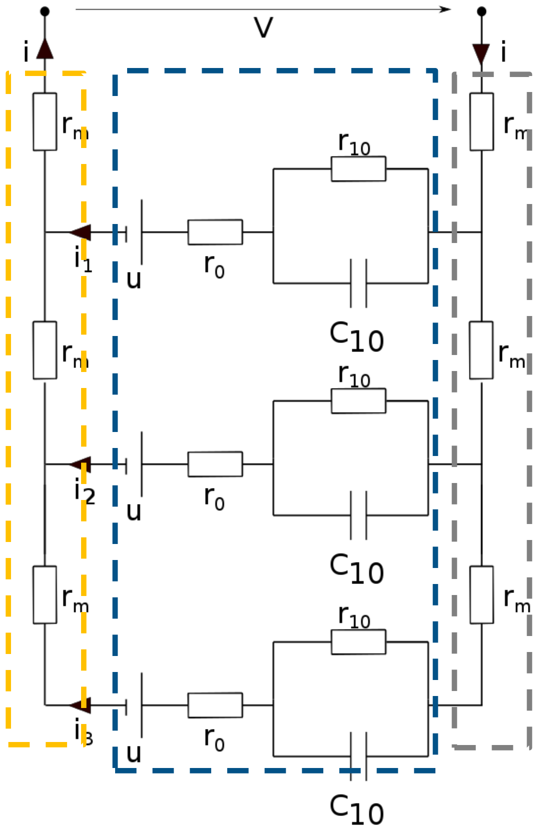
=> Battery crush
=> local internal short
=> large localized current densities
=> Joule heating
=> temperature increase
=> thermal runaway
=> fire, explosion

Distributed Equivalent Circuit (1st Order Randle)





- Current collectors transport electrons to/from tabs; modeled by resistive elements
- Jelly roll (anode – separator – cathode) transports Li+ ions; modeled with Randle circuit



r_0: Ohmic & kinetic

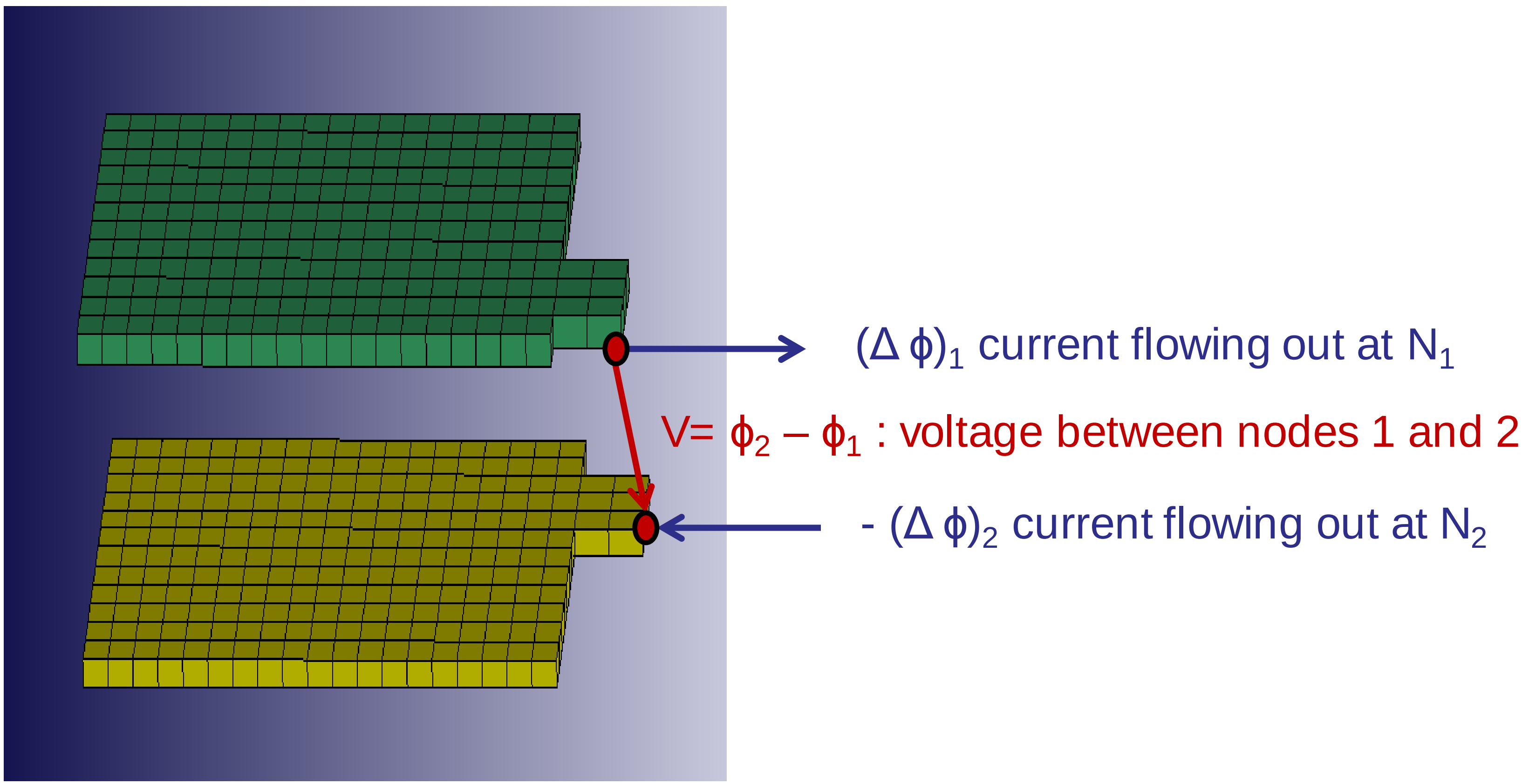
r_{10} & c_{10}: Diffusion

u: Equilibrium voltage (OCV)

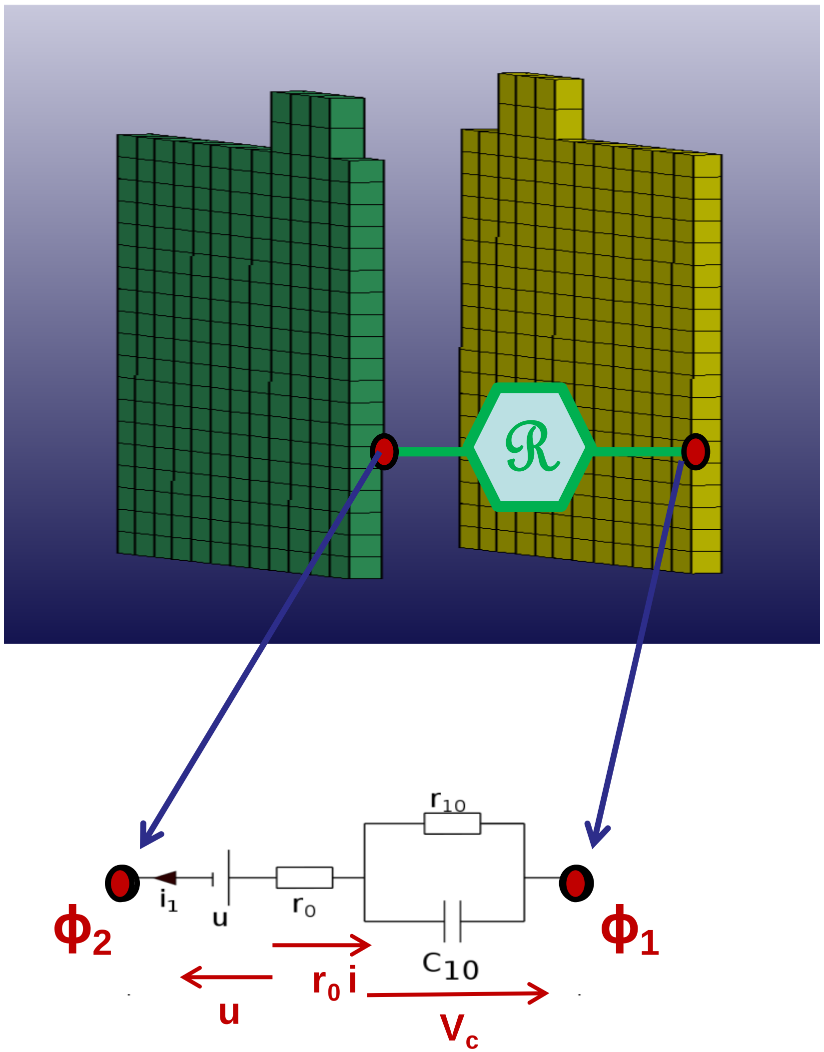
r_m: Current collectors

Standard EM resistive solver

- ϕ : potential
- $E = -\,\mathrm{grad}(\phi)$: electric field
- $V = \phi_2 - \phi_1$: voltage
- $J = \sigma E$: current density (σ = electric conductivity)
- $\mathrm{div}(J) = 0 \Rightarrow \Delta\phi = 0$ + boundary conditions



Introduction of randle circuits in resistive solver



Randle circuit

Page 5

$\phi_2 - \phi_1 = u - r_0 * I - V_c$

$r_0 * i + \phi_2 - \phi_1 = u - V_c$

$i + (\phi_2 - \phi_1) / r_0 = (u - V_c) / r_0$

FEM solve:

$(S_0 + D) * \phi = b$

Where

- S_0 is the Laplacian operator (nds x nds)
- D has
  - $1/r_0$ at (N_1,N_1) and (N_2,N_2)
  - $-1/r_0$ at (N_1,N_2) and (N_2,N_1)
  - 0 elsewhere
- b has
  - $1/r_0(u-v_c)$ at N_1
  - $-1/r_0(u-v_c)$ at N_2
  - 0 elsewhere

Actualization of randle circuits:

$i = (S_0 * \phi)(N_1)$

$V_c(t+dt) = V_c(t) + dt*(i/c_0 - V_c(t)/r_{10}/c_{10})$

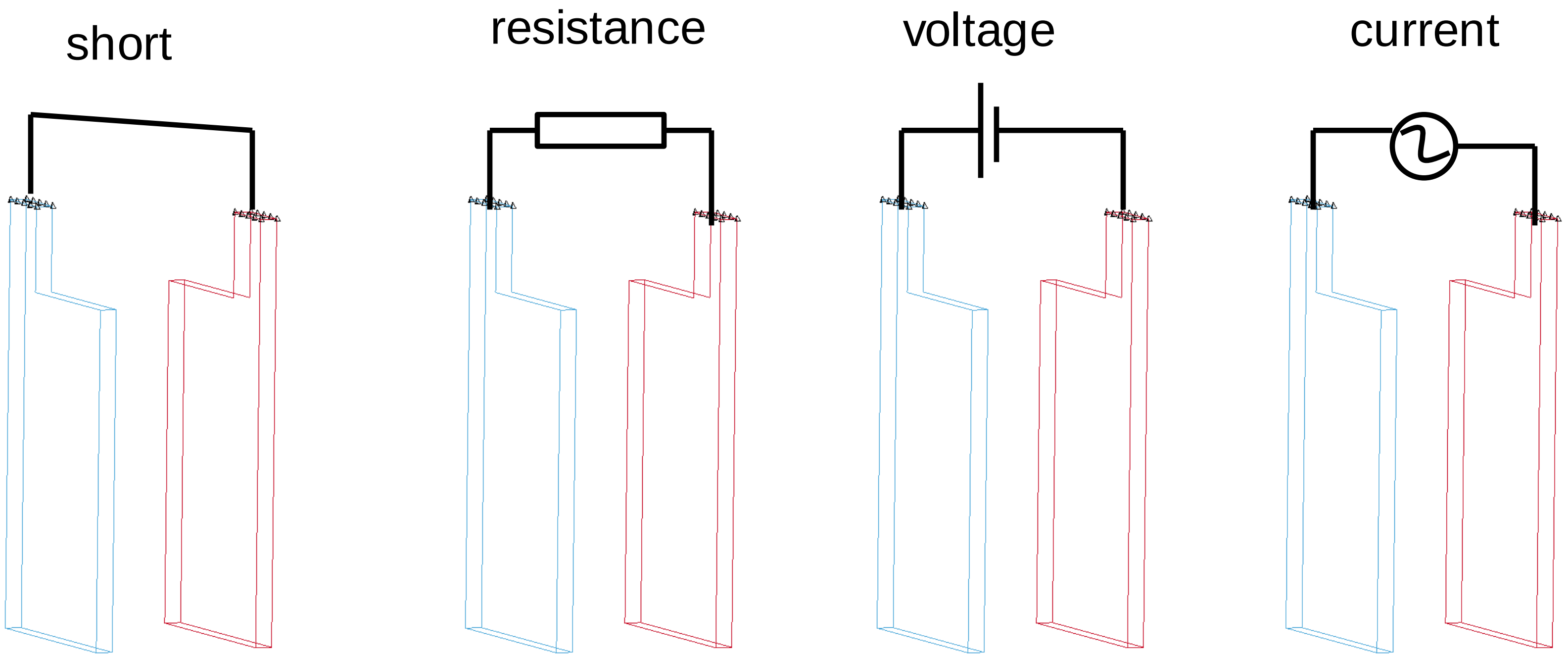
$soc(t+dt) = soc(t) - dt*i*c_Q/Q$

$u = u(soc)$

Isopotentials

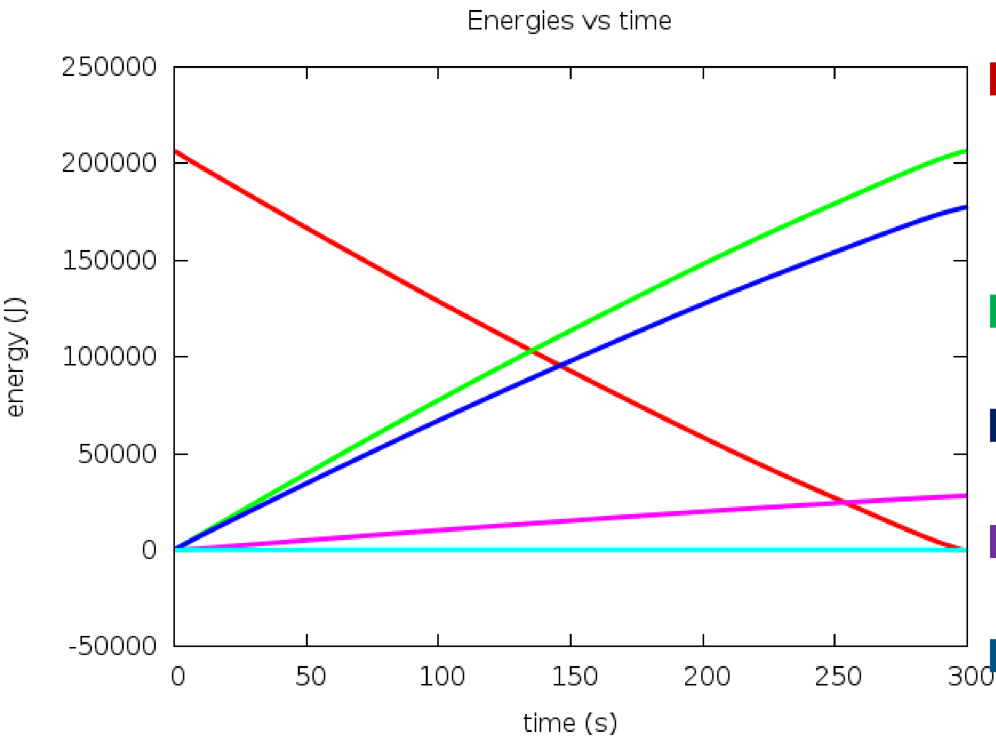
Isopotentials can be defined and connected:

- The connectors do not need to be meshed.
- Enables alignment of cell simulations with experimental conditions (low rate cycling, HPPC, continuous discharge, …).



Randle circuits energy balance

The different parts of the energy are tracked down



$$E_{available} = \sum_{randle} \int (u(t)*i(t)\,dt$$
$$= \sum_{randle} \int u\,dq$$
$$= \sum_{randle} Q/cQ \int u(SOC)\,d\,SOC$$

$$E_{delivered\ by\ u} = \sum_{randle} \int u*i\,dt$$

$$E_{delivered\ to\ load} = \sum_{randle} \int u_{load}*i_{load}\,dt$$

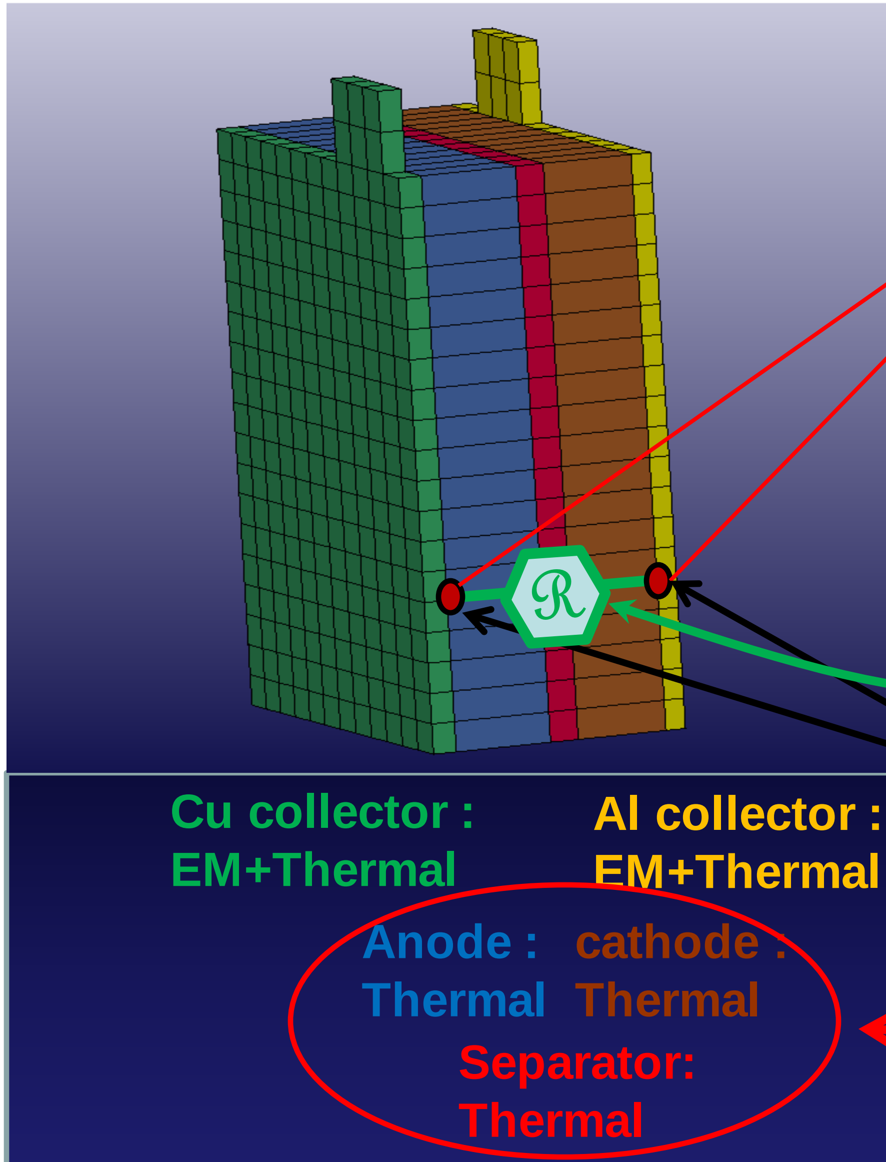
$$E_{joule\ heating\ in\ r0} = \sum_{randle} \int r_0*i^2\,dt$$

$$E_{c10} = \sum_{randle} 1/2\, C_{10} * V_c^2$$

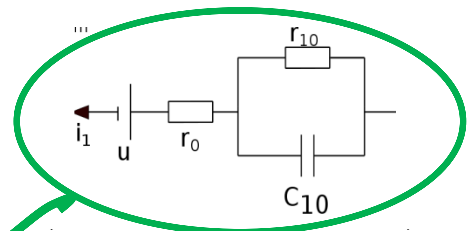
Typical discharge of unit cell in a resistance

EM/thermal connection

T from thermal for r_0, r_{10}, c_{10} vs T

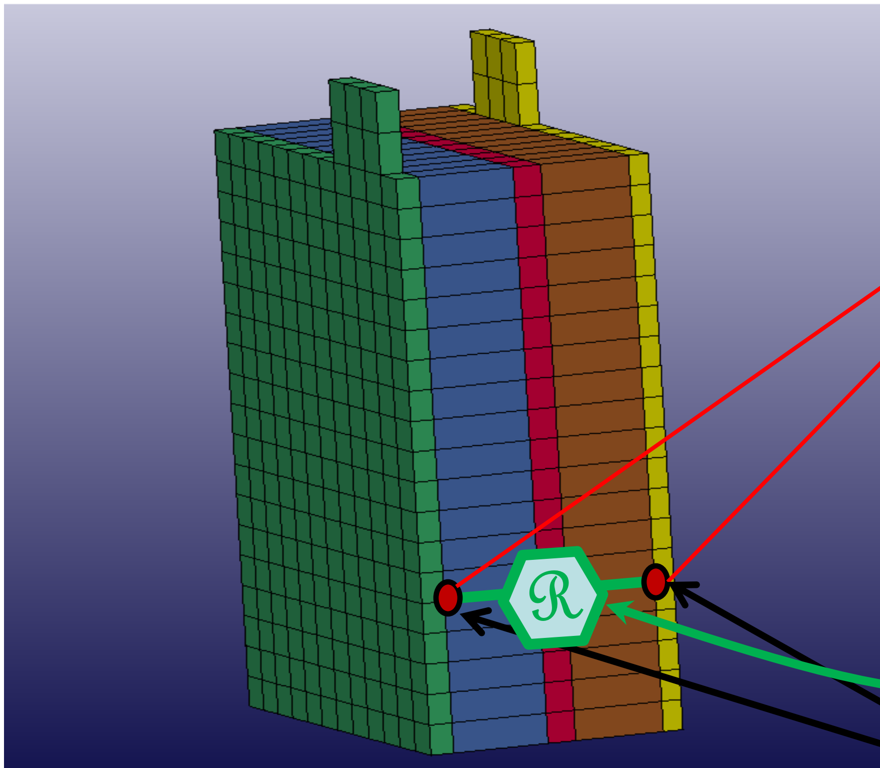


Randle circuit



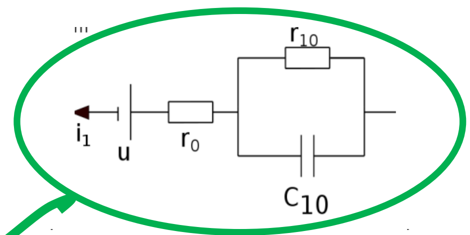
r_0 * i^2 added to thermal
ITdU/dT added to thermal

Allow correct material mass, heat capacity and thermal conductivity



T from thermal for r_0, r_{10}, c_{10} vs T

Randle circuit



$r_0 * i^2$ added to thermal
ITdU/dT added to thermal

Cu collector :
EM+Thermal

Al collector :
EM+Thermal

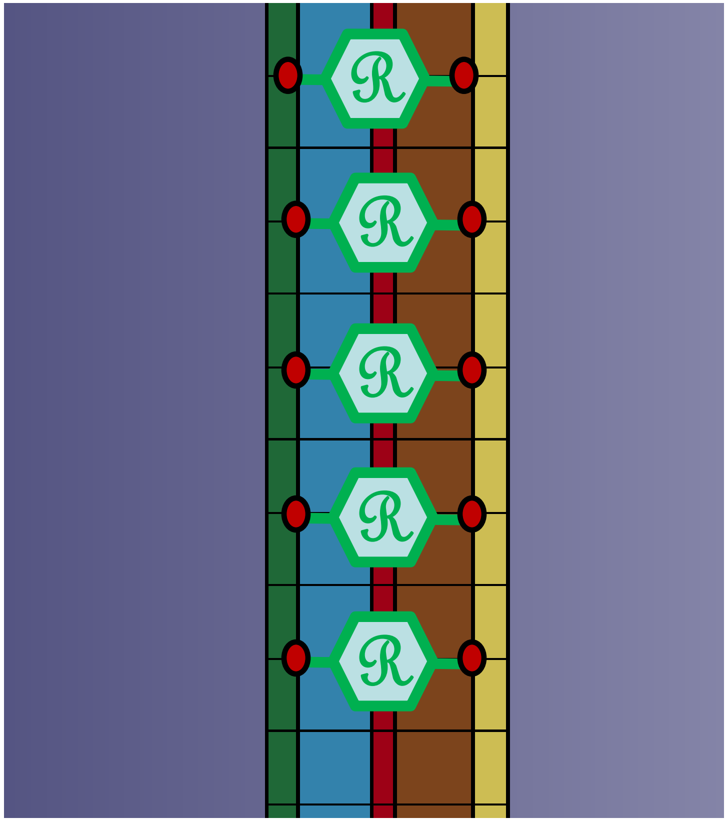
Anode :
Thermal

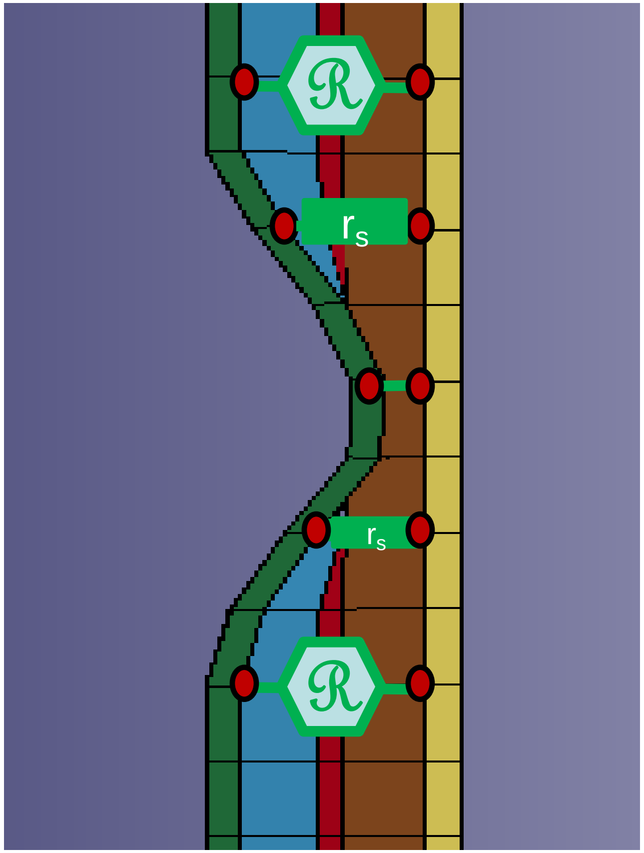
cathode :
Thermal

Separator:
Thermal

Allow correct material mass, heat capacity and thermal conductivity

Contact for Internal Short Models

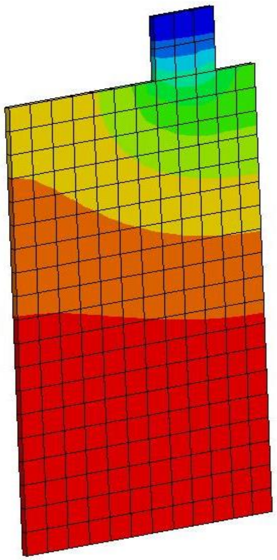




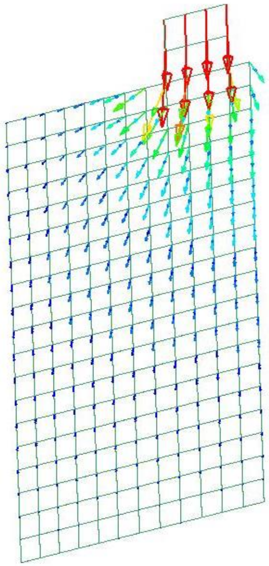
Replace randle circuit by resistance r_s
$R_s * i^2$ added to thermal

Experiment + simulation (voltage, current, temperature) should give good models

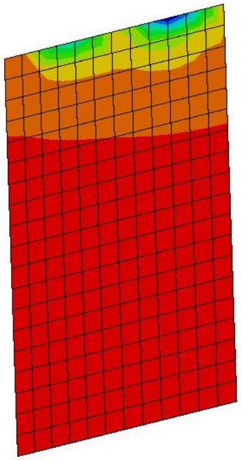
Randle circuits in LS-PREPOST



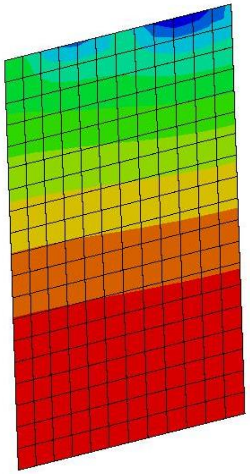
Scalar potential



Current density



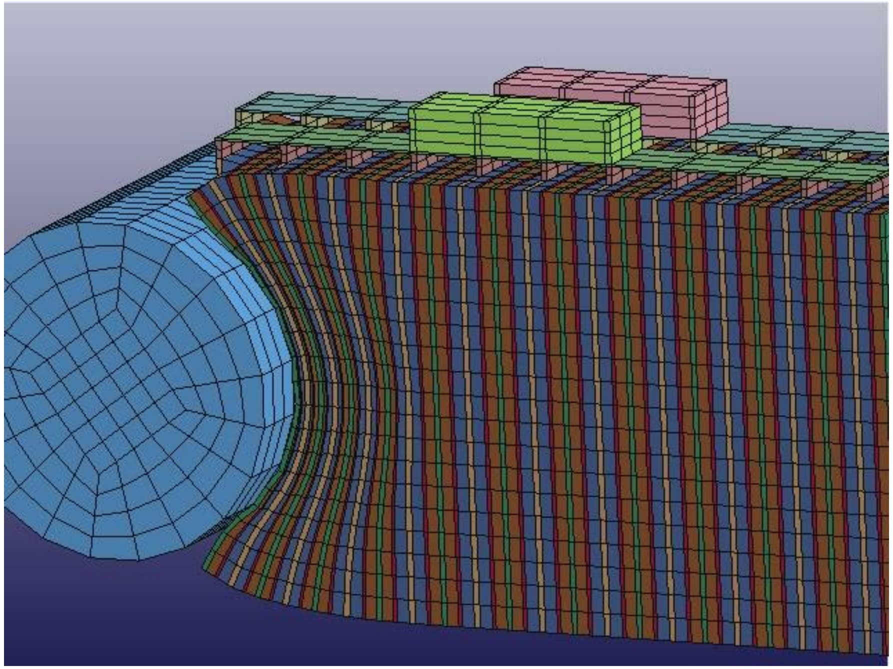
Randle r0



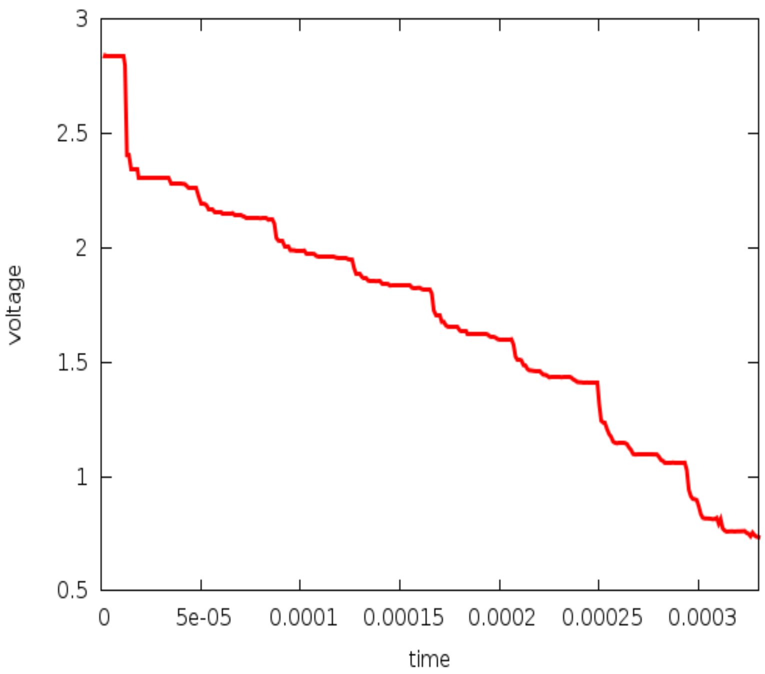
Randle SOC

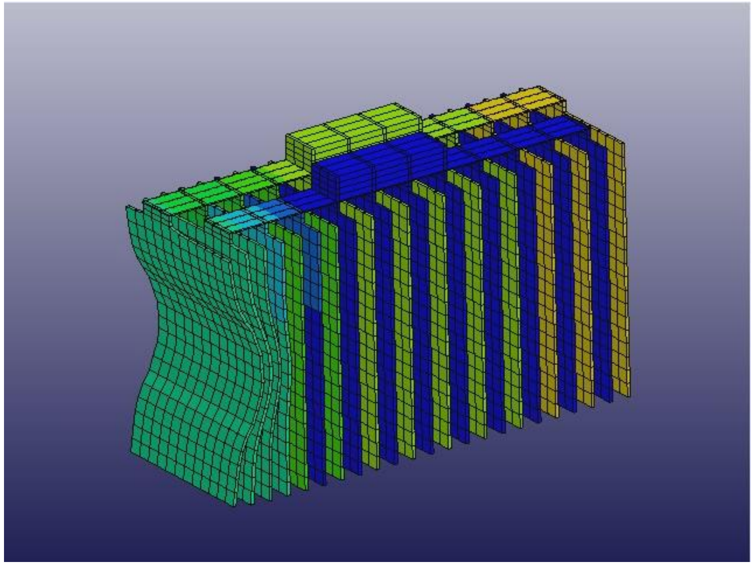
Contact illustration (1)

- Mechanical models for cells with very thin layers of materials of very different stiffnesses are still under investigation.
- In the meanwhile, in order to avoid the dificulties of the small thicknesses, model where the thickness was * 100, as proof of principle
- Rod crushes cell with 22 unit cells



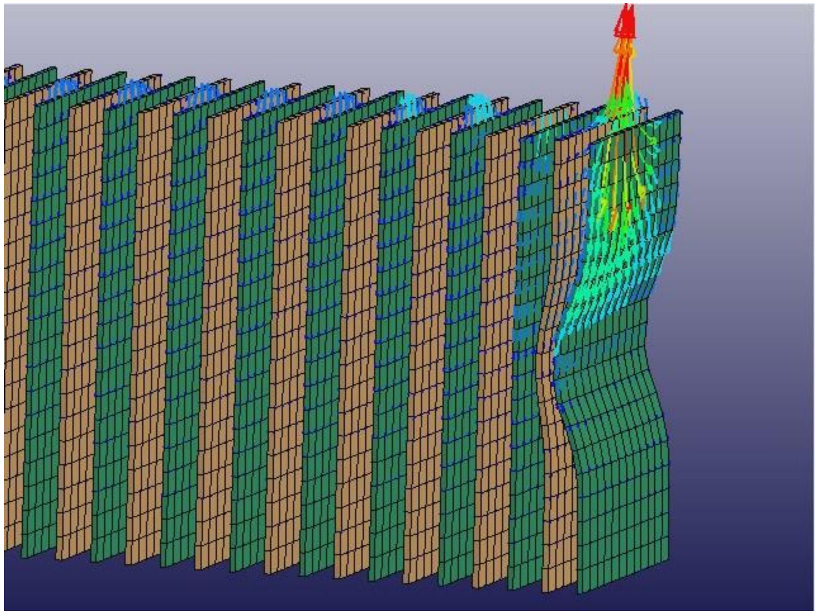
Contact illustration (2)

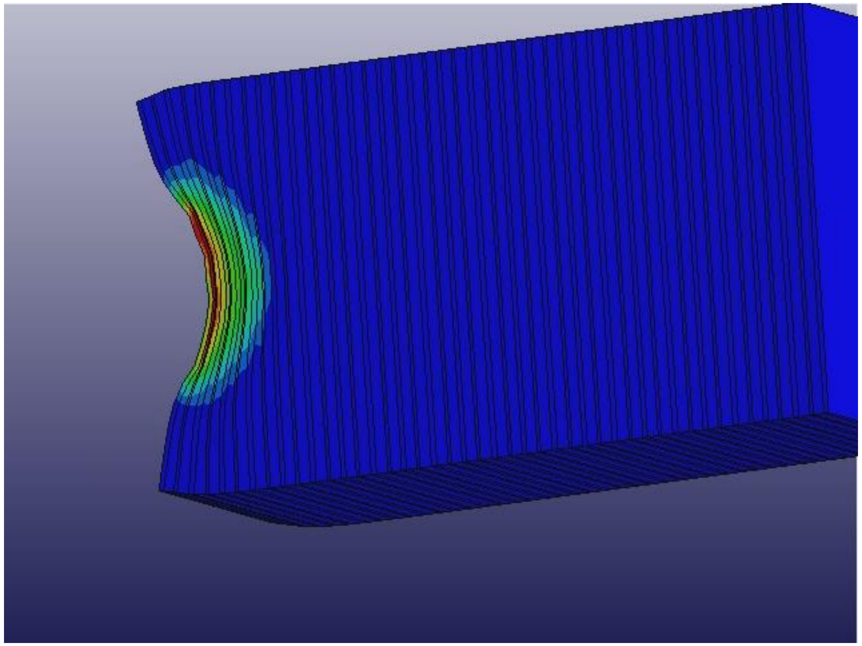




Voltage vs time

Contact illustration (3)





Current density **Temperature**

More at the 14th International LS-DYNA User's Conference Dearborn, MI, June 12-14, 2016

A Distributed Randle Circuit Model for Battery Abuse Simulations Using LS-DYNA®

Pierre L'Eplattenier[1], Iñaki Çaldichoury[1]
James Marcicki[2], Alexander Bartlett[2], Xiao Guang Yang[2],
Valentina Mejia[2], Min Zhu[2], Yijung Chen[2]
[1]LSTC, Livermore, CA, USA
[2]Ford Research and Innovation Center, Dearborn, MI, USA

Battery Abuse Case Study Analysis Using LS-DYNA

James Marcicki[1], Alexander Bartlett[1], Xiao Guang Yang[1], Valentina Mejia[1],
Min Zhu[1], Yijung Chen[1], Pierre L'Eplattenier[2], Iñaki Çaldichoury[2]
[1]Ford Research and Innovation Center, Dearborn, MI, USA
[2]LSTC, Livermore, CA, USA