Recent Status of the Battery Energy Storage Technologies in Japan and Issues Related with Performance Evaluation

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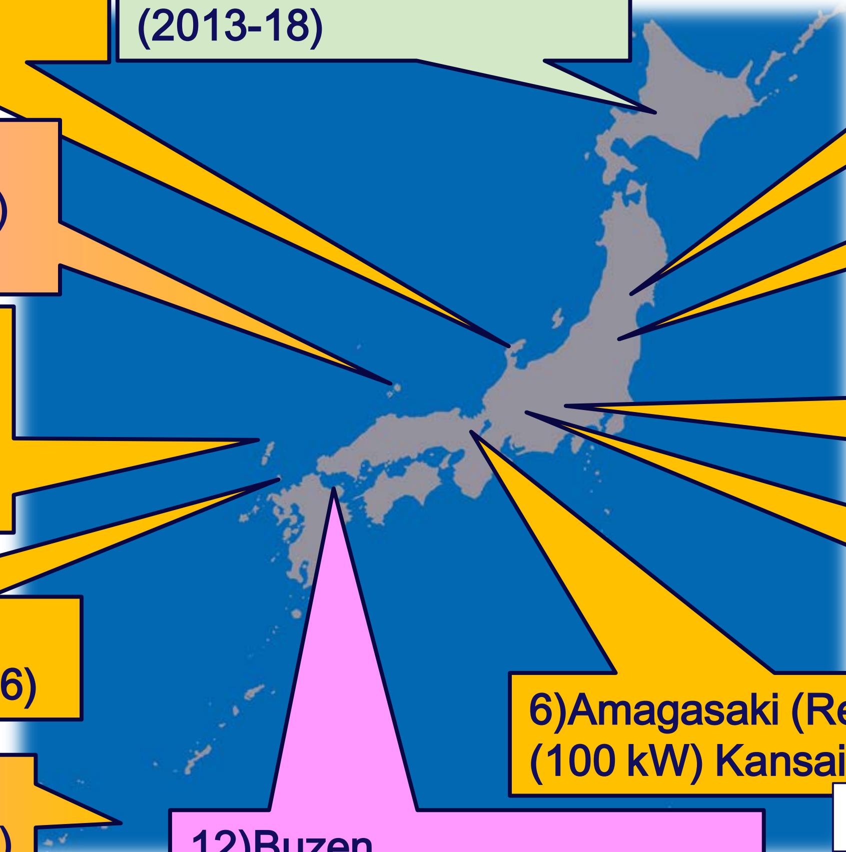
CRIEPI
Central Research Institute of Electric Power Industry
Materials Science Research Laboratory

Recent Field Tests by Electric Utilities in Japan

■: LIBs, ■: Sodium-Sulfur, ■: Redox-Flow



=> S3-2: Mr. Asajima

Recent trends
=> S4-5: Dr. Kawano

Batteries

Battery Type	Lead-acid	Nickel-metal Hydride	Lithium-ion (LIB)	Sodium-Sulfur (NaS)	Redox-flow (RF)	Molten-salt
Compact (Energy Density: Wh/kg)	× 35	△ 60	◎ 200	○ 130	× 10	◎ 290
Cost (JPY/kWh)	50,000	100,000	200,000	40,000	Evaluating	Evaluating
Capacity Enlargement	○ - MW Class	○ - MW Class	○ - MW Class	◎ Over MW Class	◎ Over MW Class	Evaluating
Measurement Accuracy of State of Charge	△	△	△	△	◎	△
Safety	○	○	△	△	◎	◎
Material Resource	○	△	○	◎	△	◎
Heat-up during Operation	Not Need	Not Need	Not Need	Need (> 300 °C)	Not Need	Need (> 50℃)
Life Time (Charge-discharge Cycle)	17 Yrs. 3,150 Cyc.	5 – 7 Yrs. 2,000 Cyc.	6–10 Yrs. 3,500 Cyc.	15 Yrs. 4,500 Cyc.	6-10 Yrs. Non-limit	Evaluating

For Power Grid: Nas, RF, Nickel-metal hydride, LIB

For Customer: LIB, Lead-acid etc.

Source: METI(2012).

Li-ion Batteries for Grid-Use

◆Merits

- High energy efficiency (>80%)
- Short construction term(1-2 years)
- No significant destruction of nature

40MWh Li-ion Storage System
(Tohoku Electric Company)

◆Issues

- Long life (20 years) ➡ Life estimation is a critical issue
- Safety
- Cost

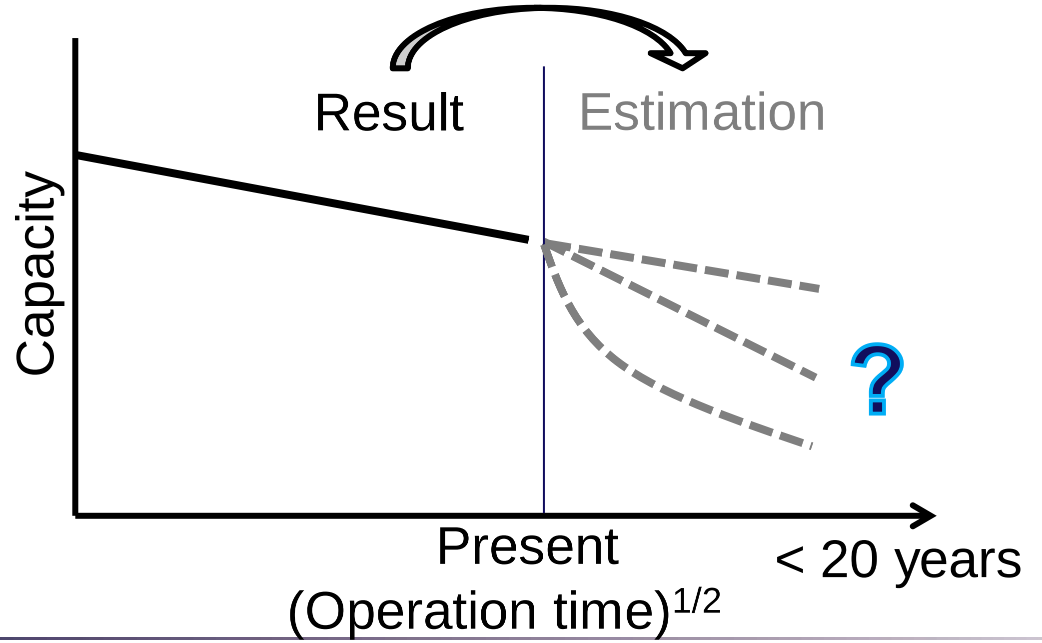
How to estimate by nondestructive analysis?

- Voltage?
- Impedance?
- Temperature?

Background

Issues of lifetime of lithium ion batteries for grid application

- Degradation behaviors of lithium ion battery
  - ✓ Depends on operation conditions?
  - ✓ Available to reuse?
- What is degradation mechanism of lithium ion battery?
  - ✓ Capacity fading amount is related to growth of SEI layer?



Contents

Two topics related with lithium ion battery lifetime evaluation

1. Lifetime test results for PV use
2. Analysis of lithium ion battery degradation

Part 1: Lifetime test for PV use

1. Battery System Operations for Smoothing Photovoltaic (PV) and Wind Farm (WF) Power Generations
2. Lifetime Test Conditions of Lithium Ion Battery
   - Simplified Charge-Discharge Profile: “PV Pulse”
   - Charge-Discharge Profiles and Rest, Cycle and Storage Test
3. Test Results of Lifetime Test
   - Effect of Cycle Test Conditions
   - Extraction of Cycle Degradation Factor
4. Summary

Typical Battery Systems for PV & WF

For 1 MW PV / WF System

At the NEDO research PJ, from 2009 to 2012

	PV			WF		
Leveling Conditions	Short 20min	Short 120min	Long 120min	Short 20min	Short 120min	Long 120min
System Output / MW	0.7	0.7	0.7	0.4	0.5	1.0
Energy / MWh	0.225	1.4	2.8	0.2	1.5	4.0
ΔSOC	50%	60%	60%	80%	40%	50%
Max. C-Rate	2.5C	0.4C	0.2C	2.0C	0.3C	0.3C
Avg. C-Rate	0.2C	0.1C	<0.1C	0.3C	<0.1C	<0.1C

Battery Charge-Discharge Test Conditions

- Battery charge-discharge operating conditions for typical battery systems for PV / WF were calculated.

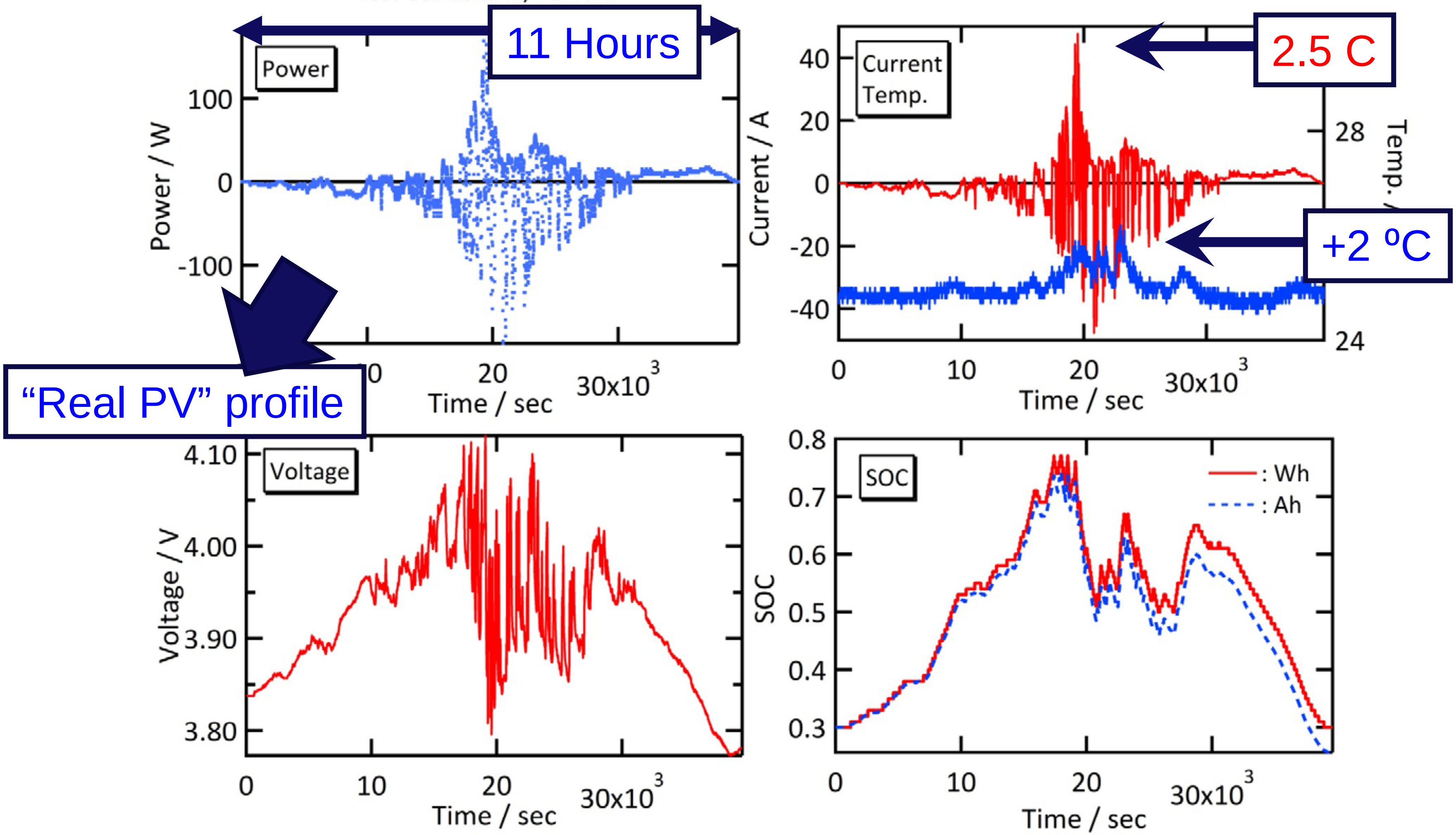
	PV			WF		
Leveling Conditions	Short 20min	Short 120min	Long 120min	Short 20min	Short 120min	Long 120min
ΔSOC	50%	60%	60%	80%	40%	50%
Max. C-Rate	2.5C	0.4C	0.2C	2.0C	0.3C	0.3C
Avg. C-Rate	0.2C	0.1C	<0.1C	0.3C	<0.1C	<0.1C

- Parameters (ΔSOC, Max. and Average C-Rate) were confirmed by the experimental results of lithium ion cells (laminate-type, 20 Ah)

- We tested for lifetime estimation using PV 20 min short-term leveling condition, but also the constant-current charge-discharge cycle condition for reference.
  => Constant Current Cycle: SOC 10 - 90%, 0.5 C "Normal Cycle"

Battery Test Results of Charge-Discharge For PV Output Short Term Leveling (20 min)

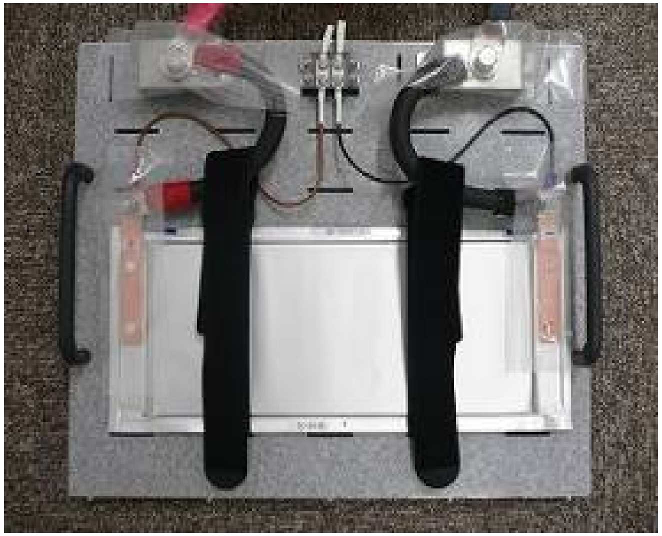
PV short-term 20min-average, Battery: 70%kW x 20min
Test Cell 19.2Ah, 72.4Wh



Battery Test System

【Control System】

【Test Cell】



Test Cell：20Ah, LMO/Graphite, Pouch Cell

Simplified Charge-Discharge Profile

- Include pulse current (max. c-rate)

  Short-term 20 min leveling operation

  => PV: 2.5C

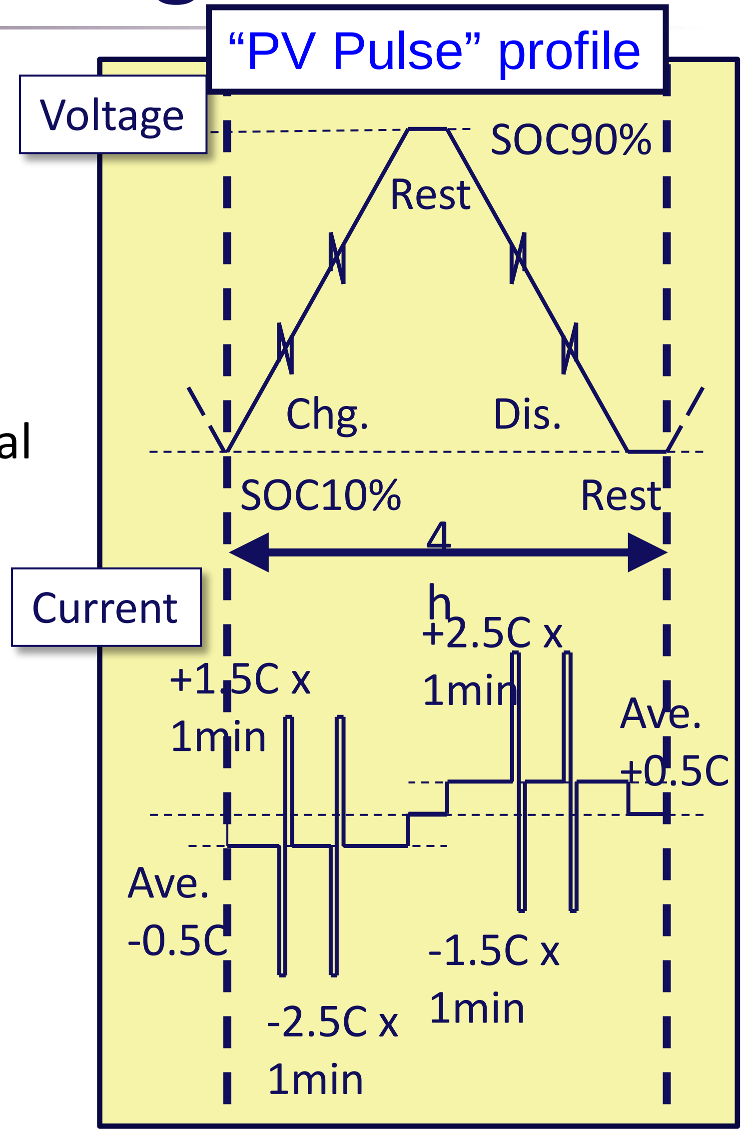
- Similar temperature profiles

  60 sec pulse => accord to temp. increase of "Real PV" profile (≈ Δ2^{o}C)

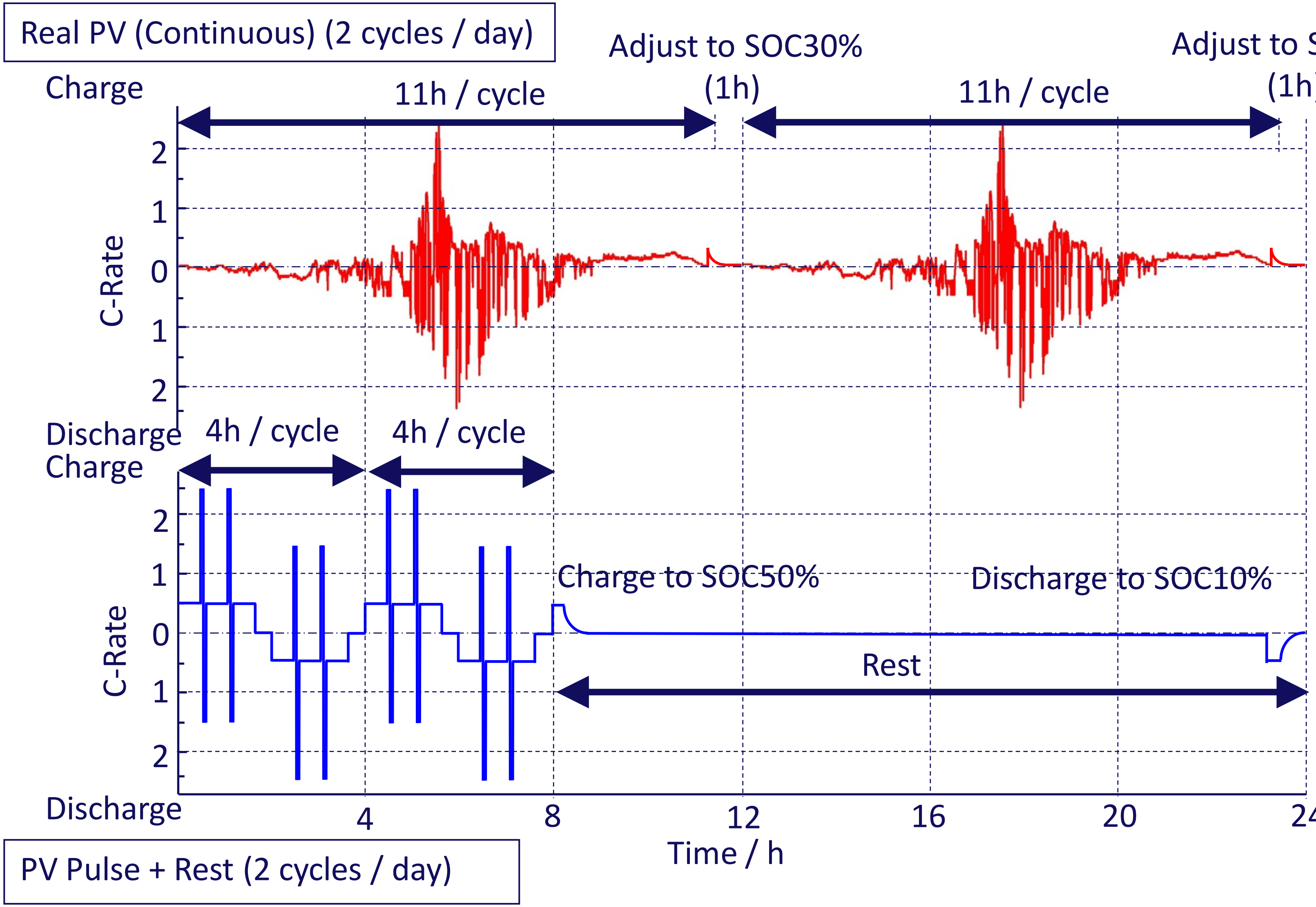
- Easy to setup on general test facilities
  - Less than 20 steps including rest

- Compatibility with "Normal Cycle" (constant current condition)

=> [0.5C, SOC10%-90%] + 2.5C Pulse

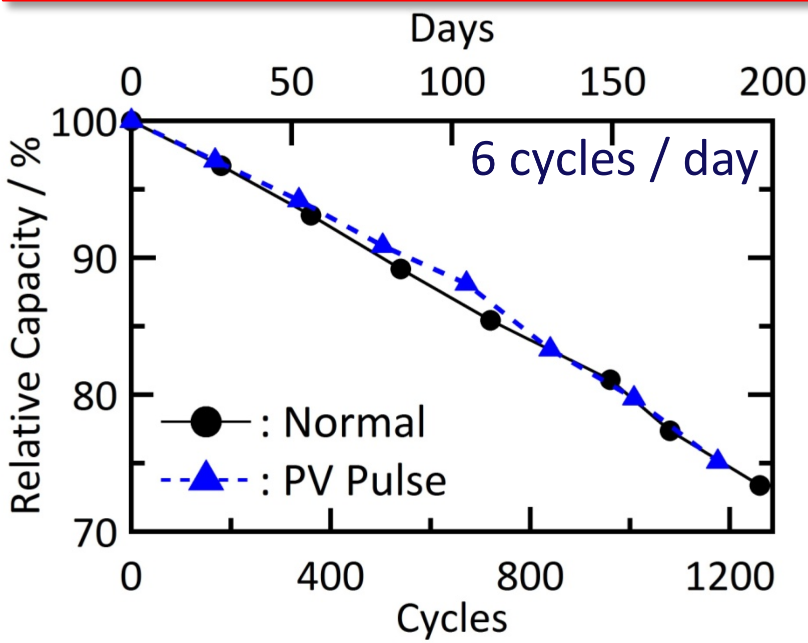


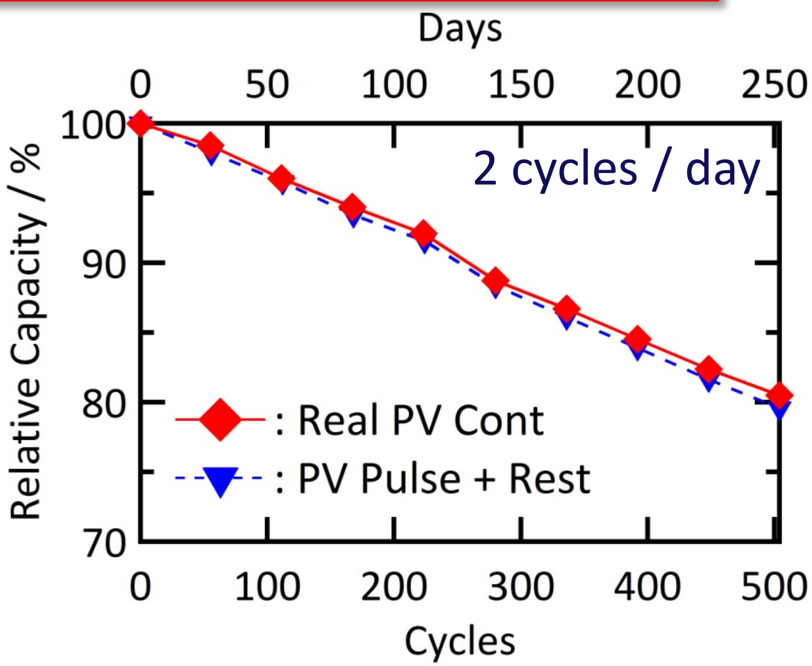
Operation of “Real PV” & “PV Pulse + Rest”



Test Results: Effect of Cycle Condition

Test results of the prototype cells at 2010 (NOT Commercial)



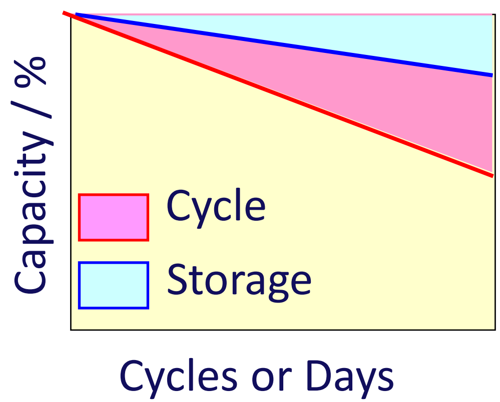


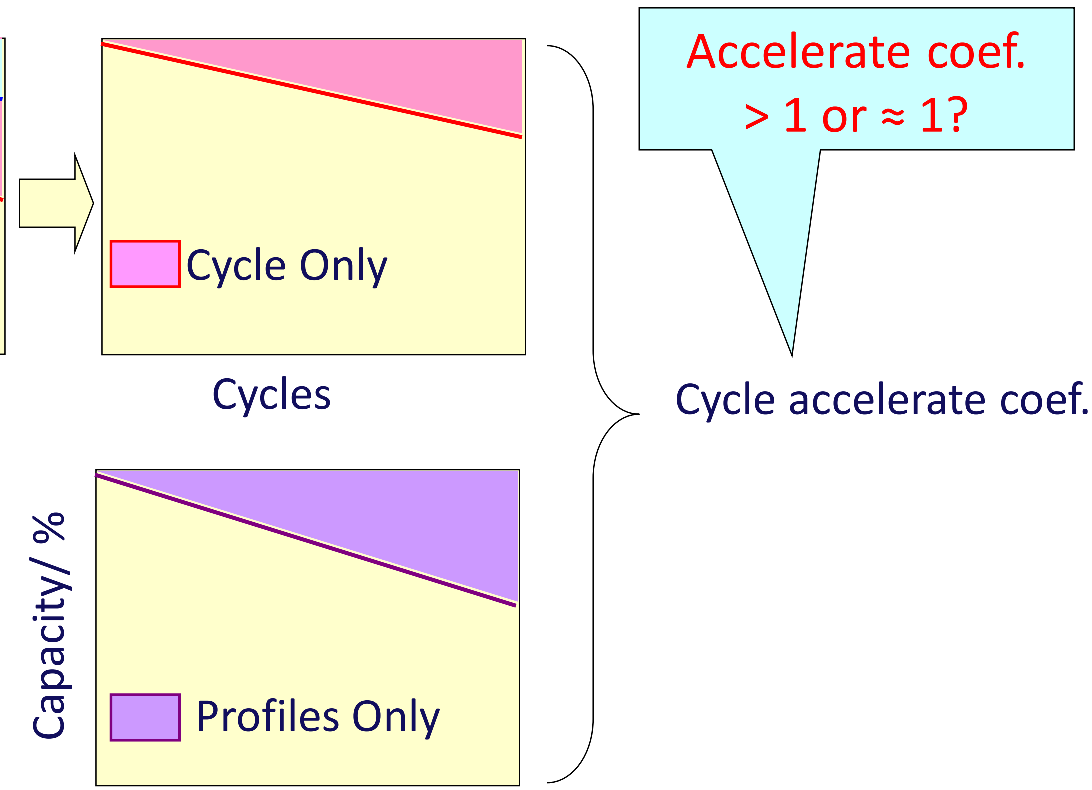
- Pulse current added to constant current was little effective to degradation ("PV Pulse" vs. "Normal")
- Capacity decrease of "Real PV" was similar with "PV Pulse + Rest"

Mainly, Calendar Life due to Storage? Or Cycling Operation?

Accelerated by Cycle Test Condition ?

Normal Cycle
(Constant Current)





"PV Pulse" (simplified profile)
"Real PV" (simulated profile)

Extraction of Cycle Degradation Factor

Test results of the prototype cells at 2010 (NOT Commercial)

- [Cycle Only degradation] =[Total degradation]- [Storage degradation]
- Equivalent storage condition => SOC 50%

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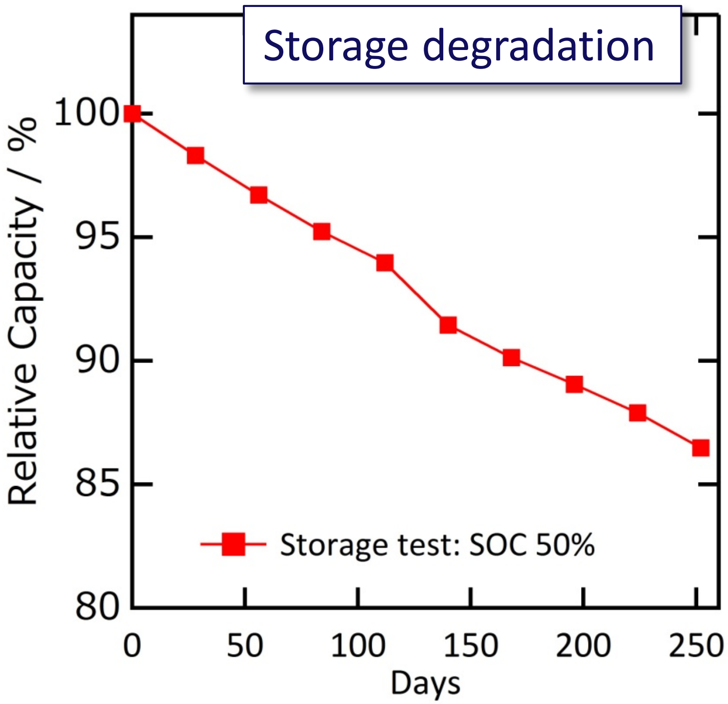
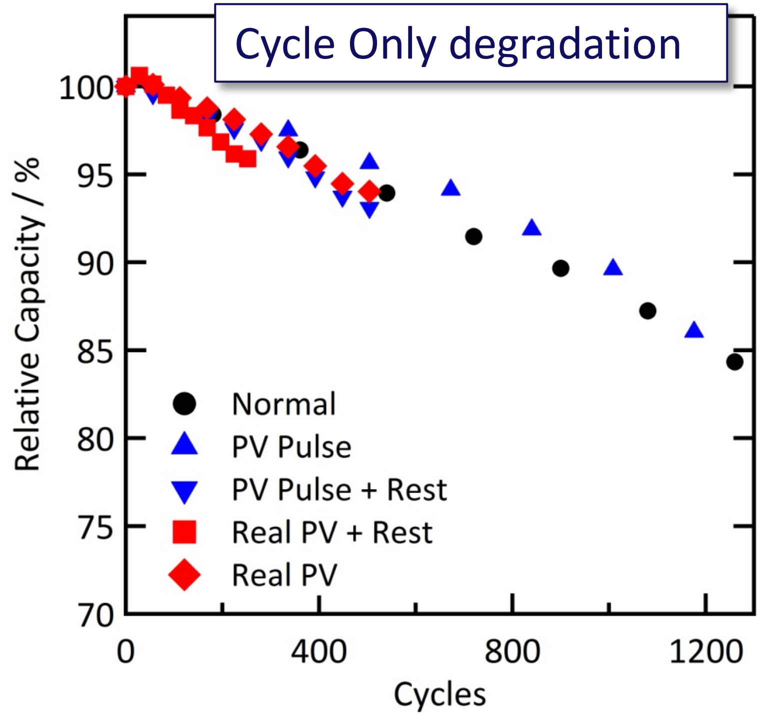




Cycle degradation factor: close within ±3% of “Normal” CC condition

➡ Accelerate coef. ≈ 1

Summary (Part 1)

1. Lithium ion cells were tested for life-time estimation under the conditions simulated PV output leveling.
   - Simplified profile (PV Pulse) was proposed: ΔSOC, Max C-Rate and increase of battery temperature were similar to the “Real PV” profile based on MW class PV test data.
   - Capacity degradation trends were almost same between “Normal” Constant Current and “PV Pulse” as well as “PV Pulse + Rest” and “Real PV”. (same cycle numbers per day)
2. Cycle test performances depend on operation time including rest time (storage effect may be large).

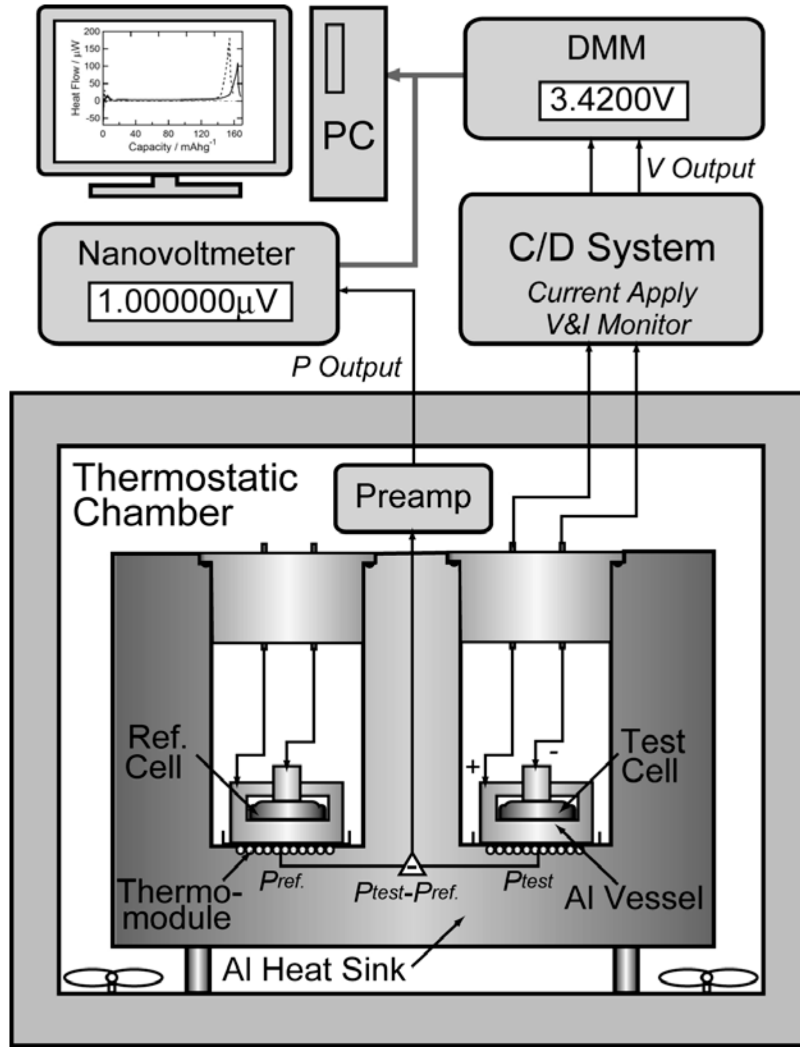
We are now continuing test
- Other test cells: LTO, LMO, NMC, LFP systems (commercial cells)
- Other use conditions: LFC, Peak Shift, Backup
- Temperature effects

Part 2: Analysis of LIB degradation

- About Electrochemical Calorimetry
- Sample cells & test conditions
- Analysis of heat flow during charge/discharge and capacity degradation
- Cell disassembly and reassembly
- Summary

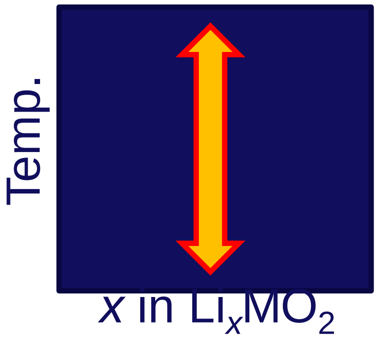
Schematic of Calorimeter

Calorimeter + C/D System

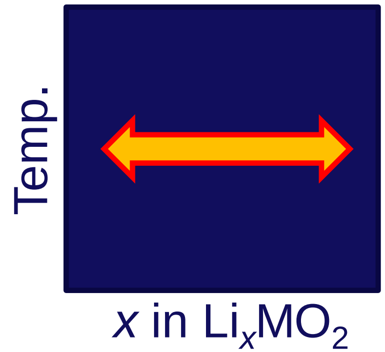


1. Contrast to DSC (Differential Scanning Calorimetry)

DSC



Calorimeter + C/D

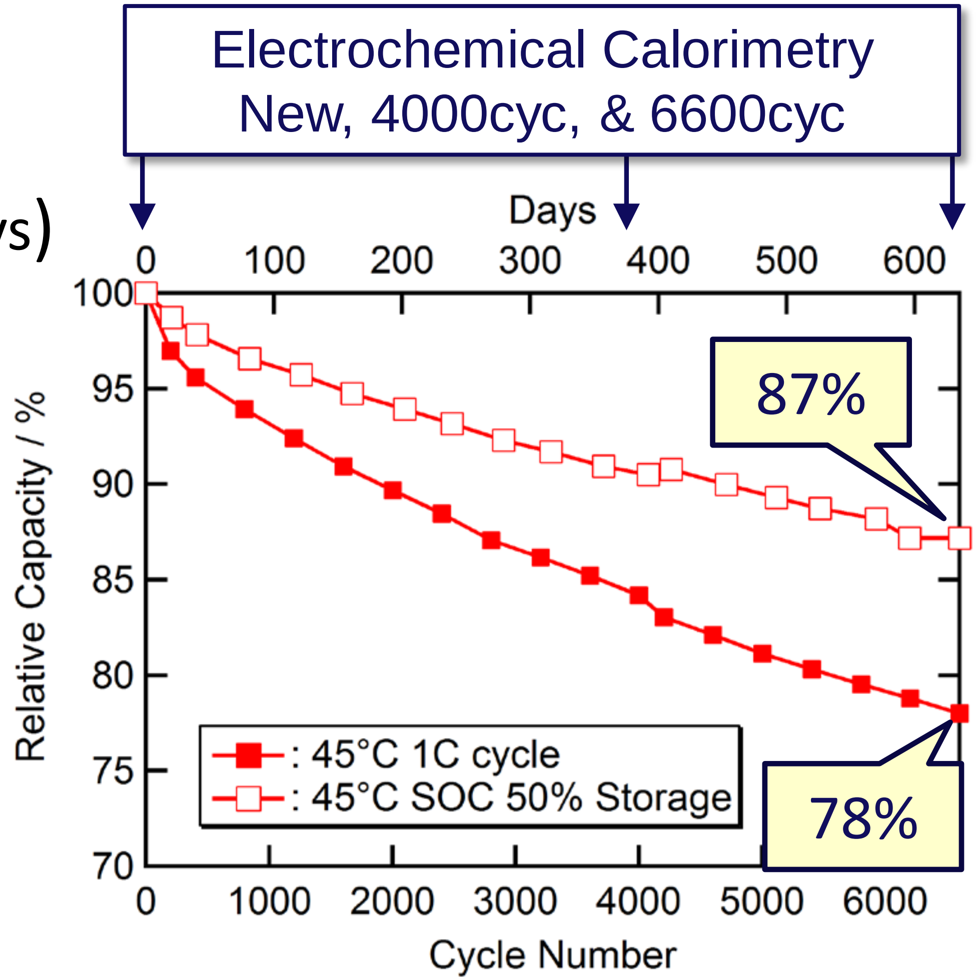


2. Sensitivity
   - Heat flow between Test/Ref. cells
   - Detectable changes:0.1µW
   - Application: 2032 - 26650[1-2)]
3. Condition
   - Rate: C/20
   - Relaxation between C/D: 10h

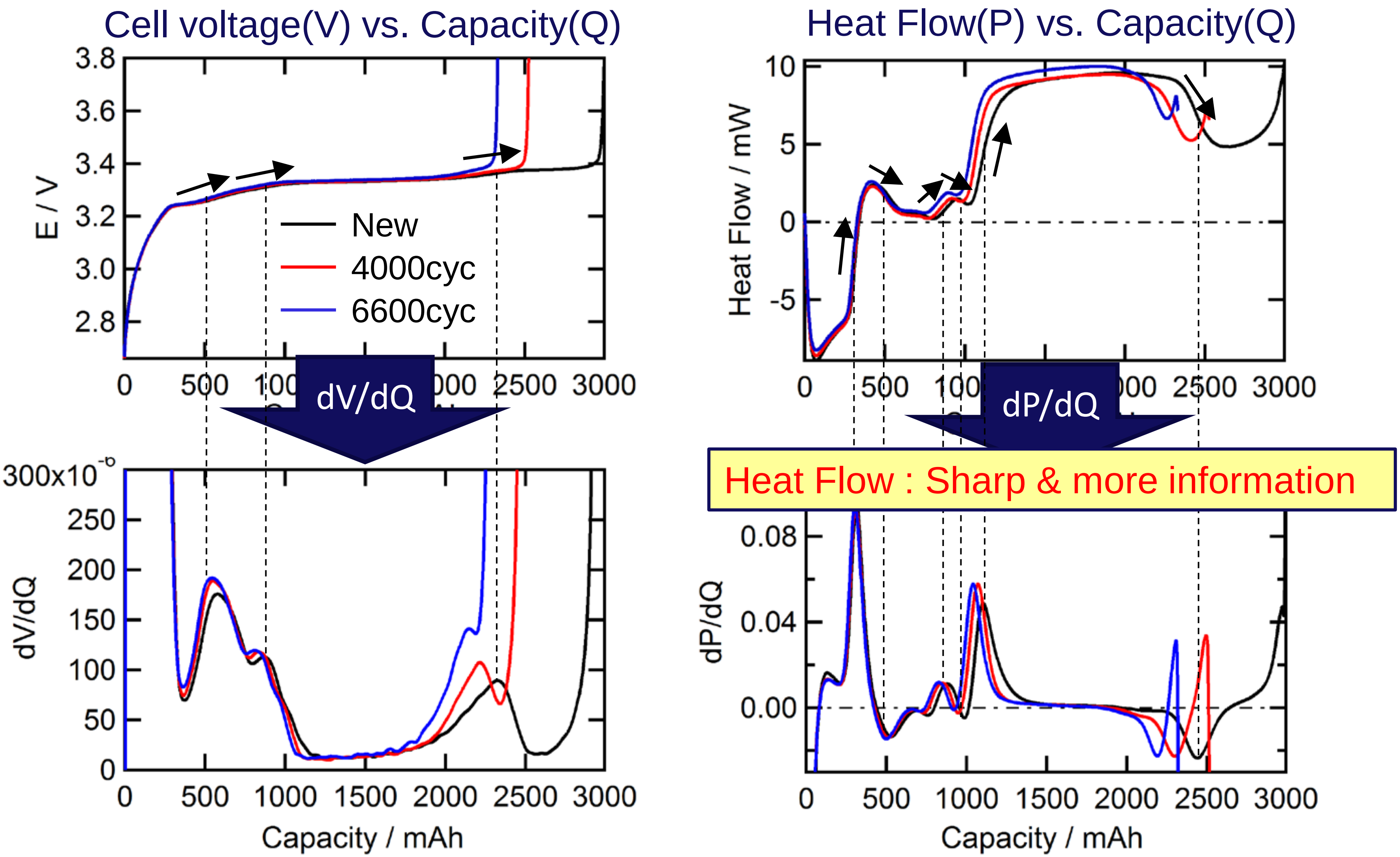
1) Y. Kobayashi, et. al., *J. Power Sources* **81,** 463 (1999).
2) Y. Kobayashi, et. al., *J. Electrochem. Soc.* **149,** A978 (2002).

Test cells & Conditions

- LiFePO$_4$ / Graphite, cylindrical 3000 mAh, commercial
- Temp. 45℃
  - 1C Cycle (6600cyc)
  - SOC 50% Storage(635days)
- Capacity Check
  - Every 400cyc/7weeks
  - C/20 at 25°C

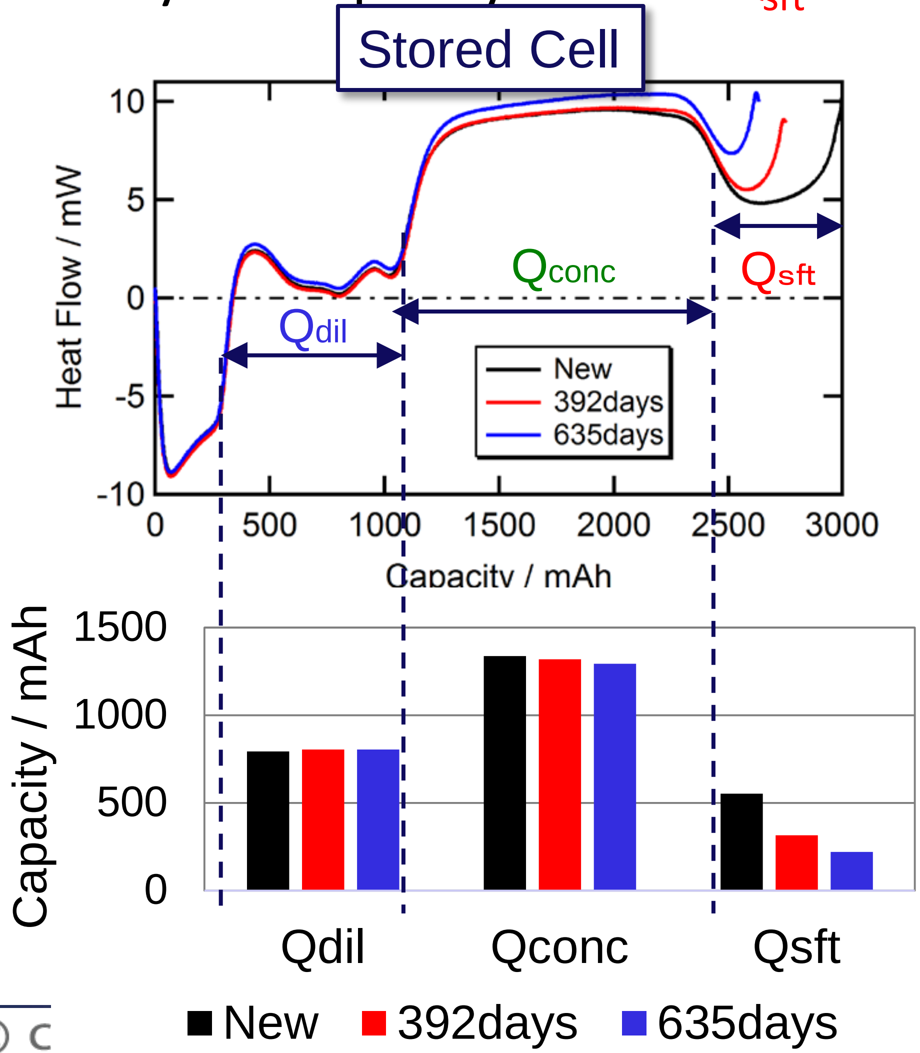


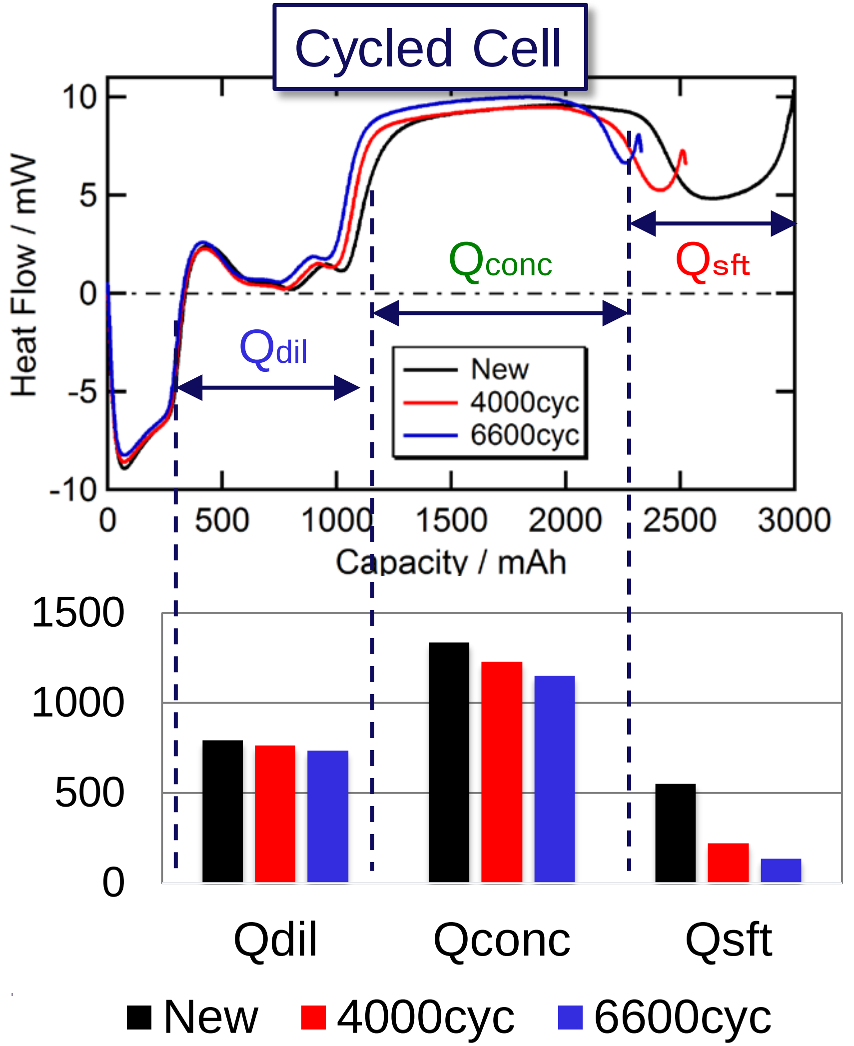
Cell voltage & Heat flows in charge

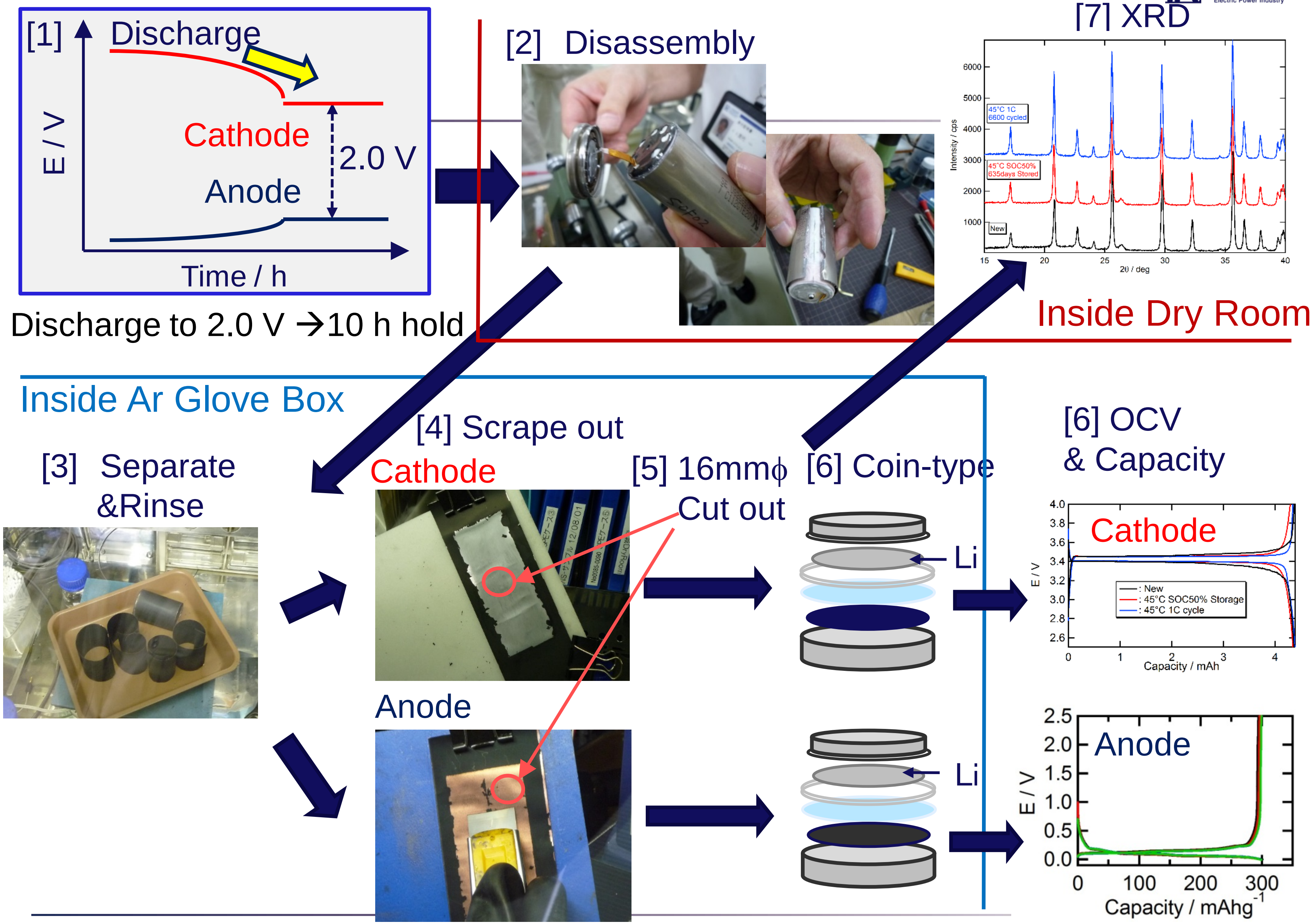


Capacity fade of Stored & Cycled cells

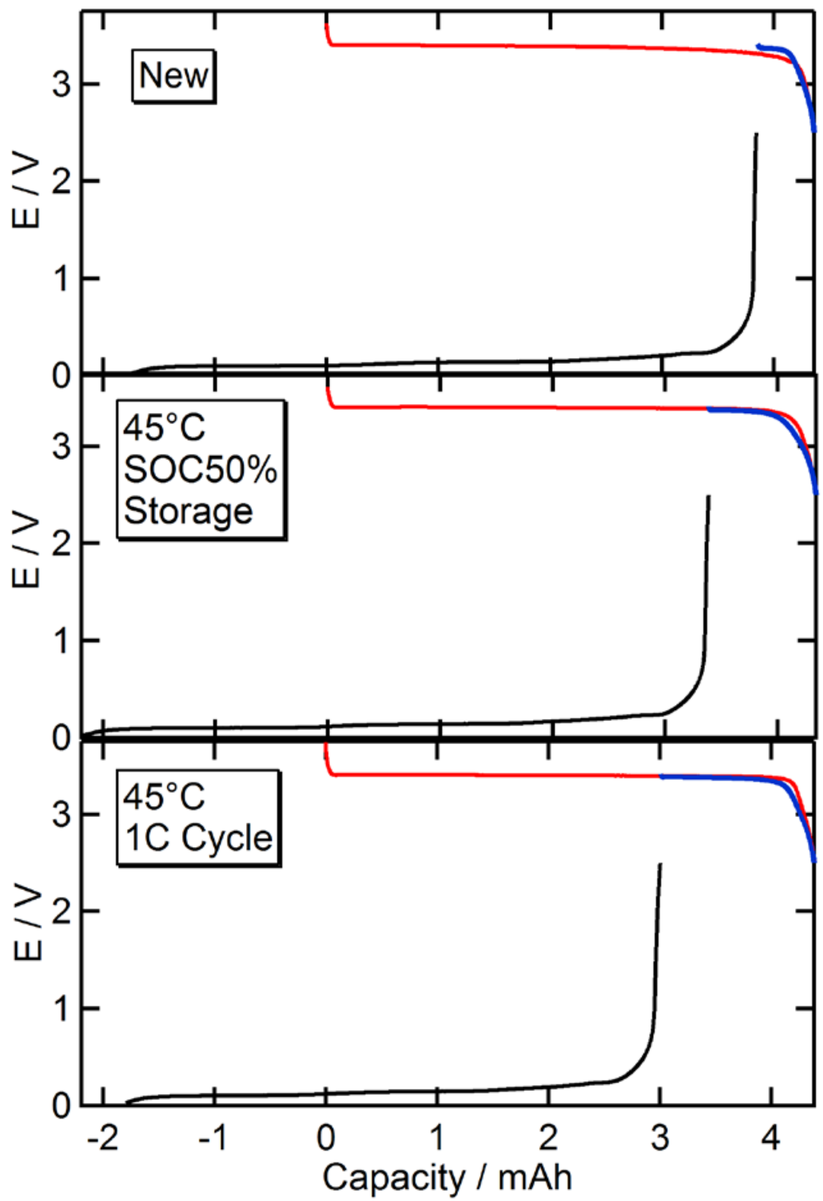
- Storage: Capacity fade of Q_{sft} → Misalignment of cathode/anode
- Cycle: Capacity fade of Q_{sft} + Shrink of graphite capacity (Q_{conc})






[1] Discharge
Cathode
Anode
2.0 V
E / V
Time / h
Discharge to 2.0 V →10 h hold
[2] Disassembly
[7] XRD
45°C 1C 6600 cycled
45°C SOC50% 635days Stored
New
Intensity / cps
2θ / deg
Inside Dry Room
Inside Ar Glove Box
[3] Separate &Rinse
[4] Scrape out
Cathode
Anode
[5] 16mmϕ Cut out
[6] Coin-type
Li
Li
[6] OCV & Capacity
Cathode
E / V
: New
: 45°C SOC50% Storage
: 45°C 1C cycle
Capacity / mAh
Anode
E / V
Capacity / mAhg-1

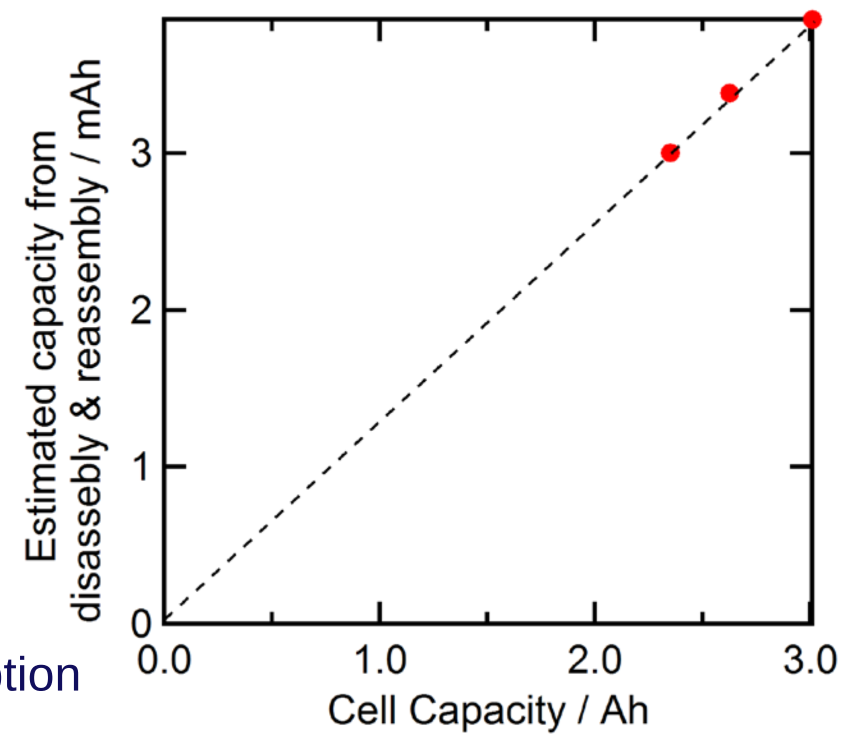
Main factor of capacity fade cells = Misalignment



Residual capacity of LFP
=Misalignment of cathode/anode capacity

Cell capacity before disassembly

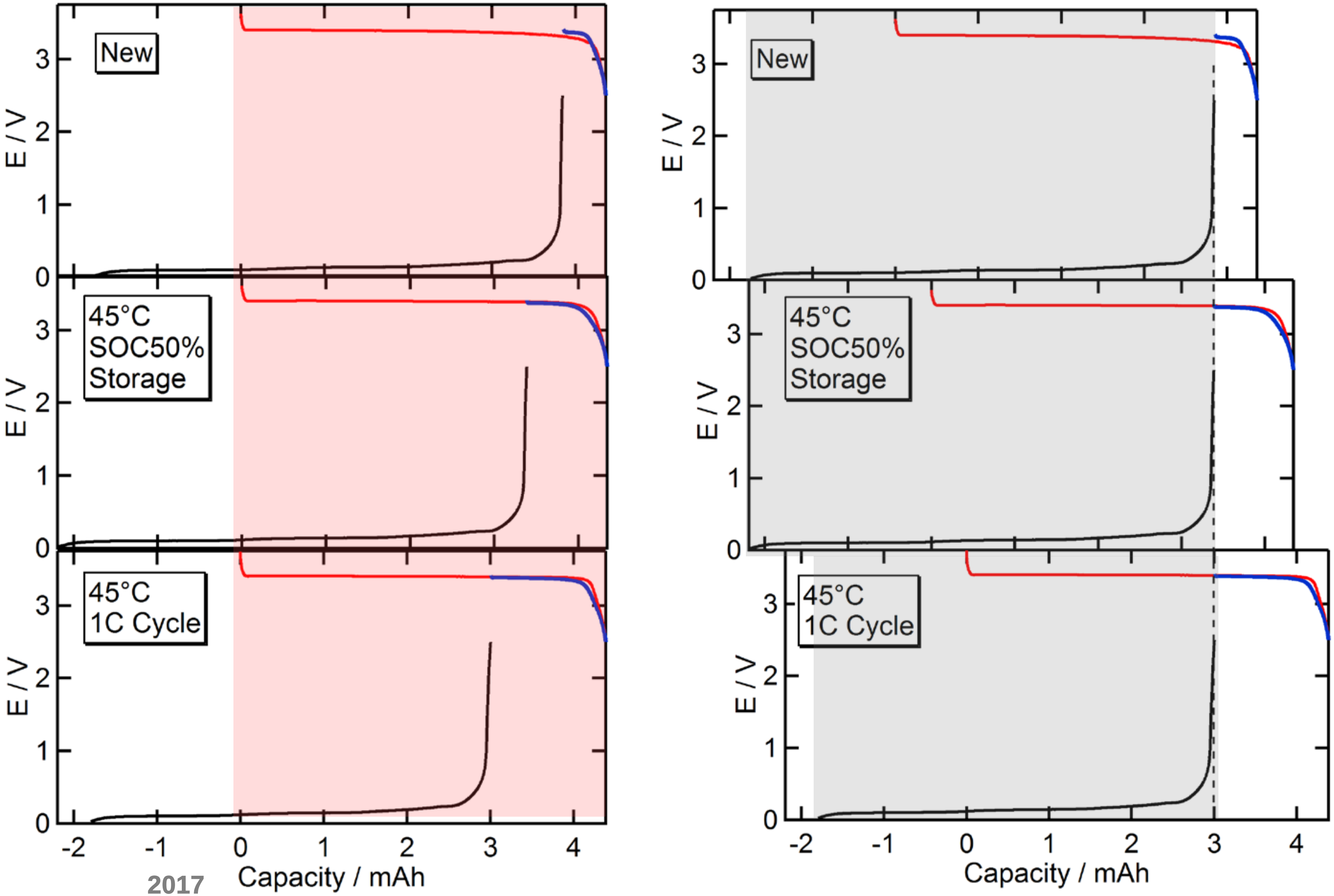
= Estimated capacity by cell disassembly & reassembly



umption

Cathode capacity=Constant

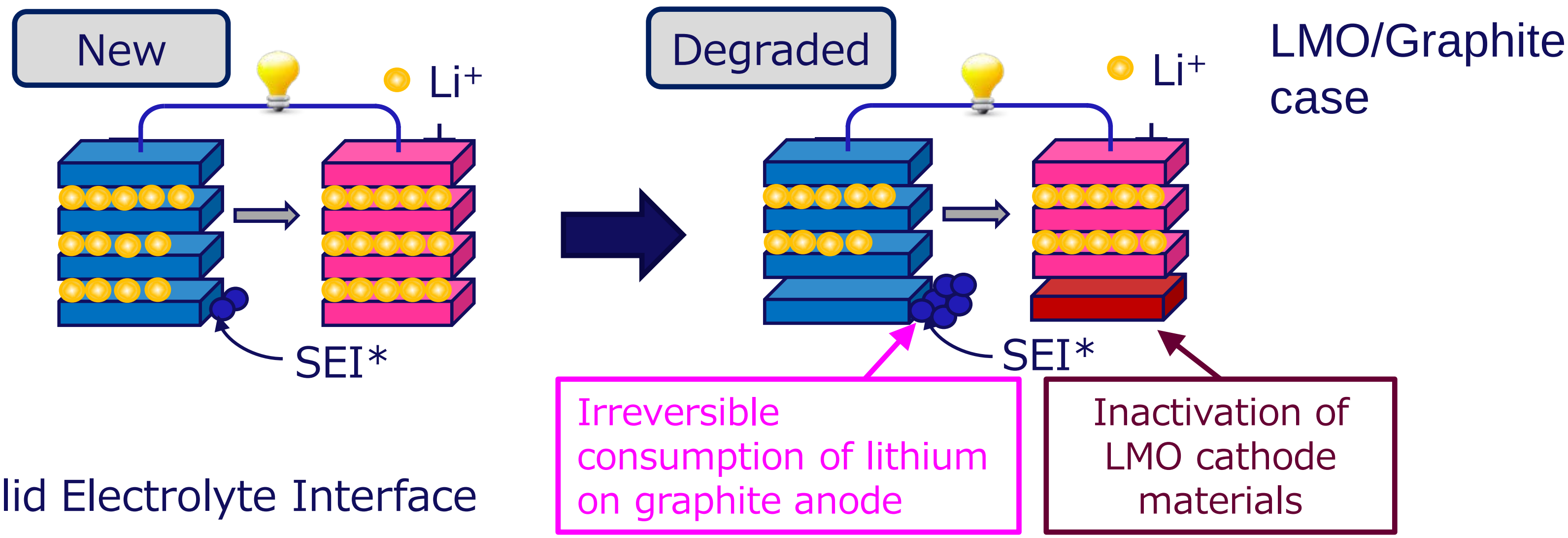
Anode capacity (New=Storage>cycle)



Summary (Part 2)

- Capacity fade of cylindrical LFP/Gr cell
  - Main factor: Misalignment of cathode/anode region
  - LFP: No capacity fade
  - Graphite: Slight capacity fade in cycled cell

Differ from LMO/Graphite case



● SEI* : Solid Electrolyte Interface

We were also researching…Other materials, Temperature effects
Can the degradation model explain the lifetime test results?

I hope our R&D leads to accurate estimate of SOC: state of charge, and SOH: state of health, for optimization of battery system setting and operation.

Thank you for your kind attention.

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