FIRST ATTEMPT TO BREAK THE 10 KWH/KG BARRIER USING A WIDE CELL DESIGN

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Plan of the Presentation

- Introduction: previous work presented in 2018
  - TMS 2018: 650 kA wide cell design running at 11.3 kWh/kg
  - IAJ 2018: 650 kA wide cell design running at 11.0 kWh/kg
- 570 kA wide cell design running at 10.6 kWh/kg
- 530 kA wide cell design running at 10.2 kWh/kg
- Future work
- Conclusions

650 kA wide cell design 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

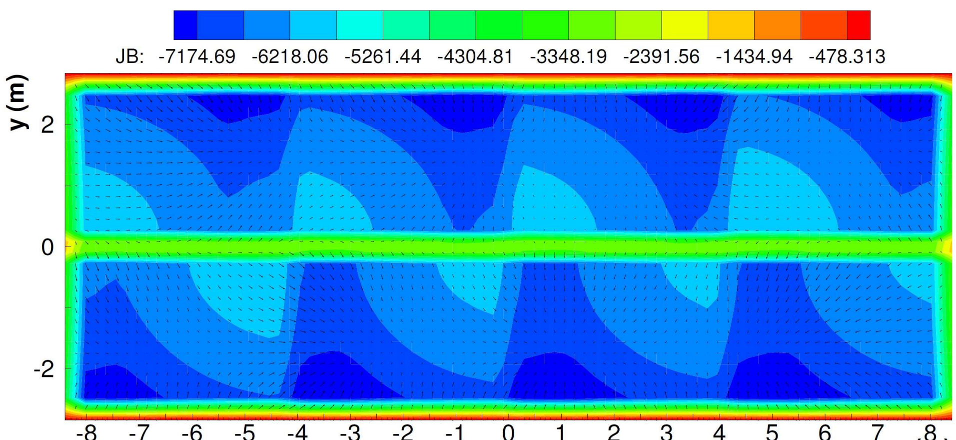
Design of a 650 kA wide cell running at 11.0 kWh/kg

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%

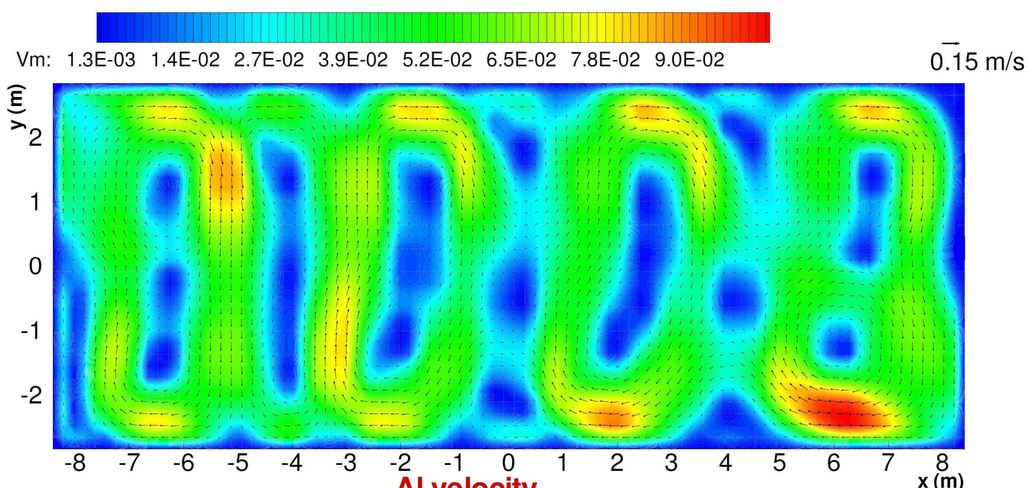
Anode drop (A)	347 mV	296 mV	252 mV
Cathode drop (A)	118 mV	109 mV	109 mV
Busbar drop (A)	300 mV	220 mV	170 mV
Anode panel heat loss (A)	553 kW	327 kW	339 kW
Cathode total lieat loss (A)	715 kW	499 kW	482 kW
Operating temperatur (D/M)	968.9 °C	967.0 °C	966.5 °C
Liquidus superheat (D/M)	10.0 °C	8.1 °C	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

Design of a 570 kA wide cell running at 10.6 kWh/kg

Reducing metal pad thickness from 20 to 10 cm



Electric current density at the cell bottom



Al velocity

MHD cell stability study at reduced metal pad thickness

Design of a 570 kA wide cell running at 10.6 kWh/kg

Dyna/Marc was used to calculate the steady-state cell conditions at 570 kA and 2.8 cm ACD. Table 1 presents the Dyna/Marc results summary where the cell voltage is predicted to be 3.36 V, the cell internal heat using Haupin's equation to calculate the equivalent voltage to make the metal is 613 kW at the calculated current efficiency of 94.4% and the cell superheat is predicted to be 7.5 °C. Finally, the cell power consumption is calculated to be 10.61 kWh/kg.

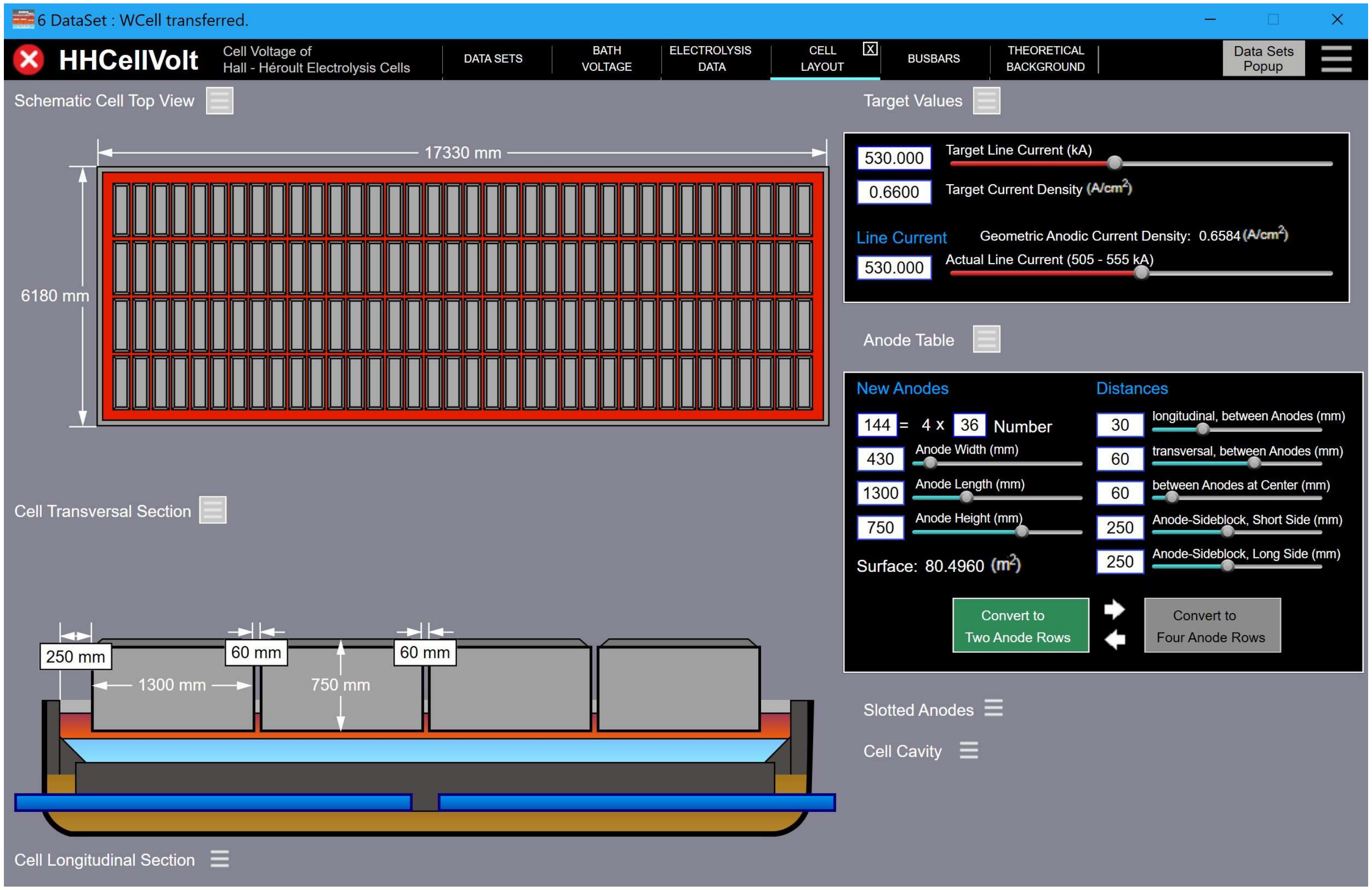
Table 1

Steady State Solution

Cell amperage	570.0 [kA]
Anode to cathode distance	2.80000 [cm]
Operating temperature	964.064 [C]
Ledge thickness, bath level	8.90003 [cm]
Ledge thickness, metal level	3.19020 [cm]
Bath chemistry:	
Cryolite ratio	2.20470 [mole/mole]
Bath ratio	1.10235 [kg/kg]
Conc. of excess aluminum fluoride	11.50000 [%]
Conc. of dissolved alumina	2.80000 [%]
Conc. of calcium fluoride	6.00000 [%]
Heat balance:	
Superheat	7.5402 [C]
Cell energy consumption	10.6072 [kWhr/kg]
Total heat loss	612.992 [kW]
Electrical characteristics:	
Current efficiency	94.3733 [%]
Anode current density	0.708110 [A/cm*cm]
Bath resistivity	0.454942 [ohm-cm]
Cell pseudo-resistance	2.99735 [micro-ohm]
Bath voltage	0.94007 [V]
Electrolysis voltage	1.87543 [V]
Cell voltage	3.35849 [V]
Voltage to make the metal	2.03522 [V]

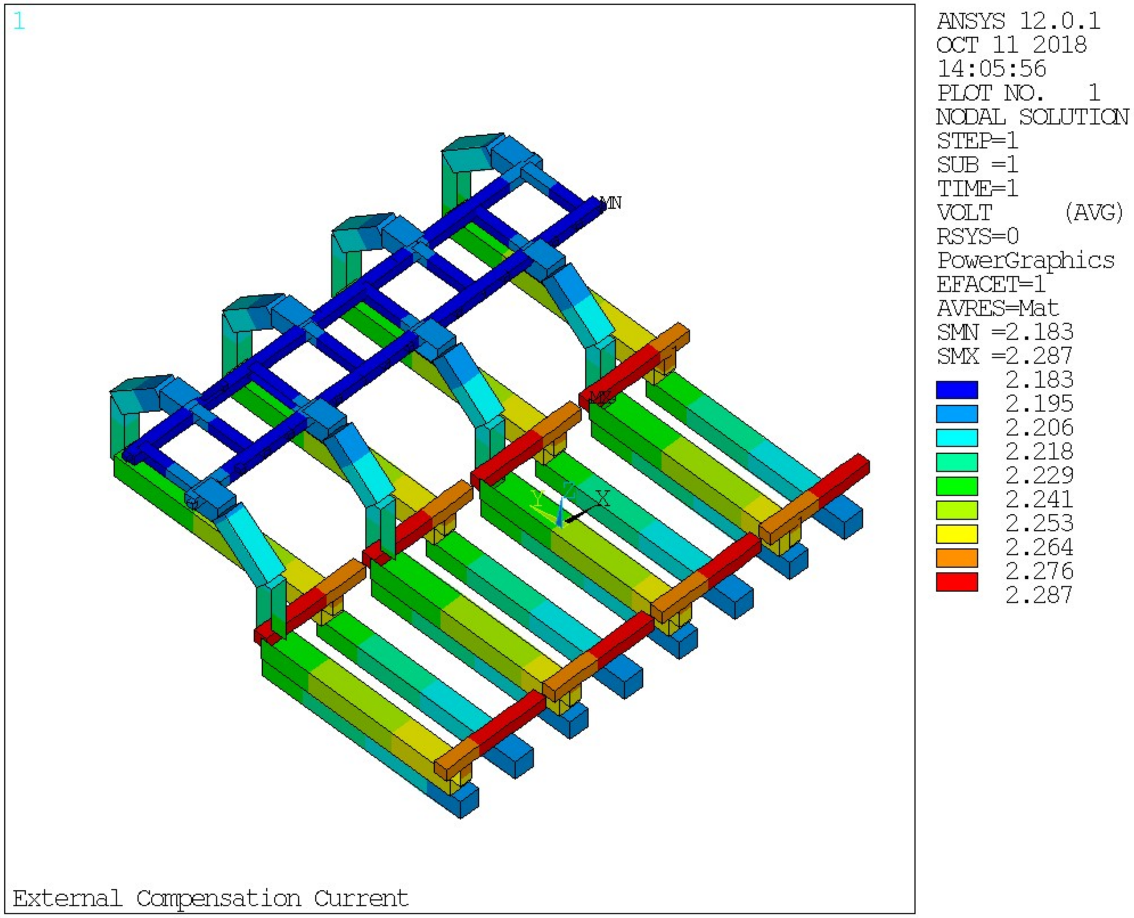
Design of a 530 kA wide cell running at 10.2 kWh/kg

HHCellVolt's cell layout showing the 4 rows of anode blocks



Design of a 530 kA wide cell running at 10.2 kWh/kg

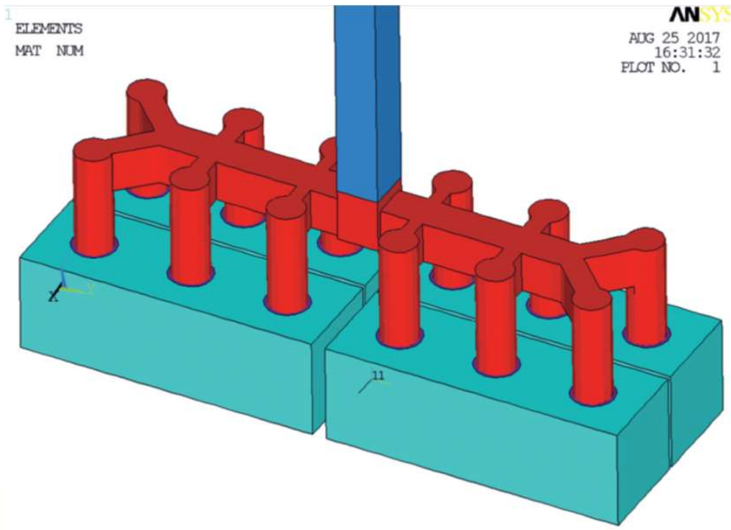
This figure is presenting the obtained busbar drop at 530 kA and it is calculated to be 104 mV.

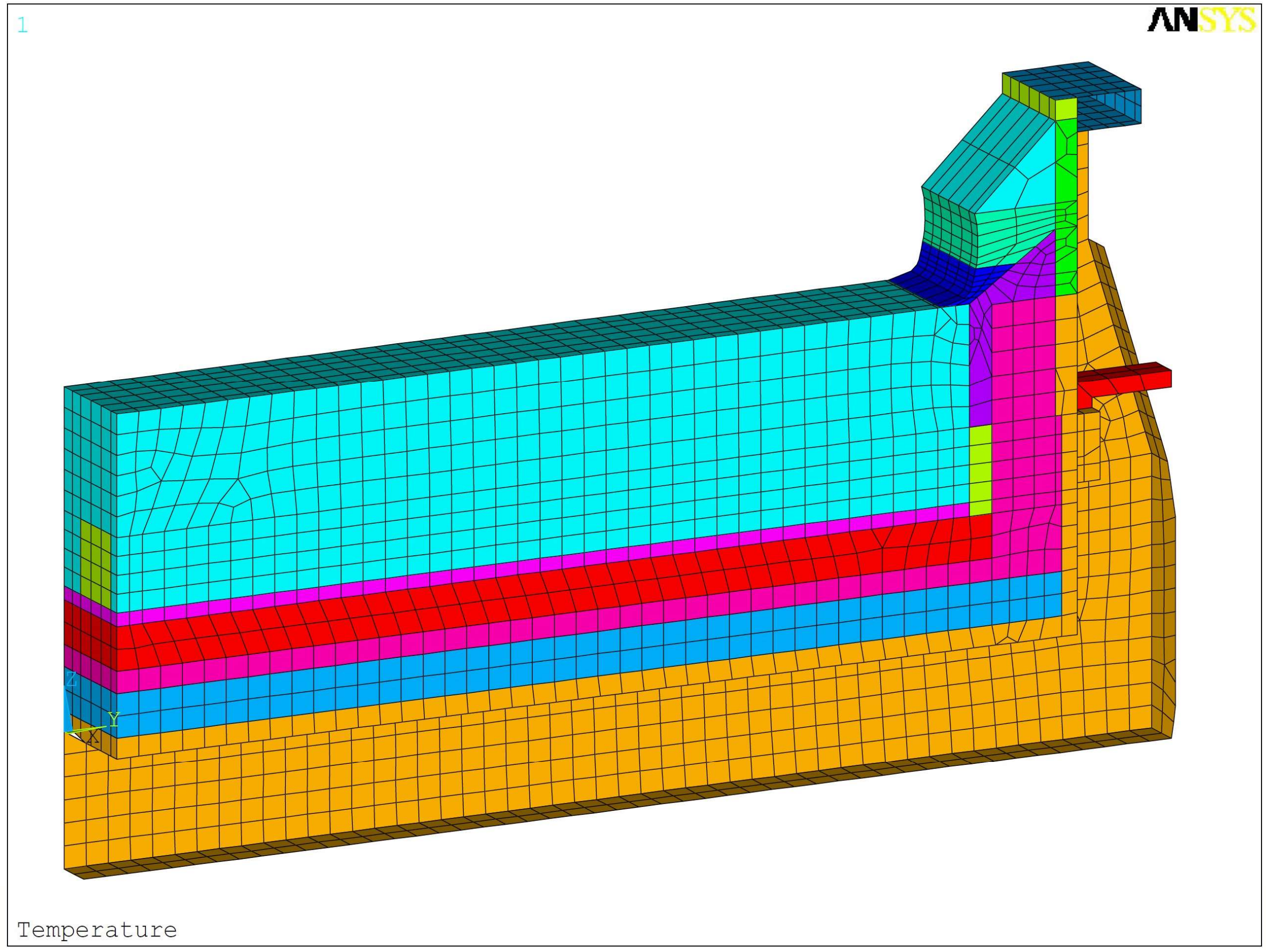


Design of a 530 kA wide cell running at 10.2 kWh/kg

Mesh of the cathode model with reduced metal pad and ramming paste slope height.

Same anode design than in the previous study.

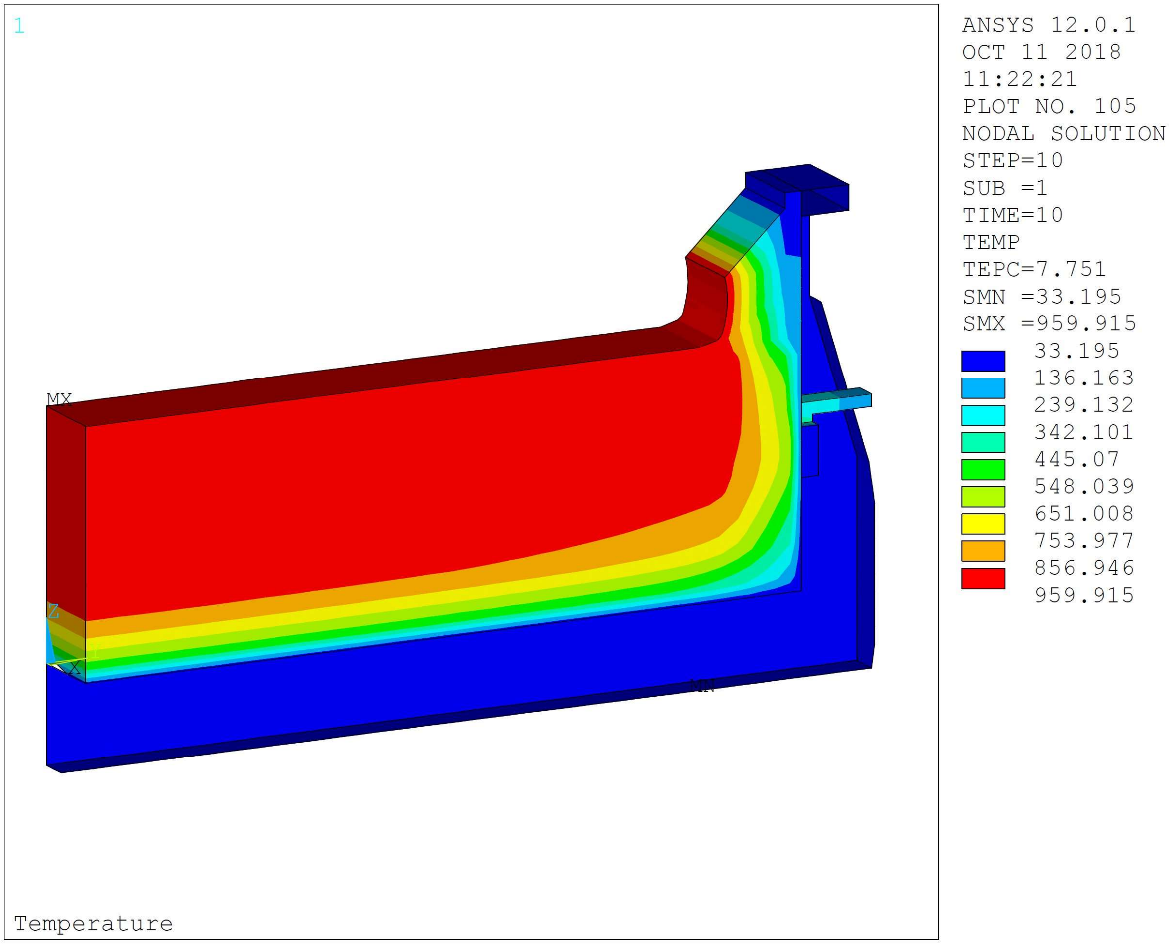




Design of a 530 kA wide cell running at 10.2 kWh/kg

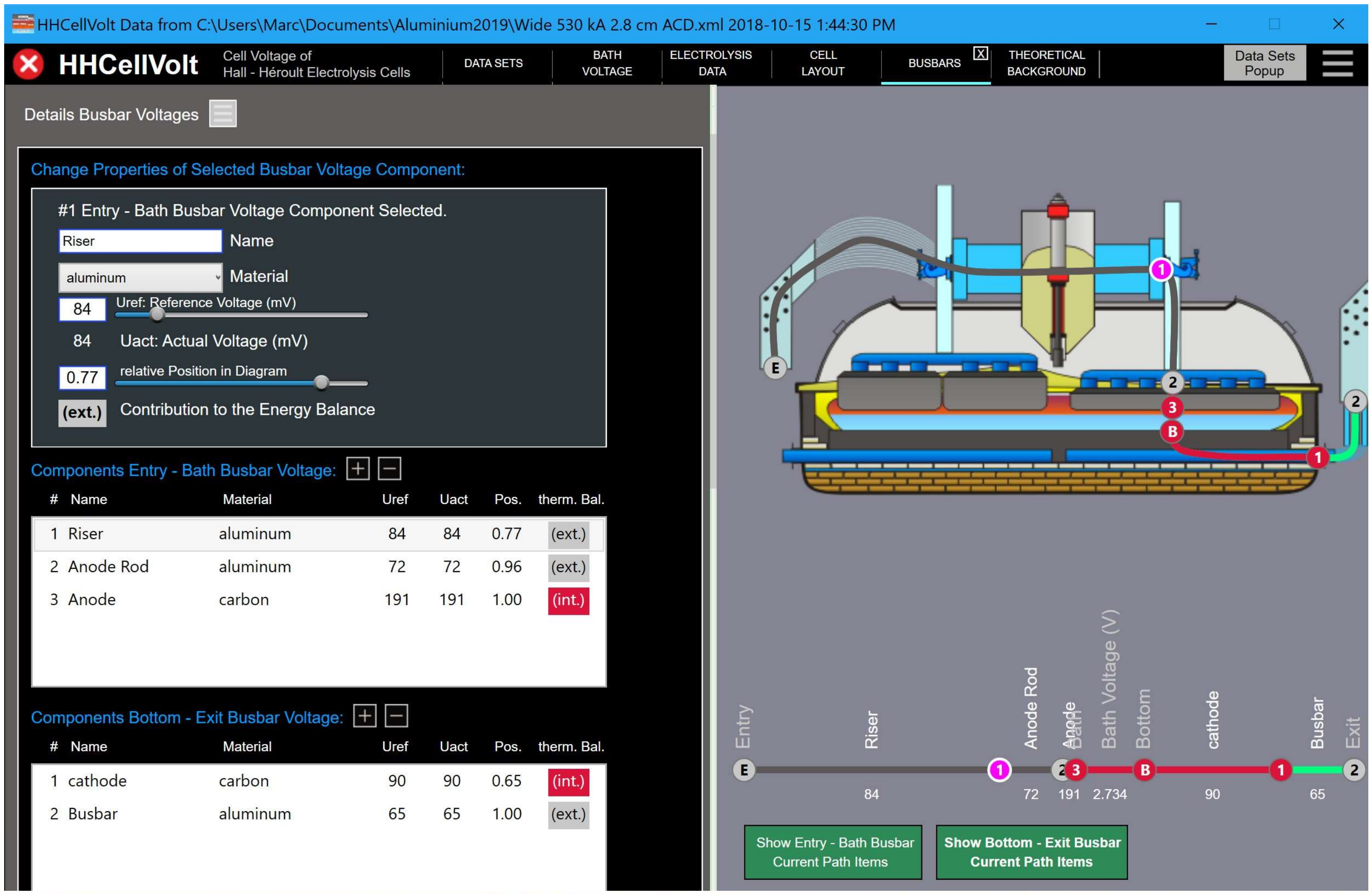
At 530 kA, the internal anode drop is predicted to be 191 mV and the external anode drop (studs outside the crust, the yoke and the rod) is predicted to be 72 mV. The internal anode heat loss is 218 kW.

The figure is showing the cathode temperature solution. The model is predicting an internal cathode drop of 90 mV and an external cathode drop of 45 mV. The heat loss of the internal part of the cathode at 5 °C of cell superheat is 311 kW.



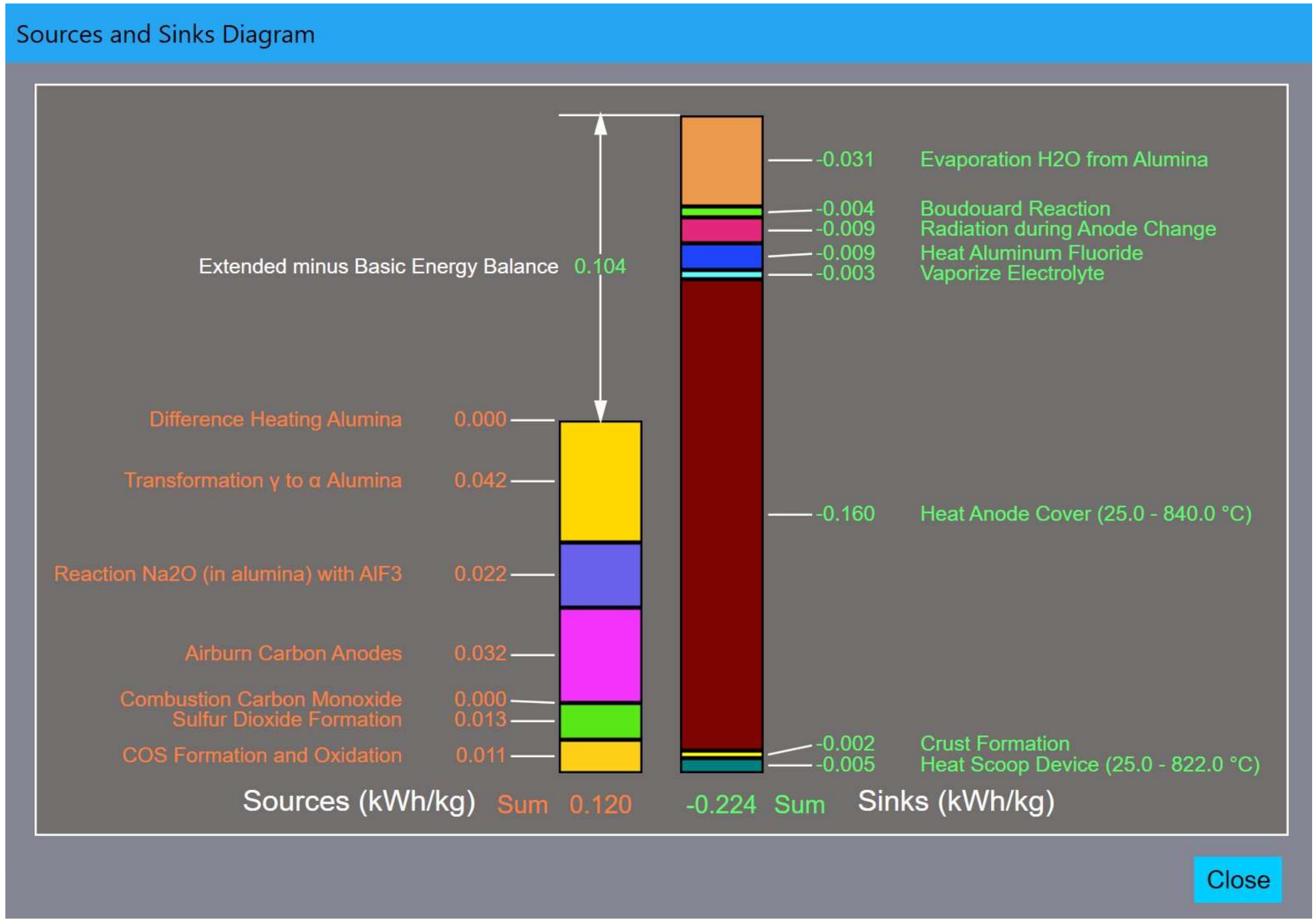
Design of a 530 kA wide cell running at 10.2 kWh/kg

Those ANSYS based electrical results can be entered in HHCellVolt's busbars tab.



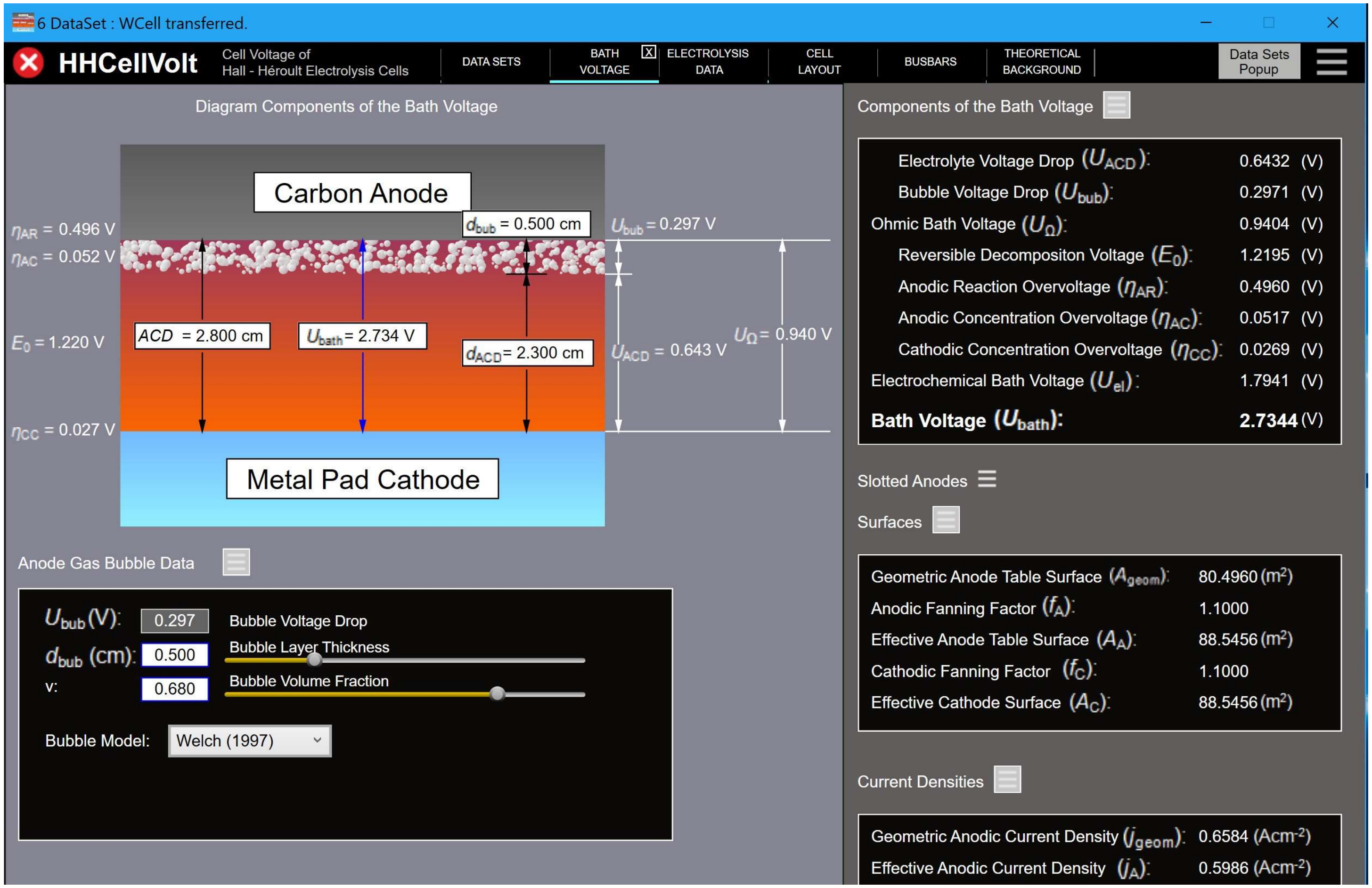
Design of a 530 kA wide cell running at 10.2 kWh/kg

The extended reactions in HHCellVolt can be adjusted to add 0.1 kWh/kg Al extra energy requirement to make the metal in HHCellVolt's electrolysis data tab.



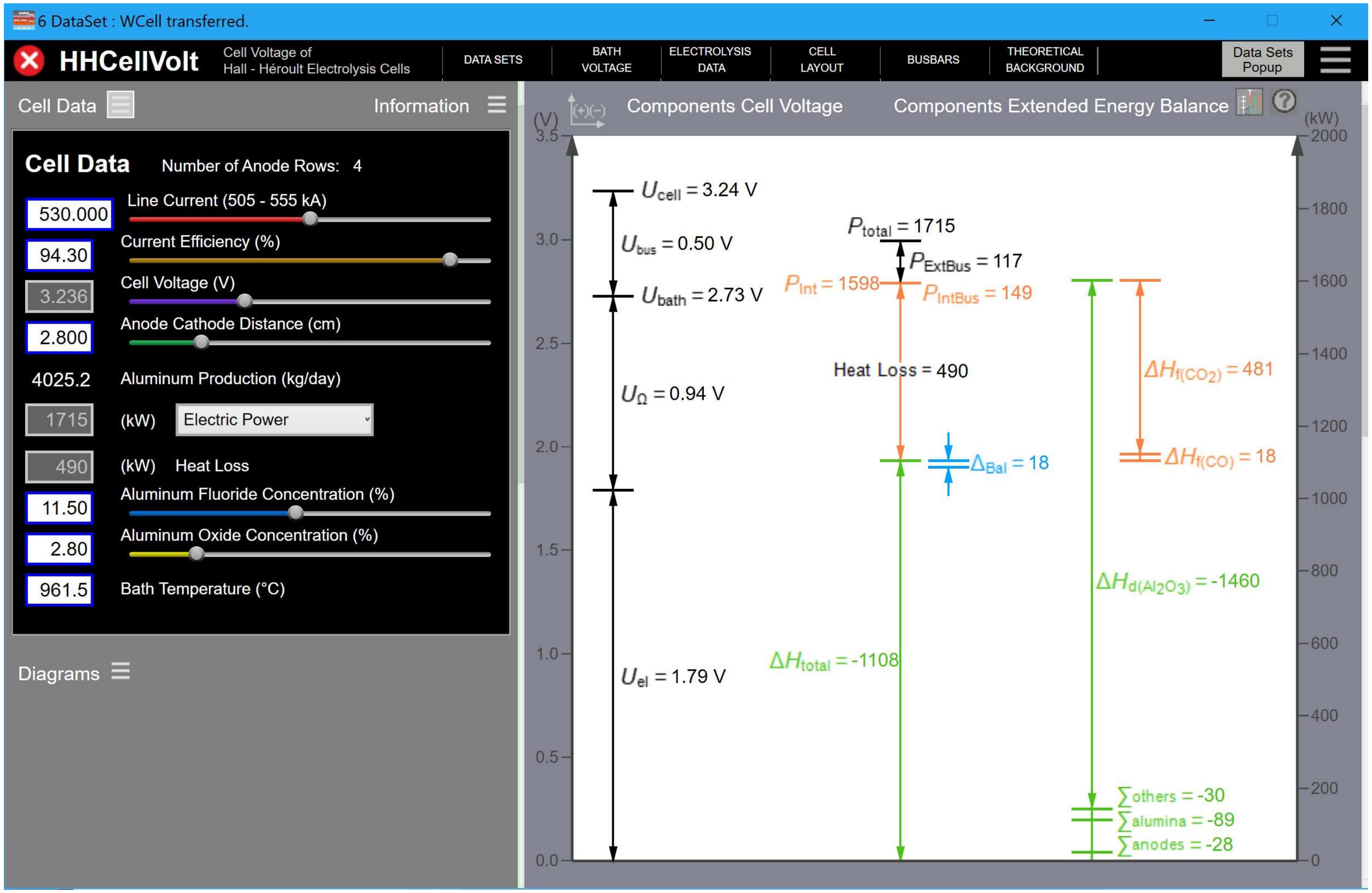
Design of a 530 kA wide cell running at 10.2 kWh/kg

The bubble model is selected and calibrated in the bath voltage tab.



Design of a 530 kA wide cell running at 10.2 kWh/kg

As a final results, HHCellVolt calculates the total cell voltage and cell internal heat using user specified cell operating temperature and current efficiency.



Design of a 530 kA wide cell running at 10.2 kWh/kg

Dyna/Marc is used to calculate the steady-state cell conditions at 530 kA and 2.8 cm ACD. Table II presents the Dyna/Marc results summary where the cell voltage is predicted to be 3.24 V, the cell internal heat using Haupin's equation to calculate the equivalent voltage to make the metal is 516 kW at the calculated current efficiency of 94.3% and the cell superheat is predicted to be 5.0 °C. Finally, the cell power consumption is calculated to be 10.23 kWh/kg.

Table 2

Steady State Solution	
Cell amperage	530.0 [kA]
Anode to cathode distance	2.80000 [cm]
Operating temperature	961.560 [C]
Ledge thickness, bath level	15.79983 [cm]
Ledge thickness, metal level	9.99283 [cm]
Bath chemistry:	
Cryolite ratio	2.20470 [mole/mole]
Bath ratio	1.10235 [kg/kg]
Conc. of excess aluminum fluoride	11.50000 [%]
Conc. of dissolved alumina	2.80000 [%]
Conc. of calcium fluoride	6.00000 [%]
Heat balance:	
Superheat	5.0367 [C]
Cell energy consumption	10.2313 [kWhr/kg]
Total heat loss	516.203 [kW]
Electrical characteristics:	
Current efficiency	94.3031 [%]
Anode current density	0.658418 [A/cm*cm]
Bath resistivity	0.456250 [ohm-cm]
Cell pseudo-resistance	2.99443 [micro-ohm]
Bath voltage	0.87661 [V]
Electrolysis voltage	1.85844 [V]
Cell voltage	3.23705 [V]
Voltage to make the metal	2.03346 [V]

Design of a 530 kA wide cell running at 10.2 kWh/kg

Amperage	762.5 kA	650 kA	570 kA	530 kA
Nb. of anodes	48	36	36	36
Anode size	2.6m X .65m	2.6m X .86m	2.6m X .86m	2.6m X .86m
Nb. of anode studs	4 per anode	12 per anode	12 per anode	12 per anode
Anode stud diameter	21.0 cm	16.0 cm	18.0 cm	18.0 cm
Anode cover thickness	15 cm	25 cm	25 cm	25 cm
Nb. of cathode blocks	24	24	24	24
Cathode block length	5.37 m	5.37 m	5.37 m	5.37 m
Type of cathode block	HC10	HC10	HC10	HC10
Collector bar size	20 cm X 12 cm	20 cm X 15 cm	20 cm X 15 cm	20 cm X 15 cm
Type of side block	HC3	HC3	HC3	HC3
Side block thickness	7 cm	7 cm	7 cm	7 cm
ASD	25 cm	25 cm	25 cm	25 cm
Calcium silicate thickness	3.5 cm	6.0 cm	6.0 cm	6.0 cm
Inside potshell size	17.02 X 5.88 m	17.02 X 5.88 m	17.02 X 5.88 m	17.02 X 5.88 m
ACD	3.0 cm	2.8 cm	2.8 cm	2.8 cm
Anode current density	0.93 A/cm^2	0.81 A/cm^2	0.71 A/cm^2	0.66 A/cm^2
Metal level	20 cm	20 cm	10 cm	10 cm
Excess AlF_3	11.50%	11.50%	11.50%	11.50%

Design of a 530 kA wide cell running at 10.2 kWh/kg

Anode drop (A)	347 mV (T)	252 mV (T)	207 mV (I)	191 mV (I)
Cathode drop (A)	118 mV (T)	109 mV (T)	91 mV (I)	90 mV (I)
Busbar/External drop (A)	300 mV (B)	170 mV (B)	227 mV (E)	221 mV (E)
Anode panel heat loss (A)	553 kW (T)	339 kW (T)	221 kW (I)	218 kW (I)
Cathode total heat loss (A)	715 kW (T)	482 kW (T)	417 kW (I)	311 kW (I)
Operating temperature (D/M)	968.9 °C	966.5 °C	964.1 °C	961.6 °C
Liquidus superheat (D/M)	10.0 °C	7.6 °C	7.5 °C	5.0 °C
Bath ledge thickness (A)	6.82 cm	14.25 cm	18.36 cm	21.38 cm
Metal ledge thickness (A)	1.85 cm	4.58 cm	6.88 cm	7.60 cm
Current efficiency (D/M)	95.1%	94.9%	94.4%	94.3%
Internal heat (D/M)	1328 kW	804 kW	613 kW	516 kW
Energy consumption	12.85 kWh/kg	11.0 kWh/kg	10.6 kWh/kg	10.2 kWh/kg

A = ANSYS; D/M = Dyna/Marc; T = Total; B = Busbar; I = Internal; E = External

Future work

- The previous table summarizes the results of the four wide cell designs presented so far all using the same wide potshell platform. The cell operating at 530 kA, 0.66 A/cm^2 and 10.23 kWh/kg dissipates only 39% of the heat dissipated by the cell operating at 762.5 kA, 0.94 A/cm^2 and 12.85 kWh/kg.
- Both HHCellVolt and Dyna/Marc can easily be used to quickly investigate what would be the cell amperage required to operate at 10.0 kWh/kg assuming no other changes, the answer is 505 kA, 0.63 A/cm^2 and 436 kW of cell internal heat. 436 kW represents 33% of the heat dissipated by the cell operating at 762.5 kA and 12.85 kWh/kg and 84% of the heat dissipated by the cell operating at 530 kA and 10.23 kWh/kg.

Future work

- **This 15% extra reduction of the cell heat loss must be achieved without further reducing the cell superheat. It is also fair to assume that it would not be safe to further reduce the metal pad thickness. Yet, after the reduction of that metal pad thickness, there is now plenty of spare cell cavity. This is providing the opportunity to increase the thickness of the cell lining below the cathode block. New semi-insulating lining material that resists sodium vapor have also become available, this combination may provide an opportunity to design a more insulating cathode lining and hence reduce the cathode heat loss at constant cell superheat without risking to have that cathode lining degraded by exposing it to high temperature and sodium vapor.**

Conclusions

- **Two extra steps toward the design of a cell operating at 10.0 kWh/kg have been presented here. The last step is the design of a wide cell operating at 530 kA, 0.66 A/cm^2 and 10.23 kWh/kg. That cell is operating at the assumed lowest ACD of 2.8 cm (EGA reported operation at 2.5 cm ACD in December), the lowest assumed metal pad thickness of 10 cm and the lowest assumed cell superheat of 5 °C.**
- **That cell is also operating at 25 cm of anode cover thickness; that may not be the highest value possible but must be quite close to it. Despite that, and the usage of refined design features to limit the studs and collector bars heat loss reported in the TMS 2019 paper, it was not possible to design a cell operating at 10.0 kWh/kg in the current study.**