Introduction to Thermo-Electric Modeling of Aluminium Reduction Cells

Marc Dupuis GENISIM

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Plan of the Presentation

- Modeling the Hall-Héroult Cell
- Mass and Thermal Balance
- Voltage Break Down Concept
- The Two Zones Heat Partition Concept
- List of Modeling Tools from GeniSim
- Dr Marc Dupuis Experience Building T/E Models
- GeniSim T/E Modeling Success Story
- Conclusions

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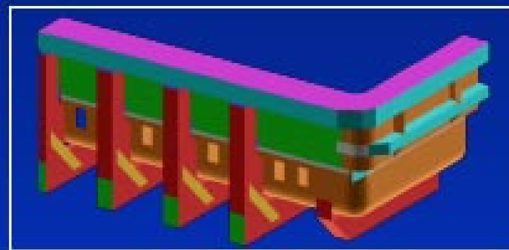
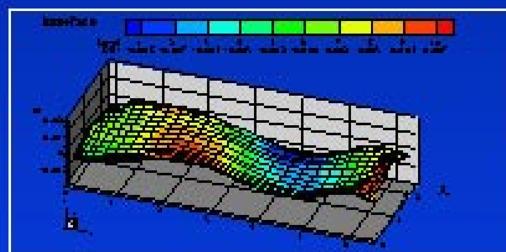
Modeling the Hall-Héroult Cell

The main three pillars of Hall-Héroult cell design

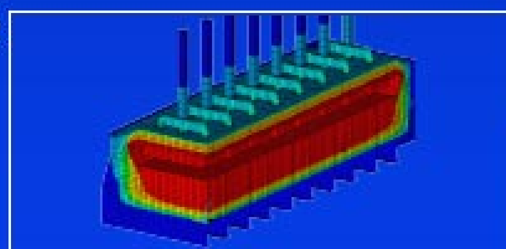
- Stress models which are generally associated with cell shell deformation and cathode heaving issues.



- Magneto-hydro-dynamic (MHD) models which are generally associated with the problem of cell stability.



- Thermal-electric models which are generally associated with the problem of cell heat balance.



Cell Design

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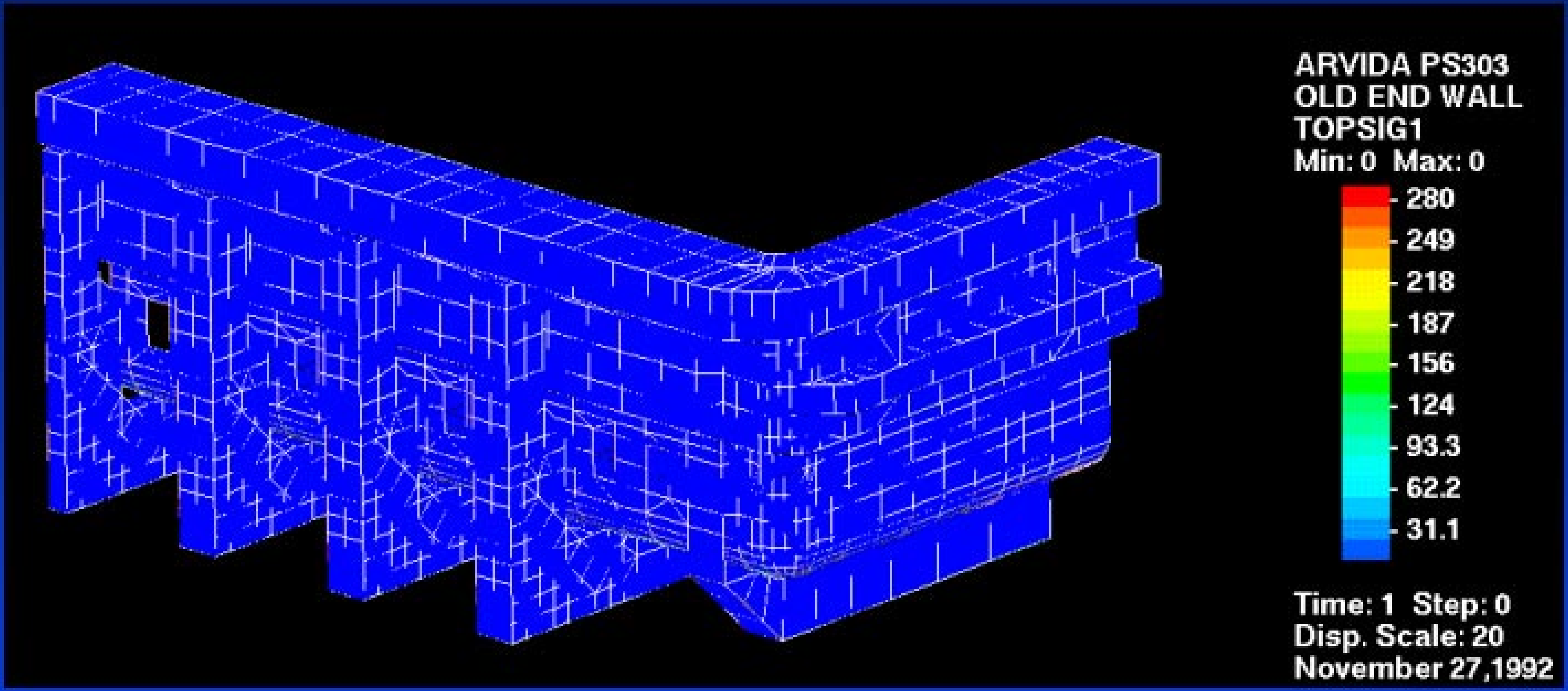
Stress Modeling



To prevent excessive deformation of the potshell

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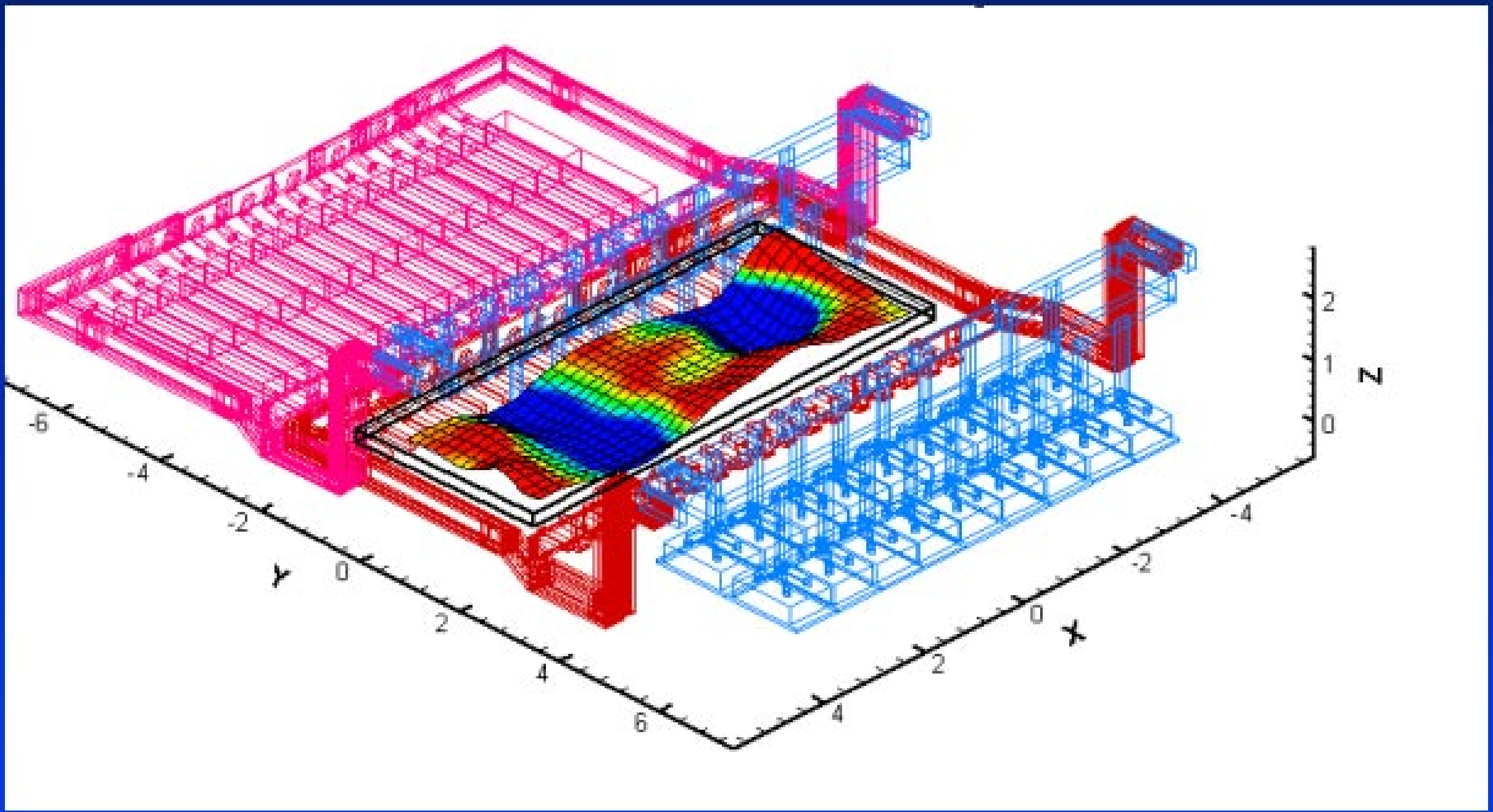
MHD Modeling



To ensure the stability of the bath-metal interface of the cell

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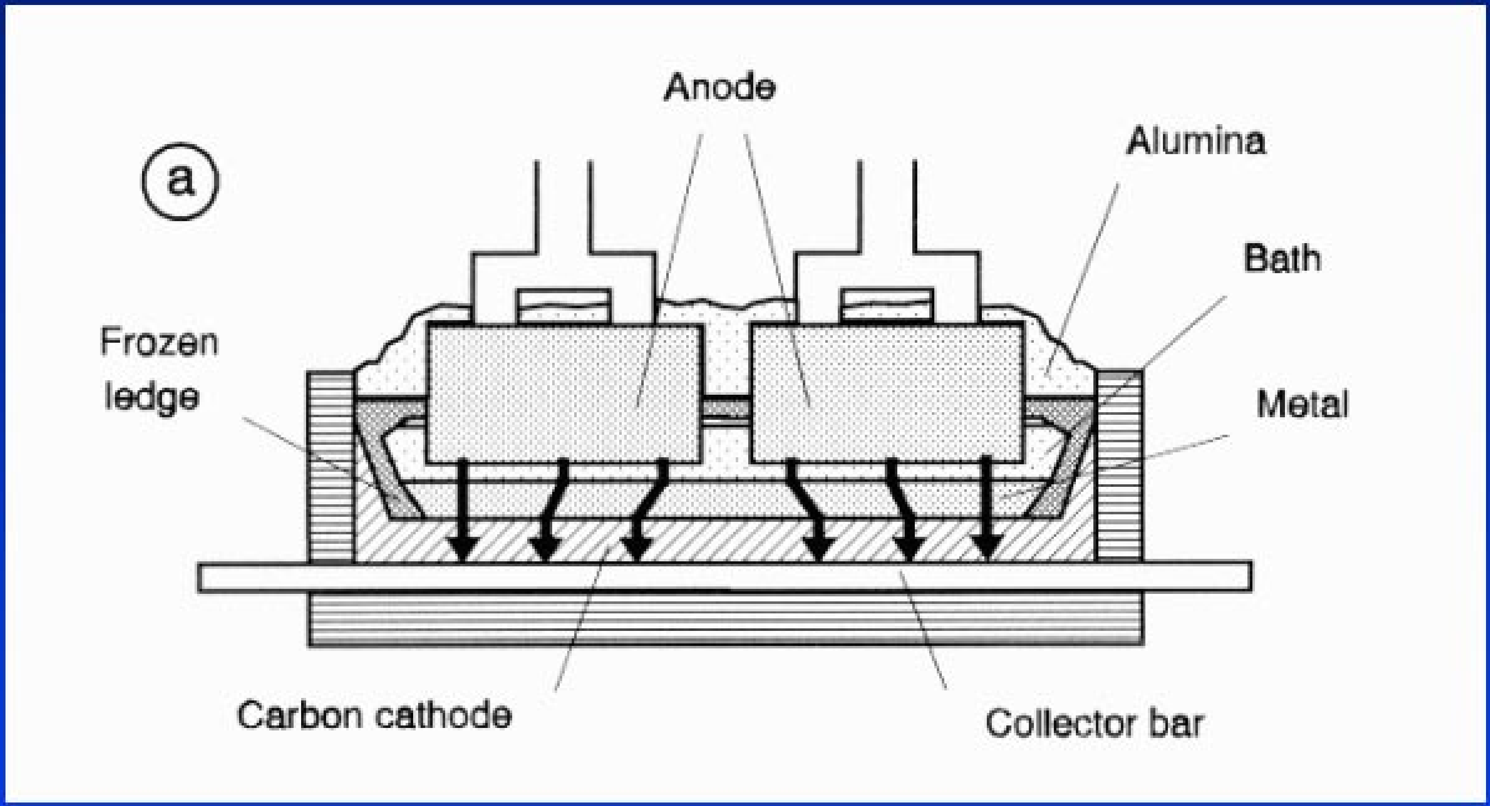
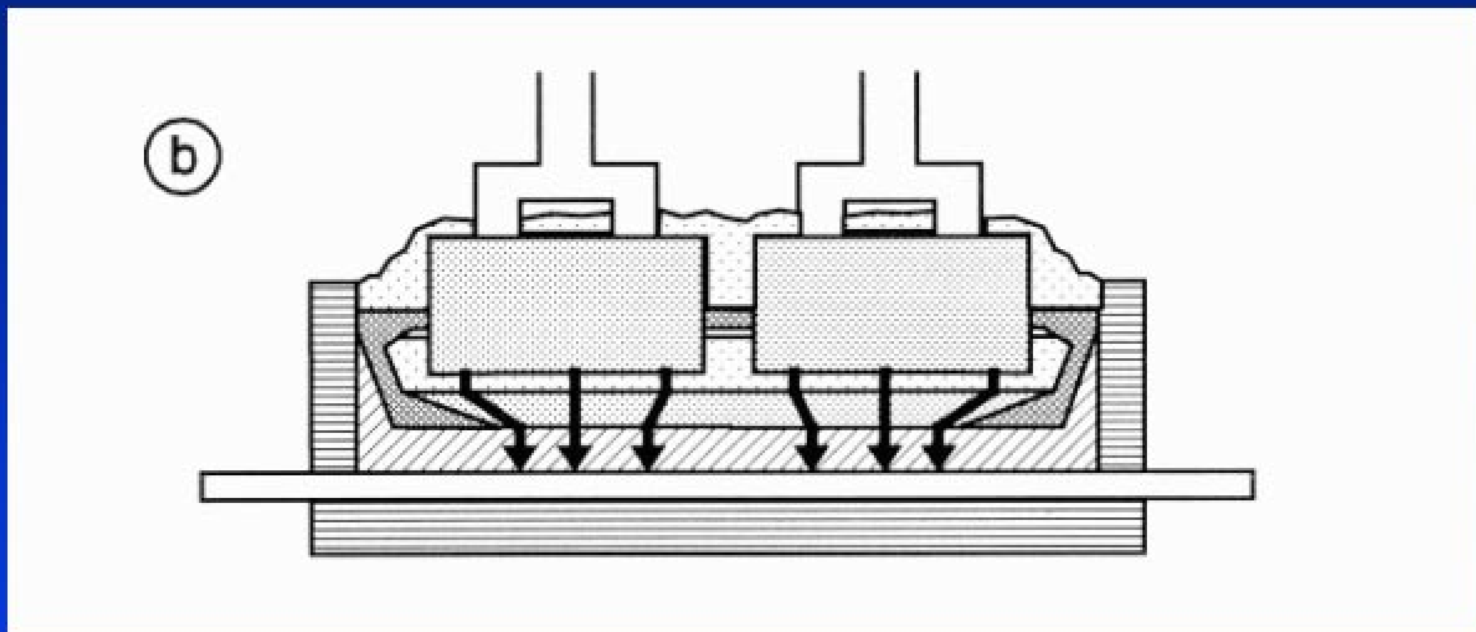
Thermo-Electric Modeling



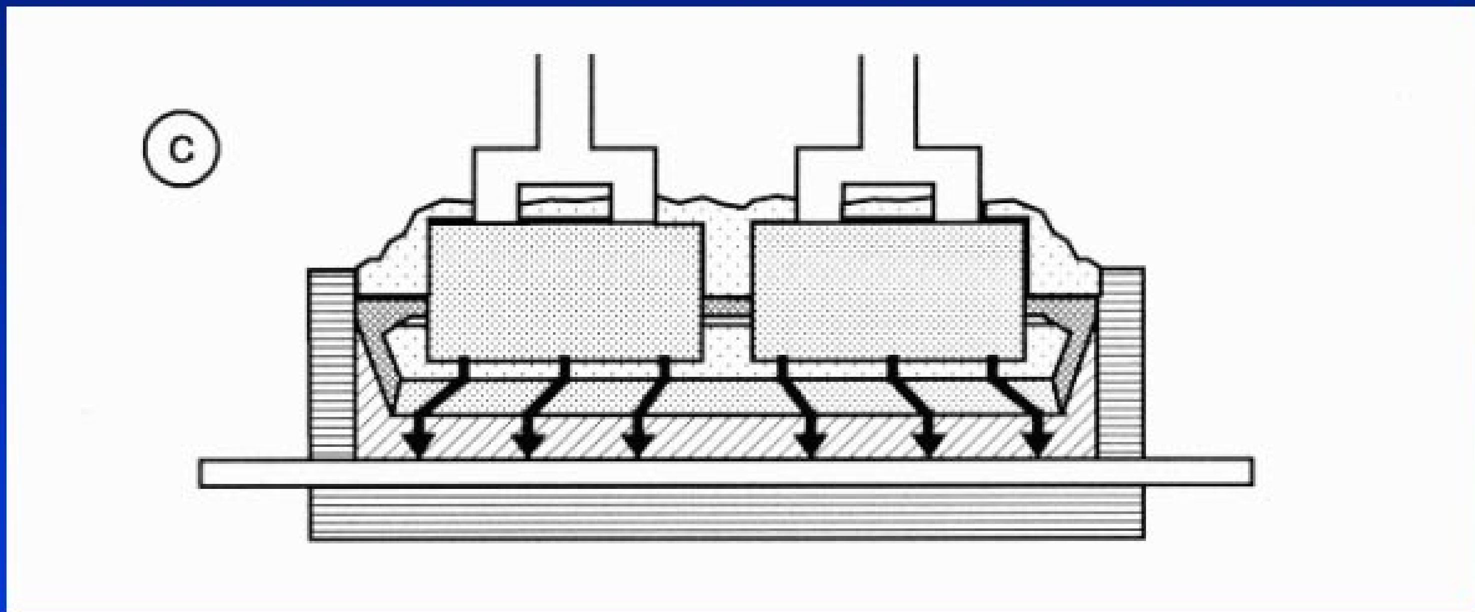
To ensure that the cell is operating with the optimum ledge protection

Thermo-Electric Modeling



Too much is bad for the cell stability

Thermo-Electric Modeling



Not enough is not good for cell stability

and especially bad for the cell life

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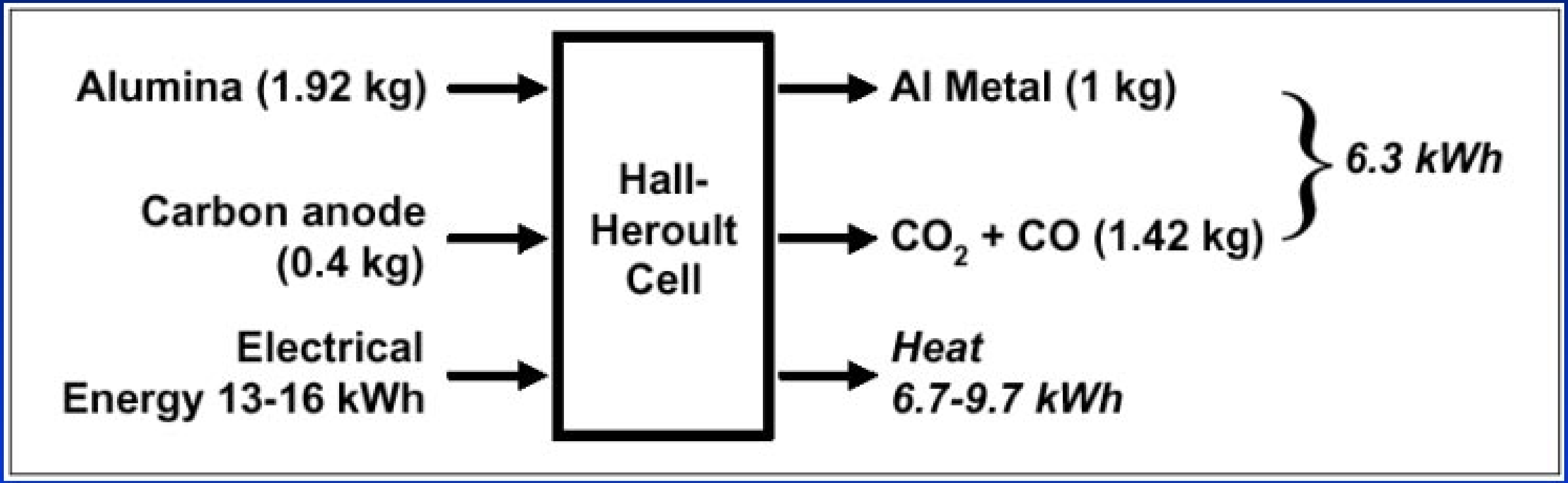
Mass and Thermal Balance



Over long periods of time neither mass or energy can accumulate in a cell, it must globally operates in mass and thermal balance

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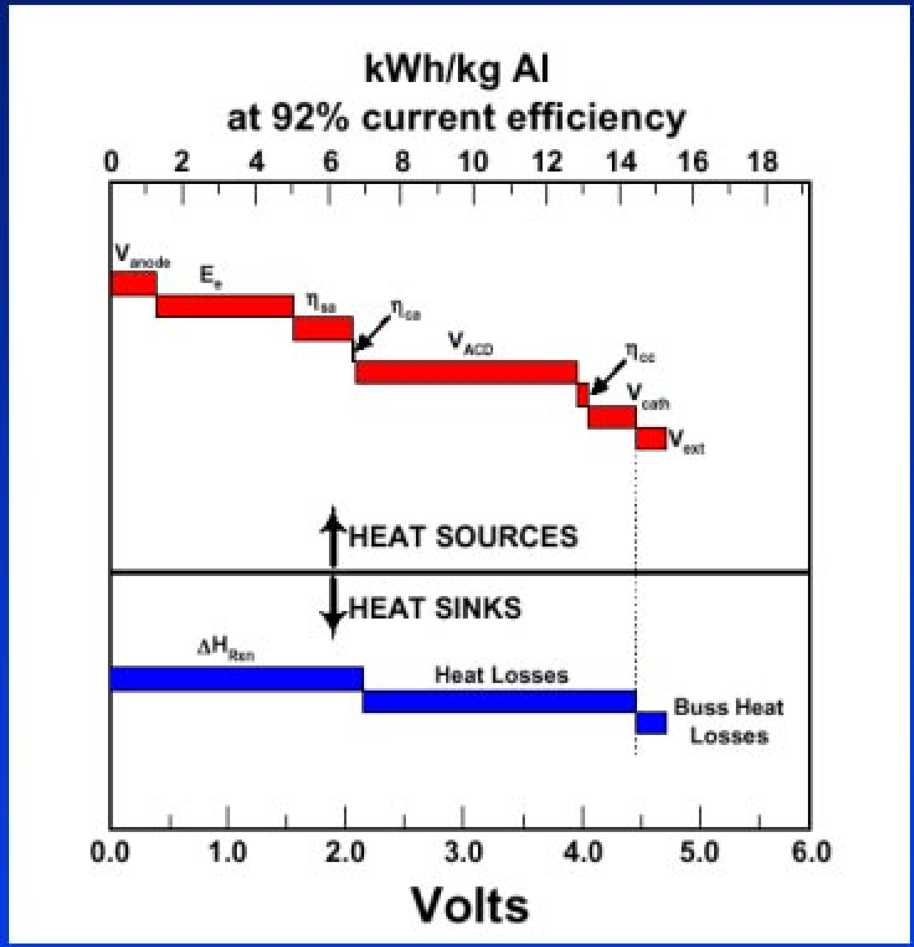
Voltage Break Down Concept

In thermal balance, the cell voltage minus the external voltage is equal to the equivalent voltage to make the metal plus the equivalent internal heat voltage



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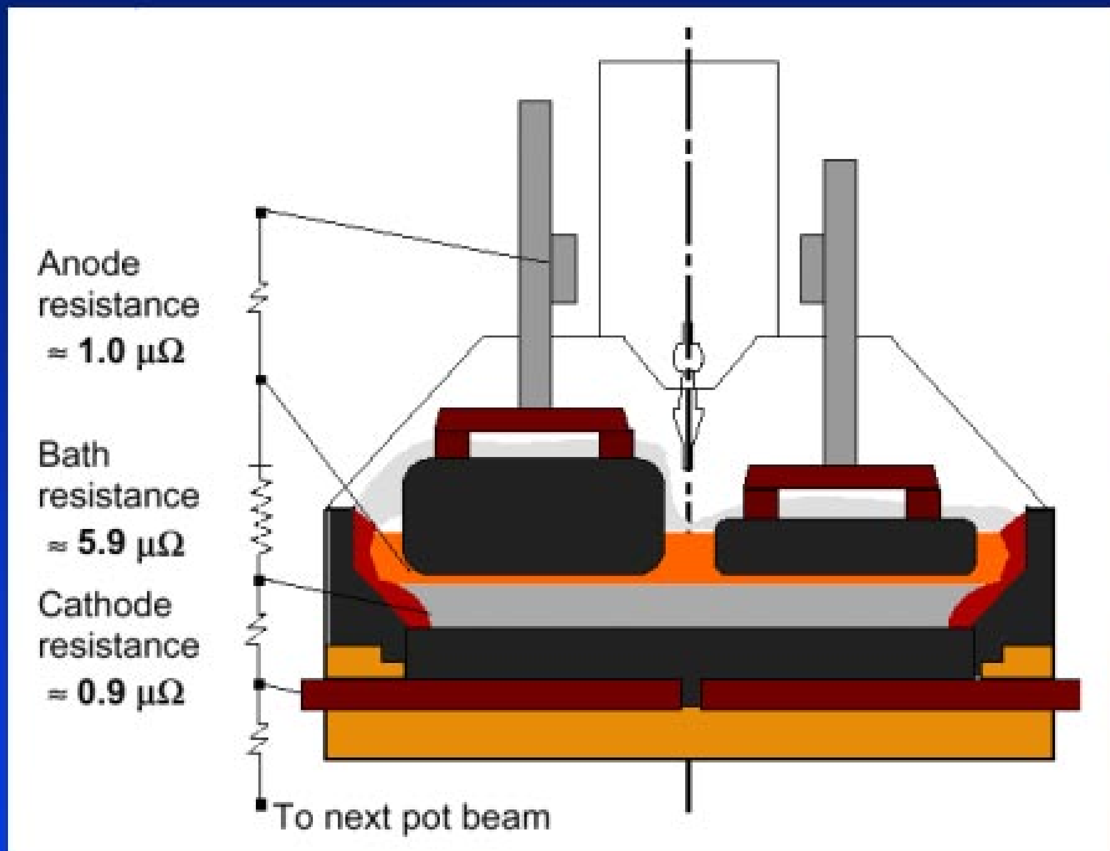
Heat Generated by the Joule Effect



Most of the Joule Heat is produced in the Bath

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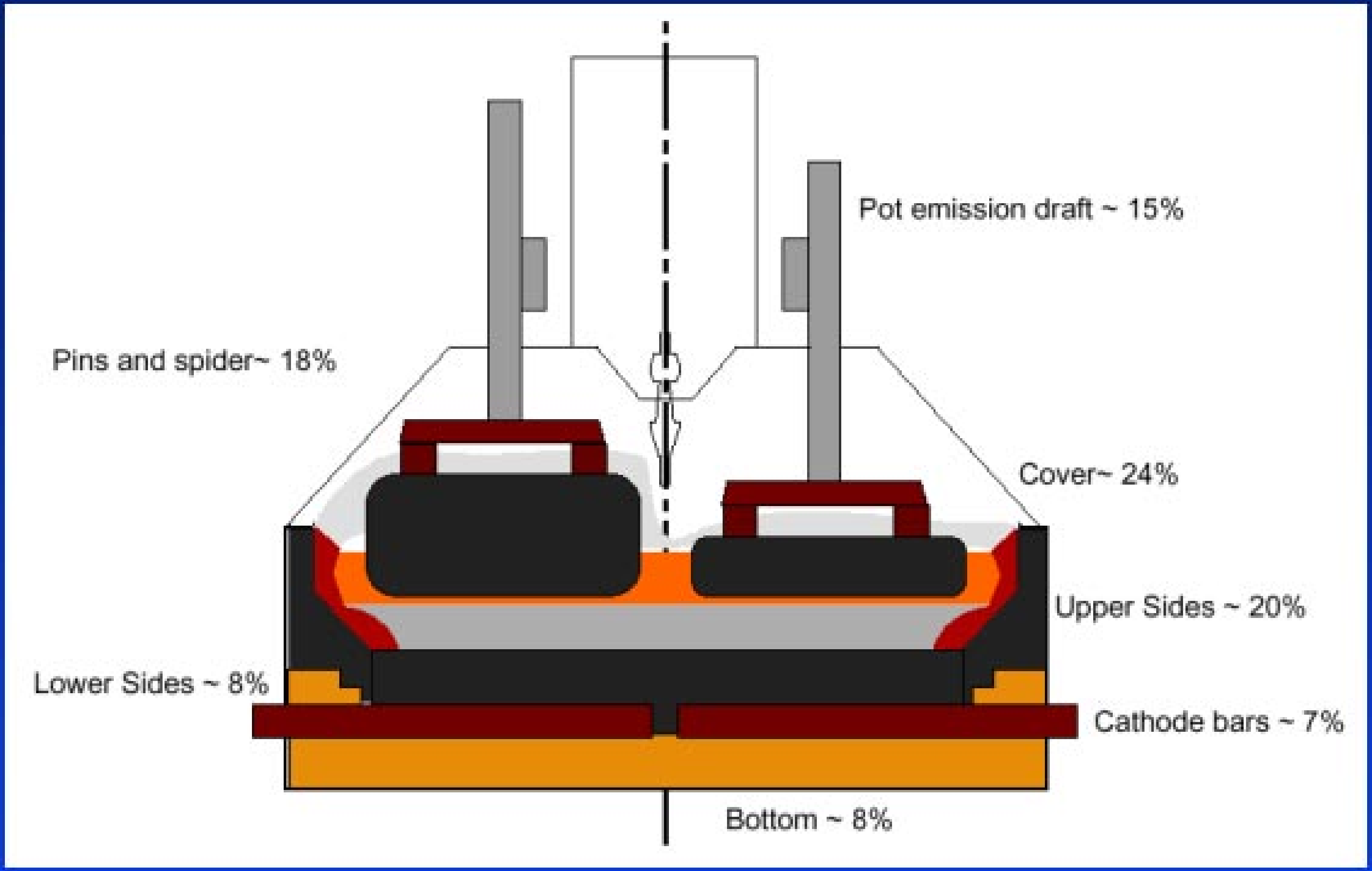
Heat Loss by Convection and Radiation



Heat Partition depends on the anode and cathode lining design

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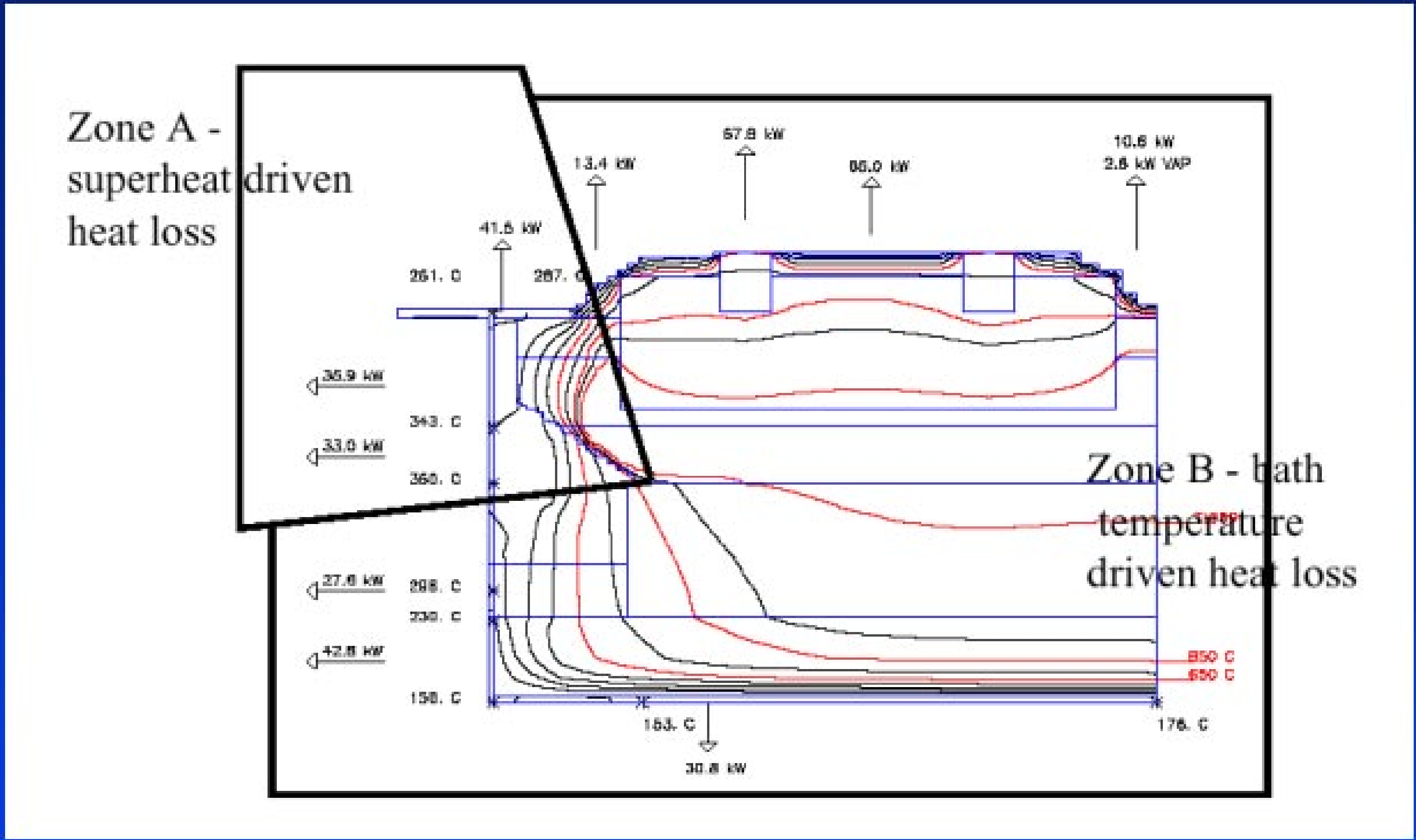
Two Zones Heat Partition Concept



The cell superheat dictates the amount of heat dissipates in zone A

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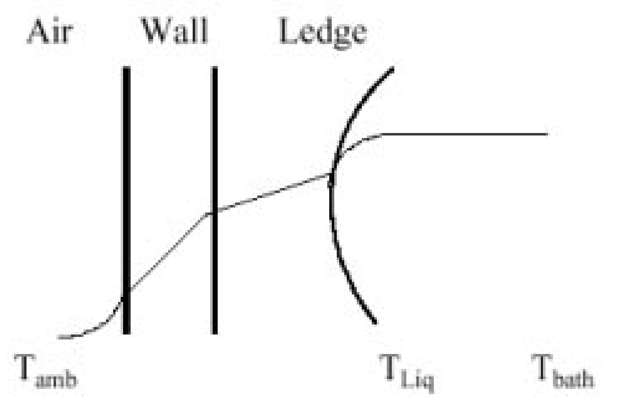
Zone A Heat Loss Mechanism

The difference between the cell internal heat and the cell heat loss in zone B will dictates the cell superheat that in turn will dictates the ledge thickness.

So in order to design a cell with an optimum ledge thickness, the cell designer must ensure that the need for cell heat loss in zone A will in turn be optimum, by proper evaluation of the cell internal heat and proper design of the zone B heat loss.

Zone A Heat Loss

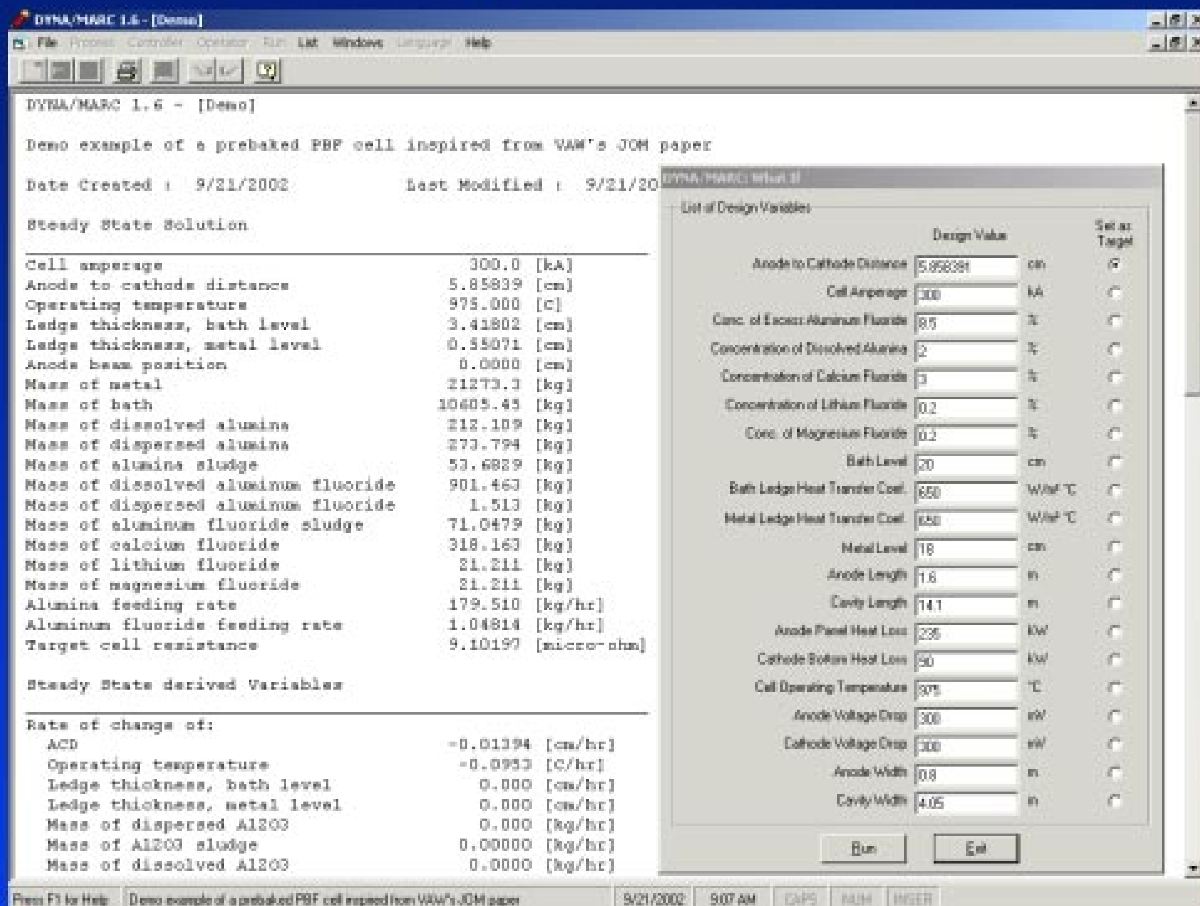


$$Q_{zoneA} = \frac{T_{bath} - T_{amb}}{R_{total\ zoneA}}$$

Bath/ledge boundary constrained to liquidus, therefore:

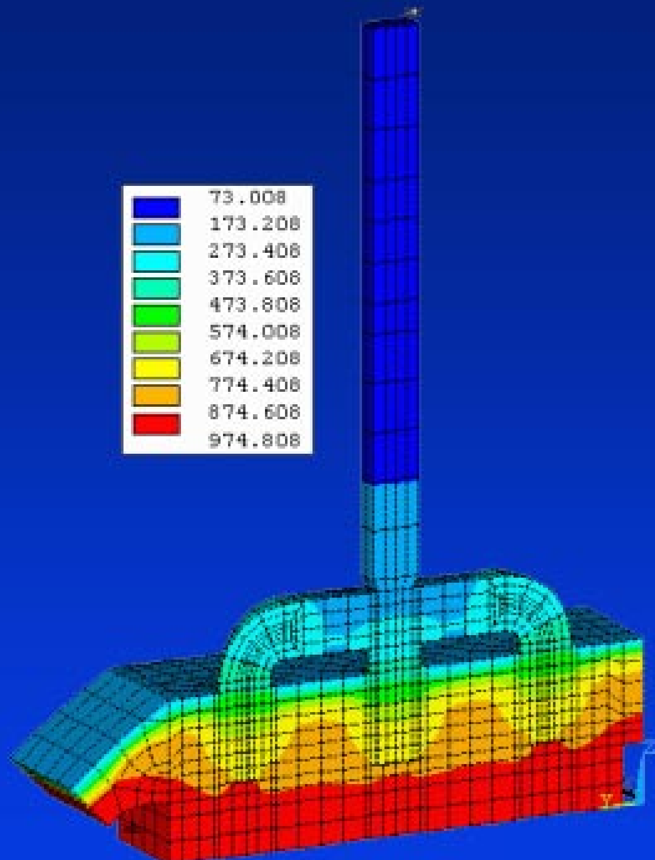
$$Q_{zoneA} = \frac{T_{liq} - T_{amb}}{R_{ledge} + R_{wall} + R_{shell\ to\ air}} = \frac{T_{bath} - T_{liq}}{R_{bath\ to\ ledge}}$$

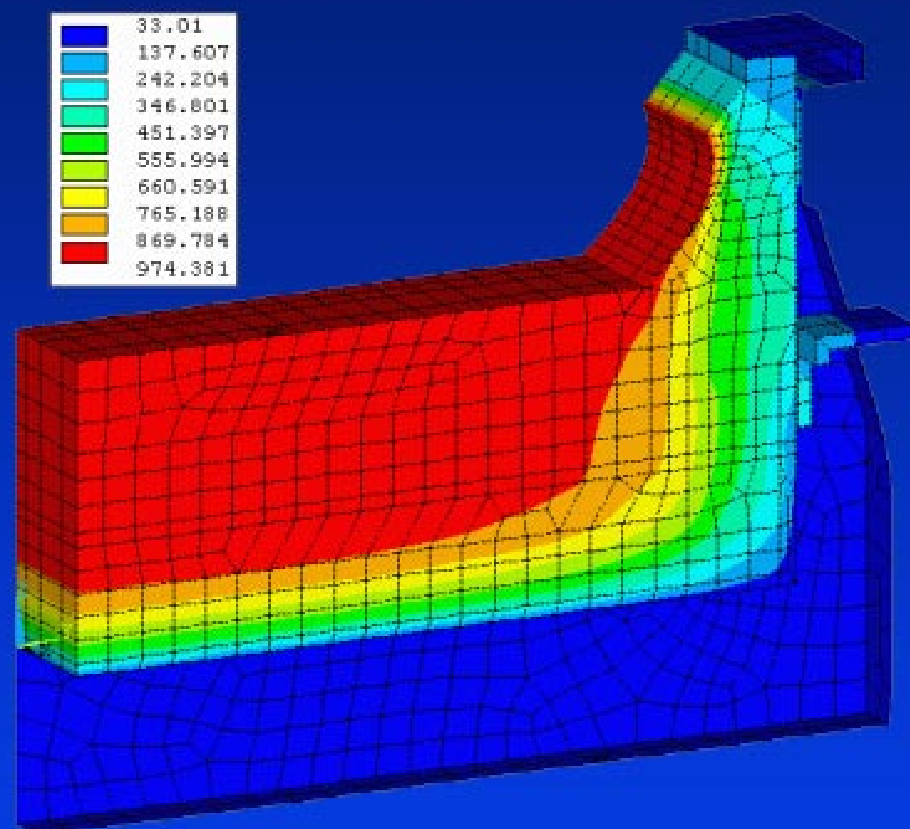
List of Modeling Tools from GeniSim



Steady/MARC, lump parameters+: simplest and fastest approach

List of Modeling Tools from GeniSim





3D half-anode, 3D cathode slice and DOS/MARC: classic approach

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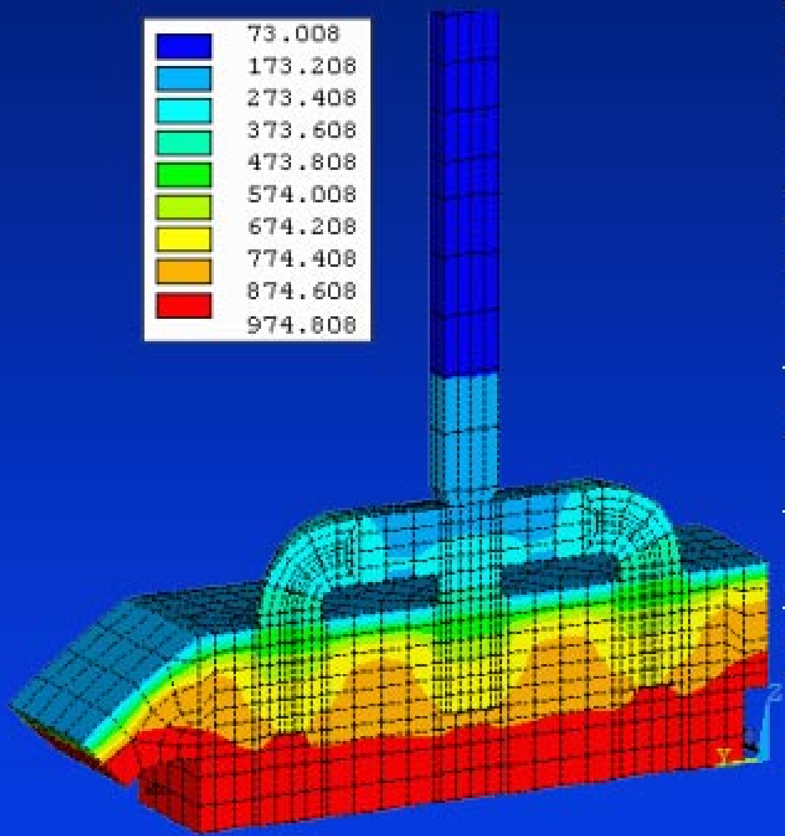
3D Half Anode Model Results



**** HEAT BALANCE TABLE ****
**** Half Anode Model : VAW 300 ****

HEAT INPUT	W	W/m^2	%
Bath to anode carbon	1491.59	1508.61	42.16
Bath to crust	642.57	3161.81	18.16
Joule heat	1403.42		39.67
Total Heat Input	3537.57		100.00

HEAT LOST	W	W/m^2	%
Crust to air	1394.79	1651.42	38.50
Studs to air	1819.48	4067.71	50.22
Aluminum rod to air	408.50	693.78	11.28
Total Heat Lost	3622.77		100.00

ANODE PANEL HEAT LOST	kW	W/m^2	%
Crust to air	89.27	1651.42	38.50
Studs to air	116.45	4067.71	50.22
Aluminum rod to air	26.14	693.78	11.28
Total Anode Panel Heat Lost	231.86		100.00

Avg. Drop at clamp (mV)	Current at anode Surf (Amps)
302.910	4687.500

Targeted cell current: 300000.00 Amps
Obtained cell current: 300000.00 Amps

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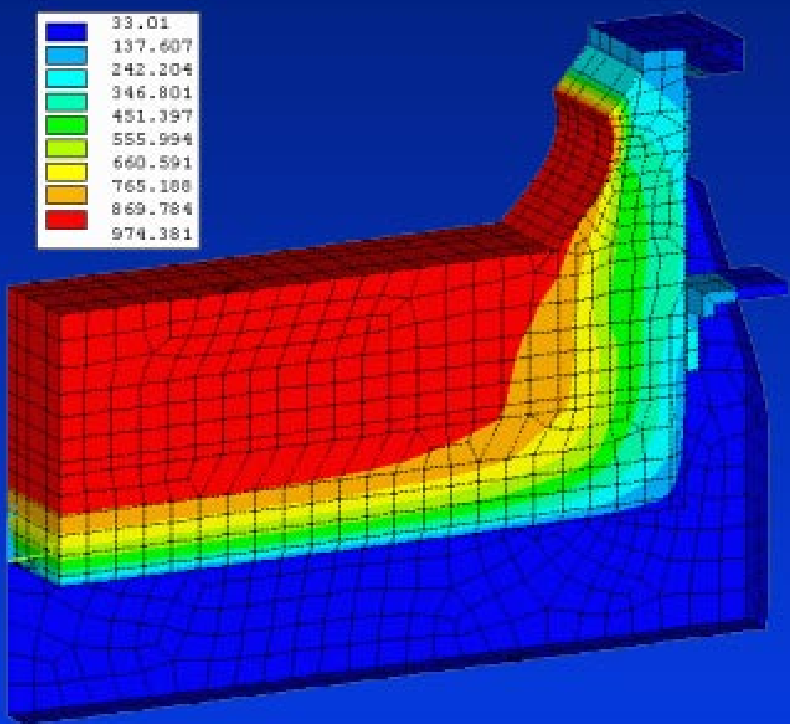
3D Cathode Side Slice Model Results



**** HEAT BALANCE TABLE ****
**** Side Slice Model : vaw_20 ****

MODEL HEAT IN/OUT	W	W/m^2	%
Total Heat Input	4517.31		100.00
Total Heat Lost	4545.21		100.00

CATHODE HEAT LOST	kW	W/m^2	%
Shell wall above bath level	62.81	1344.21	15.99
Shell wall opposite to bath	40.42	5399.96	10.29
Shell wall opposite to metal	40.61	7220.85	10.34
Shell wall opposite to block	83.88	5797.58	21.36
Shell wall below block	8.91	669.22	2.27
Shell floor	24.02	414.59	6.12
Cradle above bath level	2.67	1585.30	.68
Cradle opposite to bath	9.58	2164.69	2.44
Cradle opposite to metal	6.30	2601.20	1.60
Cradle opposite to block	25.24	927.80	6.43
Cradle opposite to brick	3.74	159.54	.95
Cradle below floor level	14.74	99.09	3.75
Bar and Flex to air	45.23	2653.04	11.52
End of flex to busbar	24.54	40579.69	6.25
Total Cathode Heat Lost	392.71		100.00

Avg. Drop at Bar End (mV)	Average Flex. Drop (mV)	Current at Cathode Surf (Amps)
285.44	7.474	4166.667

Targeted cell current: 300000.00 Amps
Obtained cell current: 300000.00 Amps

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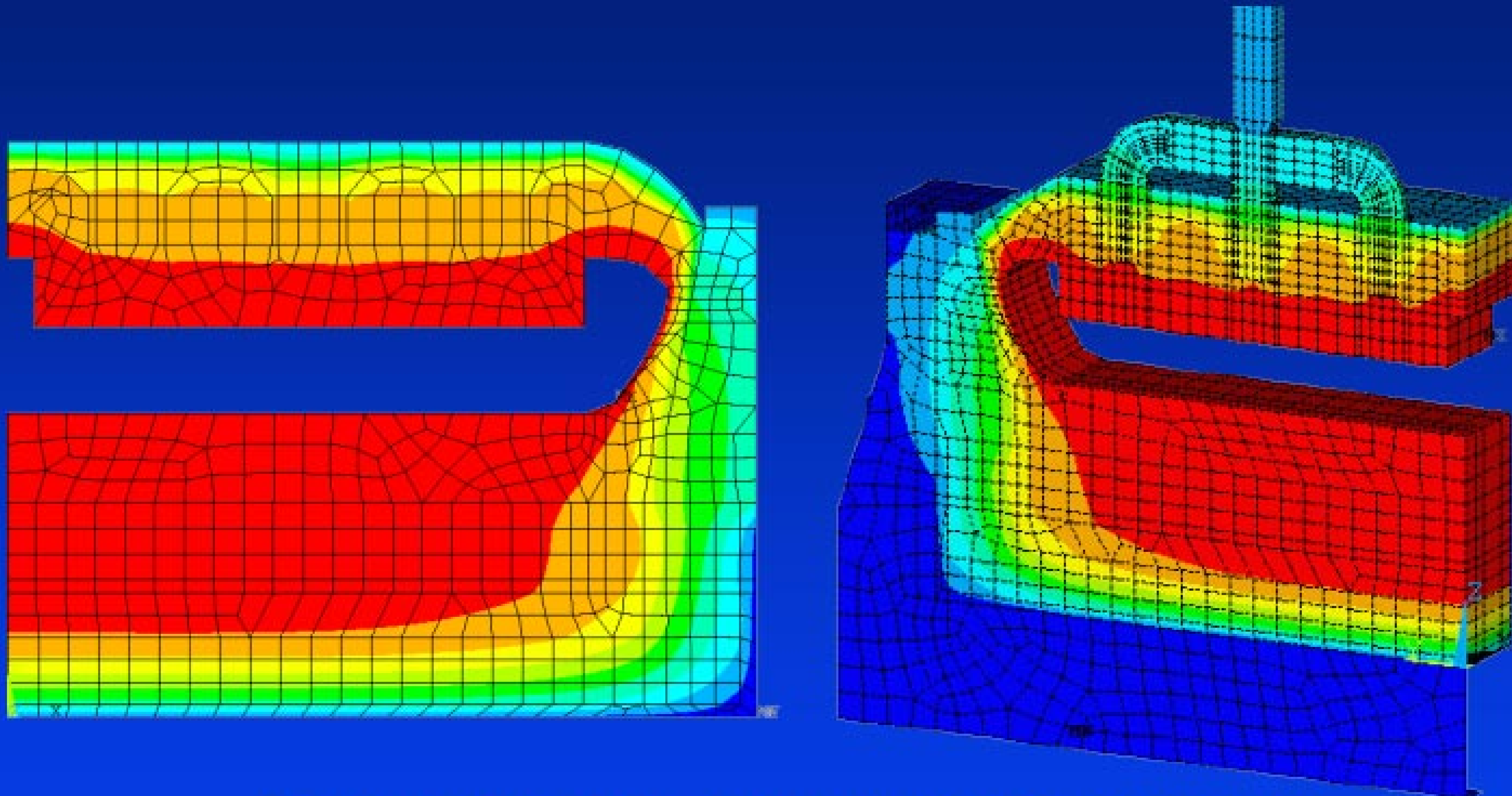
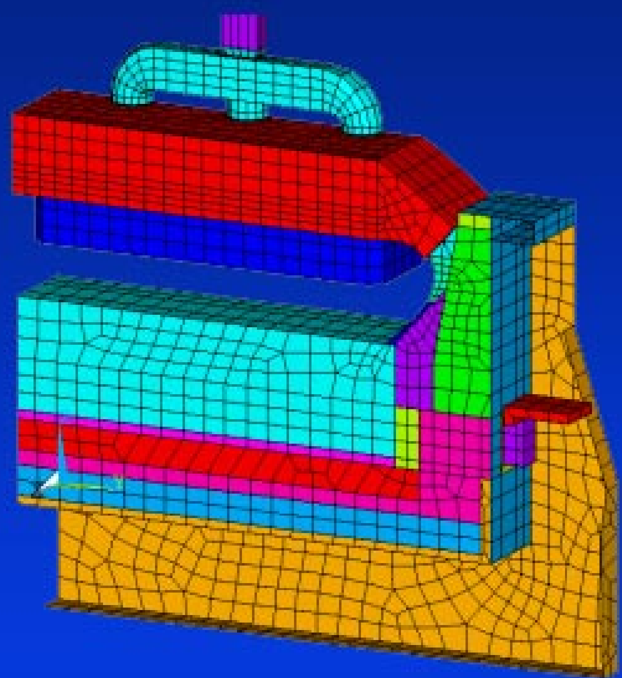
List of Modeling Tools from GeniSim



2D+ or 3D full cell slice: new standard approach

3D Full Cell Slice Model Results



**** HEAT BALANCE SUMMARY ****
**** Full slice Model : VAW 300 ****

INTERNAL HEAT CALCULATION

Operating temperature	972.17	°C
Bath Resistivity	.424563	ohm-cm
Anode Current Density	.732422	A/cm^2
Cathode Current Density	.668449	A/cm^2
Bath Voltage	1.58152	volts
Electrolysis Voltage	1.92456	volts
Total Cell Voltage	4.29380	volts
Equivalent Voltage to Make Metal	2.01837	volts
Current Efficiency	93.2480	%
Internal Heat Generation	622.630	kW

TOTAL HEAT LOST

Total Anode Panel Heat Loss	237.289	kW
Total Cathode Heat Loss	385.233	kW
Total Cell Heat Loss	622.522	kW

HEAT UNBALANCE .02 %

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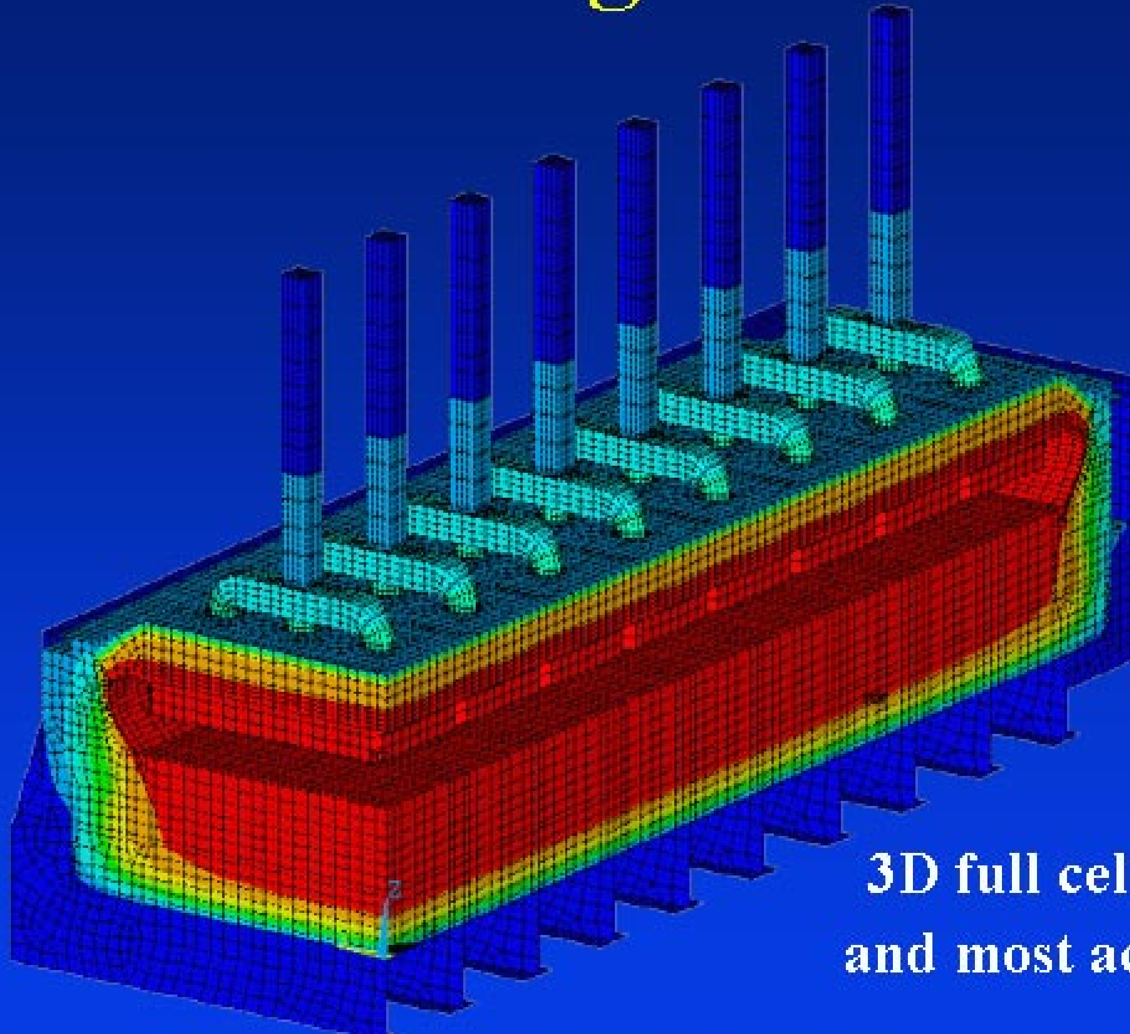
List of Modeling Tools from GeniSim



3D full cell quarter: longest and most accurate approach

Examples of Applications of a 3D Full Cell Slice Thermo-Electric Model

	Base Case	Retrofit 1	Retrofit 2
Cell amperage (kA)	300	350	265
Cell internal heat (kW)	628	713	427
Cell kWh/kg	13.75	13.40	11.94

These two extreme cases clearly demonstrate that as far as the cell thermal balance is concerned, the window of opportunities is quite wide. Only a complimentary technico-economical study will indicate which of the two retrofit scenarios offer the best return on investment .

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Dr. Marc Dupuis Experience Building T/E Models

With Alcan

1987-1994:
- Alcan prototypes: A275, A265-H, A310
- Alcan prebaked: A70, A140, A165
- Alcan HSS
- Alcoa P155
- Pechiney AP18

With GeniSim

1996-2003:
- Pechiney AP30
- Alcoa: P155, A697
- Reynolds prebaked: P-19, P-20S, P-23S
- Kaiser P69
- Reynolds HSS
- Pechiney HSS
- Alcan VSS

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GeniSim T/E Modeling Success Story

		START-UP 1992	LATEST POTS 1998
PRODUCTION :			
• Production per pot/day	(kg)	2245	2486
• Current efficiency	(%)	94.5	96
POWER :			
• Amperage	(kA)	295	319
• Pot voltage	(V)	4.330	4.185
• DC kWh/t		13 650	13 000
CONSUMPTIONS :			
• Gross carbon	(kg/t)	540	493
• Net carbon	(kg/t)	410	397
• Anodes cycle-shifts-8 hours		80	90
METAL PURITY :			
• Iron	(ppm)	---	700
• Silicon	(ppm)	---	240
POT CONDITION :			
• Anode effects	(pot/day)	0.40	0.20

Tableau no. 1 : Lauralco's results

Lauralco used GeniSim 3D ANSYS® thermo-electric models and Dyna/Marc cell simulator to improve their cell lining design.

Lauralco is now considered the most efficient smelter in the industry.

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GeniSim T/E Modeling Success Story

1993 Operating Costs
(contains no depreciation or other charge for capital)
($/ton except where noted)

Smelter	**Deschambault**	**Deschambault**
Country	**Canada**	**Canada**
Company	**Alumax**	**Alumax**
Capacity (tpy)	224	235
Electricity usage (kWh/t)	13650	13000
Electricity price ($/kWh)	0.012	0.012
Total electricity cost:	163.03	155.27
Alumina usage (t/t Al)	1.92	1.92
Alumina price ($/t Alumina)	204.80	204.80
Total alumina cost:	393.22	393.22
Other raw materials	88.44	88.44
Plant power and fuel	7.54	7.54
Consumables	38.29	38.29
Maintenance	52.93	52.93
Labor	82.00	78.00
Freight	39.09	39.09
General and administrative	67.71	67.71
Total	932.25	920.49

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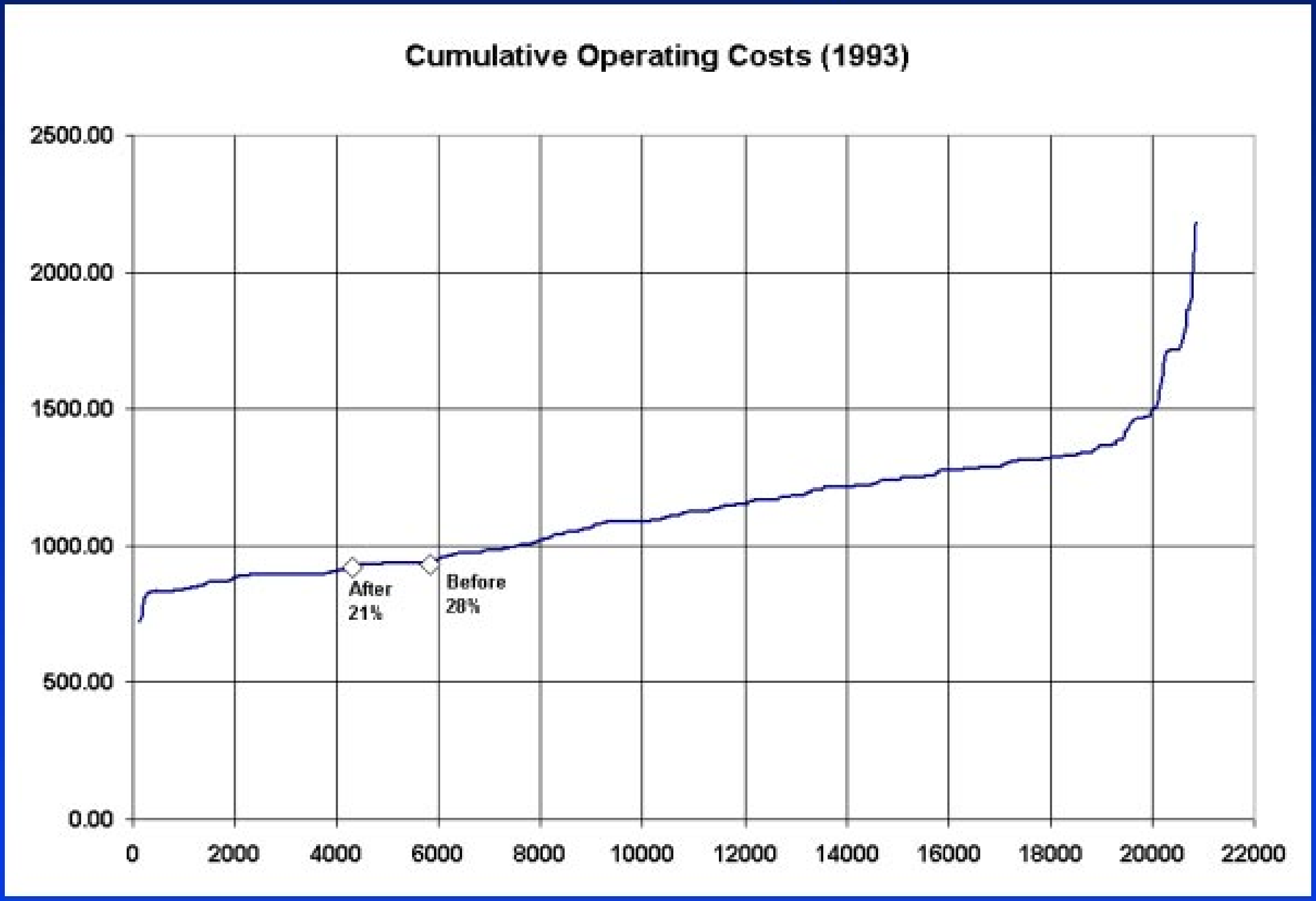
GeniSim T/E Modeling Success Story



Conclusions

- These days, with the support of well established and reliable mathematical models, older smelters operating at 17-18 kWh/kg due to a poor thermal design should be able to come up with successful retrofit design proposal(s) well within a year, test that (those) design proposal(s) in prototypes during a minimum of two years and then be able to proceed to a full implementation phase.
- As far as the thermal balance problem of the cell is concerned, there is no known technical reason that should prevent a significant reduction of their power consumption.

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