WaveTech Group, Inc.

Disrupting a World Powered by Batteries

Enhanced Battery Performance in Industrial Storage Applications Provided by Crystal Control Technology®

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Introduction to WaveTech's Technical Innovations

Innovations developed by the WaveTech R&D team in the last five years:

1. Optimized **BEAT®** - the device generating the CCT® signal and providing it to the battery,
2. A family of **BARS®** systems for battery assessment and recovery,
3. **BCAT ®** : a battery condition assessment technology to be integrated in chargers or for stand-alone use,
4. Smart **BMS** - battery monitoring and management systems,
5. CCT ® **formation**, an advanced and short formation method.

The innovations of WaveTech offer customers new opportunities to improve battery performance "**from outside**", without changing cell design, chemistry, or existing battery manufacturing technologies.

Introduction to WaveTech's Technical Innovations

Three ways to use CCT® during charge:

1. Applied all the time in cycling operation (CCT® **cycling**).
   Effect: reduced capacity decline rate, 2 x longer cycle life, 3 x higher energy throughput.
2. Applied only during the charge phase of a single cycle (i.e. during **recovery**).
   Effect: capacity recovered up to 100%, retained for as many cycles as reached prior to recovery.
3. Applied during the **formation** step of battery manufacturing.
   Effect: cycle life extended up to twice (even without applying CCT® on cycling).

Benefits from using CCT® to battery system owners:

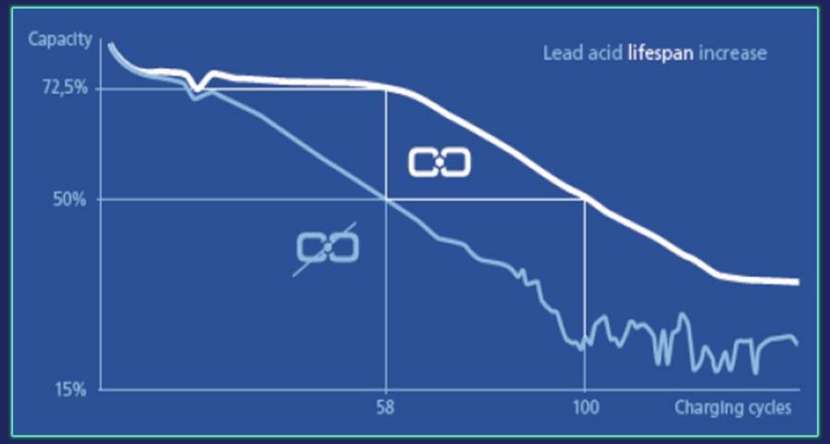
a) Reduced battery maintenance and reclaims costs (**smaller opex costs**),

b) Reduced need to buy new lead-acid batteries or shift to Li-ion ones (**less capex cost**),

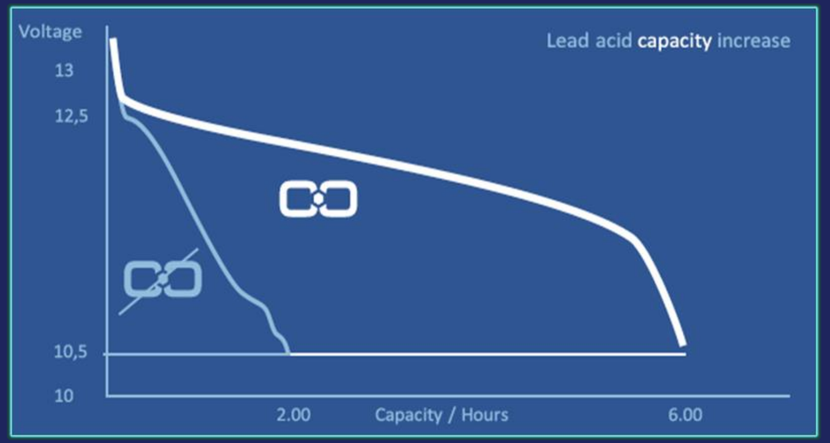
c) Extended primary and secondary battery life (lead and lithium) (**improved sustainability (ESG)).**

CCT for Lead-acid Batteries:
Better Cycle Life, Energy Throughput, Charge Acceptance

- Cycle Life doubles (2x)
- Higher capacity @ each cycle (active mass utilization)
- Lifetime energy throughput triples (3x)
- Higher charge acceptance, shorter charge time
- Reduced rate of capacity loss on cycling



- Less heat evolution during charge
- Cell equalization
- Less sensitive to temperature variation (-23°C to + 55°C)
- Capacity stability at deep discharge and undercharge
- Water loss and corrosion not increased, low maintenance



CCT for Lead-acid Batteries:
Battery Assessment and Recovery System (BARS)

How to restore reversible capacity loss (no corrosion damage, no water loss) :

Recovery? Recharge? Repair? Boost? Refreshing? Equalization charge?

Recovery = recharge® + CCT® + equal electrolyte s.g. + porous active mass microstructure,
resulting in:

a) improved active materials microstructure

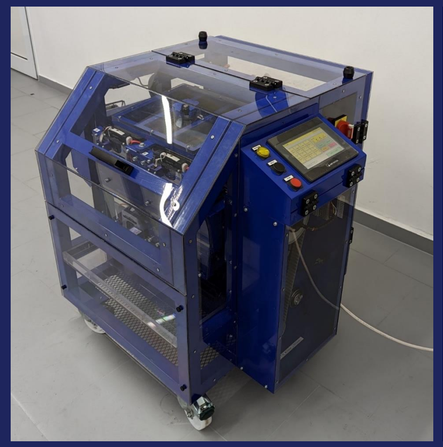
b) homogeneous electrolyte concentration in all parts of the cell

c) optimized electrolyte distribution in the pores of the active mass and the separator

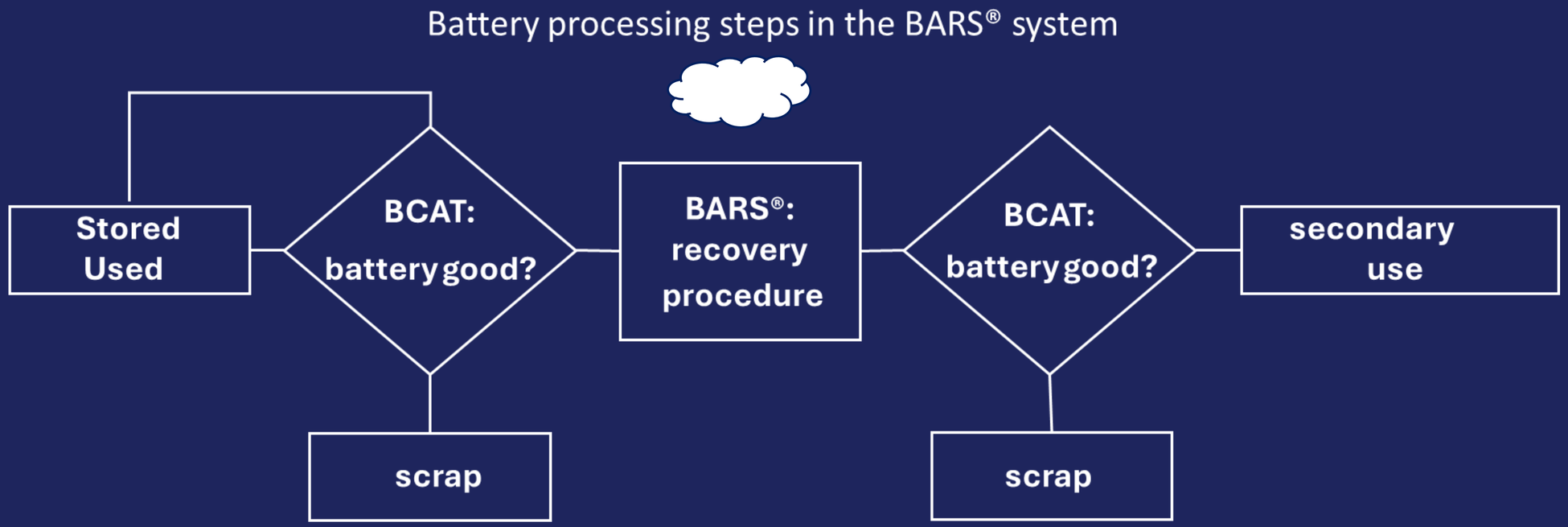
d) “free” battery screening,

e) capacity back up to normal

f) sustainable performance improvement



CCT for Lead-acid Batteries:
Battery Assessment and Recovery System (BARS)



Recent BCAT field testing with various AGM batteries:

a) not used (only stored)

b) of limited use time (guarantee time, design lifetime)

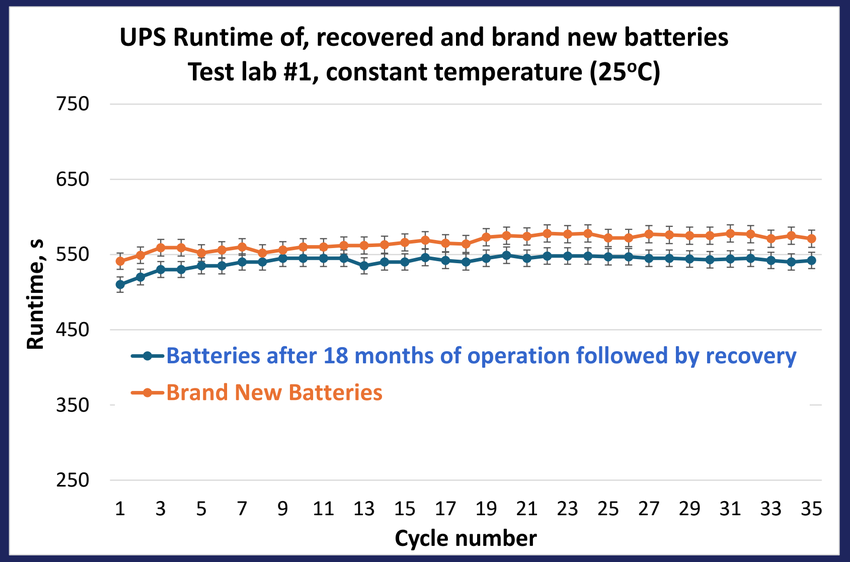
c) of long use or store time (after warranty time)

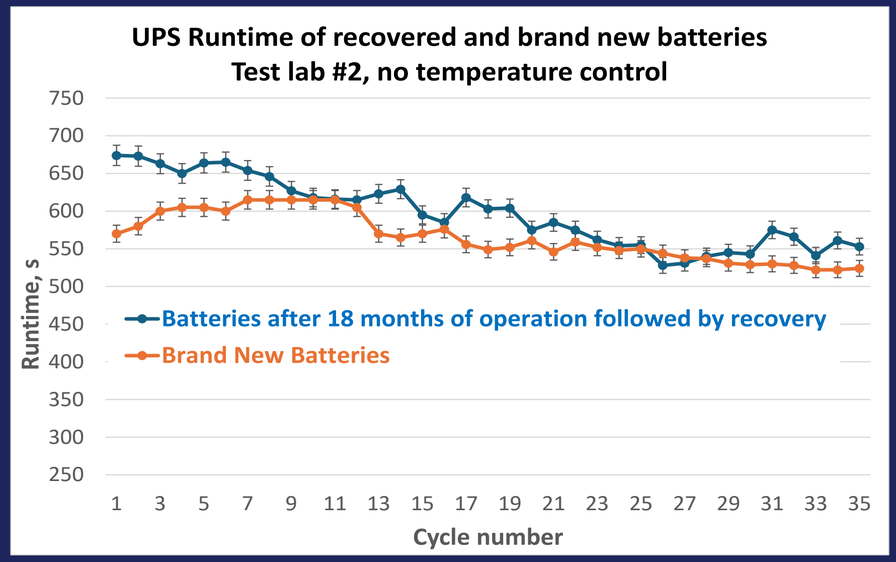
CCT for Lead-acid Batteries:
Recovery of Used and Stored Batteries

Runtime of recovered batteries (age 18+ months) and new ones, a 35 cycles test:

- 81 field used 12V-5Ah AGM batteries evaluated (by HIOKI & BCAT) as recoverable
- Recovered and evaluated again (BCAT) for success (Δ < 10%). **73/81 recovered successfully.**
- Two groups (24 + 24) of them tested for UPS Runtime in two labs (Europe and Southeast Aasia)

Recovered capacity similar to new one in a 35 cycles test, Δ < 10%





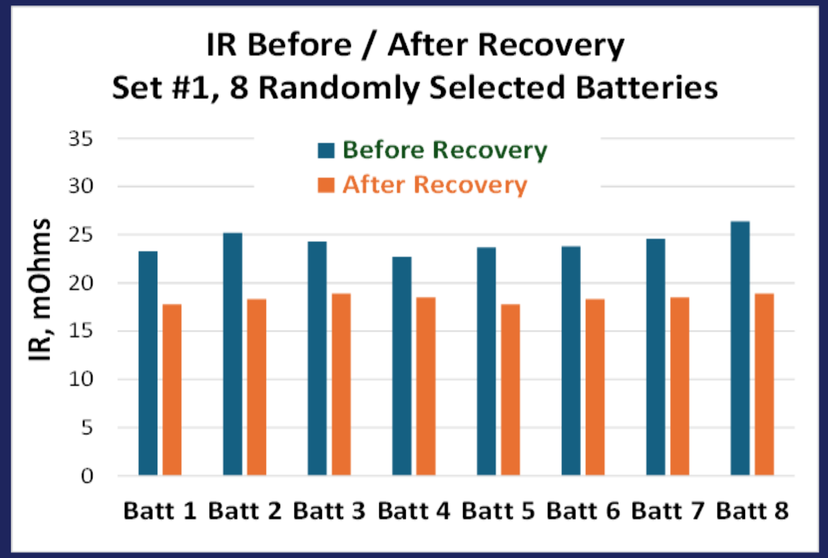
Recovered batteries can be used further for a long time in the particular application

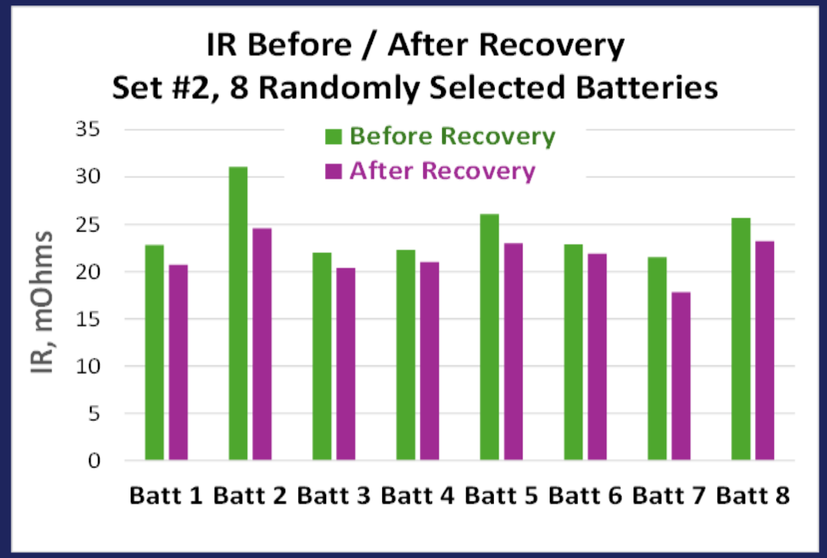
CCT for Lead-acid Batteries:
Recovery of Used and Stored Batteries

Internal resistance before and after recovery

- Successfully recovered batteries were assembled in UPS strings of 8 batteries, and tested
- Attn: String test results look always different than single battery results!

Internal resistance values of randomly selected batteries were always lower after recovery





The average IR value of recovered batteries is lower than before recovery

CCT for Lead-acid Batteries:

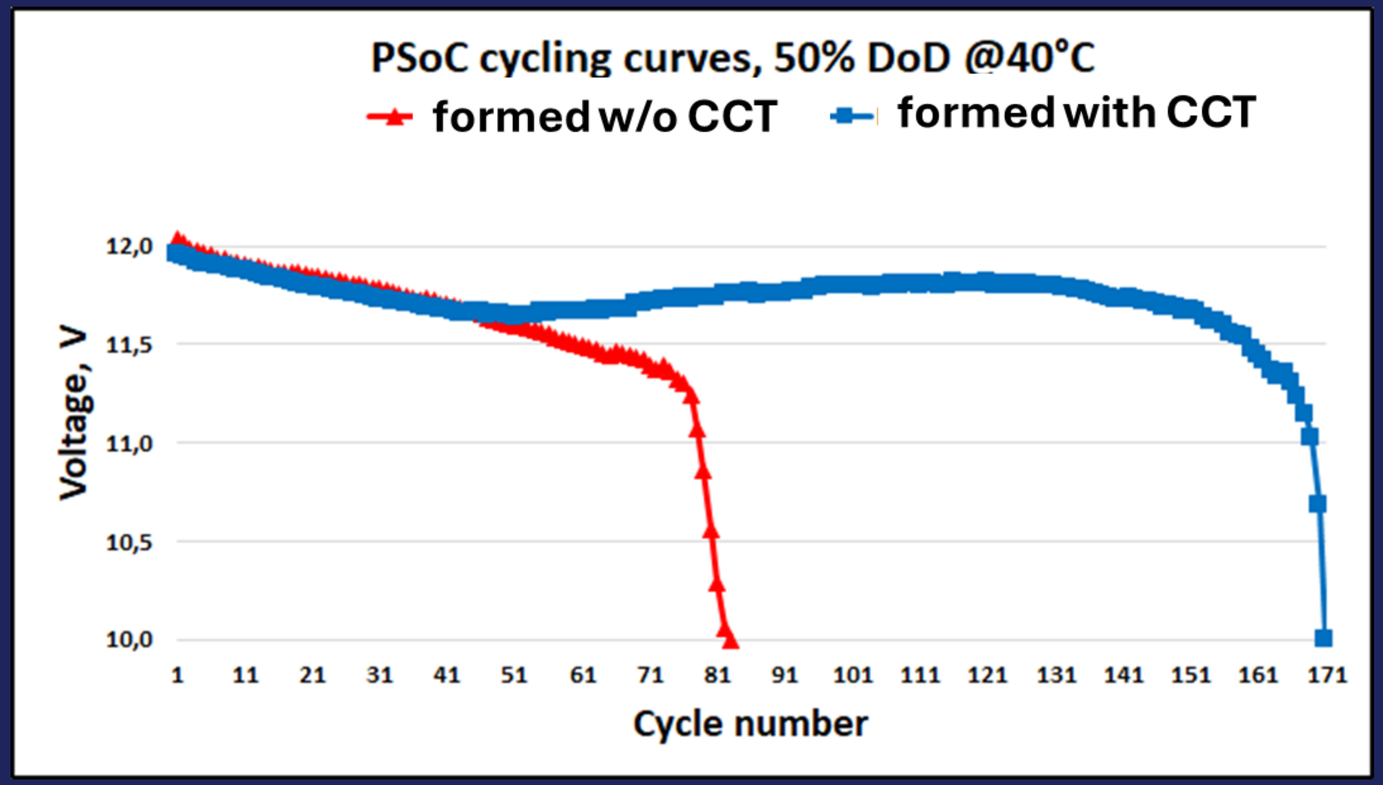
Recovery of Old UPS AGM Batteries Discarded for Scrap

age: 75 - 77 mo (6.25 - 6.4 years) condition according to customer		scrap	scrap	scrap
condition according to WT (BCAT):		**group 1:** "good"	**group 2:** "medium"	**group 3:** "bad"
nuber of batteries		20	24	36
	Recovery test with:	4		4
C10 test after recovery	first cycle	all to 100%		two reached 80%, two failed
	after 5 cycles	all about 96%		one reached 80% one - 75%
	summary:	**4 out of 4**		**3 out of 4**
IEC 60896-21 test	Recovery test	8 tested		
	Success in	5 batteries (85% - 103%)		
	Failed	3 batteries (below 80%)		
	summary:	**5 out of 8**		
Control	**NEW batteries**	100% +		

All “good” batteries recovered and passed successfully the C10 test. Good guess!
63% of them passed successfully also the IEC 60896-21 test. Good guess!
75% of the “bad” batteries passed the C10 test but failed at the IEC one.
Some “medium” batteries will probably pass both tests, too.
Roughly 40% - 50% of the “scrap” batteries have still a chance for recovery!

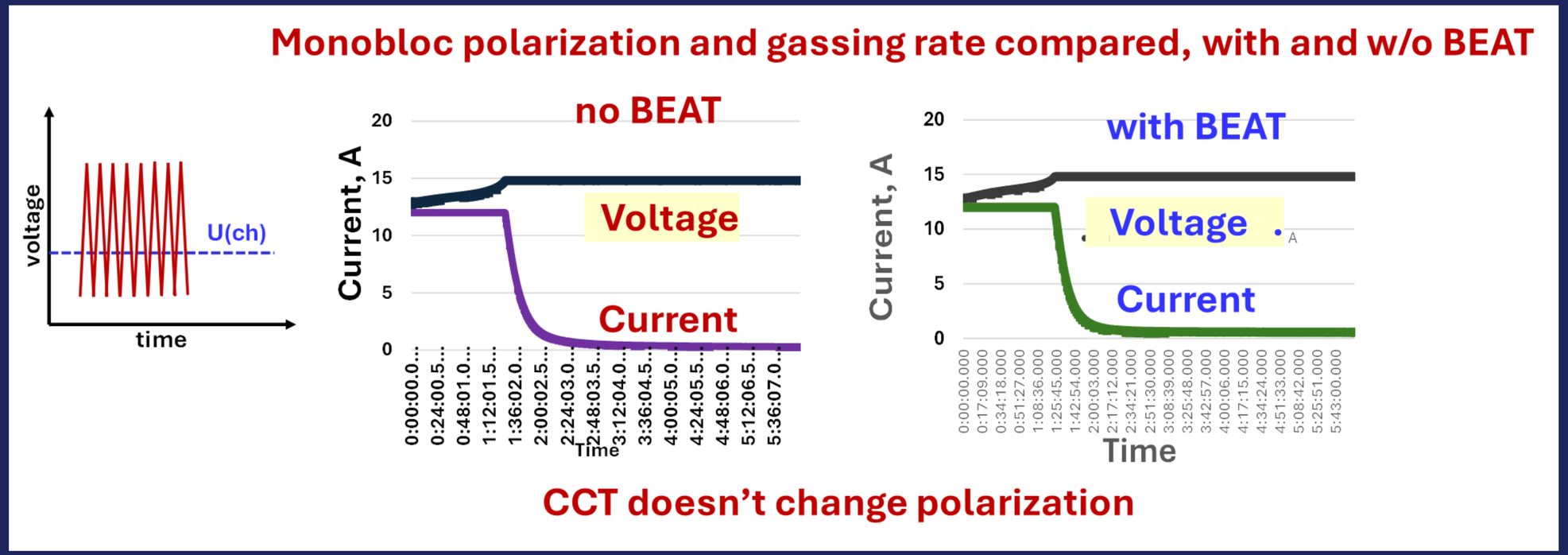
CCT for Lead-acid Batteries:
2x Cycle Life After Optimized Formation

Formation time: < 18 hours. Formation with CCT, cycling – without CCT.
The active materials "remember" the beneficial formation effect of CCT later, during operation



CCT for Lead-acid Batteries:

Gas Evolution Rate Not Increased by CCT Pulses

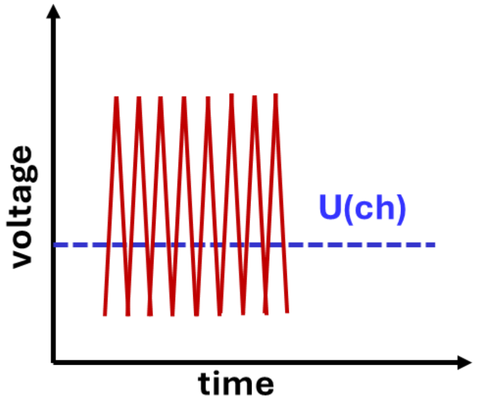


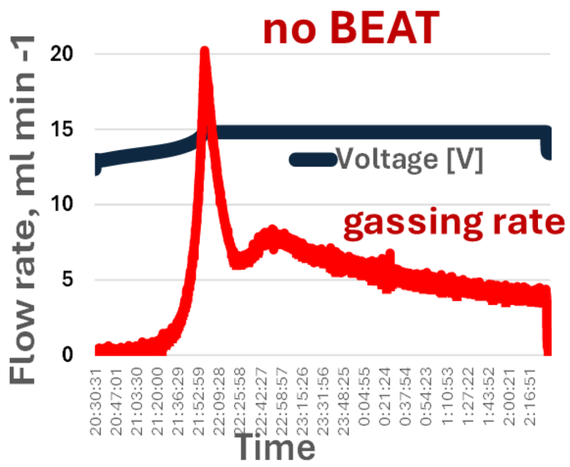
CCT for Lead-acid Batteries:

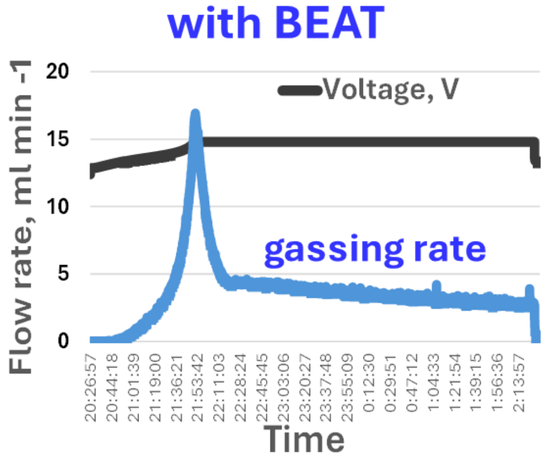
Gas Evolution Rate Not Increased by CCT Pulses

Higher charge voltage values at pulse peaks. Danger of increased water loss?

eGAS measure equipment: MeasX GmbH





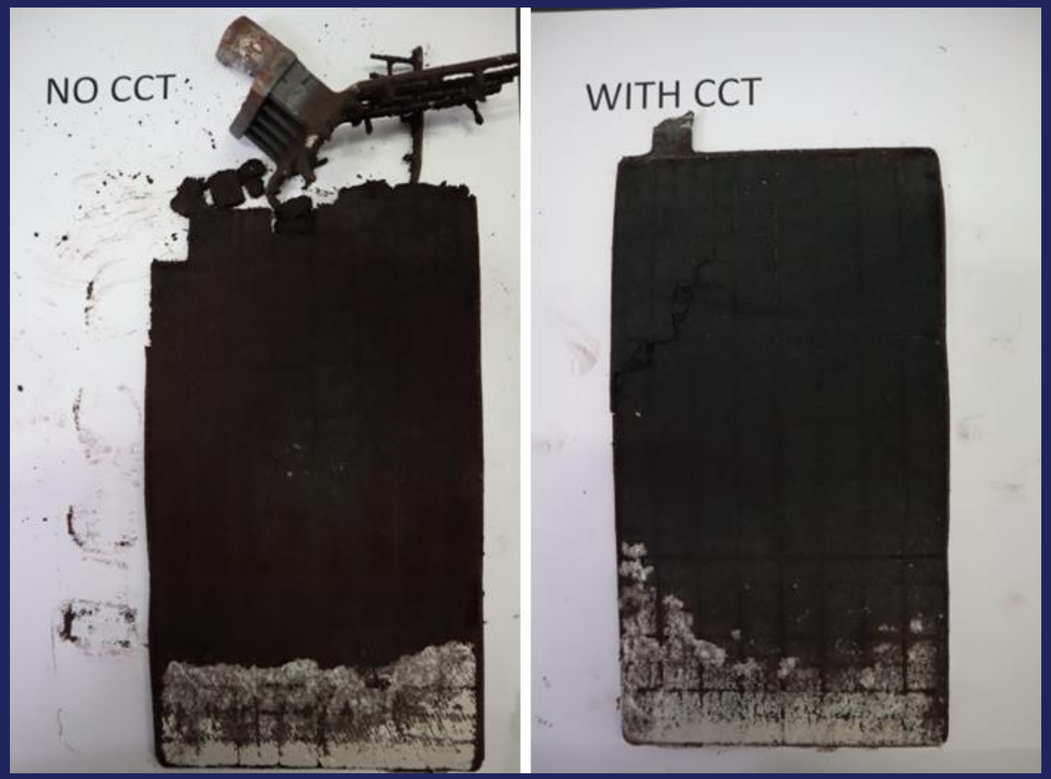


CCT does not increase gassing rate and water loss

CCT for Lead-acid Batteries:
Corrosion Attack Not Increased But Reduced

Assumption: pulses added to the charge current might increase corrosion

Observation: with CCT corrosion rate is reduced! Methods: visually, by grid thickness and grid weight



The positive grid breaks when extracted from the box

Test battery	no BEAT, GRID THICKNESS, mm			with BEAT, GRID THICKNESS, mm		
	top	middle	bottom	top	middle	bottom
5 Ah	1,00	1,00	1,20	1,20	1,20	1,25
7 Ah	1,60	1,80	1,60	1,80	1,85	1,70
9 Ah	1,00	1,00	1,15	1,20	1,10	1,20

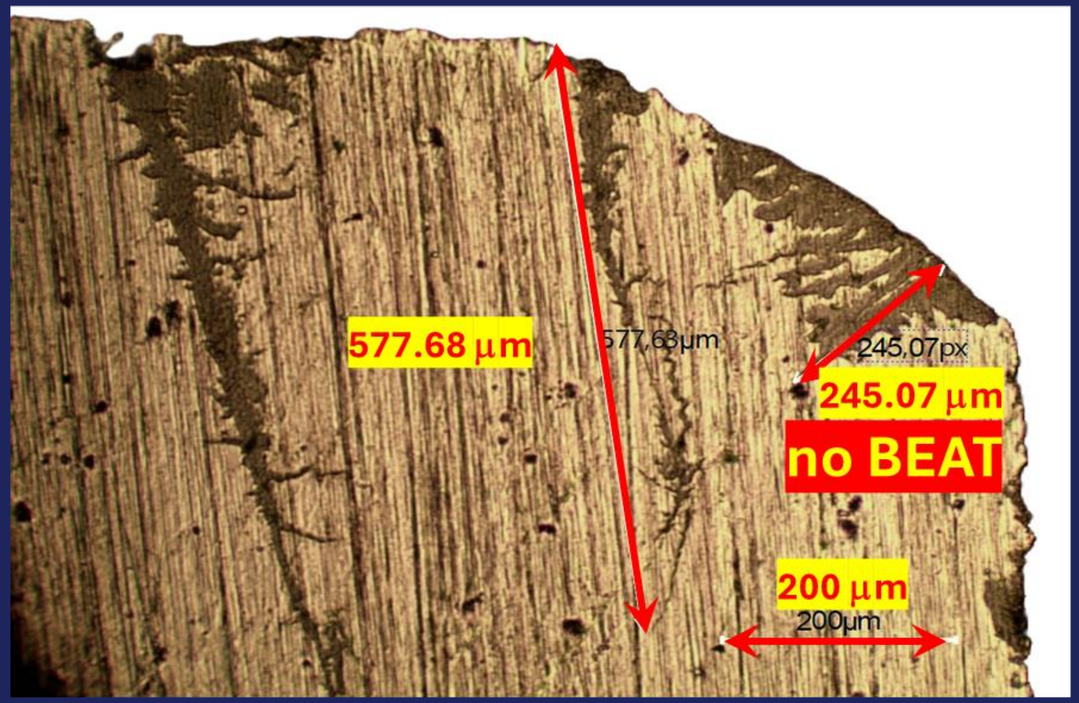
With BEAT: thicker gids = smaller corrosion attack

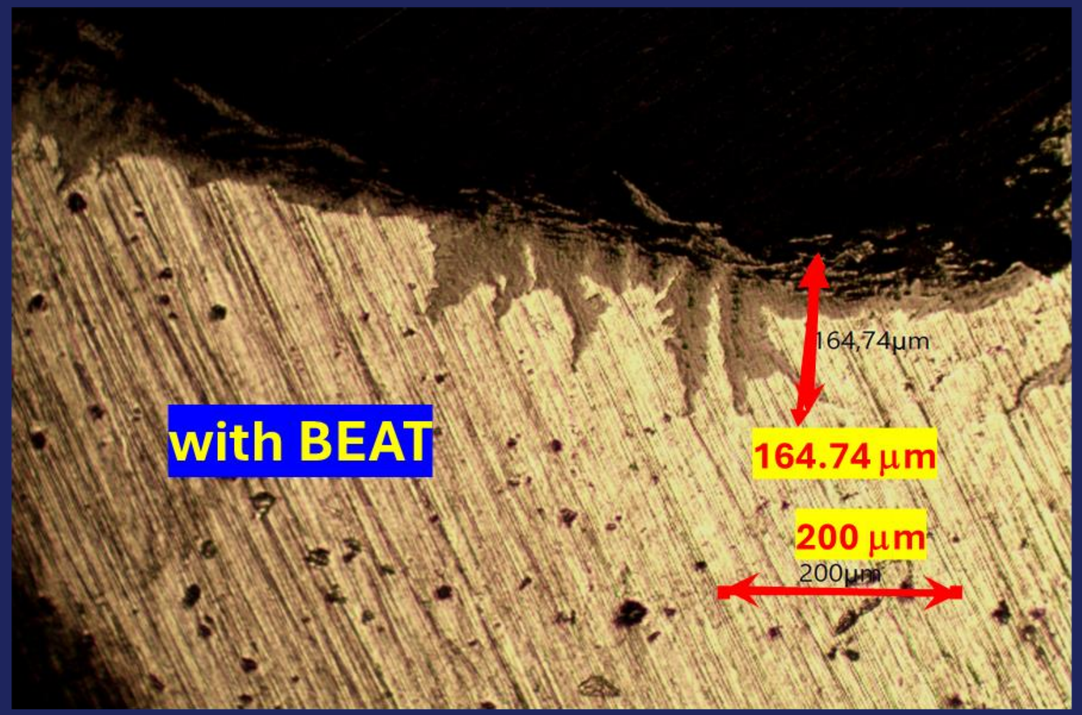
Test battery	GRID WEIGHT, g	
	no BEAT	with BEAT(R)
5 Ah	9,70	10,20
7 Ah	8,80	10,00
9 Ah	9,10	9,20

With BEAT the grids are heavier = less corrosion attack

CCT for Lead-acid Batteries:
Corrosion Attack Not Increased But Reduced

Higher charge voltage values at pulse peaks. Danger of increased corrosion attack?

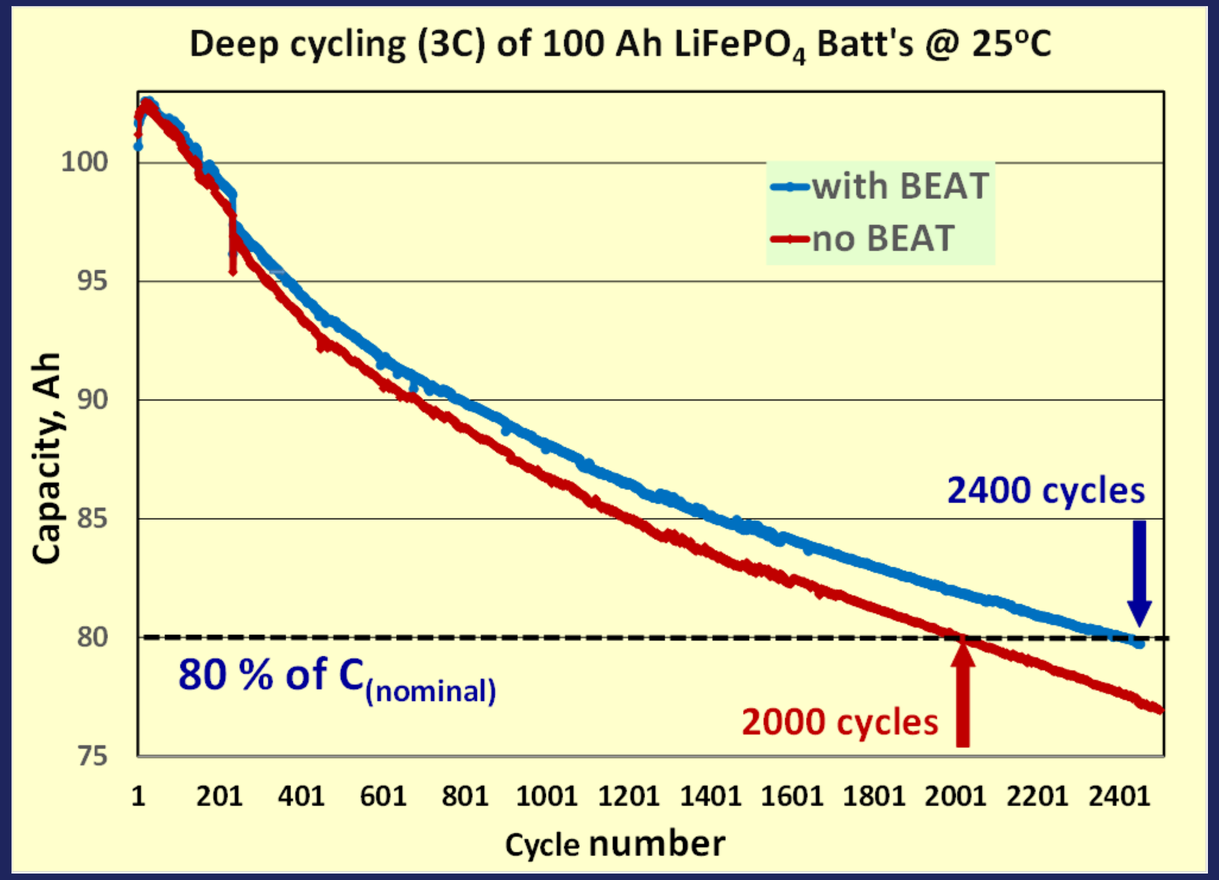




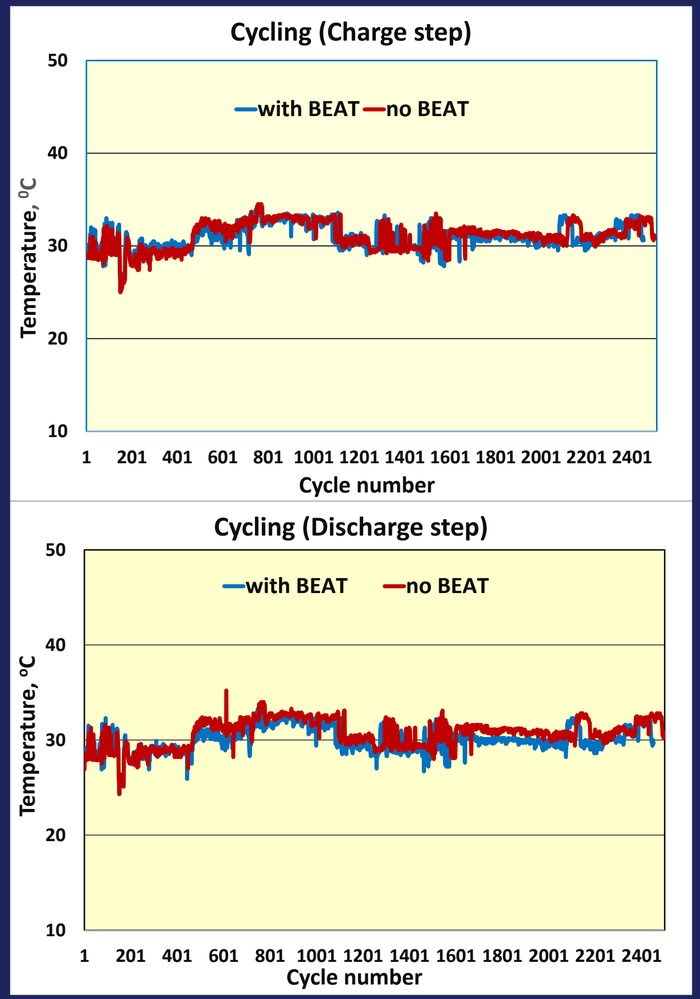
With CCT corrosion penetration is less deep, corrosion rate does not increase (it is even reduced).

CCT for Li-Ion Batteries:
20% Extended Cycle Life, no Heat Evolution

500 kWh more transferred by the battery w. CCT®



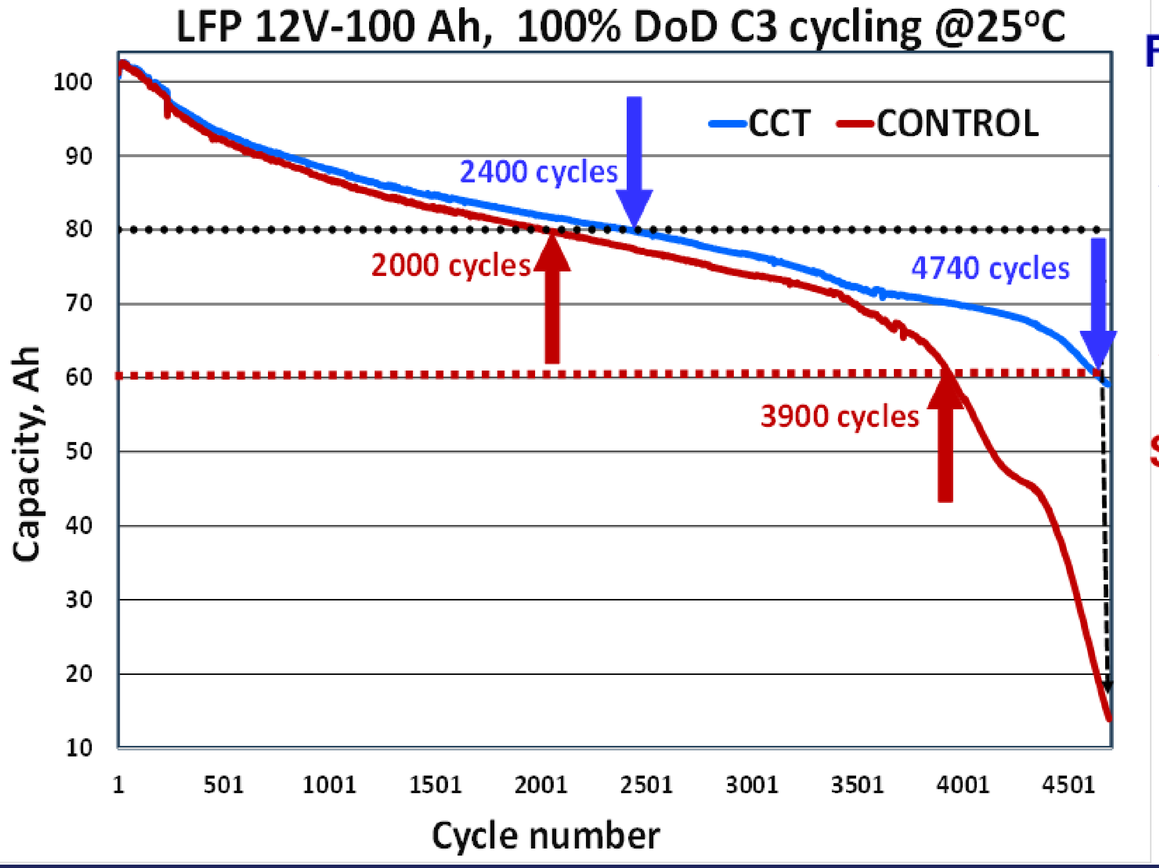
Battery temperature not increased

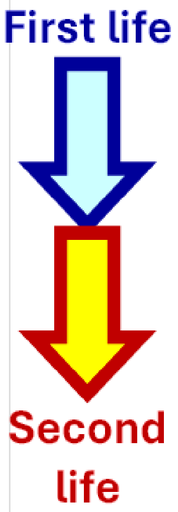


CCT for Li-Ion Batteries:

18% Longer Second Life Without Any Other Treatment

CCT extends cycle life of LFP batteries and their SECOND life, too (data for 25 deg C)





1.2 kWh battery	till the end of FIRST life	till the end of SECOND life	energy transferred	energy transferred
capacity vs. $C_{(nom)}$	till 80%	till 60%	till 80%	till 60%
no BEAT	2000 cycles	3900 cycles	2212 kWh	3982 kWh
w. BEAT	2400 cycles	4750 cycles	2650 kWh	4671 kWh
benefit of CCT	400 cycles	850 cycles	438 kWh	689 kWh
In SECOND life only		450 cycles more		251 kWh for 1.2 kWh

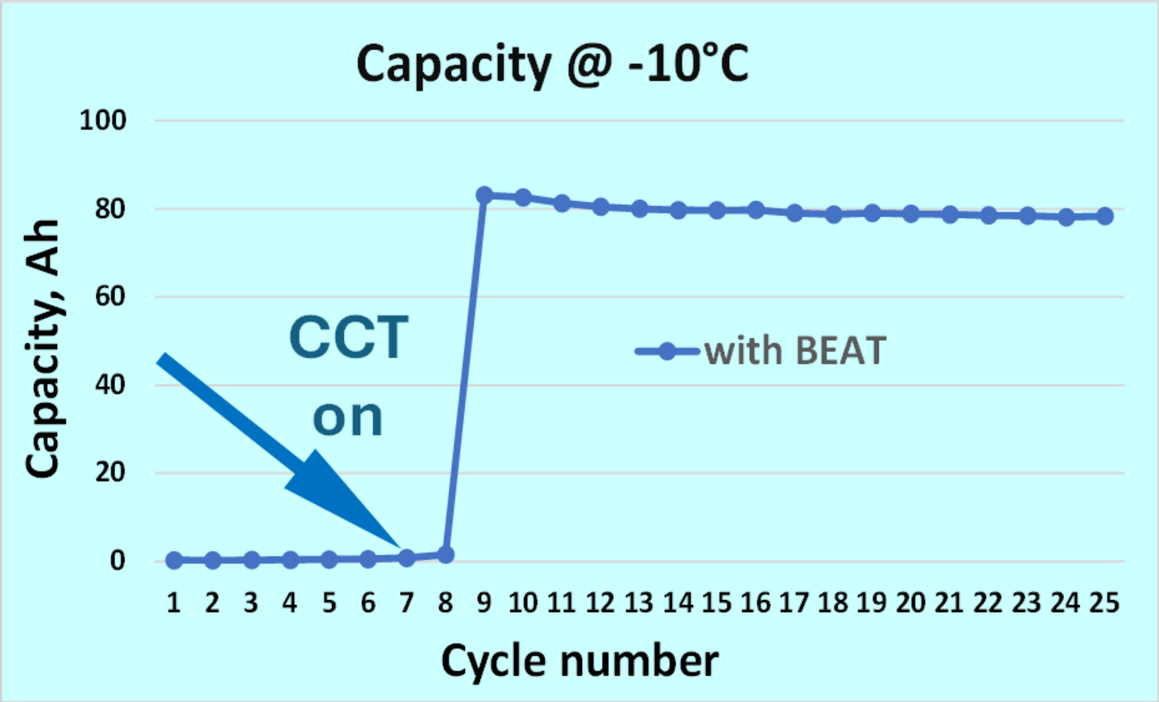
CCT: 850 more cycles and 690 kWh more transferred
SECOND life only: 450 cycles and 251 kWh energy more for a single 1.2 kWh battery only
For a 1.2 MWh battery these will be 251 MWh more. $$$!

Cycled down to 60%, the battery with CCT did 18% more cycles, and transferred 17% more energy

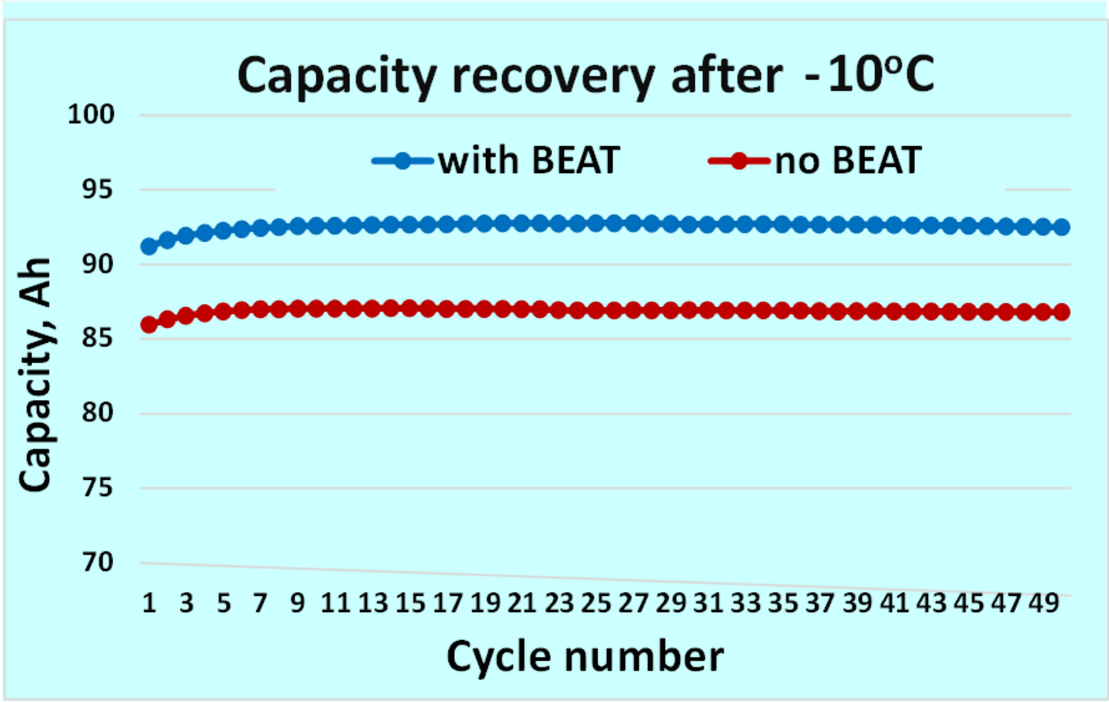
CCT for Li-Ion Batteries:

Easy Recharge at Subzero Temperatures

Cycling (3C rate) of a LFP battery (12V-100 Ah) at -10° C



no BEAT – no capacity, BEAT on : capacity restored



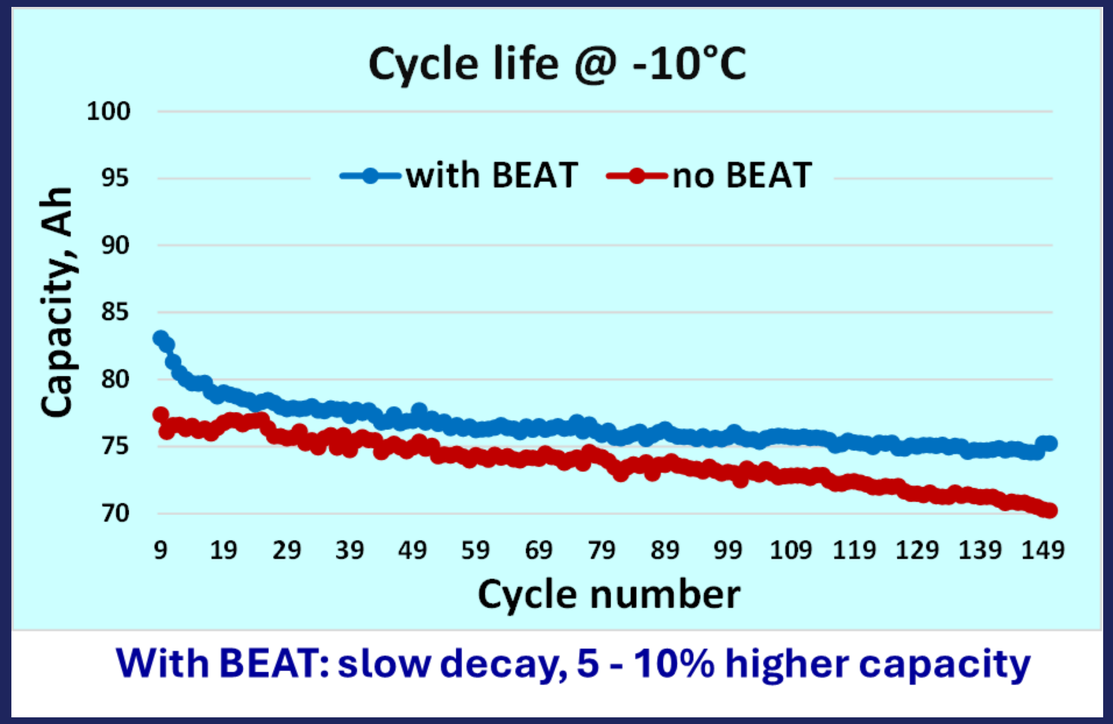
with BEAT: faster recovery after cycling at -10°C

Strong (trigger) CCT® effect on LFP batteries at -10°C: recharge and cycling are possible.
No pre-heating of the battery is needed.

CCT for Li-Ion Batteries:

Higher Capacity at Subzero Temperatures

Cycling (3C rate) of LFP batteries (100 Ah) at -10°C and recovery after this



At -10°C the capacity is lower, it declines on cycling faster than at 25°C

Cycle range	battery #1, with CCT	battery #2, with CCT	battery #3, no CCT
1 ÷ 150	53	53	88

The capacity of the battery without BEAT declined by 88 mAh per cycle, with BEAT by 53 mAh/c.

The BEAT slows down the capacity decay by 66%.

With BEAT, LFP batteries offer more capacity at subzero temperatures, their capacity declines on cycling at a 66% smaller rate.

Conclusions

WaveTech's CCT® technology offers enhanced performance parameters, reduced cost of ownership and sustainable environment benefits.

a) Applied to Lead-acid batteries it can

a) Reduce the gap in life to Ni, Li and Na based batteries in a simple, inexpensive way

b) Make re-charge more efficient and shorter

c) Optimize and shorten formation

d) Provide to used batteries a second life for better sustainability

b) Applied to Lithium-ion (LFP) batteries it can

a) Extend cycle life by 20% and second life by at least 16%

b) Recharge at subzero temperatures easy, with no battery preheating

c) Increase the capacity on cycling at subzero temperatures

Future tasks: Smart Long-life Batteries for RES, ESS, etc.

1. Renewable energy storage with optimized battery utilization
2. Advanced battery chargers for ESS with lead and Li-ion batteries
3. Fast battery assessment systems for lead- and lithium-based batteries
4. Smart battery recovery systems for all types of lead batteries
5. Smart battery monitoring and management systems with CCT®
6. Life extension of Li-ion batteries, especially at subzero temperatures

THANK YOU VERY MUCH FOR YOUR KIND ATTENTION!

QUESTIONS?

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