VERY LOW ENERGY CONSUMPTION CELL DESIGNS: THE CELL HEAT BALANCE CHALLENGE

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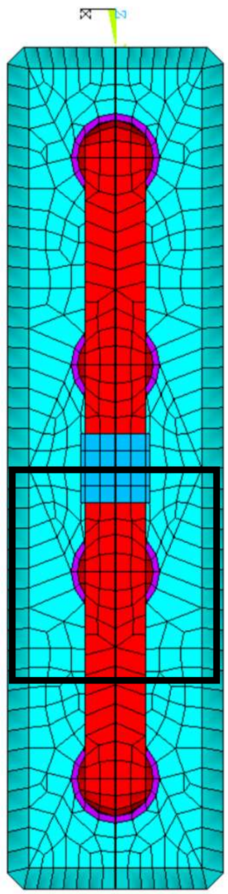
GENISIM

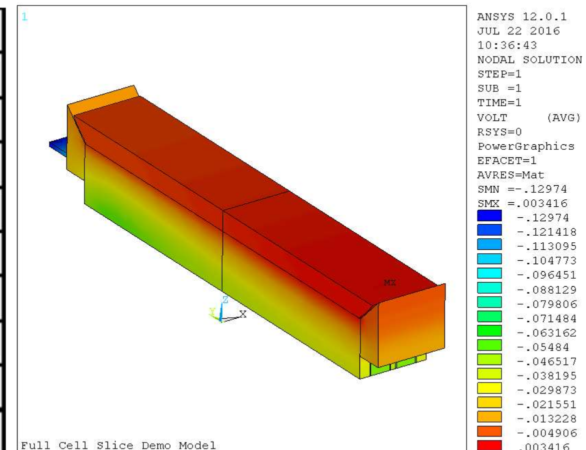
Plan of the Presentation

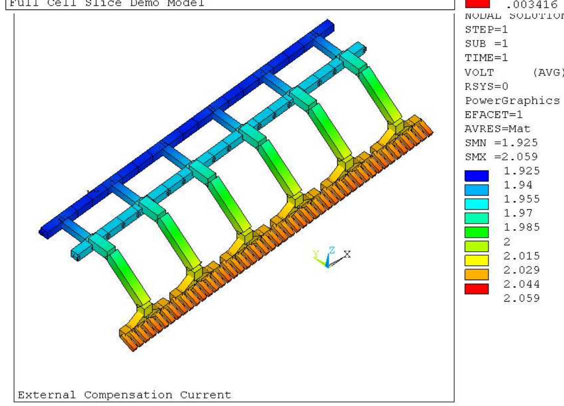
- Introduction: previous work presented in 2017
  - TMS 2017's 500 kA cell with 100% downstream current exit (electrical design only)
  - ALUMINIUM 2017's 760 kA wide cell design running at 12.85 kWh/kg
- Thermal design of the 500 kA with 100% downstream current exit cell running at 11.2 kWh/kg
- Design of a 650 kA wide cell running at 11.3 kWh/kg
- Future work
- Conclusions

Summary of the TMS 2017's retrofit study



	Base case	
Amperage	500 kA	500 kA
Nb. of anodes	48	64
Anode size	1.95m X .665m	1.95m X .5m
Nb. of anode studs	4 per anode	4 per anode
Anode stud diameter	17.5 cm	17.5 cm
Anode cover thickness	10 cm	10 cm
Nb. of cathode blocks	24	24
Cathode block length	4.17 m	4.17 m
Type of cathode block	HC10	HC10
Collector bar size	20 cm X 10 cm	25 cm X 16 cm
Type of side block	SiC	SiC
Side block thickness	10 cm +	10 cm +
ASD	30 cm	30 cm
Calcium silicate thickness	3.5 cm	3.5 cm
Inside potshell size	17.8 X 4.85 m	17.8 X 4.85 m
ACD	3.5 cm	3.2 cm
Excess AlF_3	12.00%	12.00%



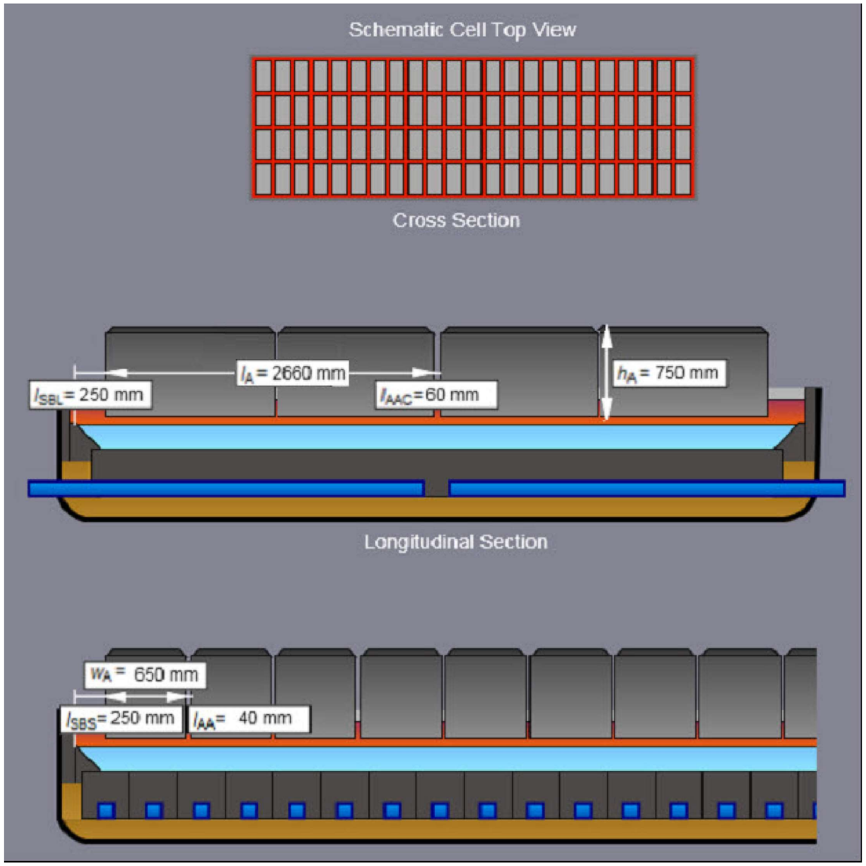


Summary of the TMS 2017's retrofit study

	Base case		
Amperage	500 kA	500 kA	400 kA
Anode drop	265 mV	224 mV	179 mV
Cathode drop	87 mV	130 mV	104 mV
Busbar drop	310 mV	134 mV	107 mV
Cell voltage	3.89 V	3.59 V	3.20 V
Current efficiency	95.90%	95.90%	95.90%
Internal heat	758 kW	699 kW	414 kW
Energy consumption	12.1 kWh/kg	11.2 kWh/kg	9.95 kWh/kg

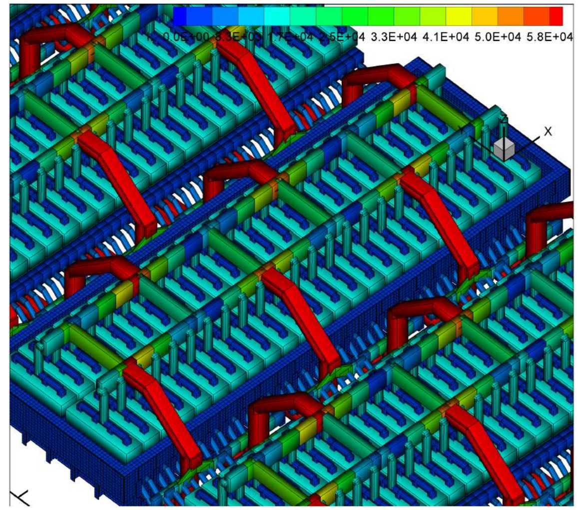
Summary of the ALUMINIUM 2017's retrofit study

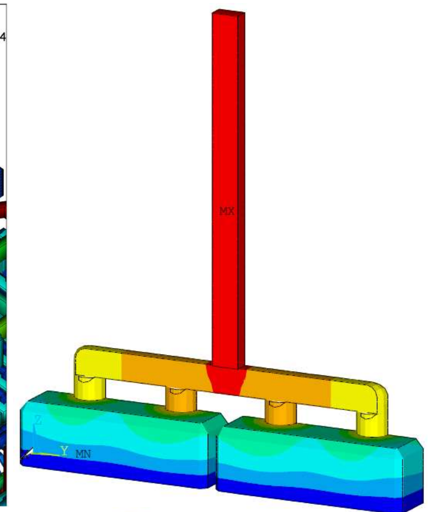
Amperage	762.5 kA
Nb. of anodes	48
Anode size	2.6 m × .65 m
Nb. of anode studs	4 per anode
Anode stud diameter	21.0 cm
Anode cover thickness	15 cm
Nb. of cathode blocks	24
Cathode block length	5.37 m
Type of cathode block	HC10
Collector bar size	20 cm × 12 cm
Type of side block	HC3
Side block thickness	7 cm
Anode side wall distance: ASD	25 cm
Calcium silicate thickness	3.5 cm
Inside potshell size	17.02 × 5.88 m
Anode cathode distance: ACD	3.0 cm
Excess AlF_3	11.50 %

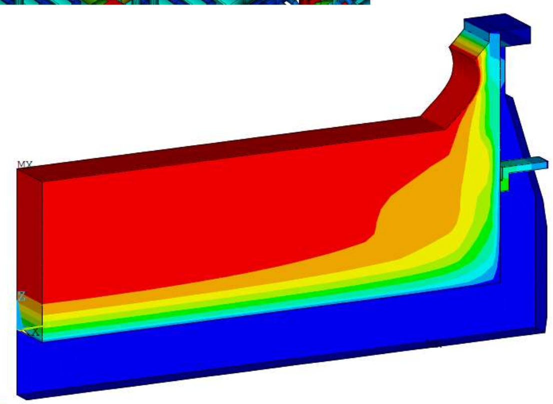


Summary of the ALUMINIUM 2017's retrofit study

Anode drop (A)	347 mV
Cathode drop (A)	118 mV
Busbar drop (A)	300 mV
Anode panel heat loss (A)	553 kW
Cathode total heat loss (A)	715 kW
Operating temperature (D/M)	968.9 °C
Liquidus superheat (D/M)	10.0 °C
Bath ledge thickness (A)	6.82 cm
Metal ledge thickness (A)	1.85 cm
Current efficiency (D/M)	95.14 %
Internal heat (D/M)	1328 kW
Energy consumption	12.85 kWh/kg



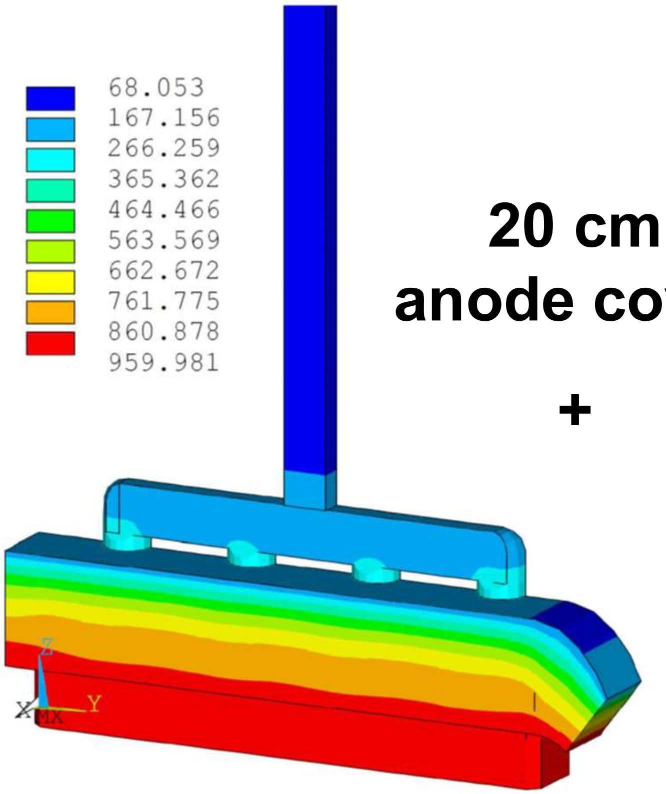




Thermal design of the 500 kA with 100% downstream current exit cell running at 11.2 kWh/kg

**** HEAT BALANCE TABLE ****
**** Half Anode Model : 500 kA ****

ANODE PANEL HEAT LOST	kW	W/m^2	%
Crust to air	85.76	1130.63	29.36
Studs to air	165.70	2093.65	56.73
Aluminum rod to air	40.64	449.31	13.91
Total Anode Panel Heat Lost	292.10		100.00



20 cm anode cover

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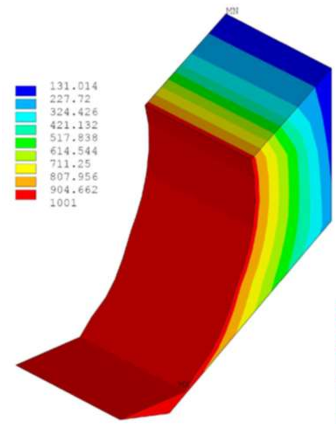
Thermal design of the 500 kA with 100% downstream current exit cell running at 11.2 kWh/kg

**** HEAT BALANCE TABLE ****

**** Side Slice Model: 500 kA ****

CATHODE HEAT LOST	kW	W/m^2	%
Shell wall above bath level	48.00	779.66	11.96
Shell wall opposite to bath	35.82	3620.92	8.92
Shell wall opposite to metal	23.04	5124.05	5.74
Shell wall opposite to block	60.50	2356.32	15.07
Shell wall below block	7.77	396.23	1.94
Shell floor	30.41	373.24	7.57
Cradle above bath level	2.08	936.98	0.52
Cradle opposite to bath	9.79	1403.73	2.44
Cradle opposite to metal	3.84	1615.32	0.96
Cradle opposite to block	18.12	386.58	4.51
Cradle opposite to brick	3.39	75.35	0.84
Cradle below floor level	35.58	97.40	8.86
Bar and flex to air	64.74	9903.13	16.13
End of flex to busbar	76.20	264566.31	18.98
Cathode bottom estimate	257.40		64.11
Total Cathode Heat Lost	401.50		100.00



Very high insulated pier

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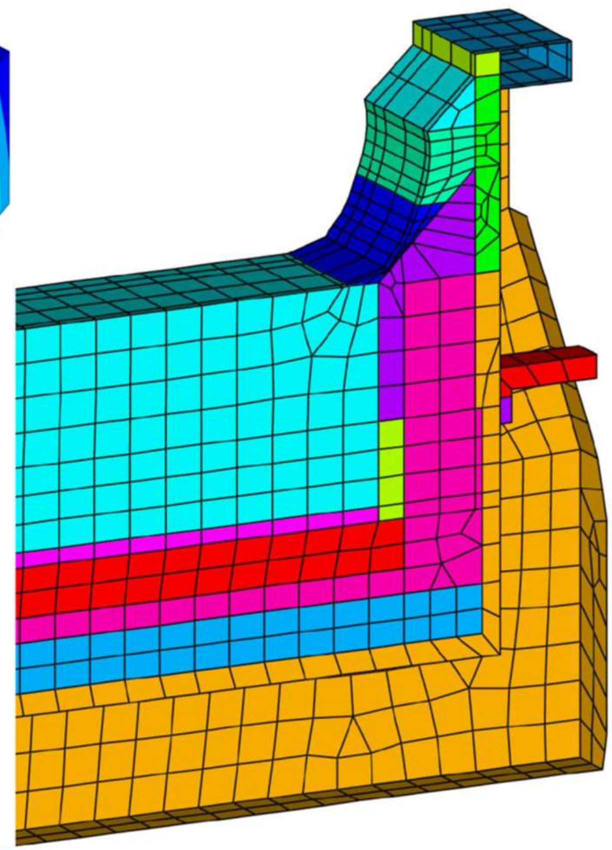
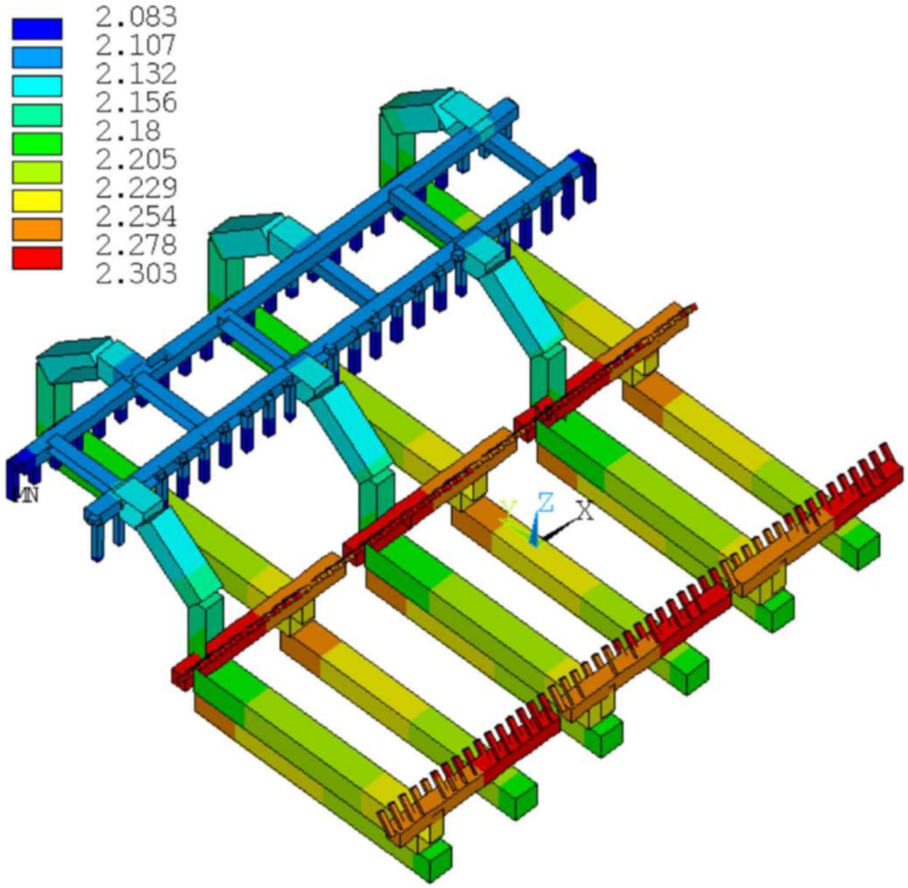


Thermal design of the 500 kA with 100% downstream current exit cell running at 11.2 kWh/kg

Amperage	600 kA	500 kA
Nb. of anodes	48	64
Anode size	2.0 m × .665 m	1.95 m × .5 m
Nb. of anode studs	4 per anode	4 per anode
Anode stud diameter	17.5 cm	17.5 cm
Anode cover thickness	10 cm	20 cm
Nb. of cathode blocks	24	24
Cathode block length	4.17 m	4.17 m
Type of cathode block	HC10	HC10
Collector bar size	20 cm × 10 cm	20 cm × 20 cm
Type of side block	SiC	HC3
Side block thickness	7 cm	7 cm
Anode side wall distance: ASD	28 cm	30 cm
Calcium silicate thickness	3.5 cm	6.0 cm
Inside potshell size	17.8 × 4.85 m	17.8 × 4.85 m
Anode cathode distance: ACD	3.5 cm	3.2 cm
Excess AlF_3	12.00 %	12.00 %

Anode drop (A)	318 mV	238 mV
Cathode drop (A)	104 mV	123 mV
Busbar drop (A)	311 mV	134 mV
Anode panel heat loss (A)	449 kW	292 kW
Cathode total heat loss (A)	692 kW	402 kW
Operating temperature (D/M)	964.8 °C	958.4 °C
Liquidus superheat (D/M)	11.8 °C	5.4 °C
Bath ledge thickness (A)	6.36 cm	11.84 cm
Metal ledge thickness (A)	1.76 cm	3.48 cm
Current efficiency (D/M)	96.40 %	96.30 %
Internal heat (D/M)	1140 kW	699 kW
Energy consumption	13.26 kWh/kg	11.2 kWh/kg

Design of a 650 kA wide cell running at 11.3 kWh/kg



Very simple RCC busbar concept with alternating upstream and downstream risers.

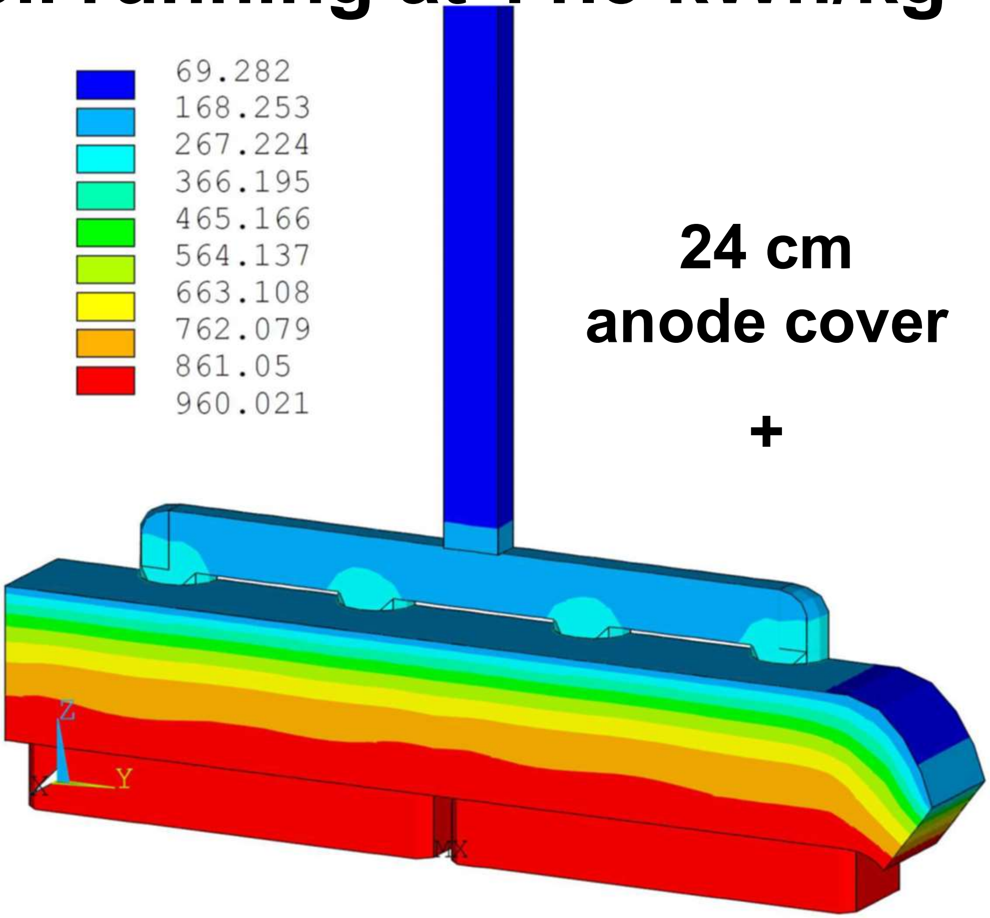
The upstream collector bars are feeding the 3 upstream risers, while the downstream collector bars are feeding the 3 downstream risers.

Magnetic compensation busbar are also presented below the cell position.

Design of a 650 kA wide cell running at 11.3 kWh/kg

**** HEAT BALANCE TABLE ****
**** Half Anode Model: 650 kA ****

ANODE PANEL HEAT LOST	kW	W/m^2	%
Crust to air	105.63	1078.21	32.32
Studs to air	177.39	2233.02	54.27
Aluminum rod to air	43.81	552.05	13.40
Total Anode Panel Heat Lost	326.83		100.00



24 cm anode cover

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Design of a 650 kA wide cell running at 11.3 kWh/kg

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****          HEAT BALANCE TABLE           ****
****      Side Slice Model: 650 kA         ****
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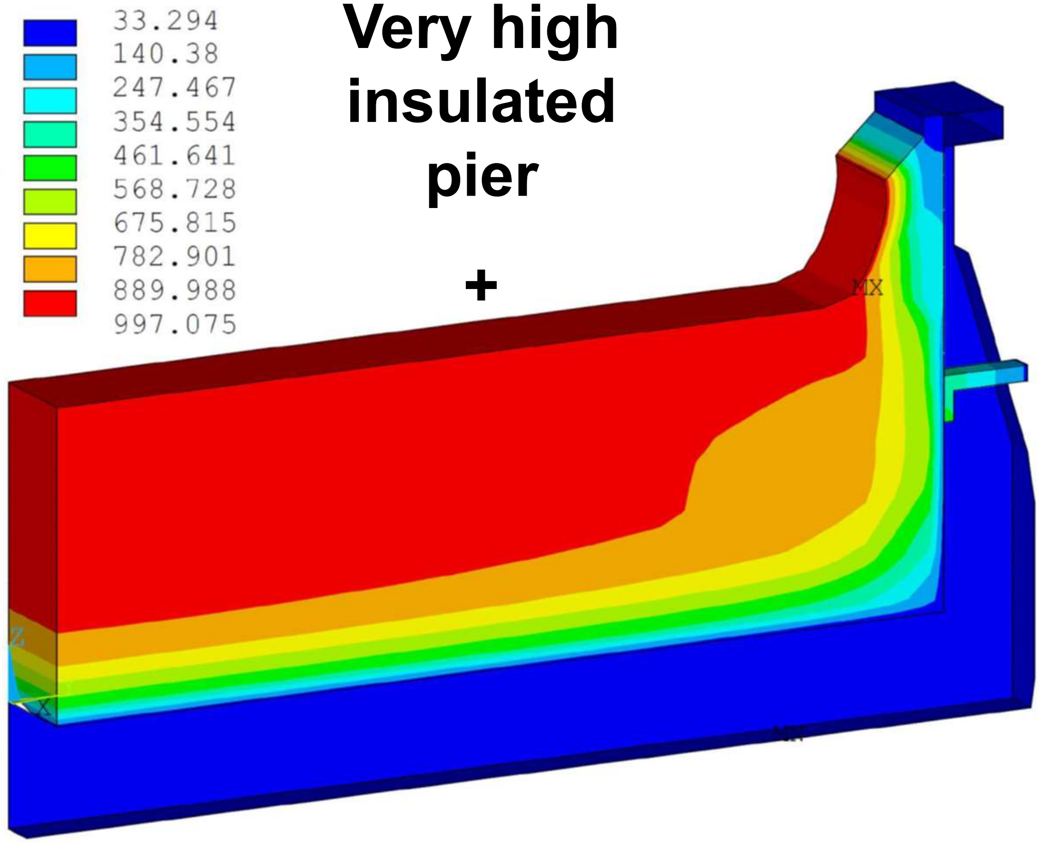
CATHODE HEAT LOST	kW	W/m^2
Shell wall above bath level	53.42	769.17
Shell wall opposite to bath	39.51	3540.15
Shell wall opposite to metal	25.30	4986.43
Shell wall opposite to block	66.30	2235.30
Shell wall below block	8.29	372.59
Shell floor	35.36	366.17
Cradle above bath level	2.44	925.21
Cradle opposite to bath	11.46	1383.66
Cradle opposite to metal	4.48	1587.32
Cradle opposite to block	20.98	376.99
Cradle opposite to brick	3.82	74.79
Cradle below floor level	21.85	98.68
Bar and flex to air	113.28	10545.17
End of flex to busbar	92.87	257964.26
Cathode bottom estimate	319.10	
Total Cathode Heat Lost	499.35	



Very high insulated pier

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Design of a 650 kA wide cell running at 11.3 kWh/kg

Amperage	762.5 kA	650 kA
Nb. of anodes	48	48
Anode size	2.6 m × .65 m	2.6 m × .65 m
Nb. of anode studs	4 per anode	4 per anode
Anode stud diameter	21.0 cm	24.0 cm
Anode cover thickness	15 cm	24 cm
Nb. of cathode blocks	24	24
Cathode block length	5.37 m	5.37 m
Type of cathode block	HC10	HC10
Collector bar size	20 cm × 12 cm	20 cm × 15 cm
Type of side block	HC3	HC3
Side block thickness	7 cm	7 cm
Anode side wall distance: ASD	25 cm	25 cm
Calcium silicate thickness	3.5 cm	6.0 cm
Inside potshell size	17.02 × 5.88 m	17.02 × 5.88 m
Anode cathode distance: ACD	3.0 cm	2.8 cm
Excess AlF_3	11.50 %	11.50 %

Anode drop (A)	347 mV	296 mV
Cathode drop (A)	118 mV	109 mV
Busbar drop (A)	300 mV	220 mV
Anode panel heat loss (A)	553 kW	327 kW
Cathode total heat loss (A)	715 kW	499 kW
Operating temperature (D/M)	968.9 °C	967.0 °C
Liquidus superheat (D/M)	10.0 °C	8.1 °C
Bath ledge thickness (A)	6.82 cm	11.86 cm
Metal ledge thickness (A)	1.85 cm	3.38 cm
Current efficiency (D/M)	95.14 %	94.80 %
Internal heat (D/M)	1328 kW	832 kW
Energy consumption	12.85 kWh/kg	11.3 kWh/kg

Future work

- On the 500 kA cell side, the current 7 m. cell to cell distance could be reduced as the 100% downstream current extraction concept hardly requires any space between cells. The “500” kA cell energy efficiency could be further reduced by decreasing the ACD to 2.8 cm and increasing the cell amperage in order to maintain the same internal heat.
- On the wide 650 kA cell side, the current 2 studs per carbon block design could be replaced by a more appropriate 3 studs per carbon block design considering the length of those carbon blocks. This is not a technical problem but it does require the construction of a new model as the topology of the anode would not remain the same. The RCC busbar network could be further optimized in order to further reduced the busbar drop by decreasing even more the busbar current density.

Conclusions

- It turned out it is possible to reduce enough the heat dissipation of a cell to be able to operate cells in thermal balance at the very low energy consumption level of around 11.2-11.3 kWh/kg. Electrically, at 0.8 A/cm^2 of anode current density, this requires operating at close to the lowest achievable ACD which is around 2.8-3.0 cm and a total ohmic resistance of the anode cathode and busbar corresponding to a total voltage drop of about 500-600 mV.
- Thermally, this requires operating at the lowest possible cell superheat, a very high anode cover thickness, very high pier height, and using a special design feature to reduce the stubs and collector bars heat loss.
- Electrically, it is easy to continue to decrease the cell internal heat production by reducing the anode current density of around 0.6-0.65 A/cm^2 in order to get to 10 kWh/kg level.

BREAKING THE 11 KWH/KG BARRIER

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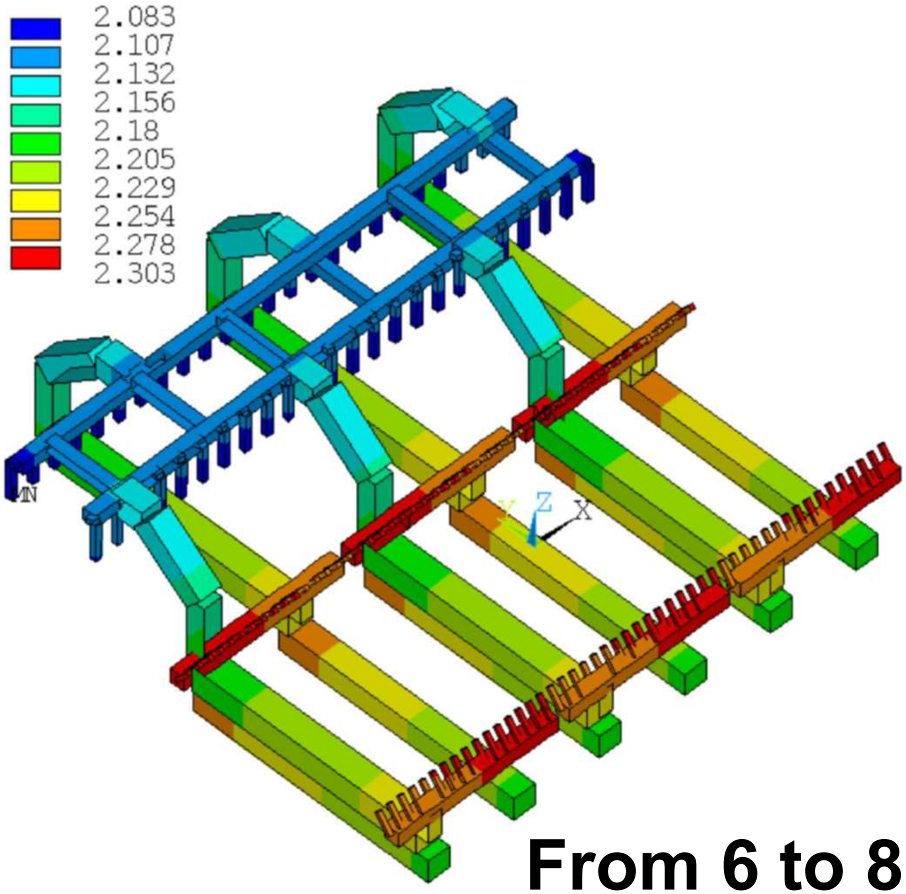
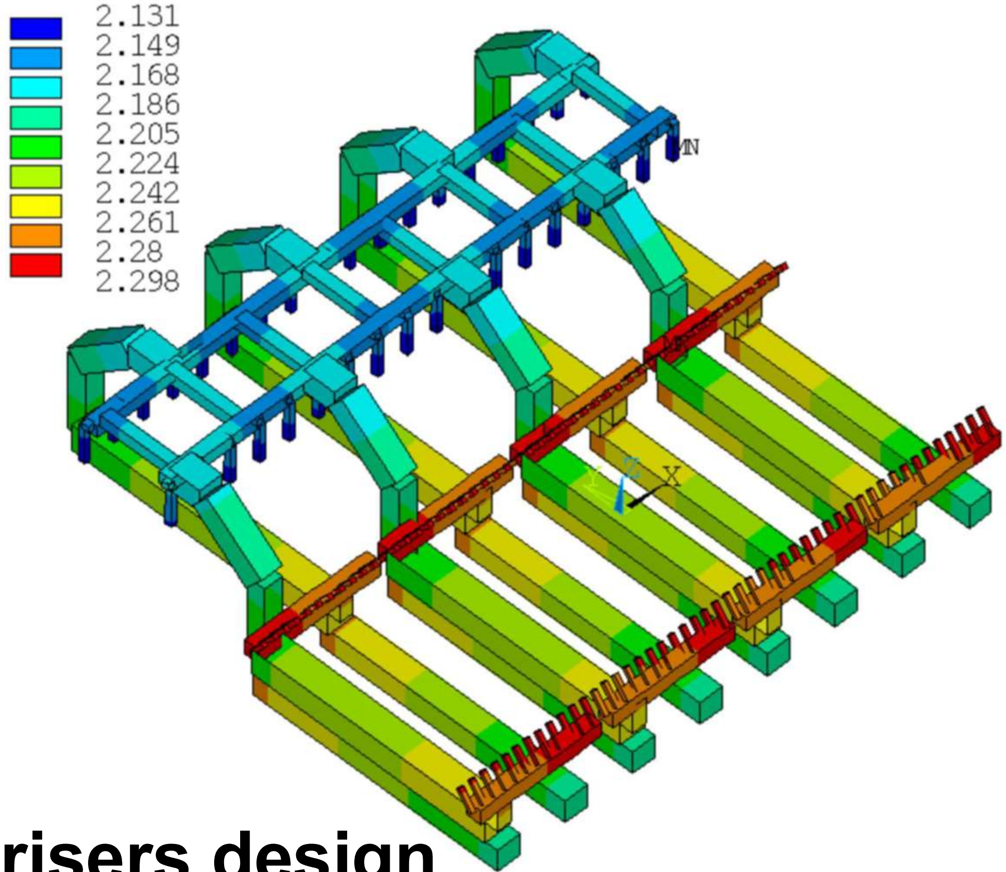
GENISIM

Plan of the Presentation

- Follow-up from TMS 2018's paper work
  - 650 kA wide cell design running at 11.00 kWh/kg
  - 520 kA cell with 100% downstream current exit running at 10.85 kWh/kg
- Future work
- Conclusions

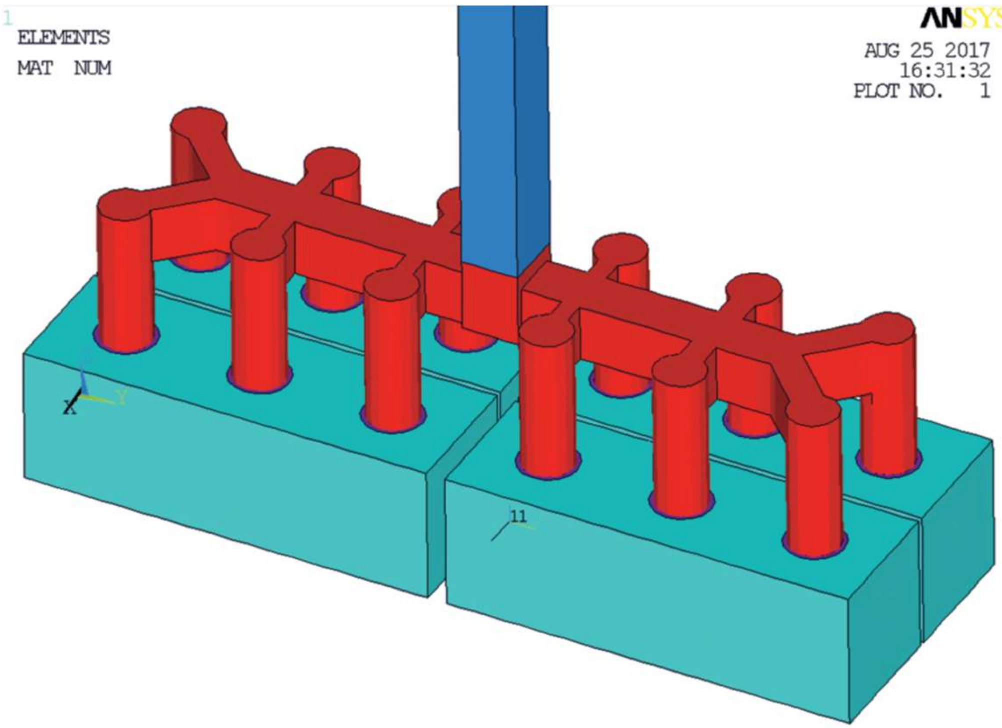
Design of a 650 kA wide cell running at 11.0 kWh/kg

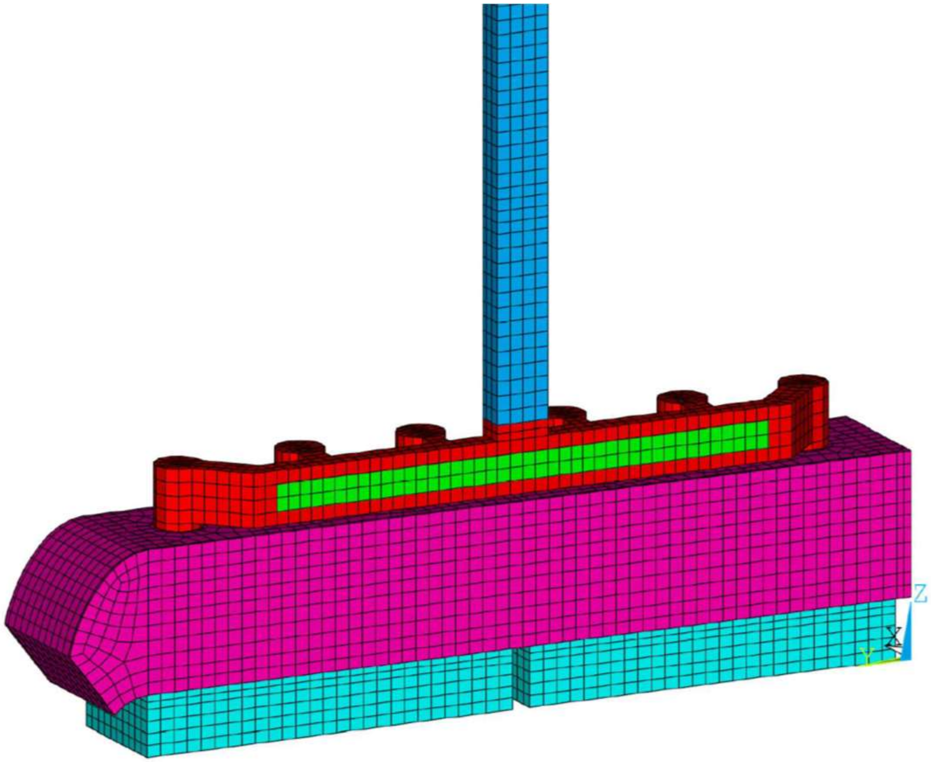




From 6 to 8 risers design

Design of a 650 kA wide cell running at 11.0 kWh/kg



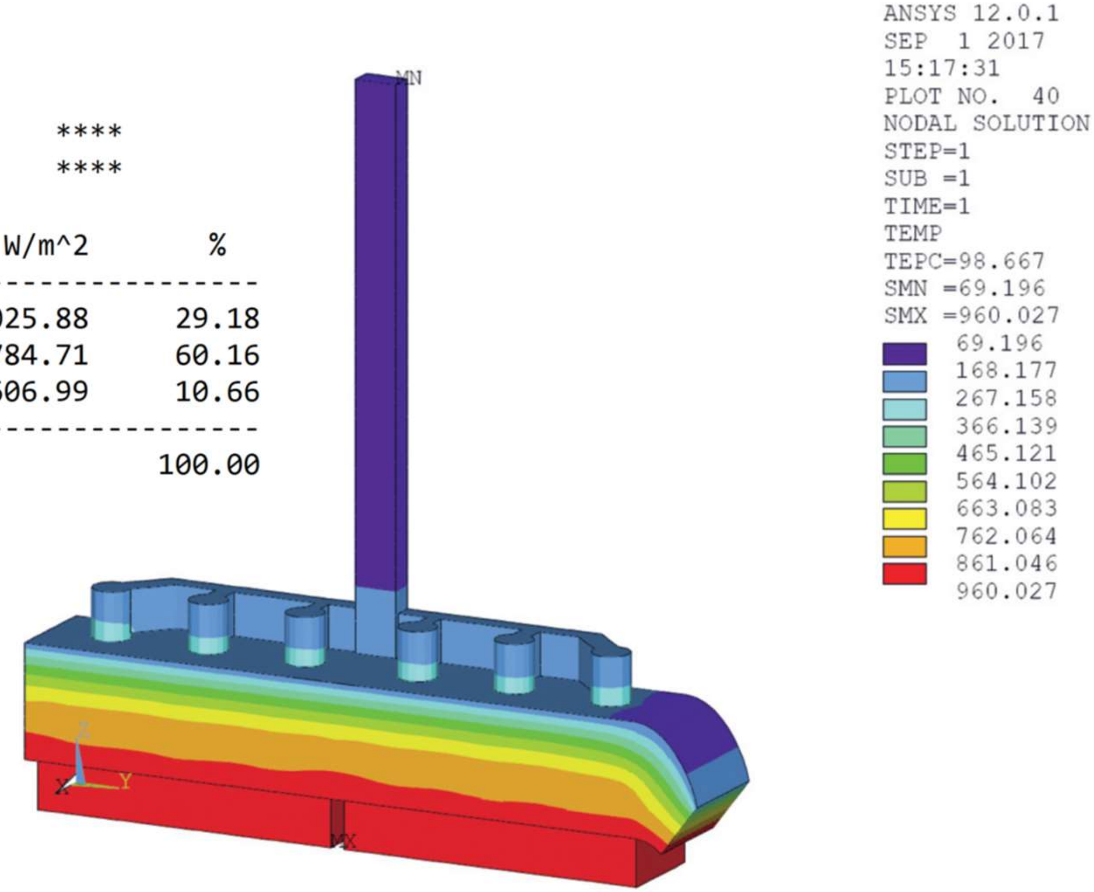


4 blocks, 3 stubs per block, anode design

Design of a 650 kA wide cell running at 11.0 kWh/kg

**** HEAT BALANCE TABLE ****
**** Half Anode Model : 650 KA ****

ANODE PANEL HEAT LOST	kW	W/m^2	%
Crust to air	98.89	1025.88	29.18
Studs to air	203.87	1784.71	60.16
Aluminum rod to air	36.13	606.99	10.66
Total Anode Panel Heat Lost	338.89		100.00

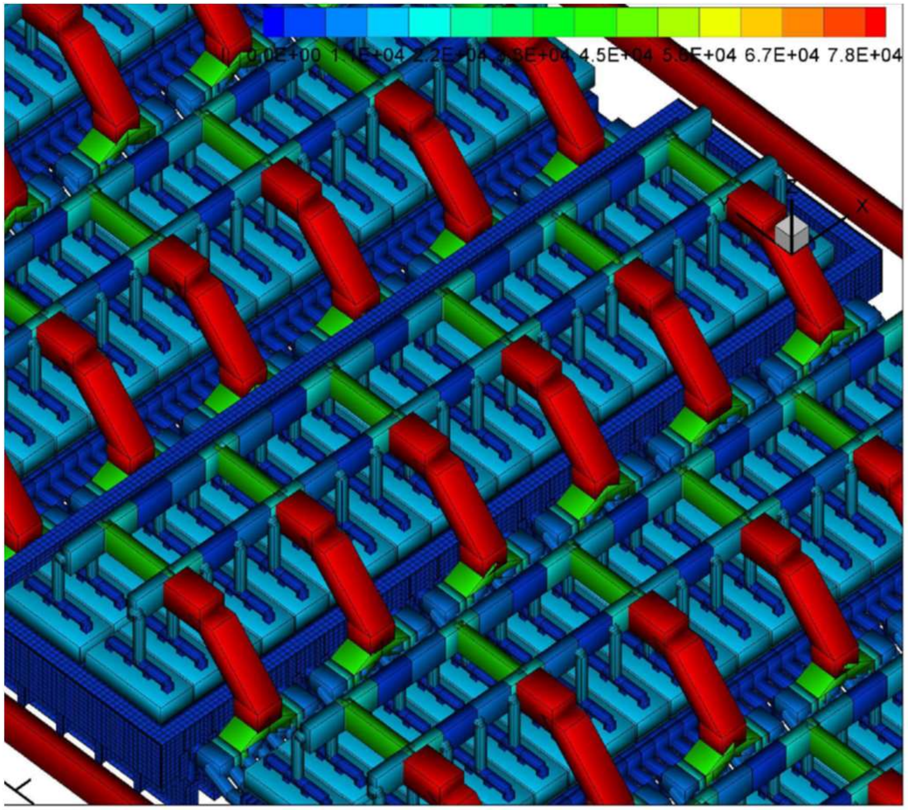


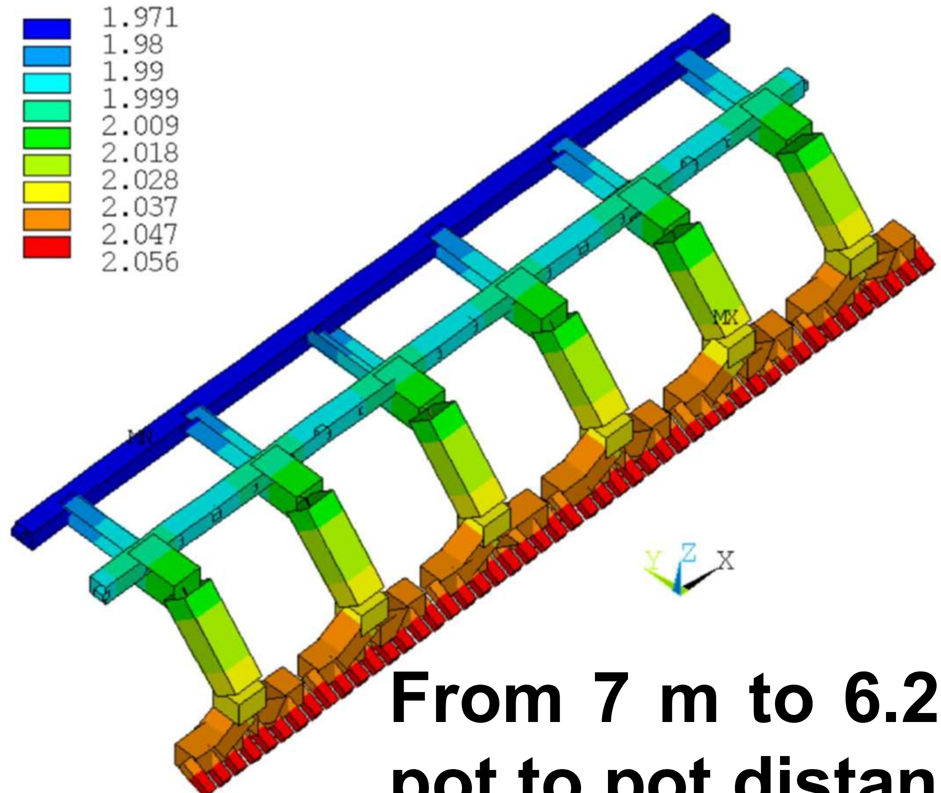
Design of a 650 kA wide cell running at 11.0 kWh/kg

Amperage	762.5 kA	650 kA	650 kA
Nb. of anodes	48	48	36
Anode size	2.6 x .65 m	2.6 x .65 m	2.6 x .86 m
Nb. of anode studs	4 per anode	4 per anode	12 per anode
Anode stud diameter	21.0 cm	24.0 cm	16.0 cm
Anode cover thickness	15 cm	24 cm	25 cm
Nb. of cathode blocks	24	24	24
Cathode block length	5.37 m	5.37 m	5.37 m
Type of cathode block	HC 10	HC 10	HC 10
Collector bar size	20 x 12 cm	20 x 15 cm	20 x 15 cm
Type of side block	HC3	HC3	HC3
Side block thickness	7 cm	7 cm	7 cm
ASD	25 cm	25 cm	25 cm
Calcium silicate thickness	3.5 cm	6.0 cm	6.0 cm
Inside potshell size	17.02 x 5.88m	17.02 x 5.88m	17.02 x 5.88m
ACD	3.0 cm	2.8 cm	2.8 cm
Excess AlF_3	11.50%	11.50%	11.50%

Anode drop (A)	347 mV	296 mV	252 mV
Cathode drop (A)	118 mV	109 mV	109 mV
Busbar drop (A)	300 mV	220 mV	170 mV
Anode panel heat loss (A)	553 kW	327 kW	339 kW
Cathode total lieat loss (A)	715 kW	499 kW	482 kW
Operating temperatur (D/M)	968.9 °C	967.0 °C	966.5 °C
Liquidus superheat (D/M)	10.0 °C	8.1 °C	7.6 °C
Bath ledge thickness (A)	6.82 cm	11.86 cm	14.25 cm
Metal ledge thickness (A)	1.85 cm	3.38 cm	4.58 cm
Current efficiency (D/M)	95.14%	94.80%	94.90%
Intenial heat (D/M)	1328 kW	832 kW	804 kW
Energy consumption	12.85 kWh/kg	11.3 kWh/kg	11.0 kWh/kg

Thermal design of the 520 kA with 100% downstream current exit cell running at 10.85 kWh/kg





From 7 m to 6.2 m pot to pot distance

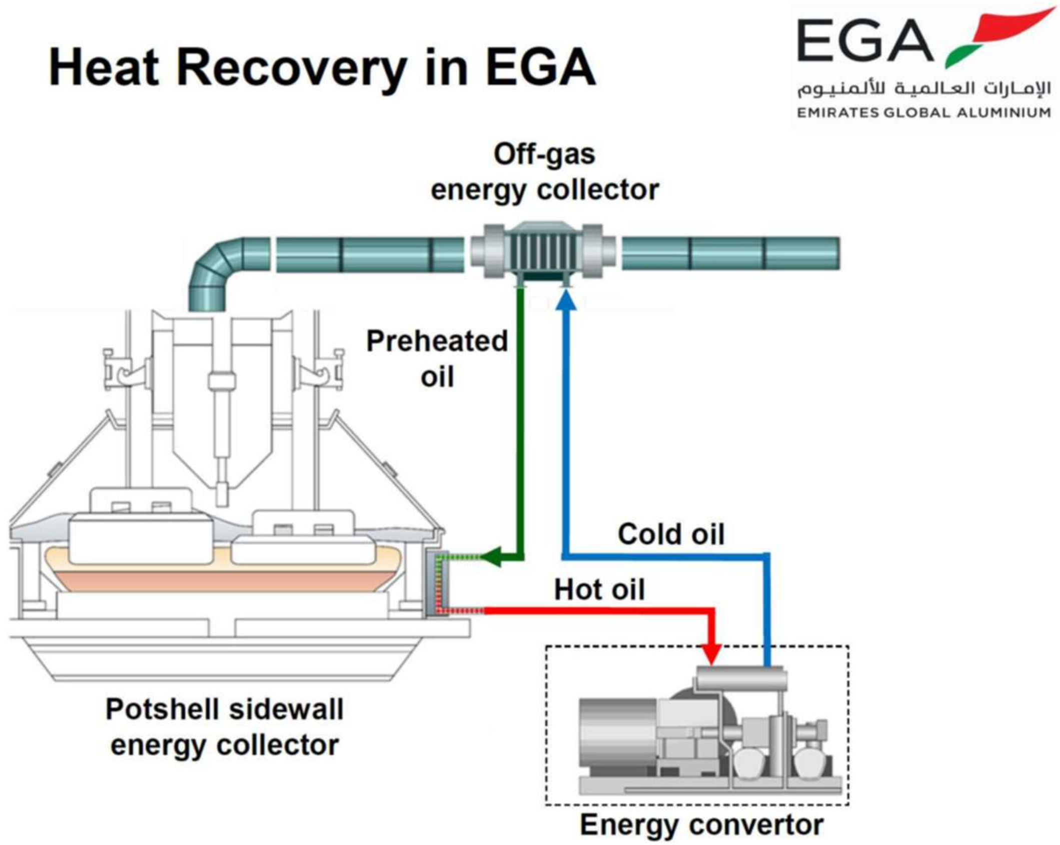
Thermal design of the 520 kA with 100% downstream current exit cell running at 10.85 kWh/kg

Amperage	600 kA	500 kA	520 kA
Nb. of anodes	48	64	64
Anode size	2.0 x .665 m	1.95 x .5 m	1.95 x .5 m
Nb. of anode studs	4 per anode	4 per anode	4 per anode
Anode stud diameter	17.5 cm	17.5 cm	17.5 cm
Anode cover thickness	10 cm	20 cm	20 cm
Nb. of cathode blocks	24	24	24
Cathode block length	4.17 m	4.17 m	4.17 m
Type of cathode block	HC 10	HC 10	HC 10
Collector bar size	20 x 10 cm	20 x 20 cm	20 x 20 cm
Type of side block	SiC	HC3	HC3
Side block thickness	7 cm	7 cm	7 cm
ASD	28 cm	30 cm	30 cm
Calcium silicate thickness	3.5 cm	6.0 cm	6.0 cm
Inside potshell size	17.8 x 4.85 m	17.8 x 4.85 m	17.8 x 4.85 m
ACD	3.5 cm	3.2 cm	2.8 cm
Excess AlF_3	12%	12%	12%

Anode drop (A)	318 mV	238 mV	248 mV
Cathode drop (A)	104 mV	123 mV	182 mV
Busbar drop (A)	311 mV	134 mV	85 mV
Anode panel heat loss (A)	449 kW	292 kW	295 kW
Cathode total lieat loss (A)	692 kW	402 kW	404 kW
Operating temperatur (D/M)	964.8 °C	958.4 °C	958.3 °C
Liquidus superheat (D/M)	11.8 °C	5.4 °C	5.3 °C
Bath ledge thickness (A)	6.36 cm	11.84 cm	11.83 cm
Metal ledge thickness (A)	1.76 cm	3.48 cm	3.46 cm
Current efficiency (D/M)	96.4%	96.3%	96.5%
Intenial heat (D/M)	1140 kW	699 kW	701 kW
Energy consumption	13.26 kWh/kg	11.2 kWh/kg	10.85 kWh/kg

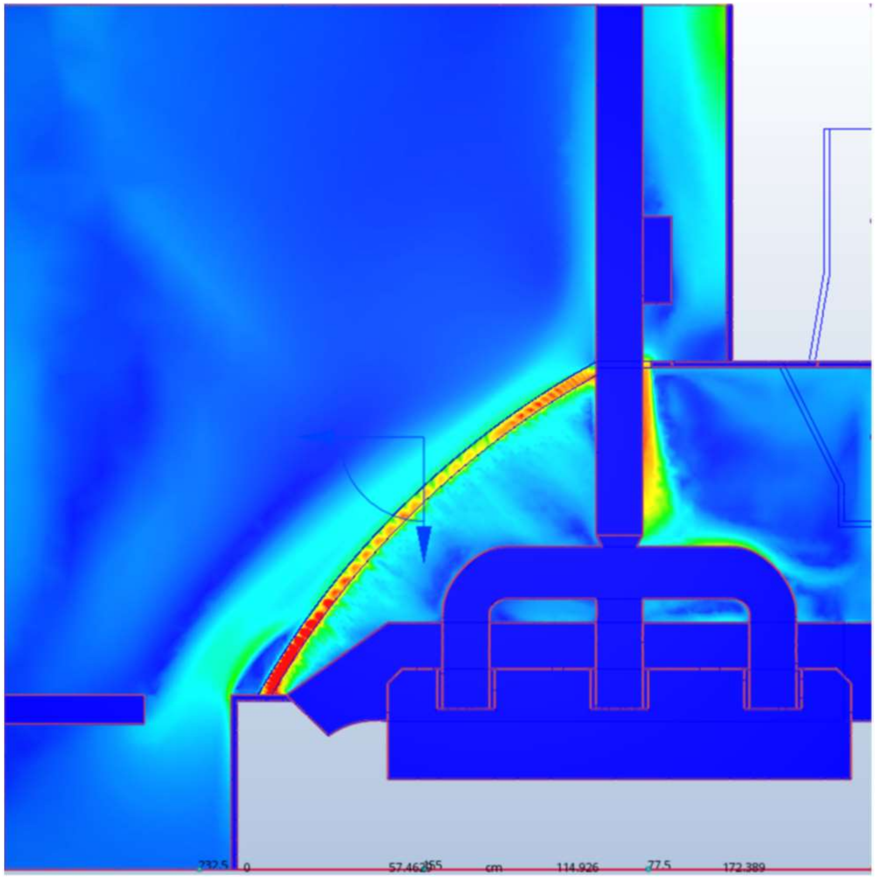
Future work

- It is the opinion of the author that further reduction of the cell energy consumption will probably have to come from the recovery of some of the heat loss by the cell. At the recent ICSOBA conference in Hamburg, such a heat recovery system (HRS) was presented by EGA.



Future work

- On the cell exhaust gas heat recovery, it would be far more efficient to first increase the gas exhaust temperature. This could be achieved by reducing the area of the hood openings and also insulating the hoods and the fume plate in order to be able to decrease the gas exhaust rate and keep more of the anode panel heat loss in the exhaust gas. Also at the ICSOBA conference, the author presented a model that was developed to study the impact of such design changes on the cell hooding system heat balance and the cell hooding HF capture efficiency.



Conclusions

- **Contrary to the author expectations one year ago, the present study has produced cell designs that have reached and in the second case broken the 11.0 kWh/kg cell energy consumption barrier. At 10.85 kWh/kg, at the time of writing this paper, the author ran out of design idea to further reduce that number without involving HRS.**
- **Several months later, it is no longer the case. The author is now planning to reveal at the next TMS conference the design feature used to reduce the anode stubs and collector bars heat dissipation and to better use that design feature to further reduce cells power consumption still without involving HRS.**
- **Yet, clearly at some point, the only way to further reduce the cells energy consumption will be to captured low grade heat energy dissipated by the cell to preheat the alumina and/or the anodes.**

Thank you

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