Reliance LithiumWerks

INFO PACK 26650 Power Cell

CONFIDENTIAL

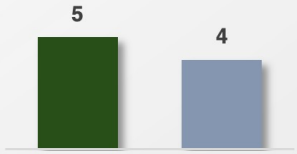
Nanophosphate® LFP power cell vs. regular LFP

VS.

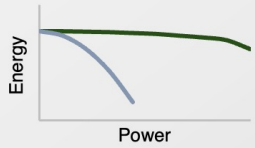
Nanophosphate® LFP

Regular LFP

Power density[1] (kW/kg)

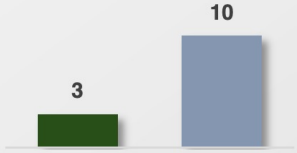


Trade-off power/energy

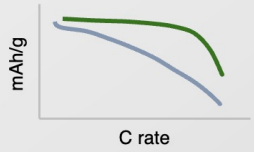


*Nanophosphate **provides more power by weight or volume** for the same energy…*

Charge time[1] (h@0°C)

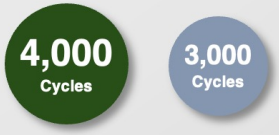


Discharge capacity

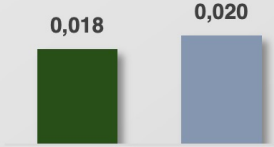


*…**much faster charge and discharge** capabilities…*

Cycle life[2]



Cycle cost[2] ($/cycle)



*…. and **consistent performance over life** allowing for **extended utilization** and **lower cost of ownership***

Nanophosphate® advantages

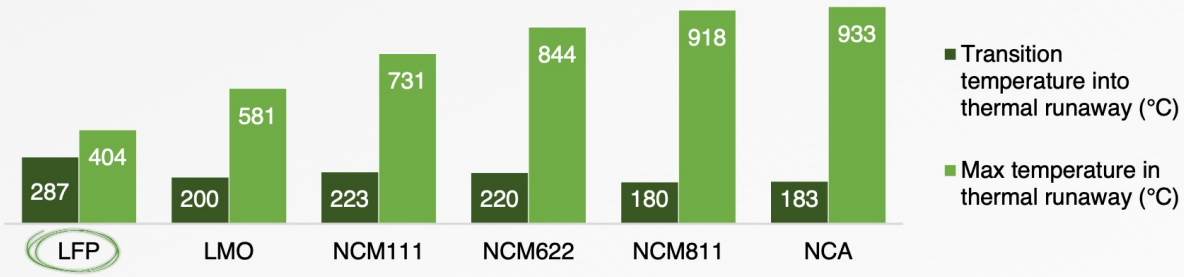
- **High power**
- **Safety / excellent abuse tolerance**
- **Long life**
- **Consistent power over wider SOC**
- **Broad operating temperature range**

Outstanding performance in **high power applications** and under **extreme temperature** conditions

LFP batteries are inherently safer than other lithium batteries

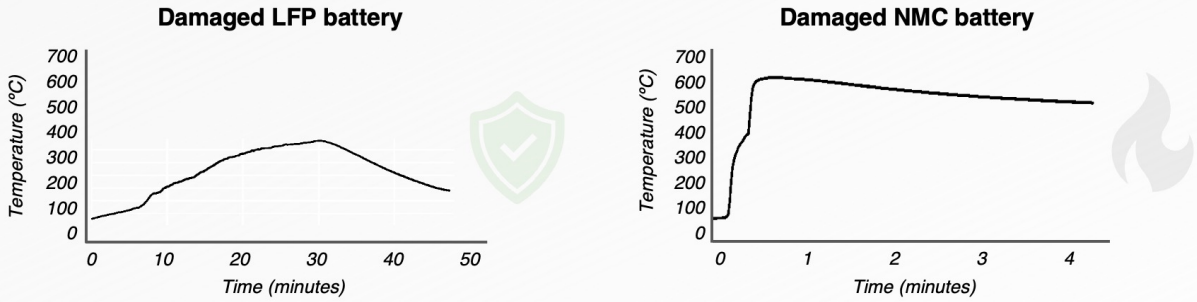
Battery safety considerations

Transition & maximum temperatures in thermal runway by cathode chemistry (ºC)[1]



Results of several experiments consistently show the superior thermal stability of battery cells using LFP cathodes

Heat development at thermal runaway – LFP vs. NMC[2]

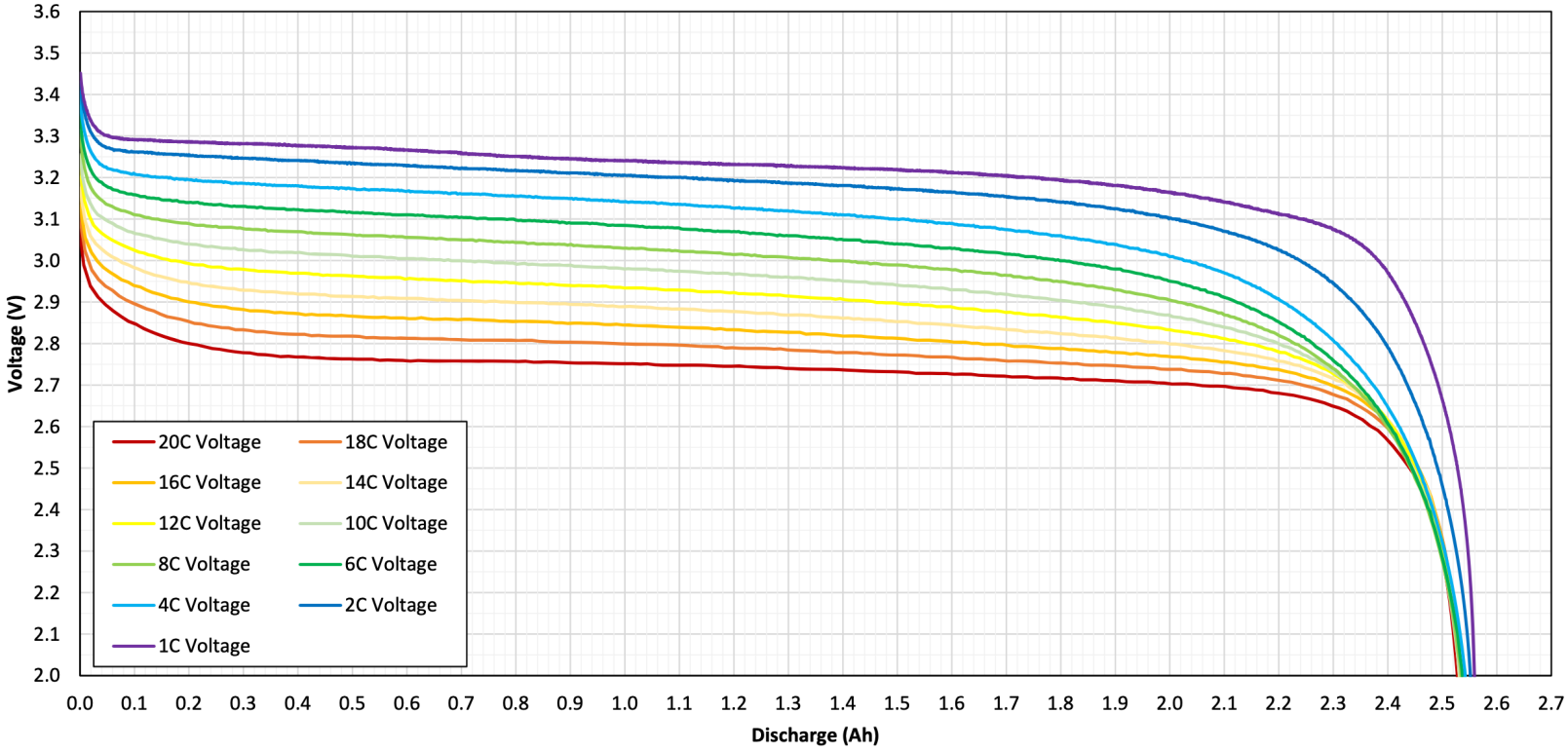


Oxygen release usually reacts with the organic electrolyte increasing the heat generation during thermal runaway. The olivine structure of LFP cathode materials leads to no exothermal decomposition reaction, so even if the LFP cathode is overheated, no gaseous oxygen is released.

> *"batteries using LFP cathode materials reduce to a minimum the likelihood of a fire event because they are **technically safer**"*
>
> Roskill, June 2020

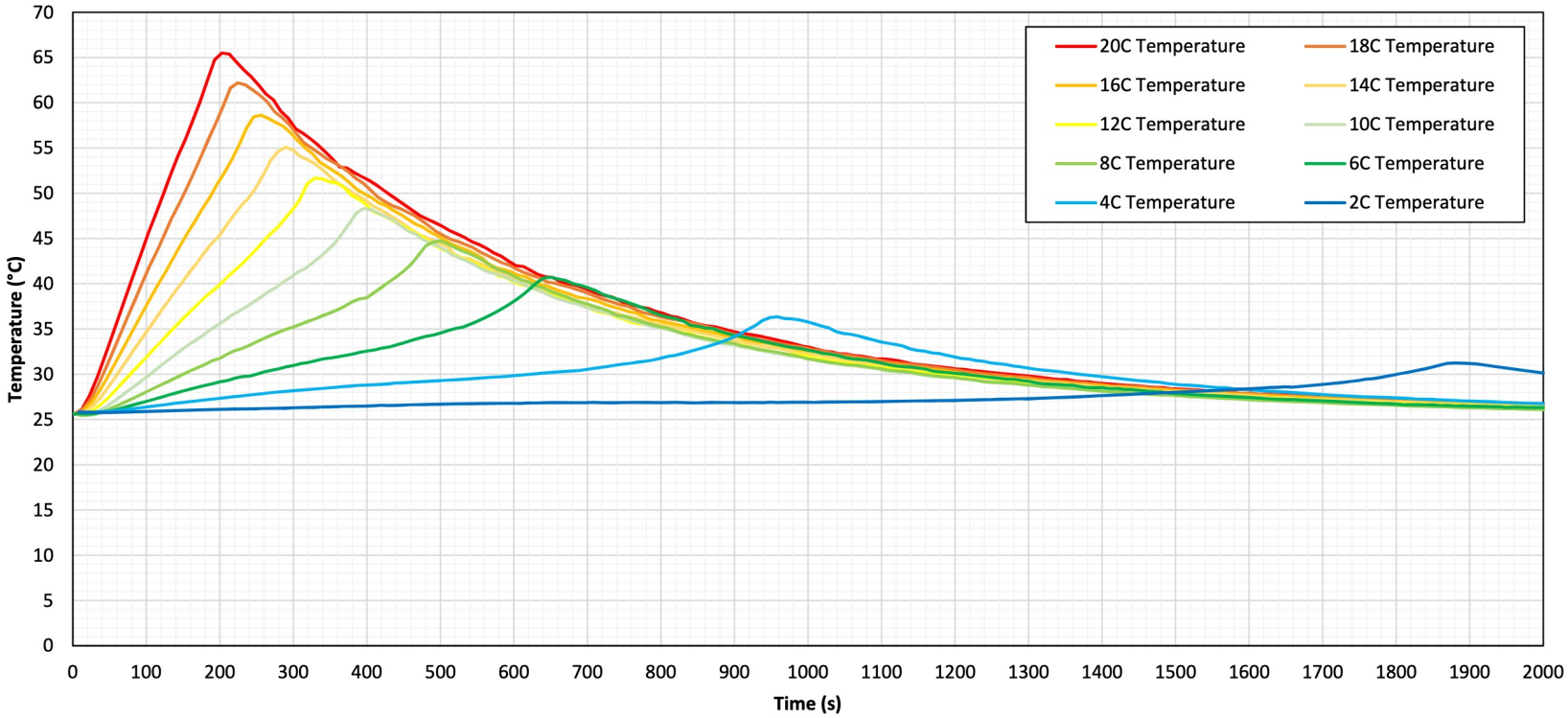
ANR26650M1B Discharge Voltage Profiles

25°C Ambient Temperature In Open Air



ANR26650M1B Discharge Temperature Profiles

25°C Ambient Temperature in Open Air



Discharge Currents

Table 23 – ANR26650*m1-B* Max continuous discharge currents wrt temperature and SOC

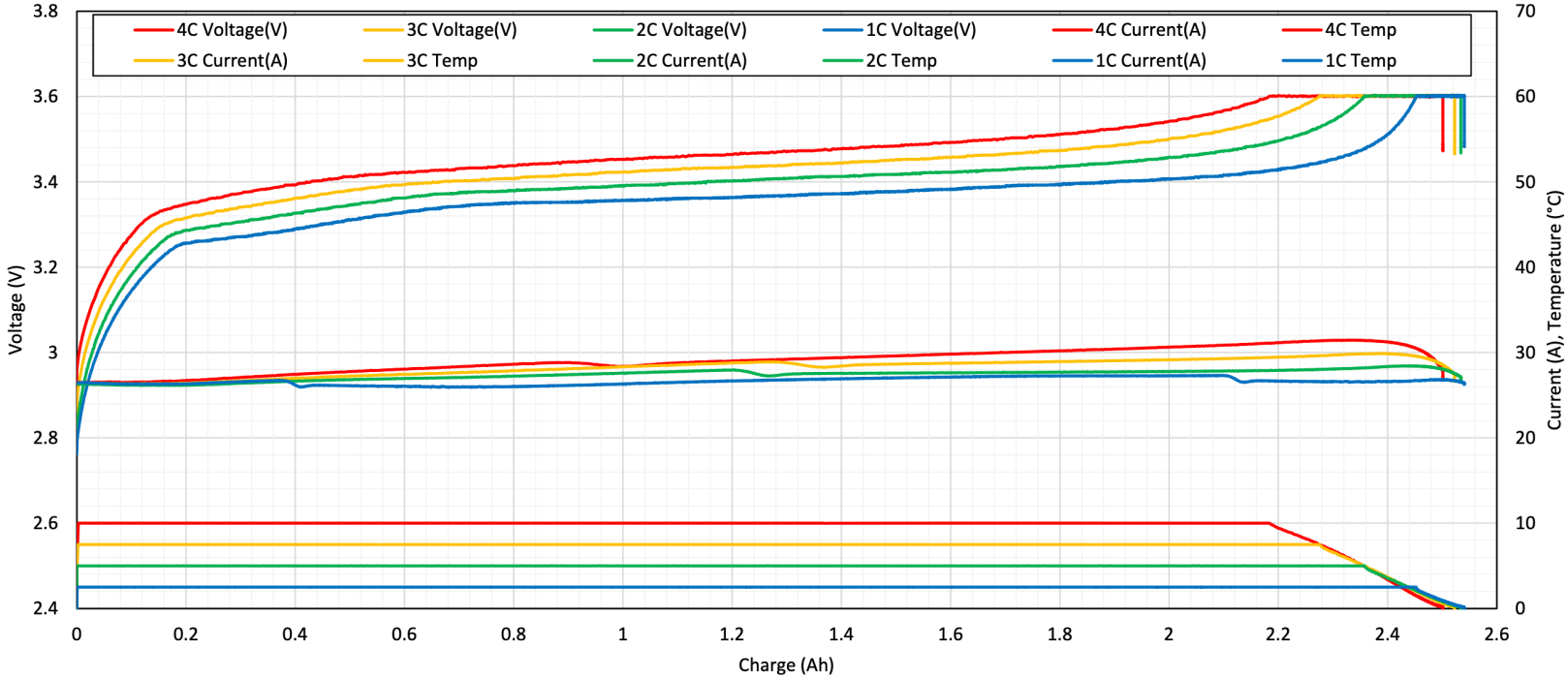
Temp(°C)↓ %SOC→	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
85	0	0	0	0	0	0	0	0	0	0	0
65	0	40	40	40	40	40	40	40	40	40	40
30	0	40	40	40	40	40	40	40	40	40	40
25	0	40	40	40	40	40	40	40	40	40	40
15	0	40	40	40	40	40	40	40	40	40	40
10	0	36	36	36	36	36	36	36	36	36	36
0	0	22	22	22	22	22	22	22	22	22	22

Table 24 – ANR26650*m1-B* Max 10s pulse discharge currents wrt temperature and SOC

Temp(°C)↓ %SOC→	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
85	0	0	0	0	0	0	0	0	0	0	0
65	0	70	70	70	70	70	70	70	70	70	70
30	0	70	70	70	70	70	70	70	70	70	70
25	0	34	64	70	70	70	70	70	70	70	70
15	0	28	52	70	70	70	70	70	70	70	70
10	0	25	46	64	70	70	70	70	70	70	70
0	0	17	31	46	57	64	70	70	70	70	70

ANR26650M1B Charging Voltage, Current, and Temperature Profiles

25°C Ambient Temperature Chamber with Convection



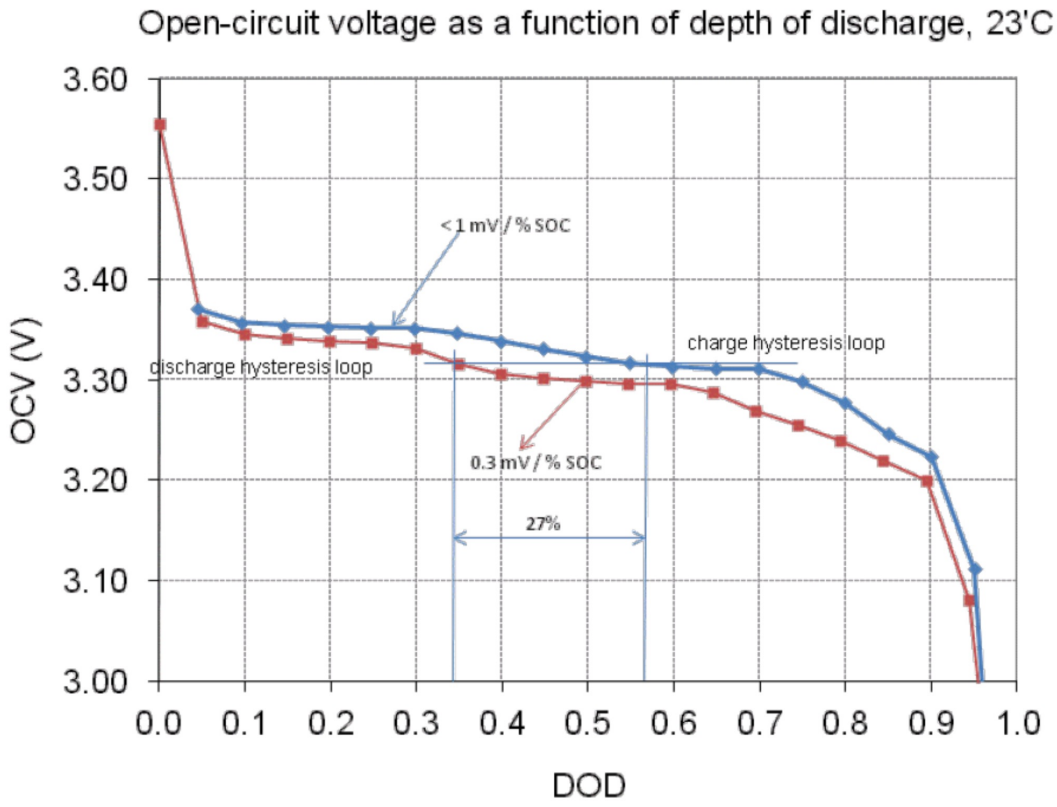
Charge Current

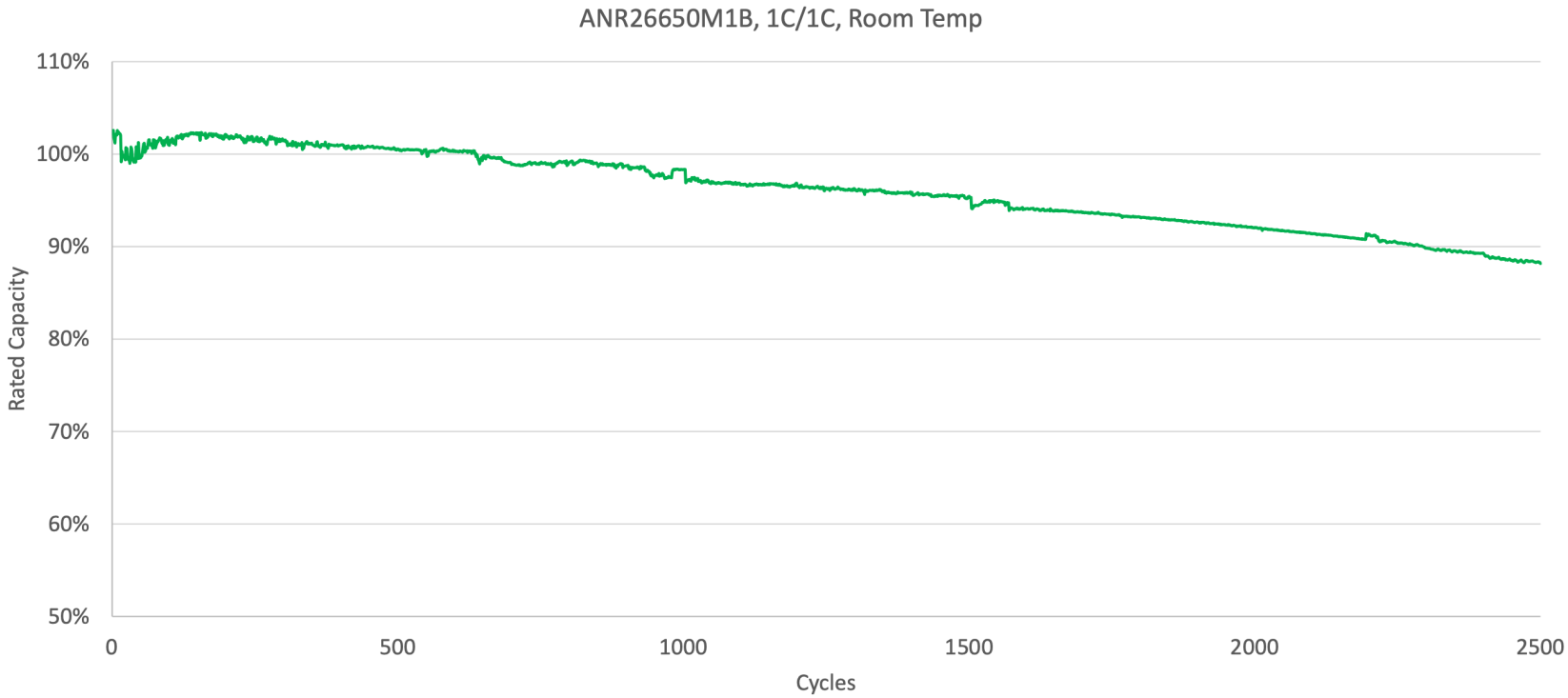
Table 21 – ANR26650*m1-B* Max continuous charge currents wrt temperature and SOC

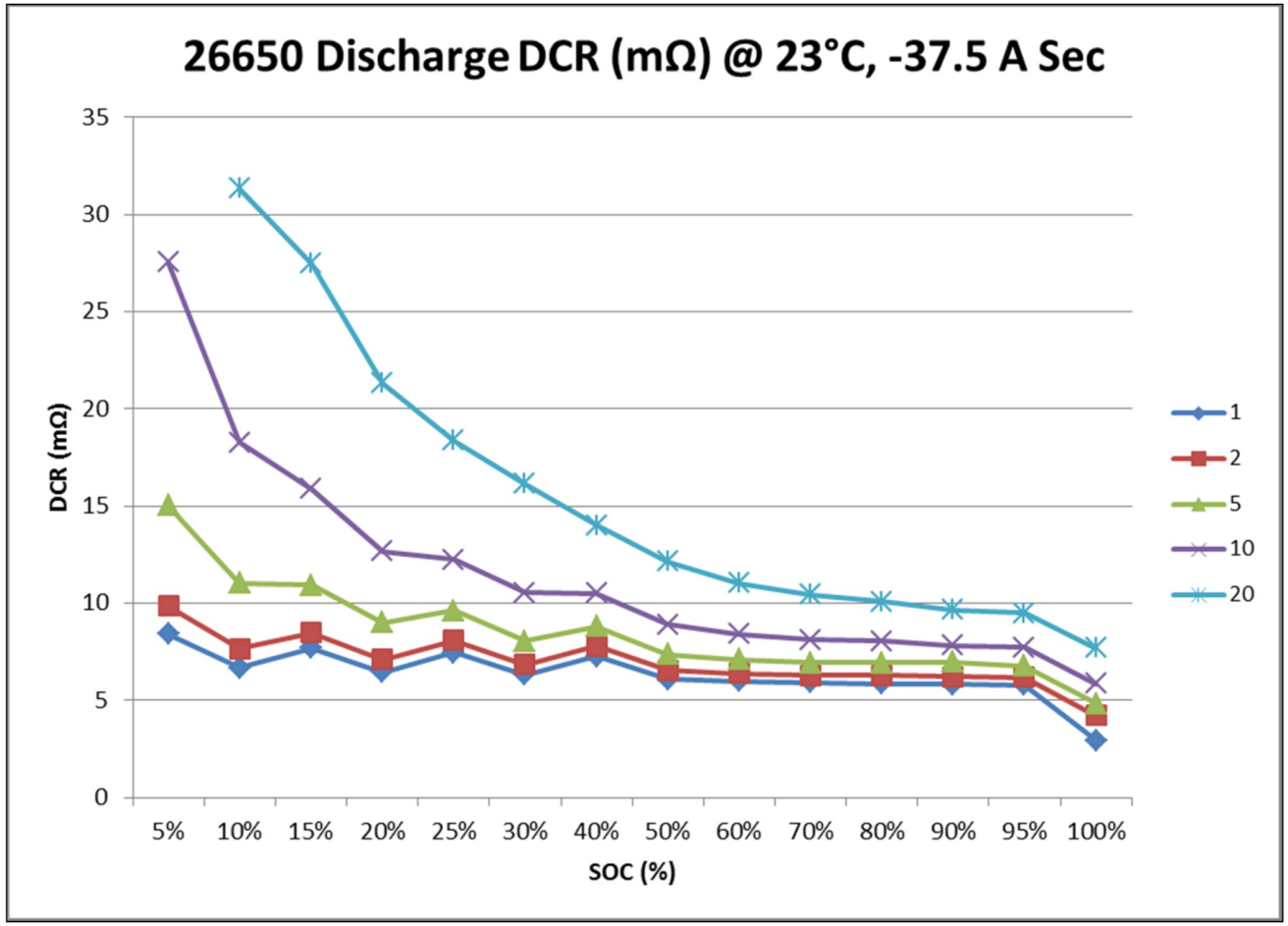
Temp(°C)↓ %SOC→	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
85	0	0	0	0	0	0	0	0	0	0	0
65	10	10	10	10	10	10	10	10	10	10	0
30	10	10	10	10	10	10	10	10	10	10	0
25	9	9	9	9	9	9	9	9	9	9	0
15	5	5	5	5	5	5	5	5	5	5	0
10	3	3	3	3	3	3	3	3	3	3	0
0	1	1	1	1	1	1	1	1	1	1	0

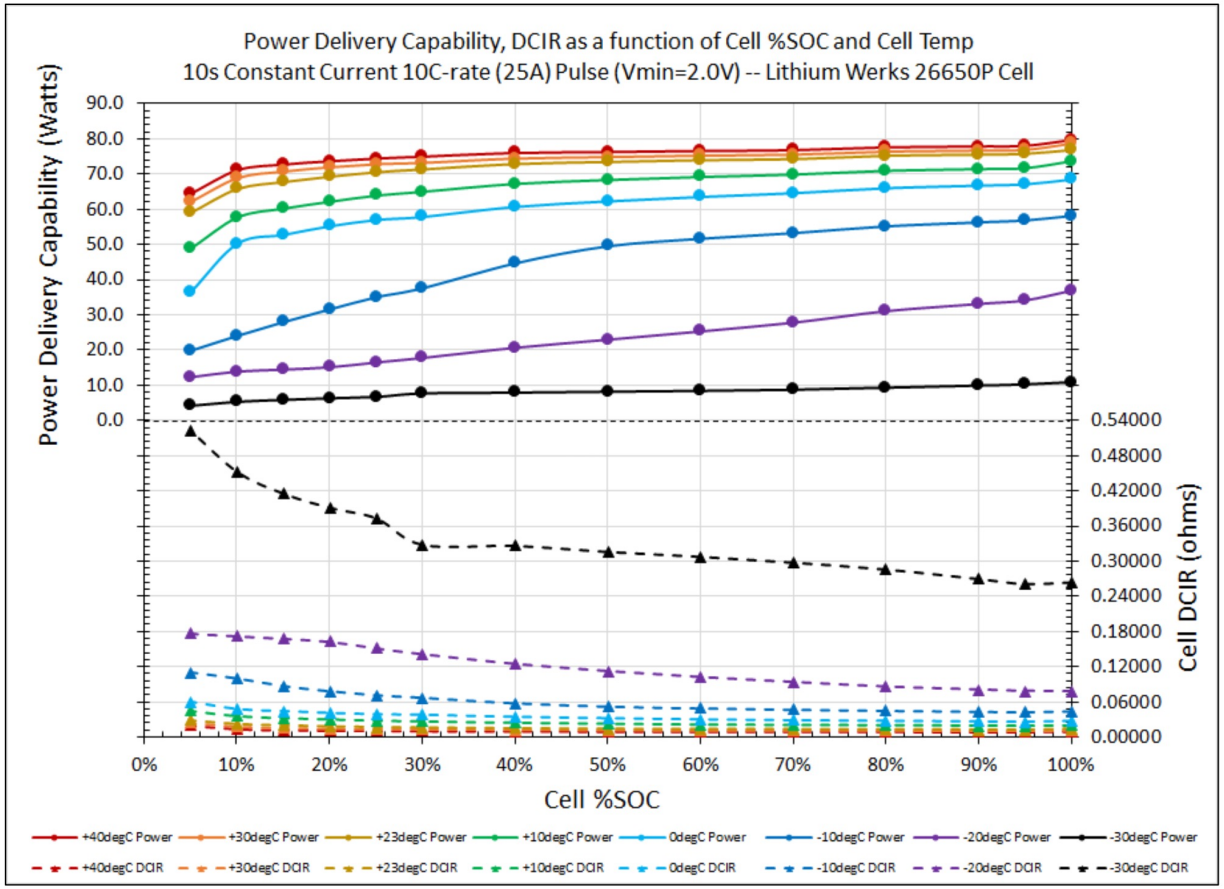
Table 22 – ANR26650*m1-B* Max 10s pulse charge currents wrt temperature and SOC

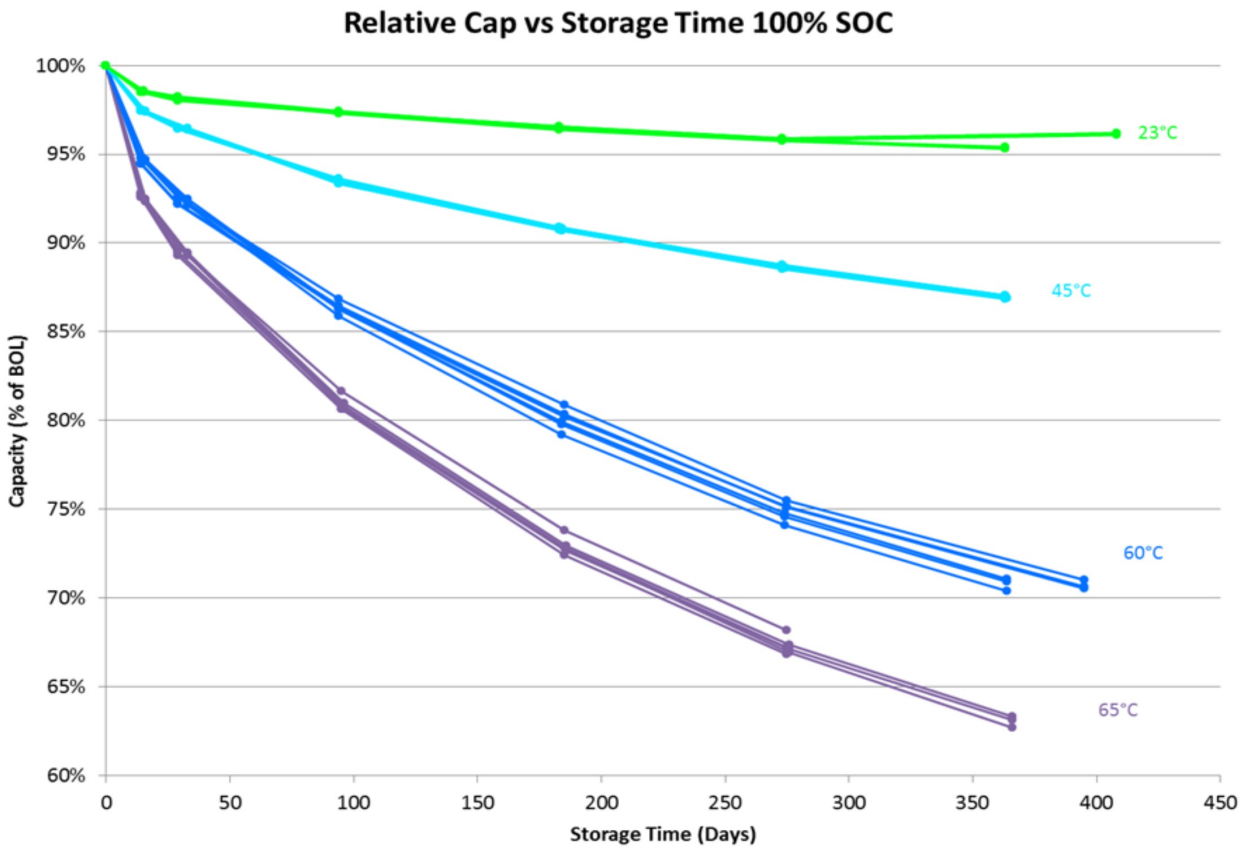
Temp(°C)↓ %SOC→	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
85	0	0	0	0	0	0	0	0	0	0	0
65	25	25	25	25	25	25	25	25	25	25	0
30	25	25	25	25	25	25	25	25	25	25	0
25	25	25	25	25	25	25	19	19	19	19	0
15	19	19	19	19	19	19	10	10	10	10	0
10	13	13	13	13	13	13	8	8	8	8	0
0	8	8	8	8	8	8	5	5	5	5	0





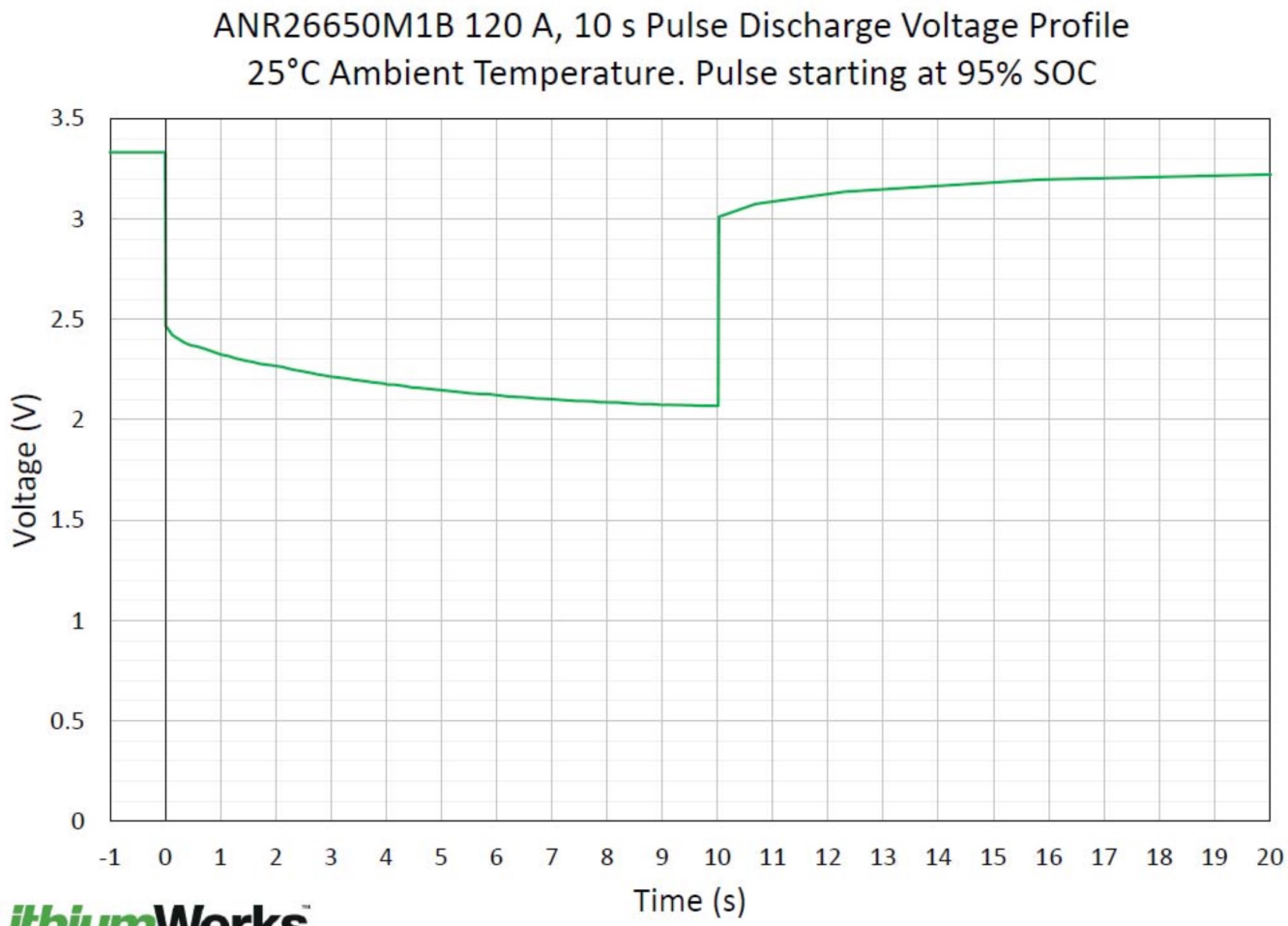






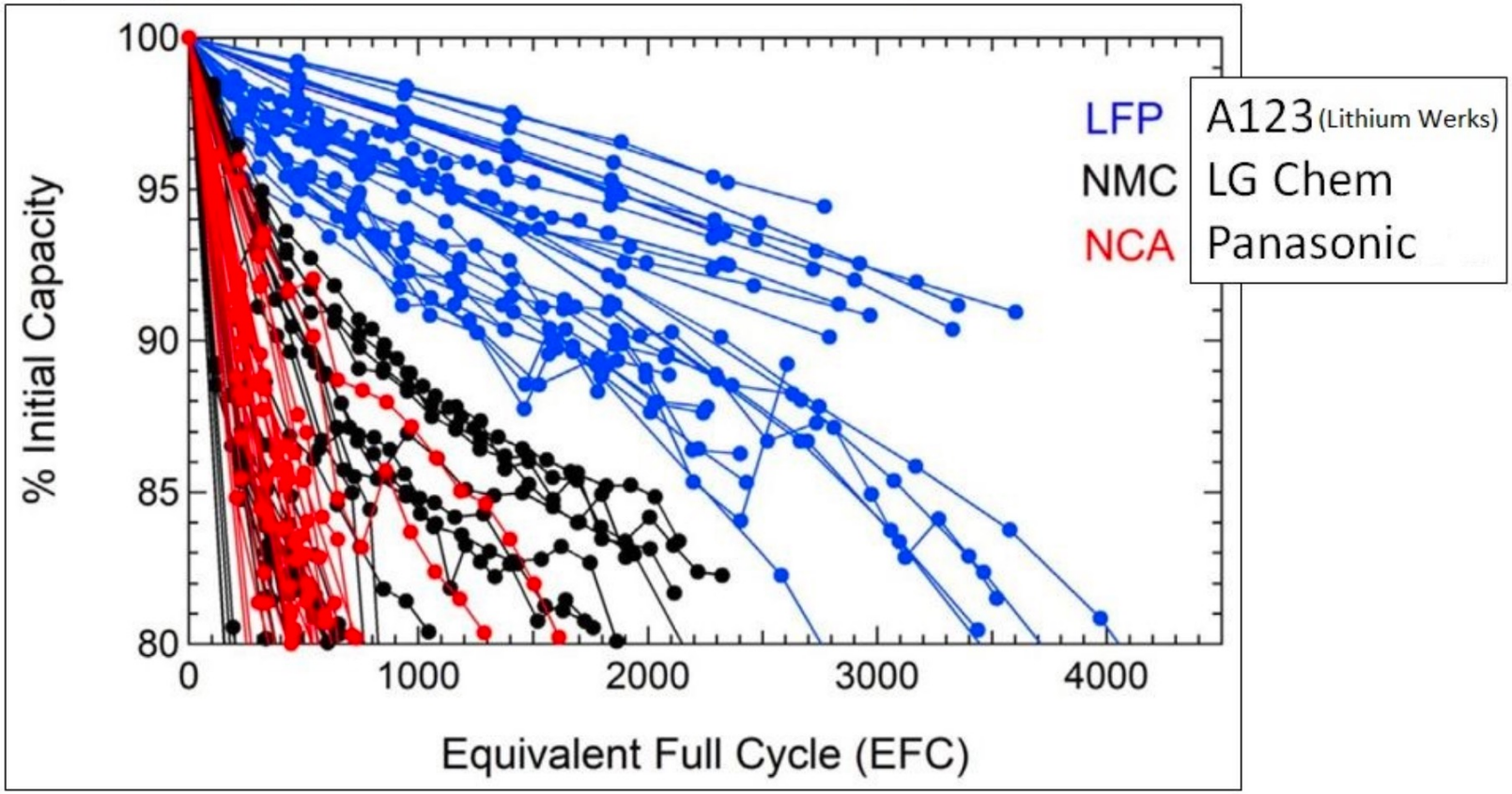
Storing Batteries

Lithium Werks cells can be stored for over 10 years in a cool environment. For long storage periods, a refresh charge is required every four years at 25 °C. For temperatures above 40 °C a refresh charge is required every year. Batteries should not be stored continuously above 65 °C.



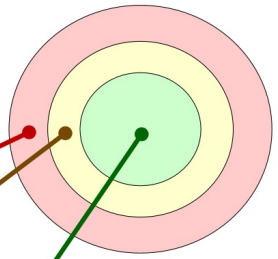
LithiumWerks

Yuliya Preger (2020): Journal of the Electrochemical Society



Capacity Fade

Cell-level – Layers of Control Limits for Practical Application

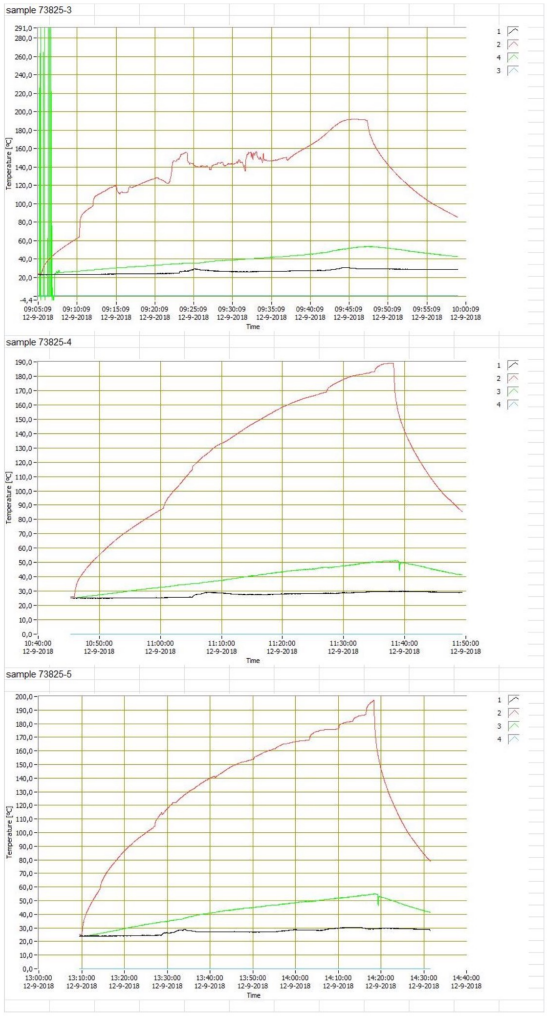


Cell Characteristic	Control Parameter	Control Purpose/Optimization		
		Safety	Performance	Life Performance
Temperature	T_{max}	80°C	65°C	45°C
	$T_{minDISCH}$	-30°C	-30°C	-30°C
	$T_{minCHRG}$	-10°C	0°C	0°C
Voltage	$V_{maxCONT}$	3.9V	3.65V	3.6V
	$V_{minCONT}$	1.0V	2.0V	2.0V
	$V_{maxPULSE}$	4.0V	3.8V	3.65V
	$V_{minPULSE}$	1.0V	1.6V	1.6V
Current	$I_{maxCONT\ (Disch)}$	20 C-rate	10 C-rate	4 C-rate
	$I_{maxPULSE\ (Disch)}$	48 C-rate	20 C-rate	10 C-rate
	$I_{maxCONT\ (Chrg)}$	6 C-rate	4 C-rate	2 C-rate
	$I_{maxPULSE\ (Chrg)}$	20 C-rate	8 C-rate	4 C-rate

sample number	code	T at start (°C)	T start venting (°C)	T at sampling (°C)	p increase due to T increase (bar)	p increase (bar)	released amount gas (l)	gas		gas concentration in reactor (mol%)	gas released from cell (l)
73825-3	AG36046, green	21	140-180	29	0,028	0,11	1,1	hydrogen	H_2	0,912	0,137
								carbon dioxide	CO_2	1,089	0,164
								carbon monoxide	CO	0,244	0,037
								methane	CH_4	0,051	0,008
								ethane	C_2H_6	0,018	0,003
								ethylene	C_2H_4	0,200	0,030
								propane	C_3H_8	0,002	0,000
								propylene	C_3H_7	0,009	0,001
								oxygen	O_2	2,85	
								nitrogen	N_2	94,50	
								sum		99,88	
73825-4	AH32117, green	21	140-180	29	0,028	0,10	1,0	hydrogen	H_2	1,003	0,150
								carbon dioxide	CO_2	1,574	0,235
								carbon monoxide	CO	0,239	0,036
								methane	CH_4	0,053	0,008
								ethane	C_2H_6	0,018	0,003
								ethylene	C_2H_4	0,225	0,034
								propane	C_3H_8	0,003	0,000
								propylene	C_3H_7	0,010	0,001
								oxygen	O_2	2,24	
								nitrogen	N_2	94,54	
								sum		99,91	
73825-5	AH34546, green	21	140-180	29	0,028	0,10	1,0	hydrogen	H_2	0,986	0,147
								carbon dioxide	CO_2	2,214	0,330
								carbon monoxide	CO	0,252	0,038
								methane	CH_4	0,053	0,008
								ethane	C_2H_6	0,019	0,003
								ethylene	C_2H_4	0,241	0,036
								propane	C_3H_8	0,003	0,000
								propylene	C_3H_7	0,011	0,002
								oxygen	O_2	8,11	
								nitrogen	N_2	87,81	
								sum		99,70	

Below, the temperature graphs of the venting process of the three tests are shown:

- red line: temperature measured by the thermocouple attached on the cell
- green line: temperature measured by the thermocouple in reactor above the cell
- black line: temperature measured by the thermocouple put on outside wall of reactor
- blue line: analogue voltage signal of the absolute pressure gauge.



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