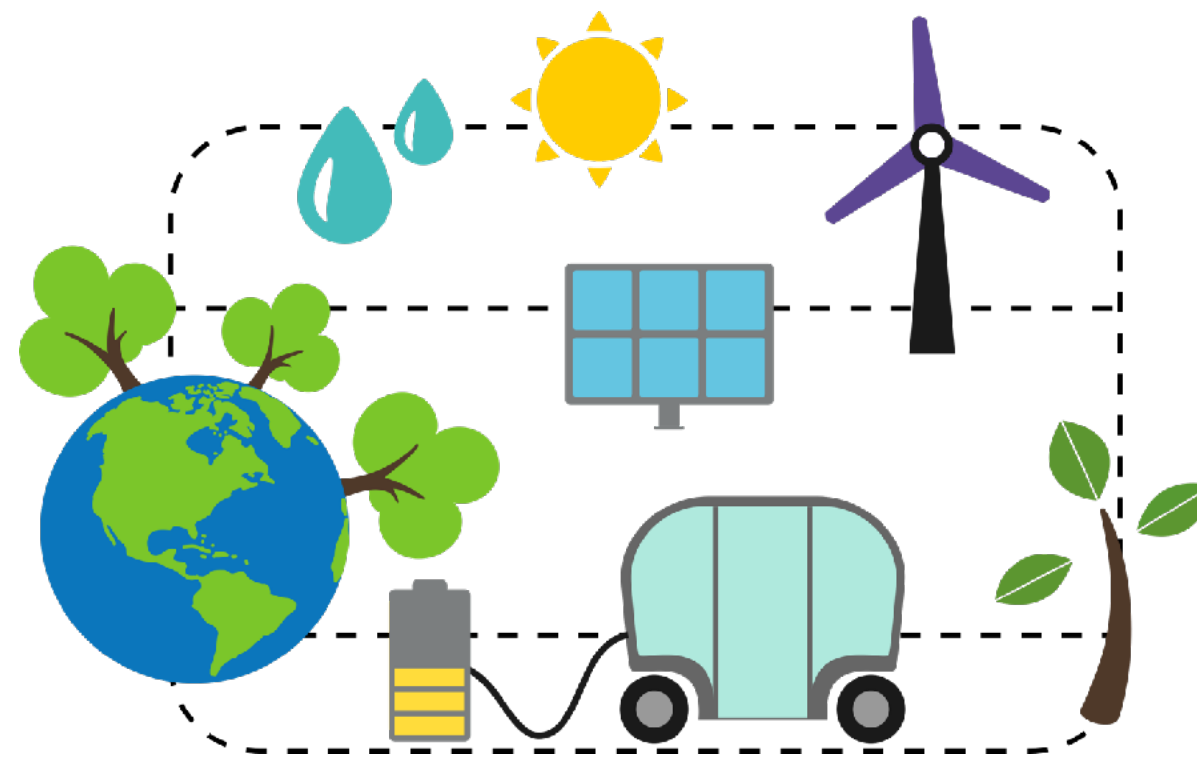


Kurt.energy:

The shift to green energy needs better batteries NOW

Evidence for Carbon based hybrid power capacitors



Hybrid carbon based power capacitors

Similar energy density like lithium-ion batteries
with the benefits of supercapacitors

1. Carbon power capacitors **DO NOT BURN**
 2. Sustained 10C to 20C **high peak power capacity**
 - **A 15 kWh battery can deliver 150 to 300 kW sustained (and more)**
 - **Very fast charging: 75% in 5 minutes**
 3. Works from **-40°C to +80°C**
 4. **Very long life: > 20000 cycles or 10 years**
 5. **No BMS needed, no active thermal management needed**
 6. Energy density cells from **80 to 230 Wh/kg**
- While there is no ideal battery for all applications, a battery must have multiple parameters right and being in production
 - Combination of energy density, high power density and safety provides a game-changing opportunity
 - Lifecycle cost significantly lower

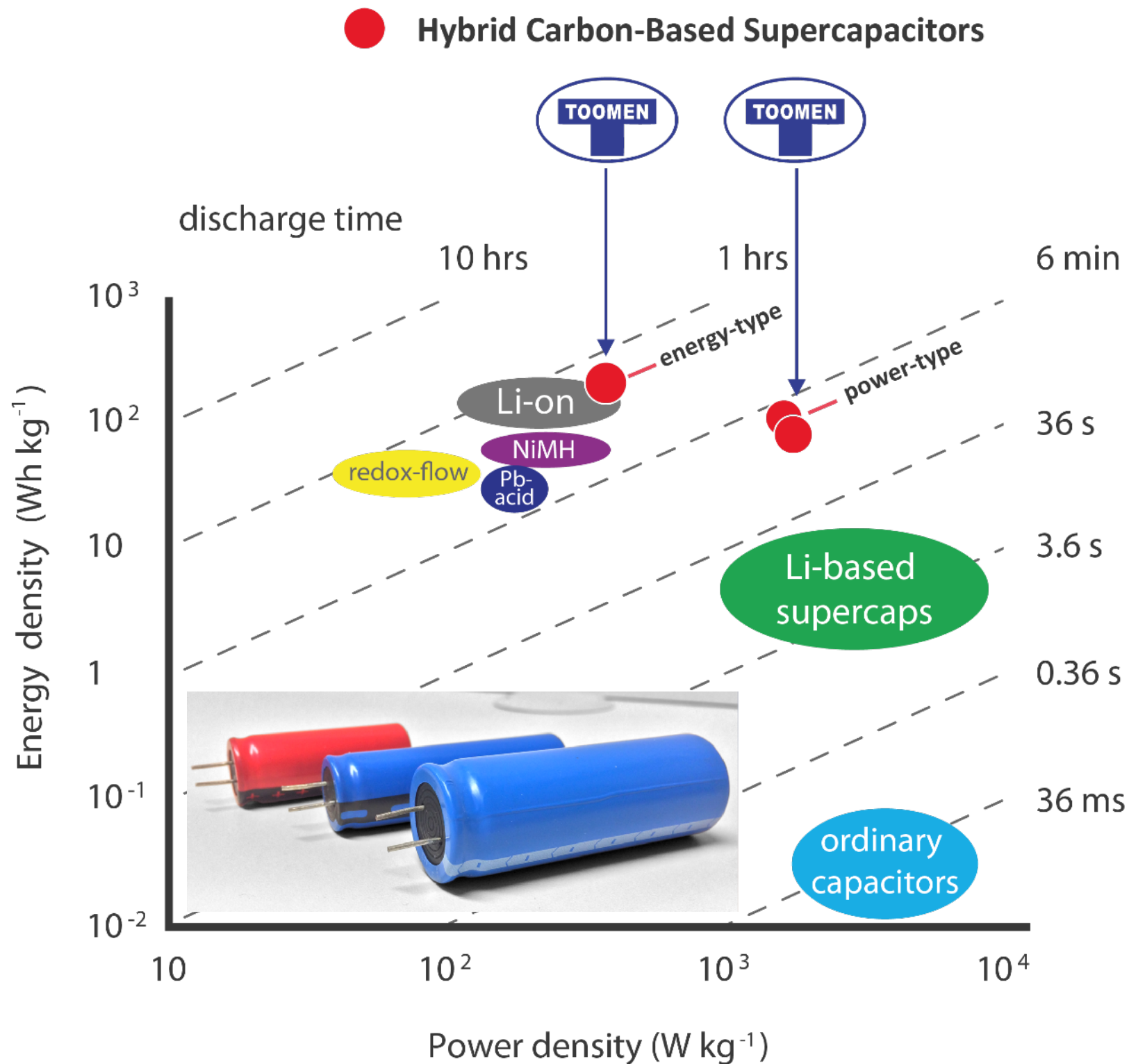


Comparison of batteries and C-powercaps

	LFP battery	NMC lithium battery	Lithium titanate battery	Lithium based super capacitor	Power-type C-powercap	Energy-type C-powercap
Energy density (Wh/kg)	90 - 150	180 - 250	70 - 95	4 - 6	80 - 100	180 - 230
Power density (kW/kg)	0.1 - 0.2	0.1 - 0.5	0.5 - 1	5 - 7	1 - 1.5	0.3 - 0.5
Typical charging/ discharging rates	1.0 C	0.7 - 1.0 C	1.0 - 5.0 C	100.0 - 200.0 C	10.0 - 20.0 C	1.0 - 1.25 C
Working temperature (°C)	-10 ~ 55	-20 ~ 45	-40 ~ 60	-40 ~ 65	-20 / -40 ~ +80	-20 / -40 ~ +80
Cycle life (times)	2000	2000	5000	> 500000	> 20000 upto 50000	> 10000
Safety	acceptable	not good	good	excellent	excellent	excellent
Complexity	Medium: BMS needed	High: BMS needed + thermal mgt	Medium: BMS needed	Low: no BMS, passive cooling	Low: no BMS, passive cooling	Low: no BMS, passive cooling



Argone chart: comparison

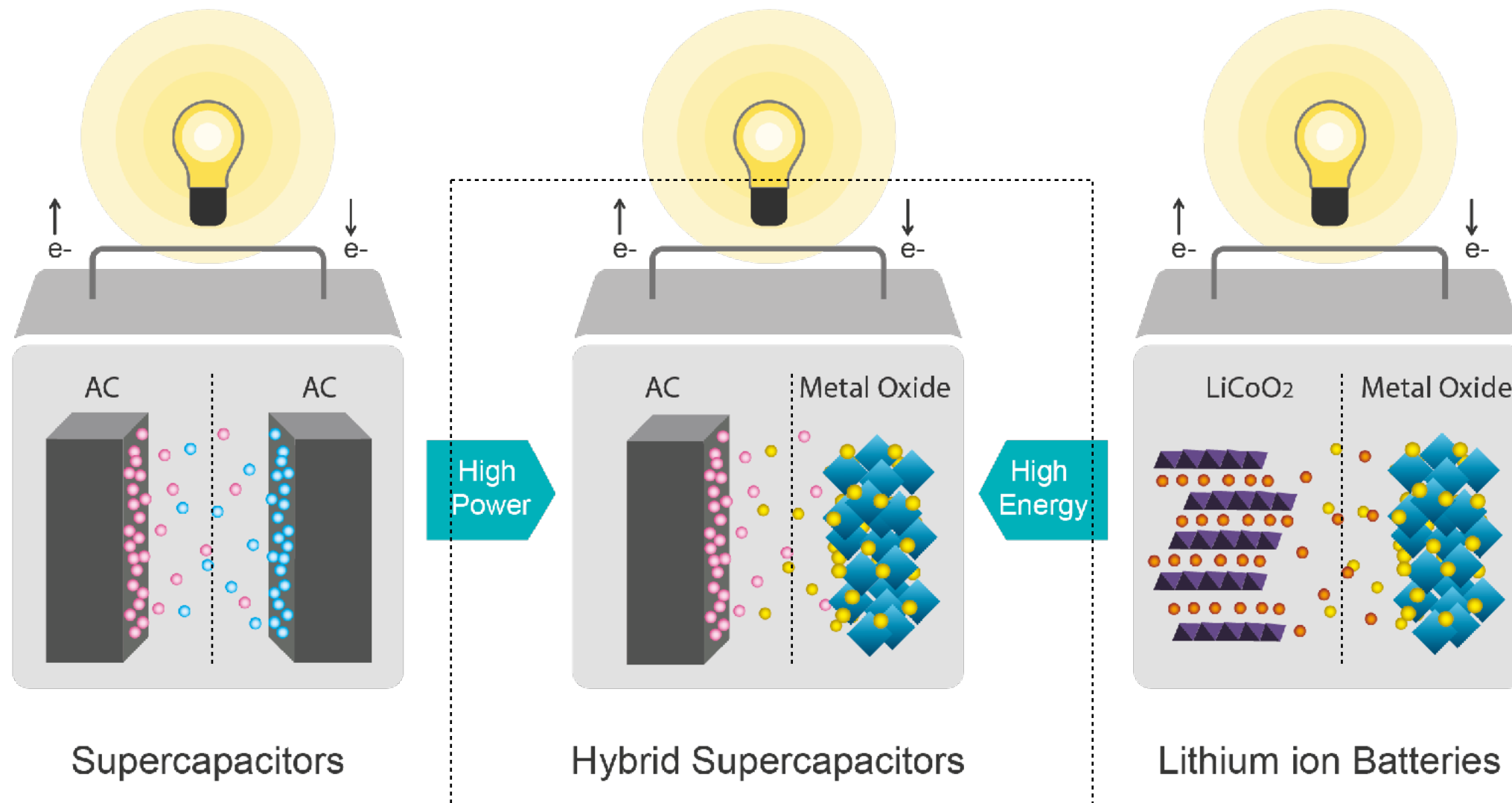


Comparison carbon power caps

Type	Power-type	Power-type	Energy-type	Energy-type
Format	Cyl 18500	Cyl 18650	Cyl 23680	Pouch 120x200
Energy Wh/cell	3,2	3,5	16,0	70,0
Energy Wh/kg	100	80	200	230
Energy Wh/dm ³	235	181	442	972
Max C-rate	10 C	20 C	1-1,25 C	1-1,25 C
Temperature range	-20 to +70 °C	-40 to +80°C	-40 to +80°C	-40 to +80°C
Lifetime	20000	> 20000	10000	10000
Max Ri (mOhm)	20	13	20	—
Status	Production	Production	pre-production	Prototype



Hybrid architecture: C-cap with a Li-side

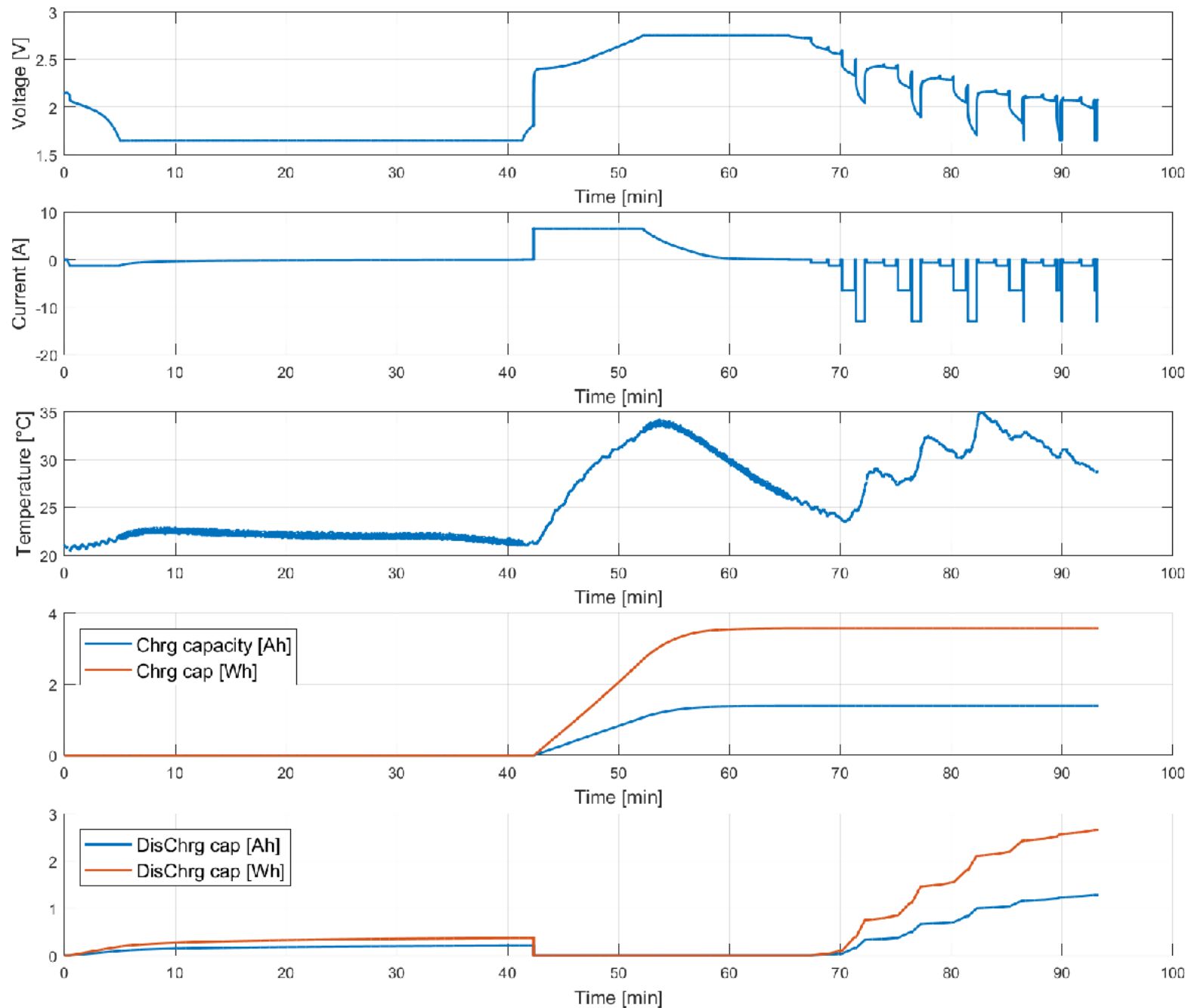


- Dominant component is activated nano-carbon
- No dendrites can form
- Low in electrolyte, absorbed by carbon
- Low in Lithium compounds (LPF, LTO, NMC like)



Confirmed by external test & stress & abuse tests

Test 4773 | 18650 | Cell 22 | WLTP test



Charging in 10 minutes to 75%

Discharging at 0.5, 1C, 5C, 10C

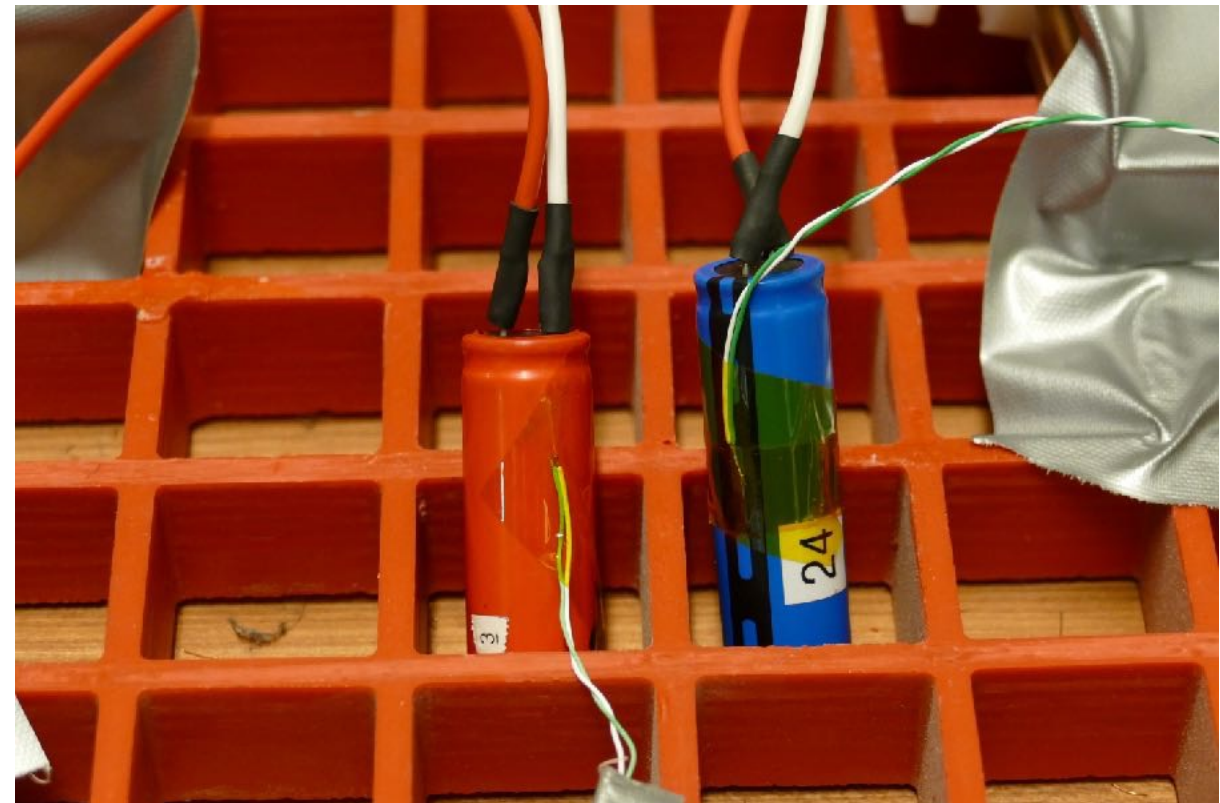
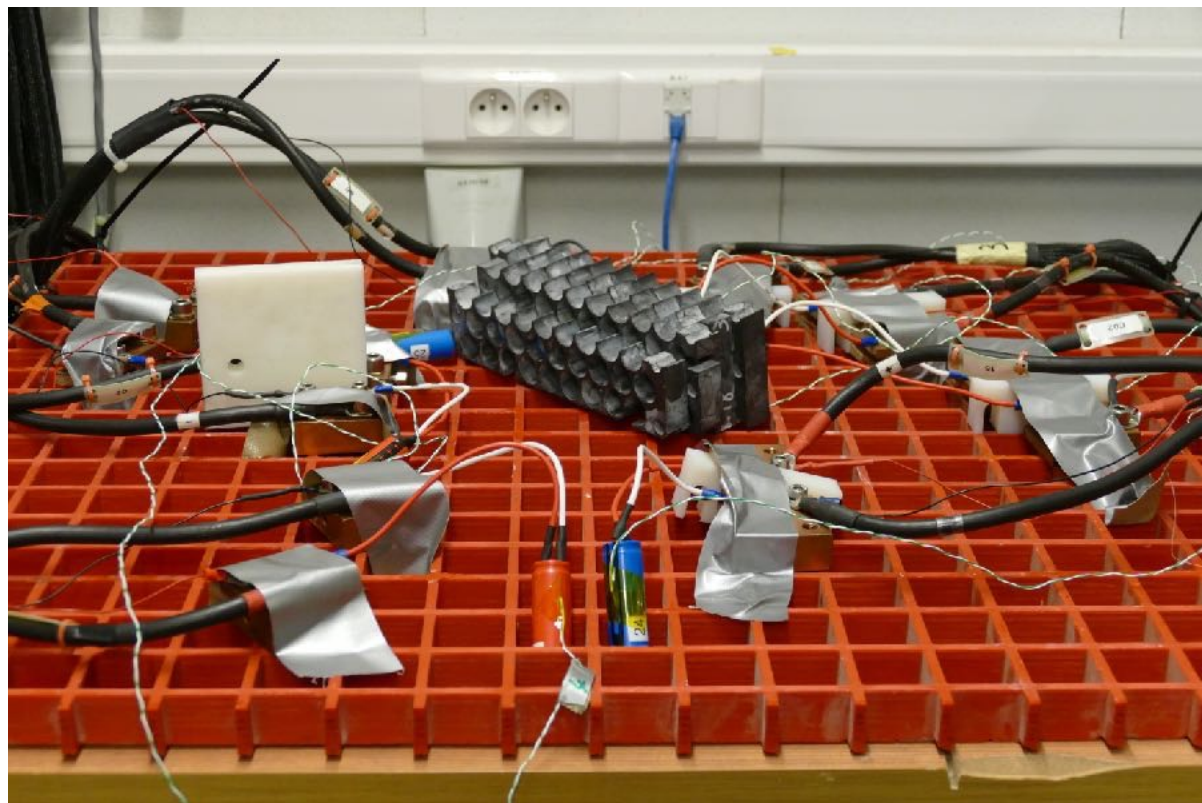
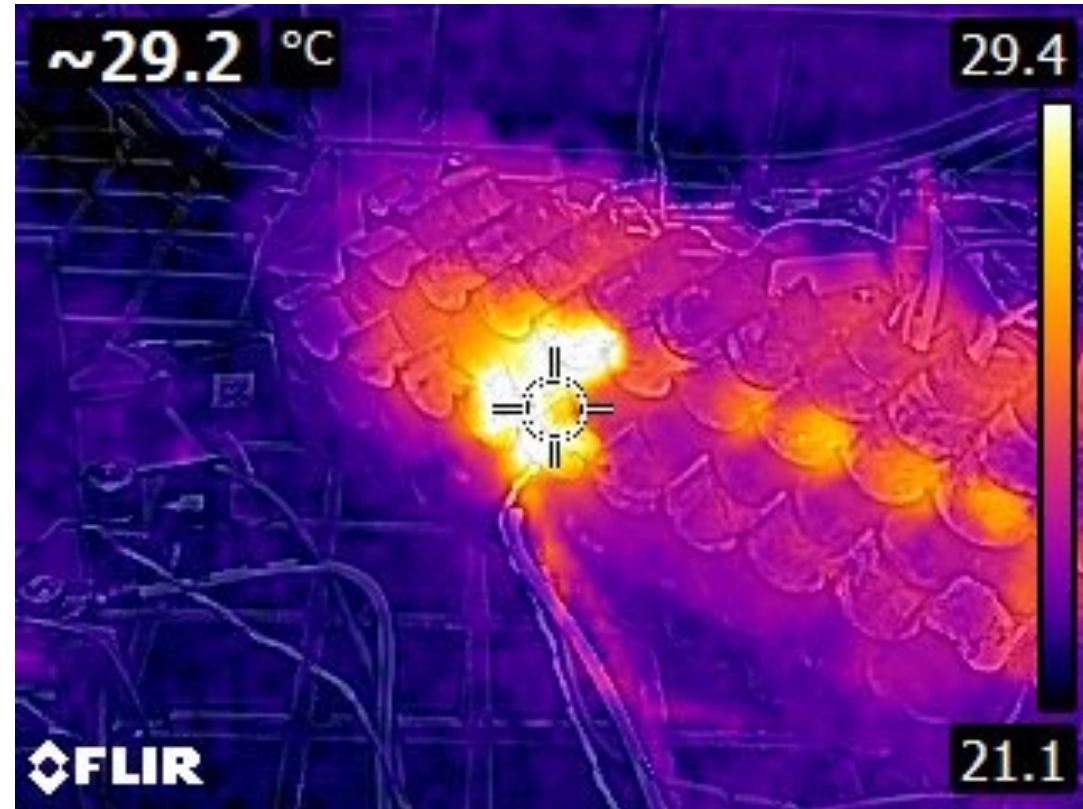
T < 35 °C in ambient air

3.4 Wh charged & discharged

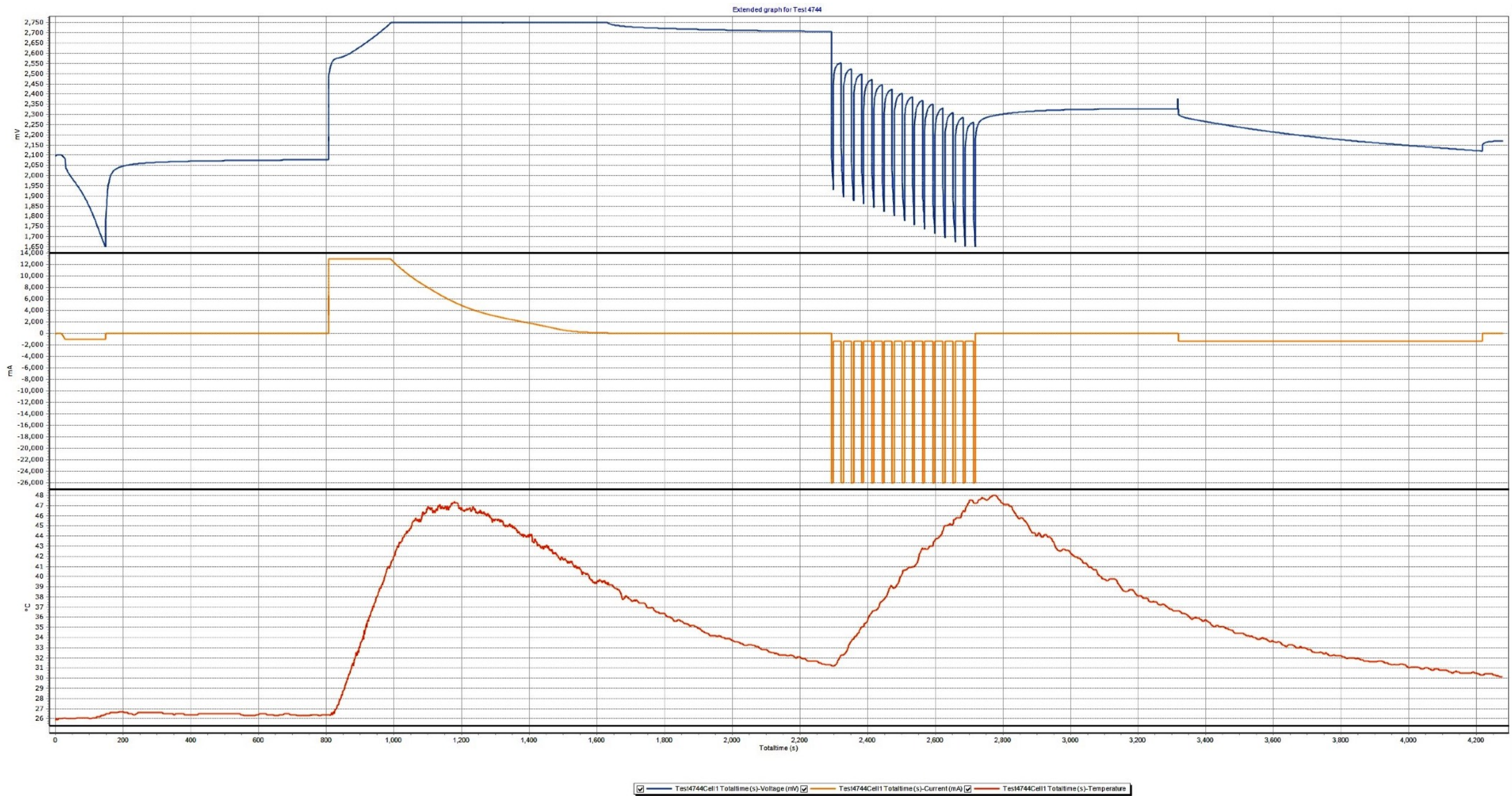
Charging at 5C (6.5 A), discharging at 0.5C, 1C, 5C, 10C, simulating WLTP cycle

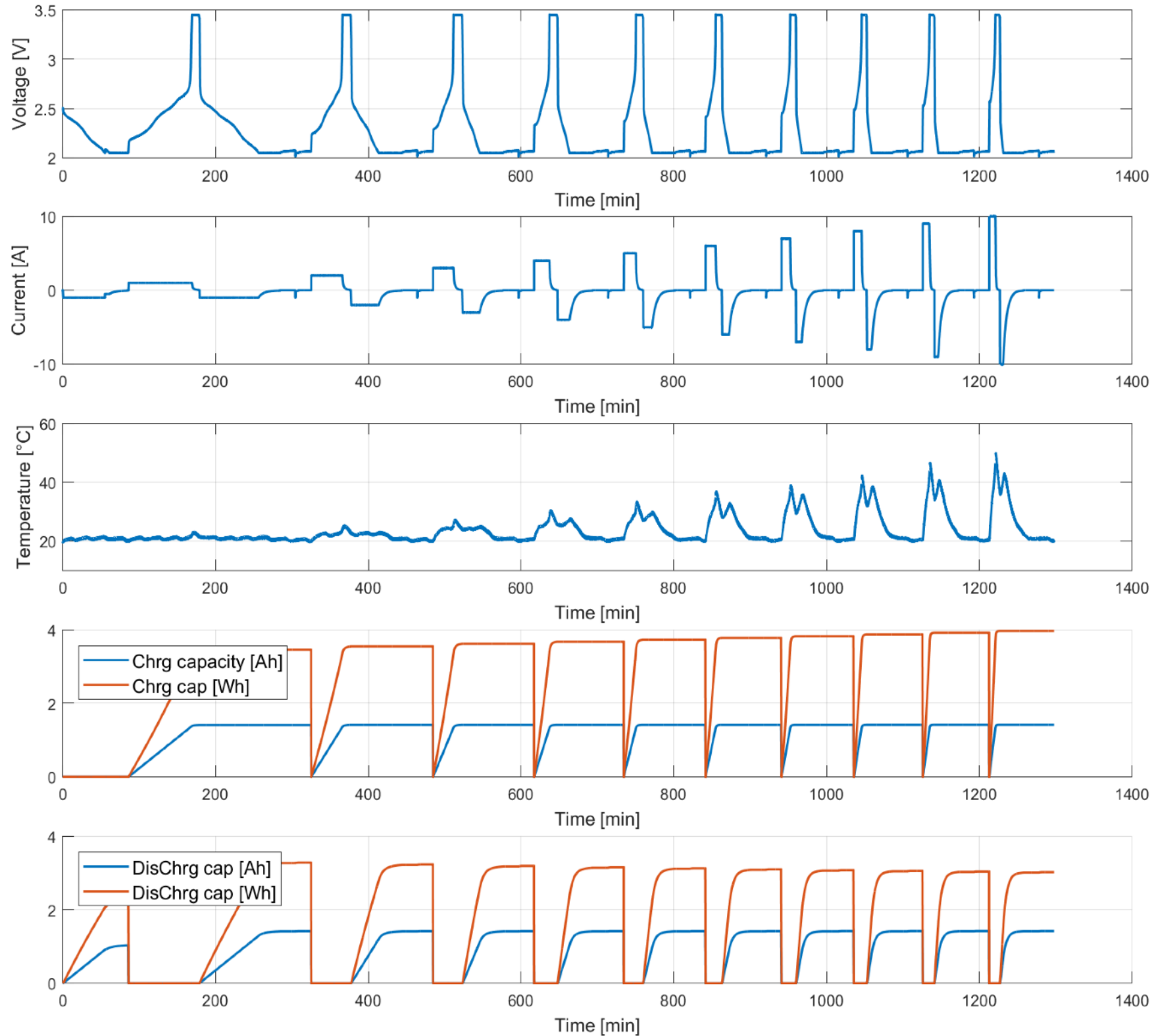


Tests at FlandersMake Lommel



Stress test: charge at 5C, discharge 6 sec at 20C (26A), rest 24 sec in between.





**Charging in
22 minutes to
75%**

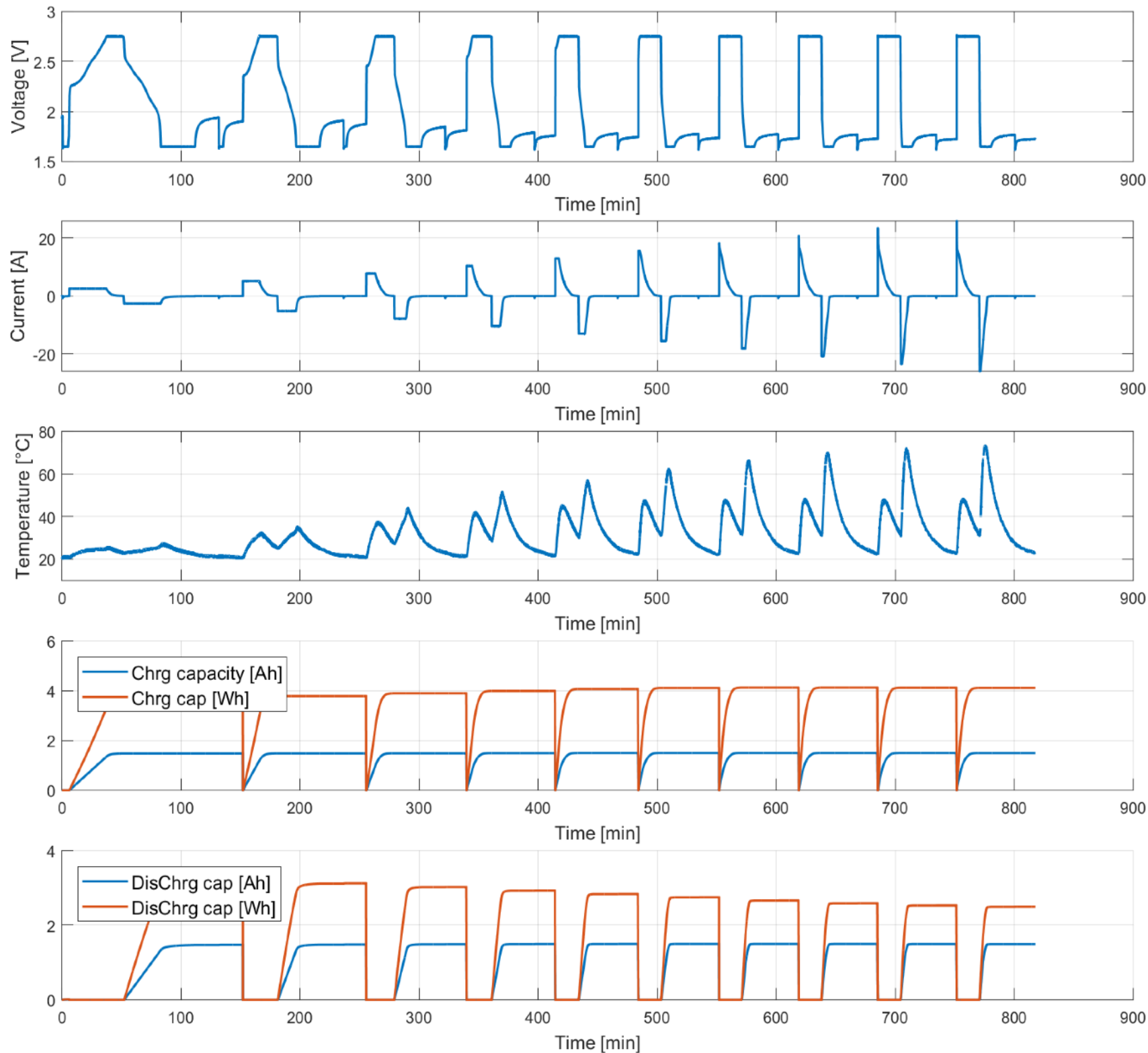
**Charging and
discharging
with 1.C (1.0 A)
upto 10C (10.0 A)**

**Temperature
peaks at 55°C
remains below
30°C up to 5C**

**3,2 Wh
charged &
discharged**

Stress test 18500 upto 10C (open air)





**Charging in
5 minutes
to 75%**

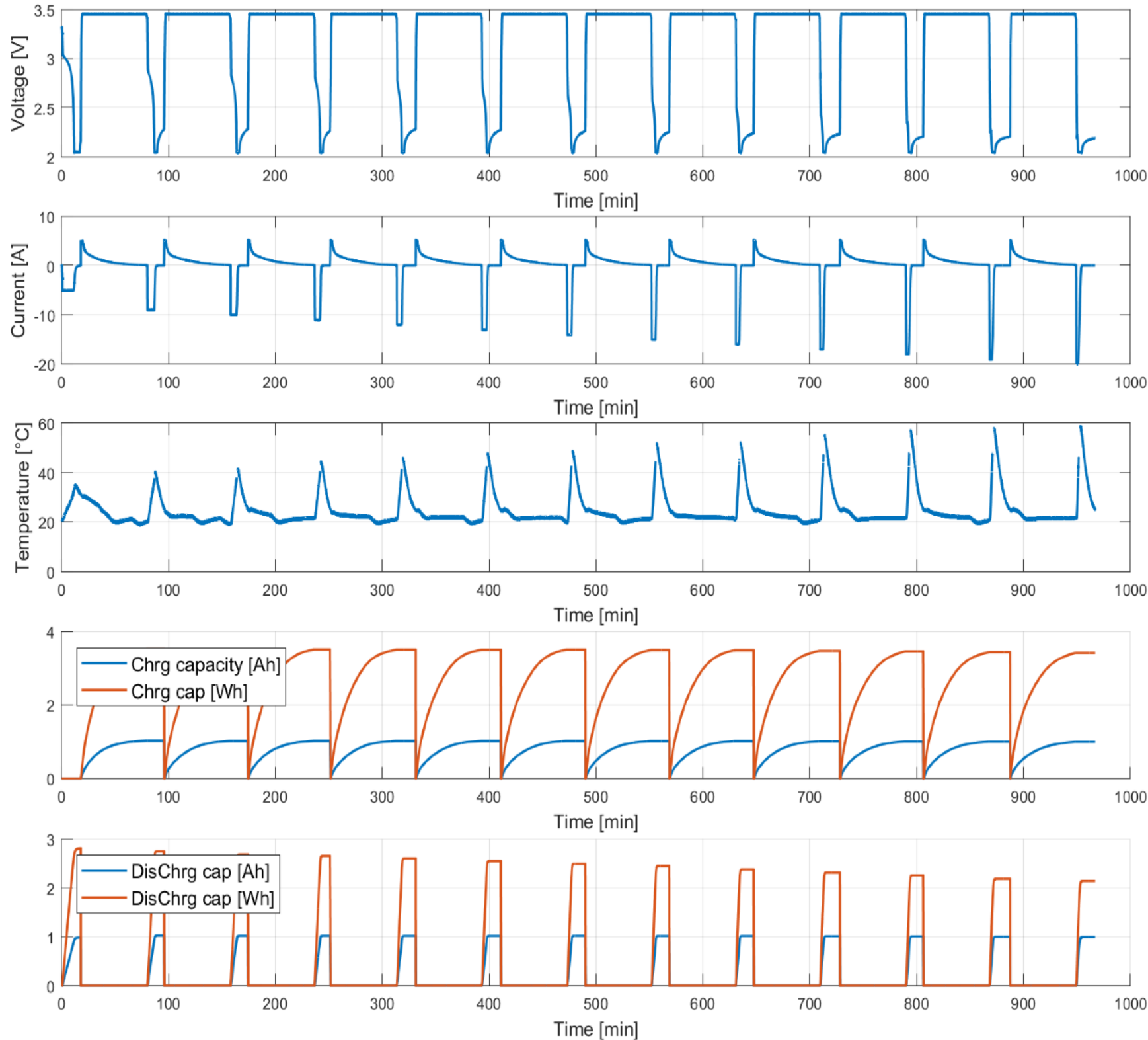
**Charging and
discharging
with 1C (1.3 A)
upto 20C (26.0 A)**

**Temperature
peaks at 75°C
remains below
60°C up to 10C**

**3,5 Wh
charged &
discharged**

Stress test 18650 upto 20C (open air)





Charging at 5C in 22 minutes to 75%

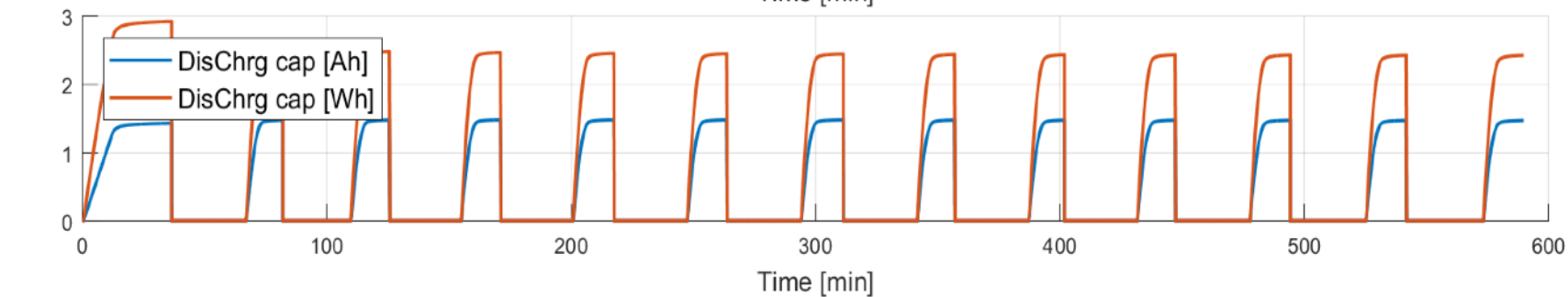
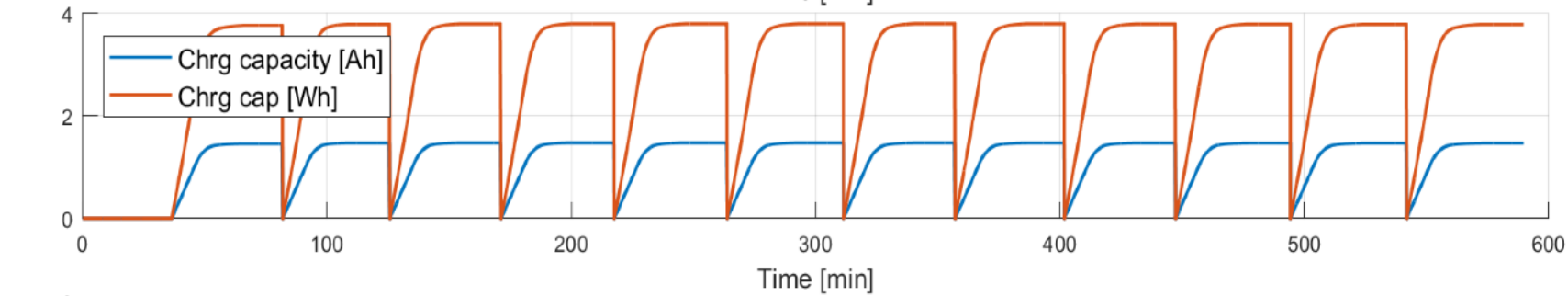
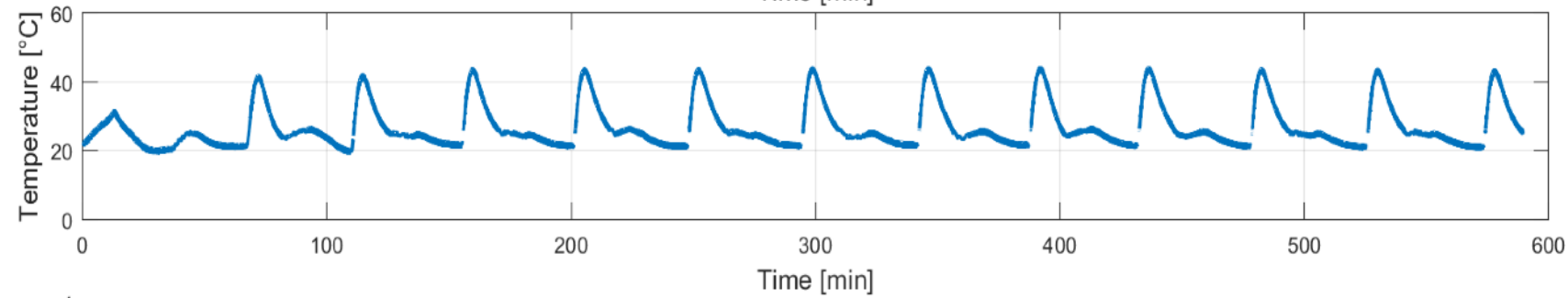
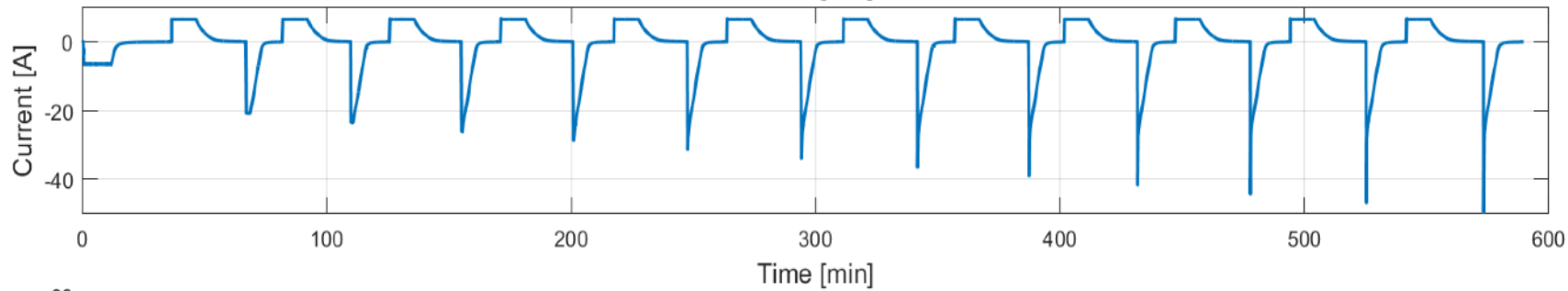
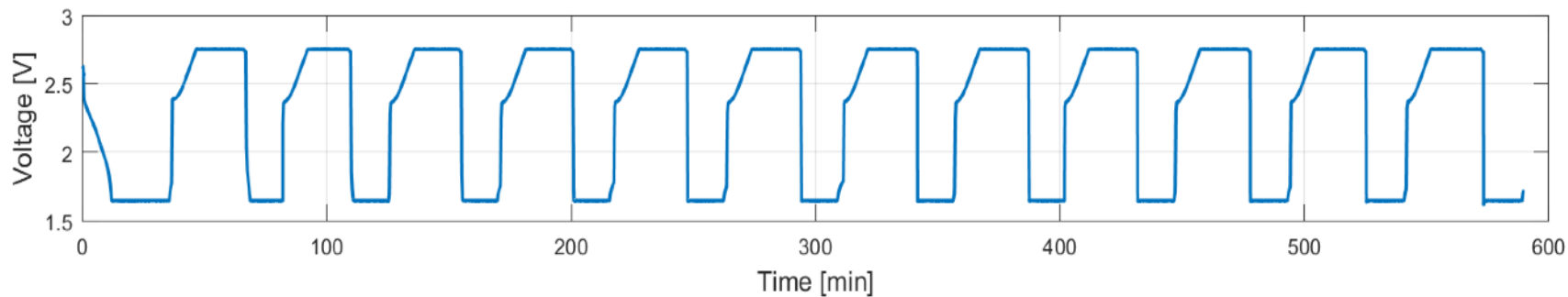
Discharging from 9C (9.0 A) upto 20C (20.0 A)

Temperature peaks at 60°, Remains below 40°C till 10C

Charge capacity unaffected

Abuse test 18500 upto 2x10C = 20C (PCM + fan)





**Charging at 5C
in 5 minutes to
75%**

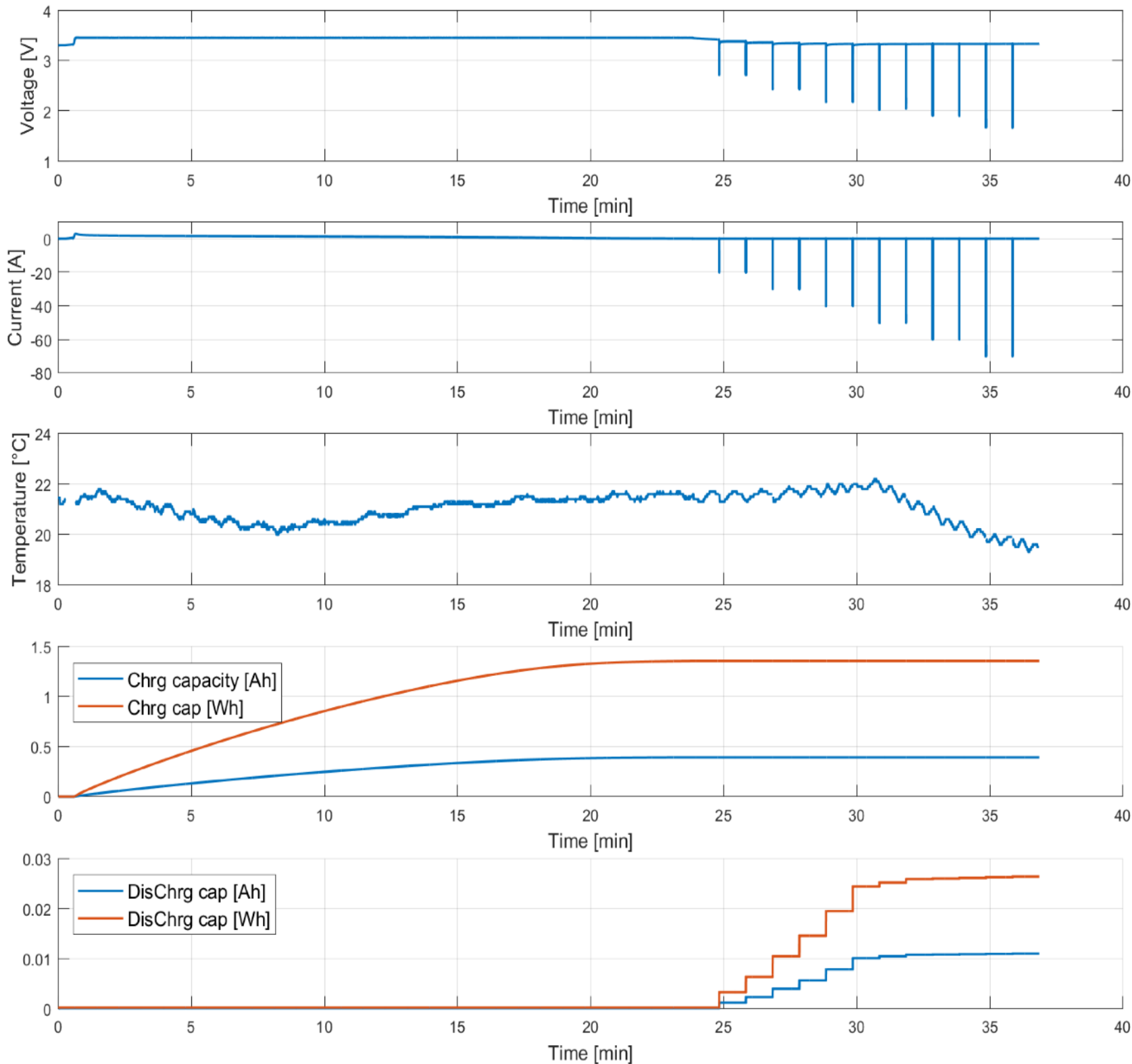
**Discharging from
16C (20.8 A) upto
38C (49.4 A)**

**Temperature
peaks at 42°C,
remains below
40°C upto 16C**

**Charge
capacity
unaffected**

Abuse test 18650 upto 2x20C => 38C (PCM + fan)





**Charging at 3C
in 25 minutes
to 50%**

**2X Pulse (200 ms)
discharging from
20C (20 A) upto
70C (70 A)**

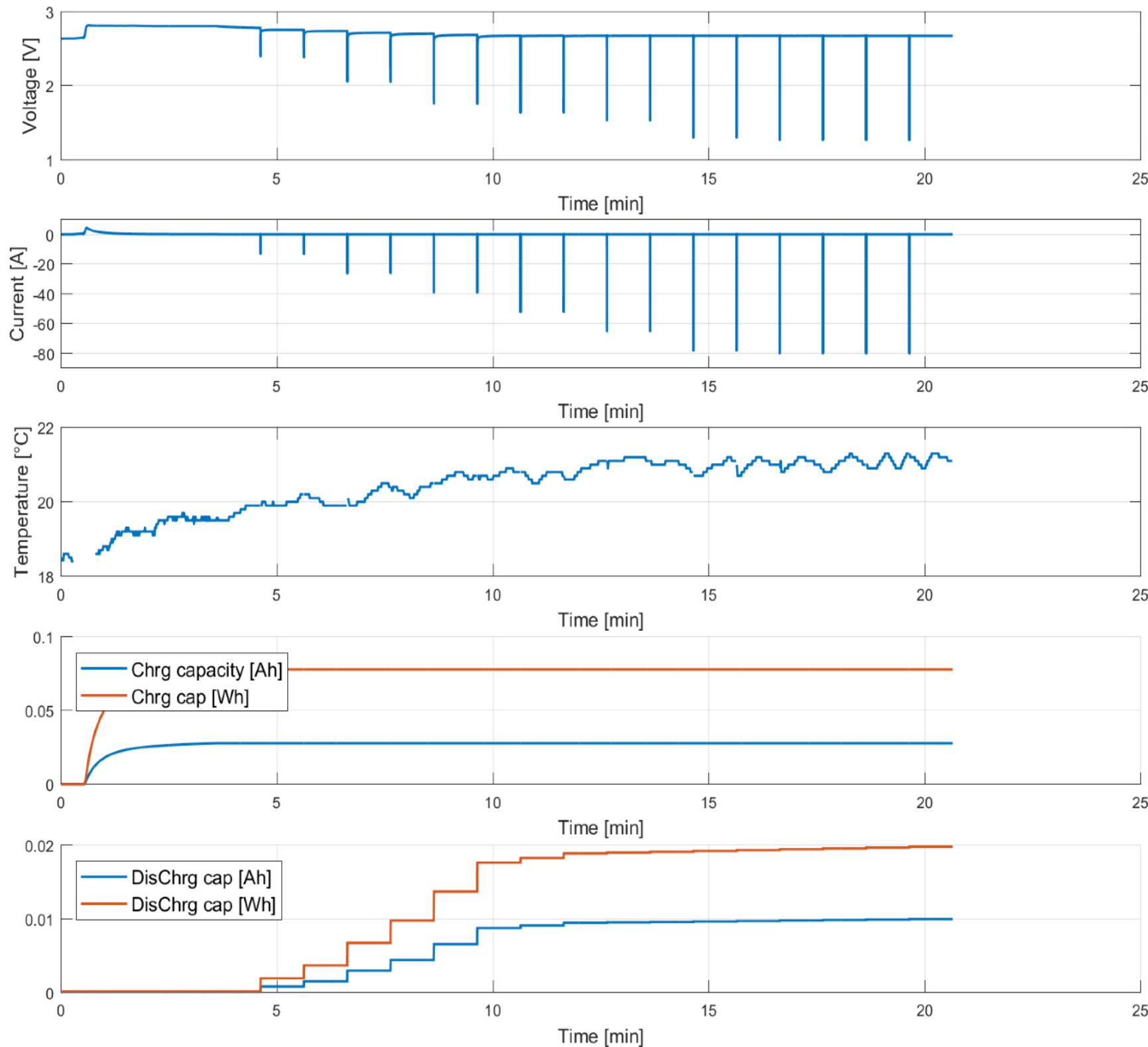
**No measurable
temperature
increase**

**Discharge
capacity not
affected**

**Note: tester limit
80A**

Pulse abuse test 18500 upto 2x20C => 70C (PCM+fan)





**Charging at 3C
in 5 minutes to
75%**

**2X Pulse (200 ms)
discharging from
10C (13 A) upto
60C (78 A)**

**No measurable
temperature
increase**

**Discharge
capacity not
affected**

Note: tester limit
80A



Pulse abuse test 18650 upto 60C (PCM+fan)

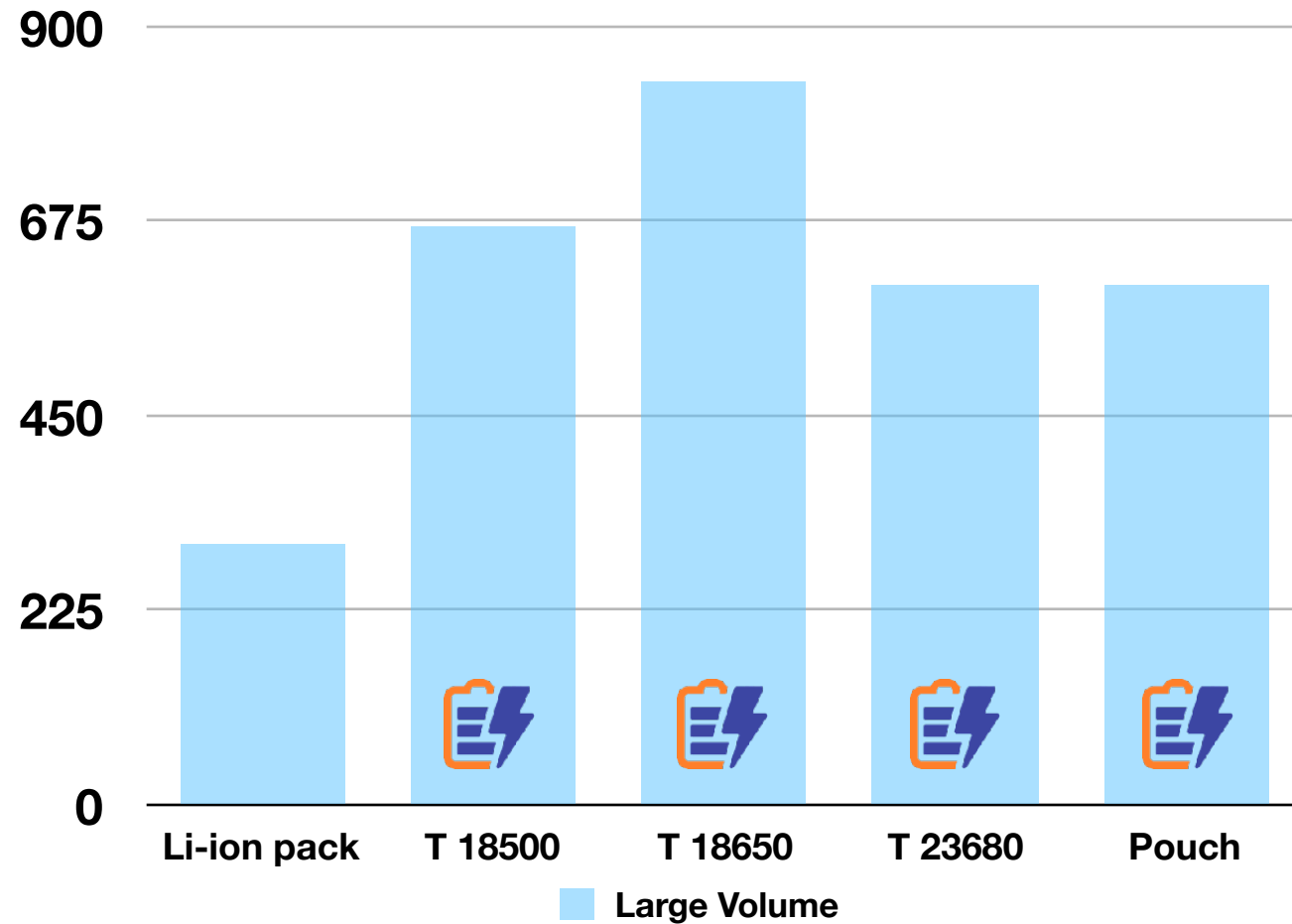
Extreme robustness

- **What do these tests show:**
 - **Use beyond the datasheet specs gives no problem**
 - **No capacity loss,**
 - **No destruction,**
 - **No heat generation**
 - **Use with very high current only limited by voltage drop**
- **=> Power capacitors are extremely robust**
- **In addition:**
 - **Failure mode is open-circuit, hence no thermal risk**
 - **Battery pack mesh architecture is failure resilient**
 - **Lifetime from 10000 to > 20000 cycles: lower cost / cycle**

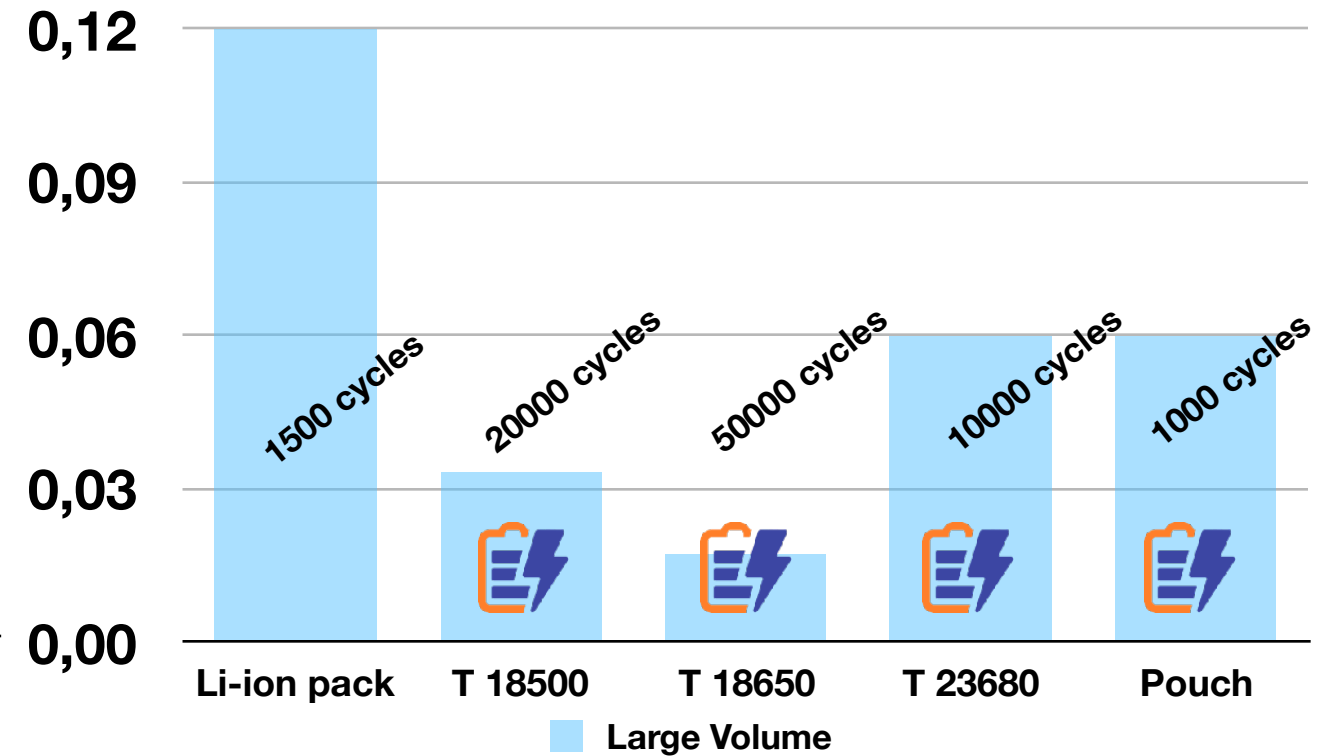


Costprice per kWh/cycle over (long) lifetime

Selling price per kWh (2018)



Calculated price per kWh per cycle



Cycle = charge/discharge

Customer advantage:

10 years lifecycle (when monitored), maintenance cost very low
 Often smaller power capacitor battery (1/3) with 10 to 20x more power
 => lower lifecycle cost



Why no BMS?

No Active balancing needed:

- Cells are matched at assembly time
- Connected in “rectangular” S xP mesh
- Hence, no need for active balancing
- Benefits:
 - Much simpler, better use of space
 - Robustness: BMS has many parts that can fail and age
 - Less “extra” weight
 - If a cell fails:
 - (unlikely, only when penetrated or short circuit)
 - Fails as an open circuit
 - Battery remains operational



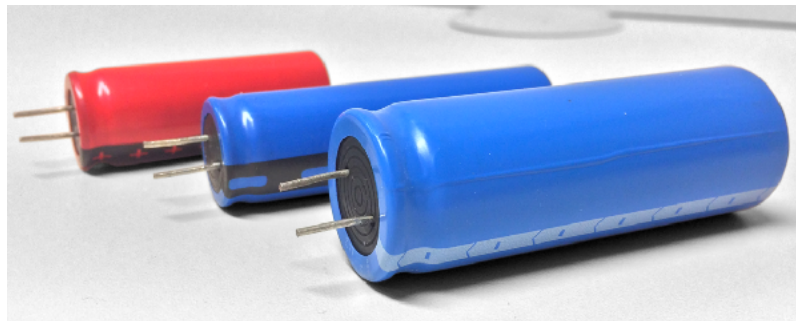
Why no active thermal management system?

Powercapacitors remain cool

- **Low internal resistance**
- **Can tolerate low and high temperatures**
 - (high temperatures will affect lifetime, as for any technology)
 - No risk of thermal runaway
- **Good design practice:**
 - Keep C-rate $< 5C$ for 18500, $< 10C$ for 18650
 - Occasional higher rates are not a problem
 - Keep things “cooled” => enclose in heat absorbing package
- **Benefits:**
 - **Save a lot of complexity**
 - **Save a lot of weight**
 - **Reliability**



Construction of a power capacitor pack





Space



Heavy mining vehicles



Hybrid trucks



E-bike battery



Old-timer electrification



Energy storage



Grid stabilization



Street lighting



Car batteries



AGVs & forklifts



Hybrid vehicles



Trains



Welding equipment



Hand-held power tools



21

Home energy system

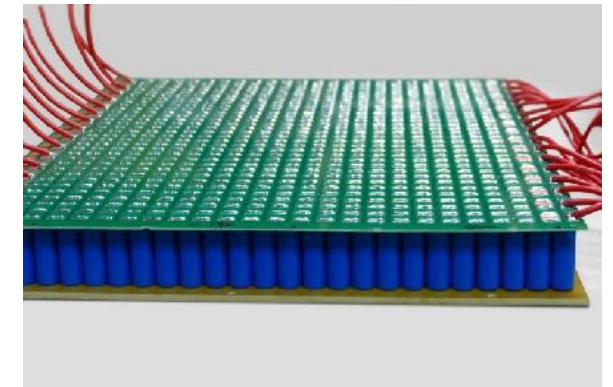


Power mills

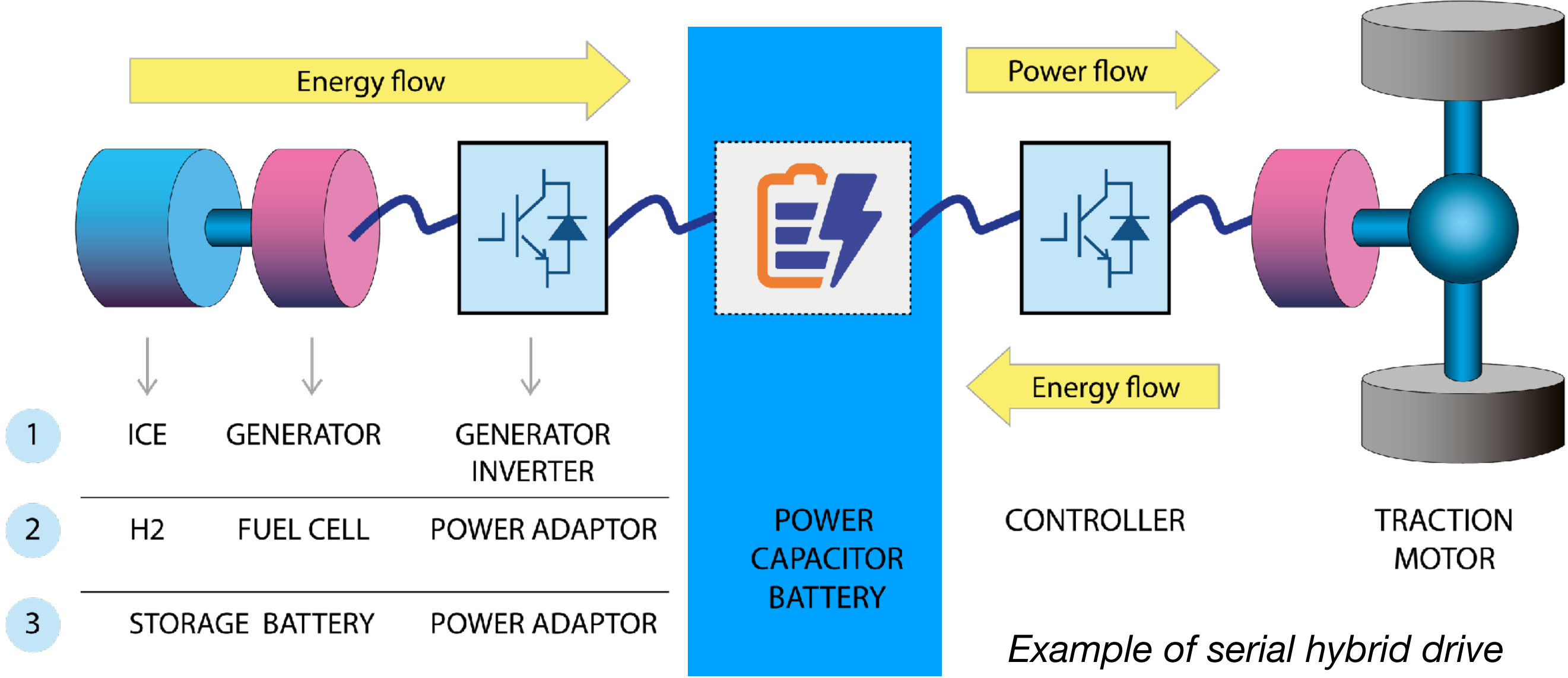
Applications

Applications of C-based supercaps

- Powerbanks (charging in (5 to 10 min)
- Starter batteries (for ICE vehicles)
- Hybrid batteries
- Serial hybrid vehicle drives
- Vehicle batteries:
 - Heavy duty vehicles (e.g. mining)
 - Fast charging vehicle batteries:
- Frequency grid adjustment
- Wind turbine blade pitch control
- Emergency power supply/ UPS
- Long life / high reliability batteries



Hybrid drives (serial - parallel)



Plug-in hybrid drives with 15 kWh battery can reduce pollution with 95% at a much lower cost than full BEV



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