Engineering integrations, potential applications, and outlooks of Li-ion batteries

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跨維綠能材料研究中心
Hierarchical Green-Energy Materials Research Center

Taiwan & Vietnam Joint International conference on Emerging Materials and Batteries

Nov. 26th (Thu.) - 28th (Sat.), Phys. Dept, NCKU, Tainan, Taiwan

Super Double Power 超倍能科技股份有限公司
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Appreciation

I appreciate that the committee invites me to give a talk at this conference.

Especially, Prof. Ming-Fa Lin for inspiring me to study this topic.

Super Double Power 超倍能科技股份有限公司
SUPER DOUBLE POWER TECHNOLOGY CO., LTD.

Super Double Power Technology Co., Ltd. (SDP), is a research and development company, established in 2010. Early, SDP has developed lithium-ion batteries for electric vehicles. Currently, SDP focuses on the development and application of lithium-ion battery energy storage systems. The company maintains a close relationship with industry, government, education, and research in developing energy storage systems.

The product line ranges from small portable energy storage suitcases to medium-sized energy storage systems.

SDP provides complete solutions for off-grid solar/wind energy storage systems, solving power supply problems in areas without power grids such as outlying islands and high mountains. Actual system operation case: The off-grid solar energy storage system of Paiyun Lodge in Mt. Jade, Taiwan, has been in operation for more than four years and is still in operation.

SDP Partners

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MIET

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Bureau of Standards, Metrology and Inspection, M.O.E.A.

Abstract

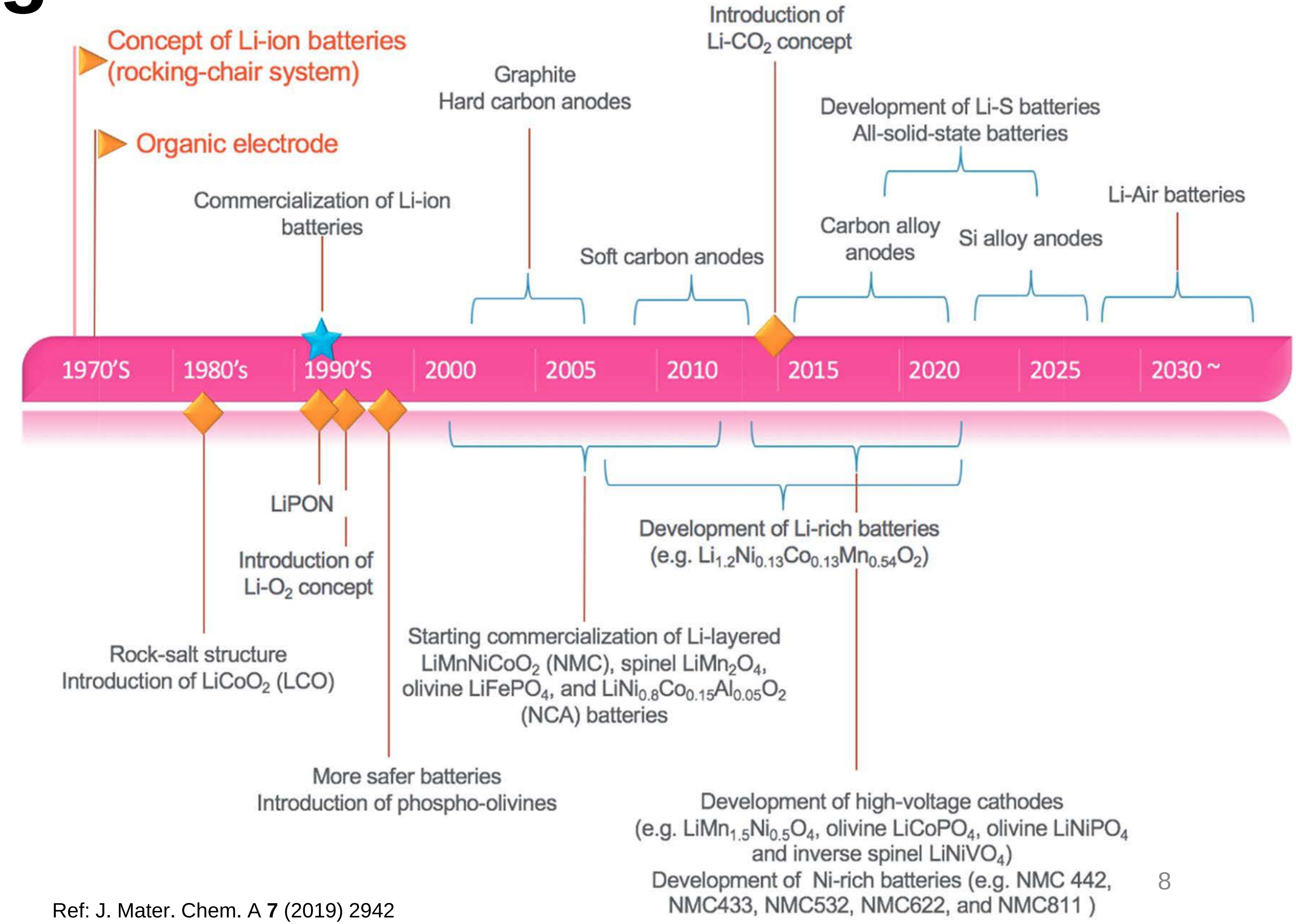
Owing to the rapid development of renewable energy and the popularity of electric vehicles, Lithium-ion (Li-ion) batteries are intensively used, causing more researches on safety standards, repurposing batteries, failure analysis, as well as next-generation energy materials, such as graphene and other two-dimensional materials. In this work, the engineering integrations on combining Li-ion battery cells to an energy storage system (ESS) are introduced. The battery management system (BMS) plays an important role in using the battery system efficiently and safely. The energy management system (EMS) can well-integrate the ESS and other systems, such as renewable power sources and loads. Current potential applications for power and stationary application on various size scales are demonstrated. The outlooks on the future of Li-ion batteries are given at last.

Outline

- Li-ion battery cells
- Engineering integrations
  - Battery management system
  - Energy management system
- Potential applications
  - Power applications
  - Stationary applications
- Outlook

Li-ion Battery Cells

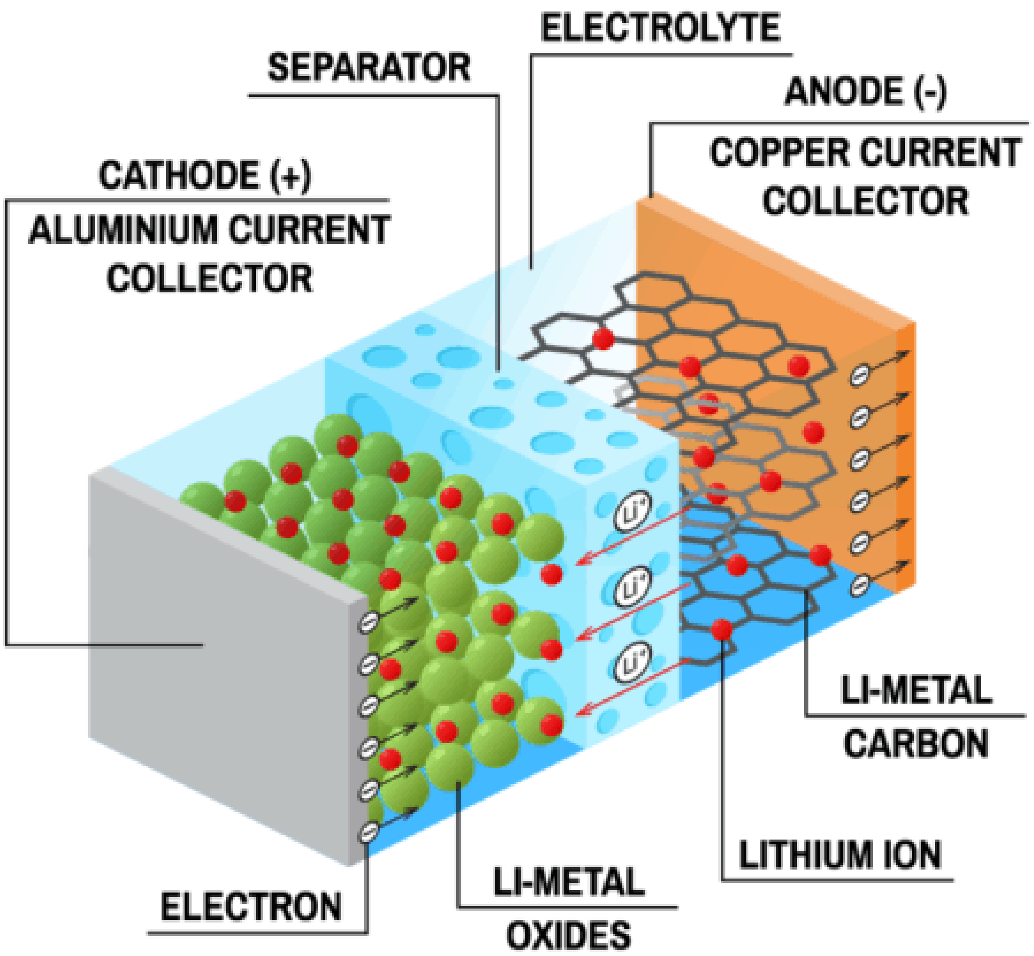
Historical evolution and advances of lithium-ion battery technologies



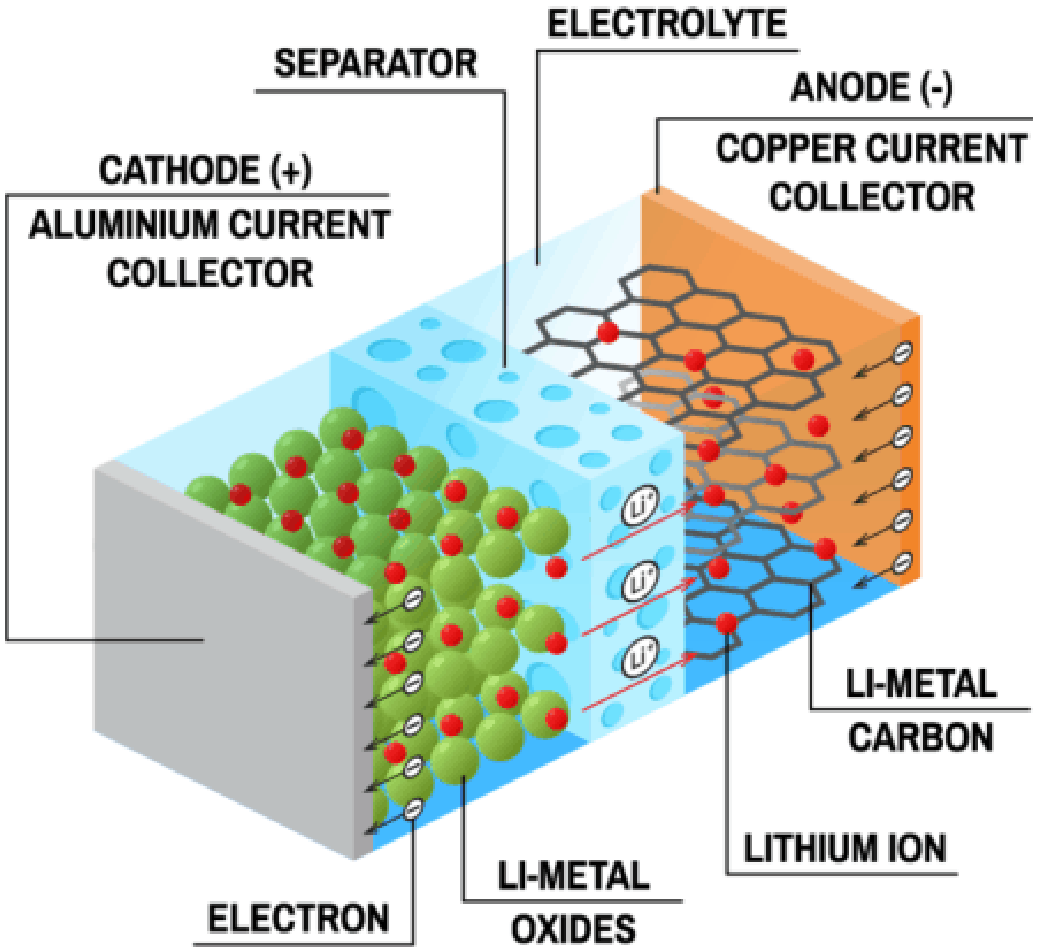
Ref: J. Mater. Chem. A **7** (2019) 2942

Schematic representation of Li-ion electrochemical cell

DISCHARGE

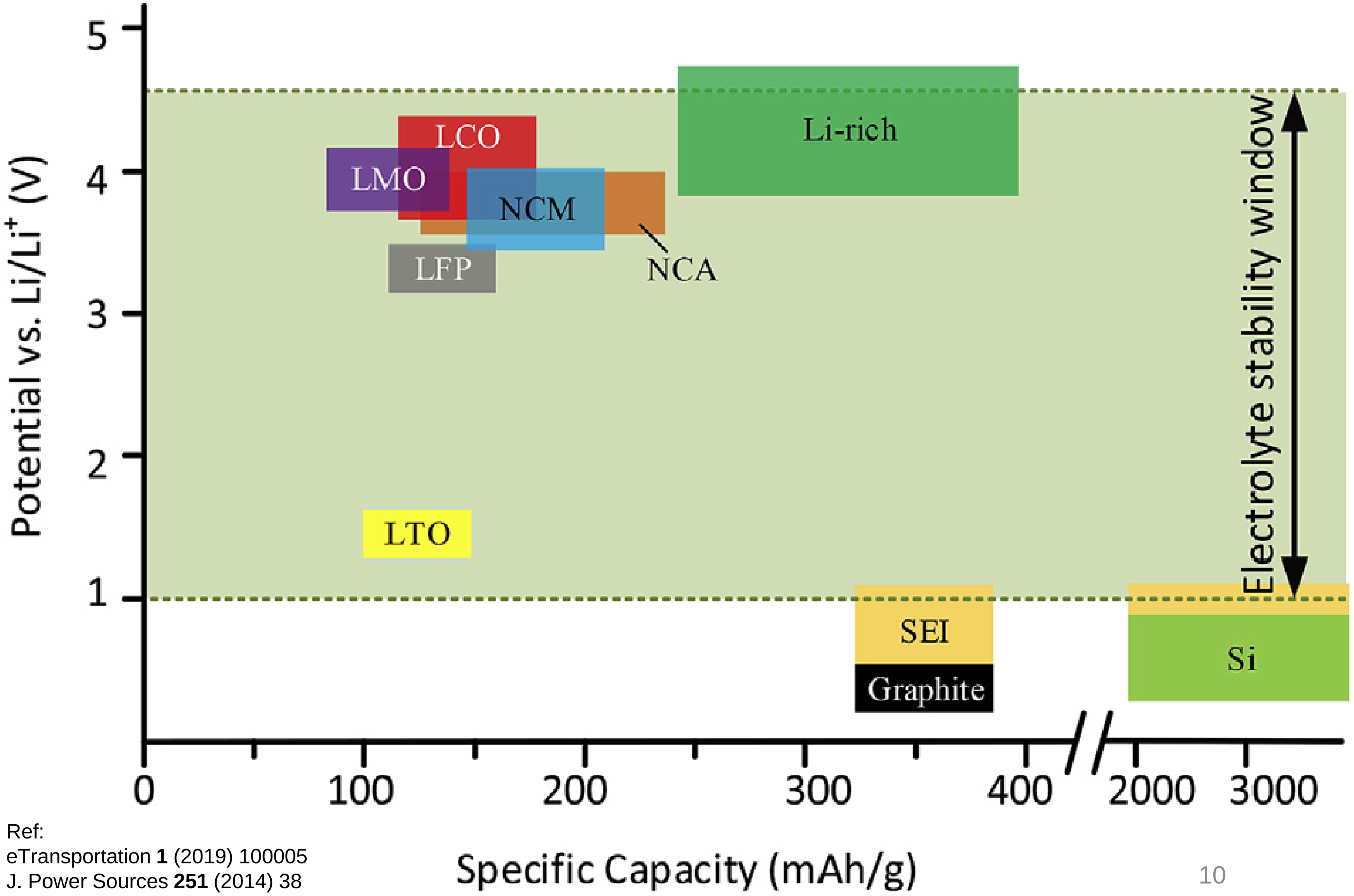


CHARGE



Source:
https://goenergylink.com/blog/key-differences-between-lithium-ion-and-lithium-iron-batteries/
https://www.osha.gov/dts/shib/shib011819.html

Potential and specific capacity of active materials in Li-ion batteries



Ref:
eTransportation **1** (2019) 100005
J. Power Sources **251** (2014) 38
J. Power Sources **195** (2010) 2419

Typical types of Li-ion batteries used in the industry

Characteristic	LFP ($LiFePO_4$)	NMC ($LiNiMnCoO_2$)	LCO ($LiCoO_2$)	LMO ($LiMn_2O_4$)	LTO ($Li_4Ti_5O_{12}$)
Nominal voltage	3.2 V_{DC}	3.6 V_{DC}	3.6 V_{DC}	3.7 V_{DC}	2.4 V_{DC}
Operating voltage range	2.5~3.65 V_{DC}	3.0~4.2 V_{DC}	3.0~4.2 V_{DC}	3.0~4.2 V_{DC}	1.8~2.85 V_{DC}
Weight energy density	90~120 Wh/kg	150~220 Wh/kg	150~200 Wh/kg	100~150 Wh/kg	50~80 Wh/kg
Volume energy density	333 Wh/l	580 Wh/l	560 Wh/l	420 Wh/l	177 Wh/l
Charge rate*	1C	0.7~1C	0.7~1C	0.7~1C (3C max)	1C (5C max)
Full charge voltage	3.5~3.65 V_{DC}	4.1~4.2 V_{DC}	4.1~4.2 V_{DC}	4.1~4.2 V_{DC}	2.8~2.85 V_{DC}
Discharge rate* and cutoff voltage	1C for stationary 2.5 V_{DC}	1C for stationary 3.0 V_{DC}	1C for stationary 3.0 V_{DC}	1C for stationary 3.0 V_{DC}	10C (30C for 5 sec) 1.8 V_{DC}
Cycle life**	2000~4000	1000~2000	500~1000	300~700	3000~7000
Thermal runaway	270°C (518°F)	210°C (410°F)	150°C (302°F)	250°C (482°F)	N/A
Prone to thermal runaway	No	Yes	Yes	Yes	No
Applications	Motive power Stationary power Needing high current and endurance	E-bikes Medical devices EVs Industrial	Smartphones Laptops Tablets Cameras	Power tools Medical devices Electric powertrains	UPS Street lighting Electric powertrains
Cost	$	$	$$	$$	$$$

* The life of the battery will reduce as the charge/discharge rate > 1C.

** The number of cycle life depends on the depth of discharge (DOD).

Types of battery cells

Cylindrical Cell
Feature: Most widely use

Source: C-LiFe Technologies, Inc.

Pouch Cell
Feature: Light weight

Source: Chang Hong Energy Technology Co., Ltd.

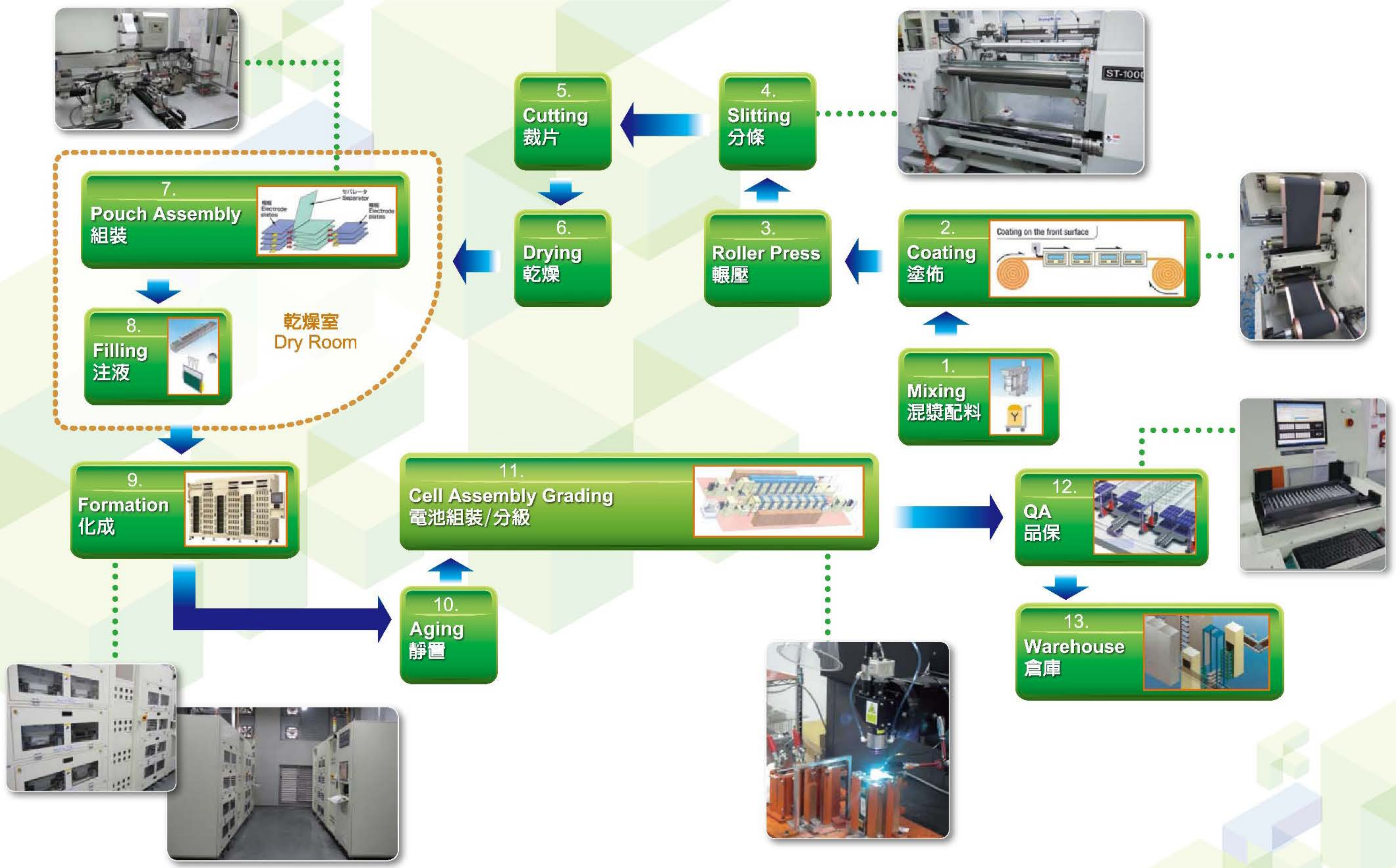
Prismatic Cell
Feature: High density

Source: C-LiFe Technologies, Inc.

From materials to battery cells

Production flow chart

1. Mixing
2. Coating
3. Roller press
4. Slitting
5. Cutting
6. Drying
7. Pouch assembly
8. Filling
9. Formation
10. Aging
11. Cell assembly grading
12. QA
13. Warehouse



Source: Chang Hong Energy Technology Co., Ltd.

Engineering Integrations

Engineering integrations

Battery management system

Energy management system

Some real cases as examples

Our responsibility is to let the battery cells work together safely and efficiently.

Solar Energy storage system (system integration)

Energy storage system

Battery cell

Source:
Chang Hong Energy Technology Co., Ltd.

An extremely simple charge/discharge strategy for a single battery cell

- In the charge process, a charger is used with a charge voltage equal to or a little lower than the maximum charge voltage of the battery cell, $V_{ch,cut}^{cell}$.

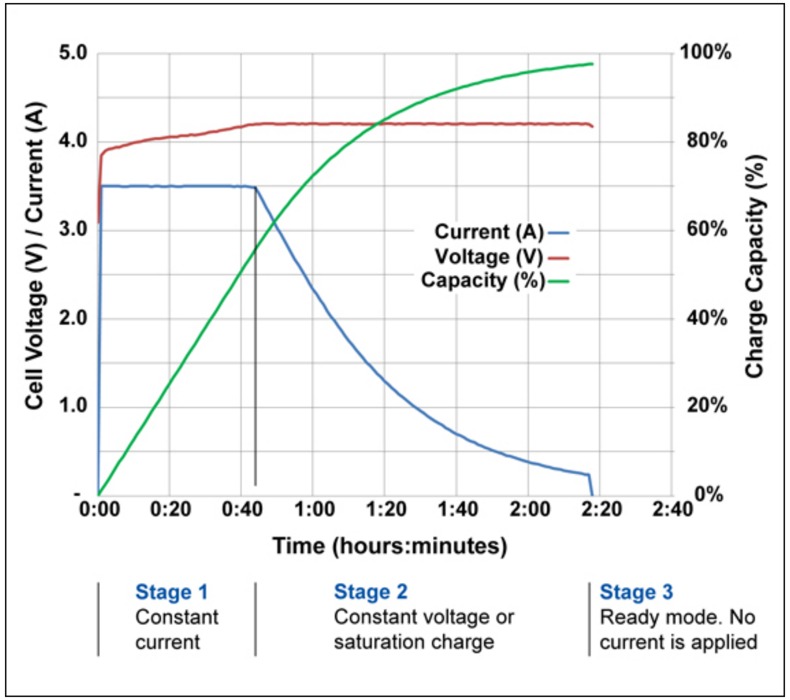
(if over → over charge)

- In the discharge process, a relay is used to cut the power off when the voltage of the battery cell is equal to or a little above the cutoff discharge voltage of the battery cell, $V_{dis,cut}^{cell}$.

(if under → under discharge)

- Similar system: smartphone
- Very simple BMS.

- The battery cell has a normal operation voltage region.



Problems of the extremely simple charge/discharge strategy for multi-battery cells

Example: A battery system is built by two battery cells in a series connection.

In the charge process, total charge cutoff voltage ? Twice? $V^{cell}_{ch,cut}$

In the discharge process, total discharge cutoff voltage ? Twice? $V^{cell}_{dis,cut}$

Can we just scale up the normal operation voltage region?

These charge/discharge processes seem reasonable and easy to predict.

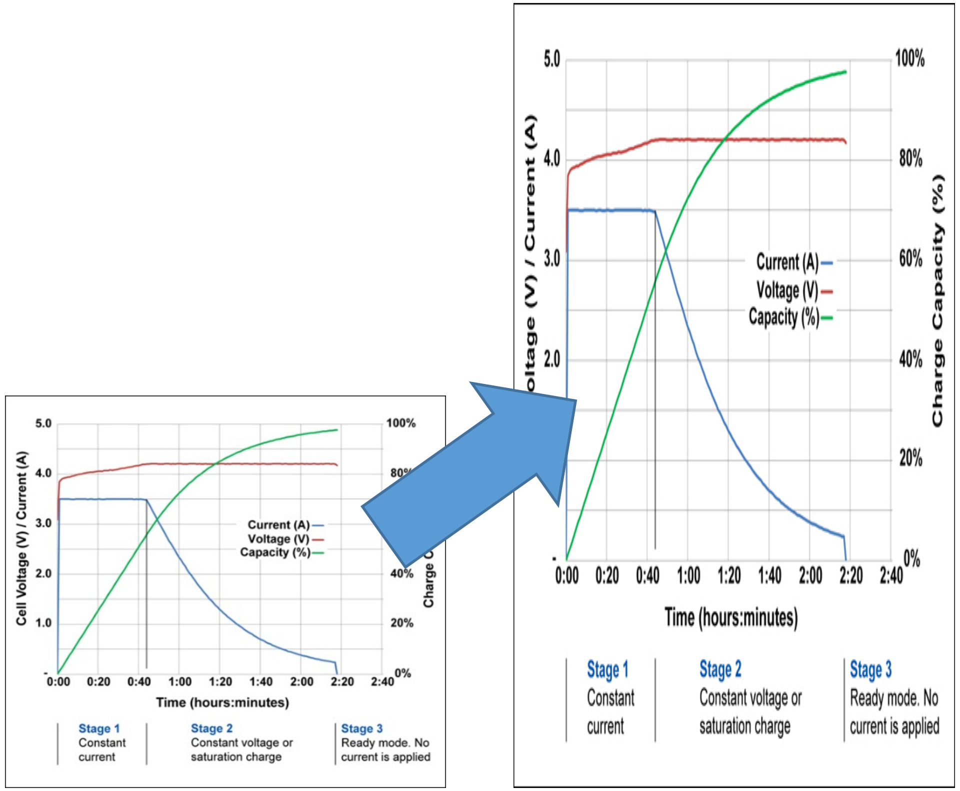
We just double the upper and lower cutoff voltages, and everything will be OK.

Indeed, the battery system actually can work under such brutal BMS, but only for a short time.

The user will encounter serious problems in the battery system, i.e., over charge and over discharge.

These problems result in the reduction of capacity and battery life, and even more dangerous fire and explosion (thermal runaway).

Double all voltage constrains?



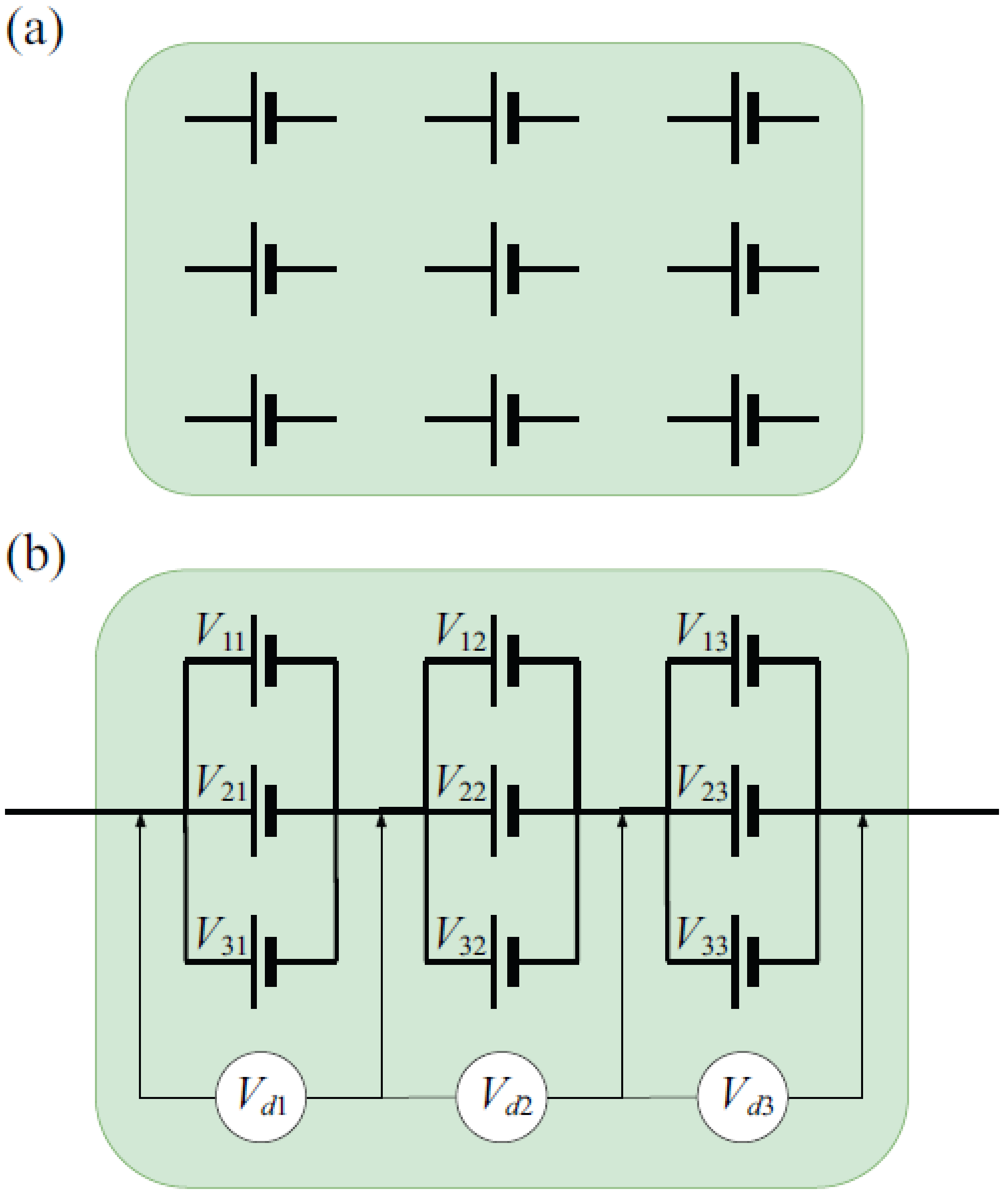
Model battery system

S: in series connection
P: in parallel connection

Battery cells in 3S3P configuration

(a) The battery system with 9 battery cells.

(b) The battery system in 3S3P configuration. The cell voltages are denoted by V_{mn}, and the three voltmeters are denoted by V_{d1}, V_{d2}, and V_{d3}.



In the charge process

$$V_{tot} = 2.9V_{ch,cut}^{cell} < 3V_{ch,cut}^{cell}$$

over charge

$$V_{d1} = 0.8V_{ch,cut}^{cell},\ V_{d2} = 1.2V_{ch,cut}^{cell},\ \text{and}\ V_{d3} = 0.9V_{ch,cut}^{cell}$$

In the discharge process

$$V_{tot} = 3.1V_{dis,cut}^{cell} > 3V_{dis,cut}^{cell}$$

over discharge

$$V_{d1} = 1.2V_{ch,cut}^{cell},\ V_{d2} = 0.8V_{ch,cut}^{cell},\ \text{and}\ V_{d3} = 1.1V_{ch,cut}^{cell}$$

Real case – over voltage demonstration

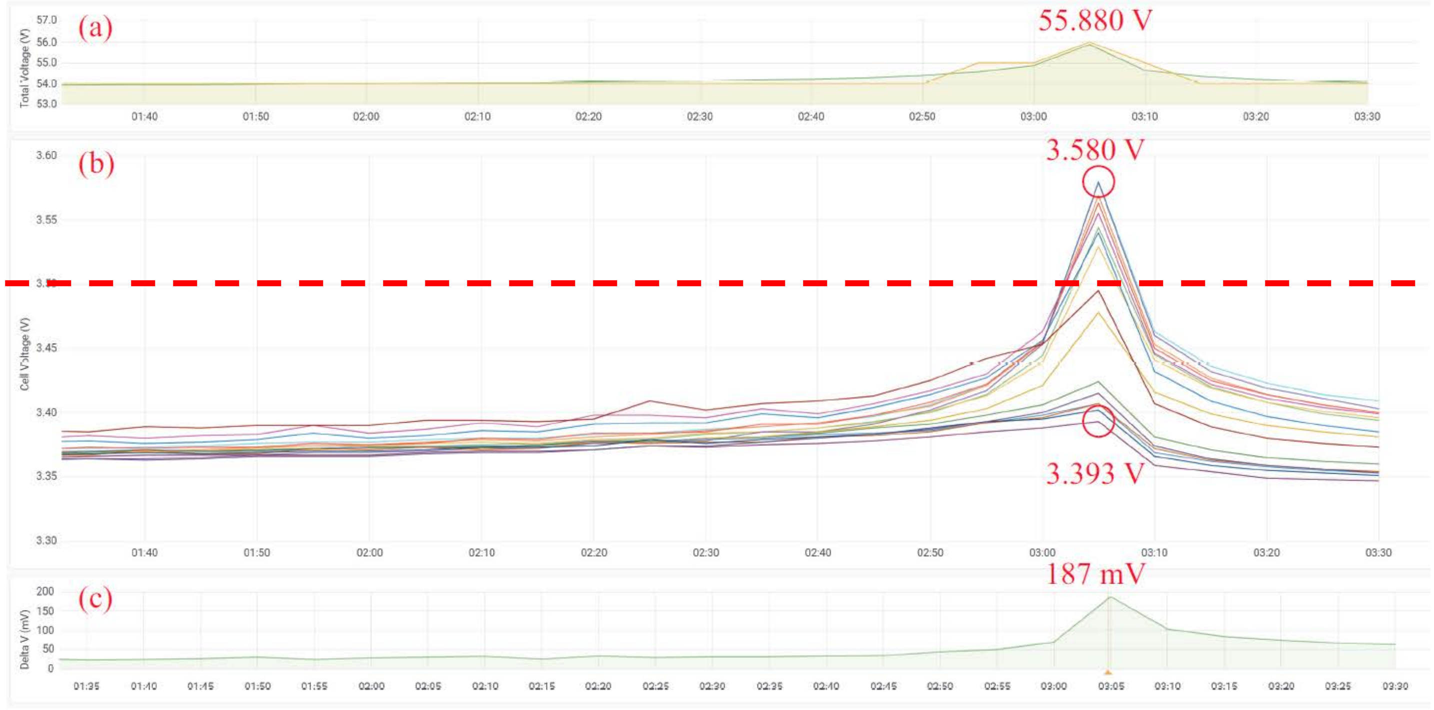
LFP battery system with 16S5P configuration (made by SDP)
Using the GreenIce 50 LFP battery cells produced by Chang Hong Energy Technology Co., Ltd., Taiwan.

Over voltage point = 3.5 V

3.5 V * 16 = 56 V   > 55.880 V   safe?

3.5 V

"over charge event of the cell" happens
There are 8 voltages above/below $V_{ch,cut}^{cell}$



Source: SDP

Functionalities of the battery management system (BMS)

Physical and electric quantities detection functions

1. Total voltage of the system
2. Voltage in parallel connection (cell voltage)
3. Current
4. Temperature
5. Pressure
6. Gas detection

Calculation functions

1. Max voltage in parallel connection (Max cell voltage)
2. Min voltage in parallel connection (Min cell voltage)
3. Voltage difference between the max and min voltages in parallel connection (ΔV)
4. Power
5. Max temperature
6. Min temperature
7. Temperature difference between the max and min temperatures (ΔT)
8. Max pressure
9. Min pressure
10. Pressure difference between the max and min pressures (ΔP)
11. State of charge (SOC)
12. State of health (SOH)
13. Impedance/Internal resistance
14. Total charge ampere hour (Ah)
15. Total discharge Ah
16. Total charge energy
17. Total discharge energy

Protection functions

1. Over total voltage protection (OTVP)
2. Under total voltage protection (UTVP)
3. Over cell voltage protection (OCVP)
4. Under cell voltage protection (UCVP)
5. Over charge current protection (OCCP)
6. Over discharge current protection (ODCP)
7. Over charge power protection (OCPP)
8. Over discharge power protection (ODPP)
9. Short circuit protection (SCP)
10. Over cell temperature protection (OCTP)
11. Under cell temperature protection (UCTP)
12. Over environment temperature protection (OETP)
13. Under environment temperature protection (UETP)
14. Over voltage difference protection (OVDP)
15. Over temperature difference protection (OTDP)
16. Over pressure difference protection (OPDP)

Alert functions

1. Light-emitting diode (LED)
2. On-screen message
3. Buzzer
4. Bluetooth
5. Alert signal to control center
6. Social media message
7. E-mail

Physical control functions

1. Charge relay
2. Discharge relay
3. Dry contact

Communication functions

1. RS-232
2. RS-485
3. RS-422
4. CAN bus
5. BACnet
6. USB
7. Ethernet
8. Bluetooth
9. Wi-Fi
10. Zigbee

Memory functions

1. Cycles of charge/discharge
2. Times of over voltage
3. Times of under voltage
4. Times of over current
5. Times of short circuit
6. Times of over temperature
7. Times of under temperature

Database functions

1. Data history
2. Event log
3. Basic statistical data

Energy saving functions

1. Normal mode
2. Sleeping mode
3. Shutdown mode

Balance functions

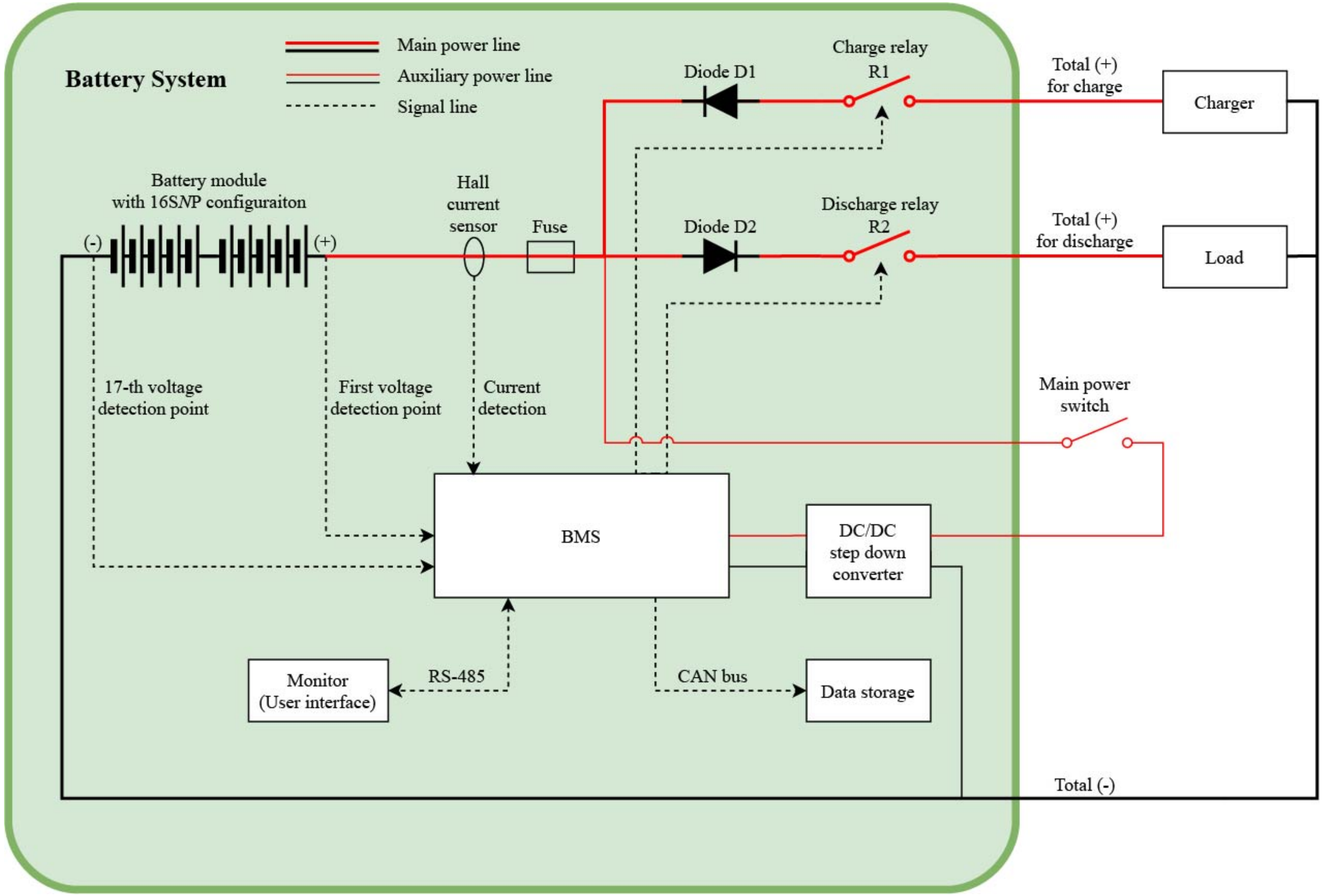
1. Passive balance
2. Active balance

Real case - an LFP battery system with 16S5P configuration

SDP chose to use a BMS providing measurements on 16 voltages in parallel connections, 4 temperatures, and 1 current.

We still need a software to monitor the key parameters.

BMS architecture



Developed by SDP

Source: SDP

Software developed by SDP for monitoring the battery system

Dashboard of BMS

Basic information:

(a) Total voltage

(b) Current

(c) Power

(d) Max cell voltage

(e) Min cell voltage

(f) Voltage difference between max and min cell voltages

(g) Max temperature

(h) SOC

(i) System current state

(j) Recent state change

Data variation:

(k) Total voltage

(l) Cell voltage

(m) Delta V

(n) Current

(o) Power

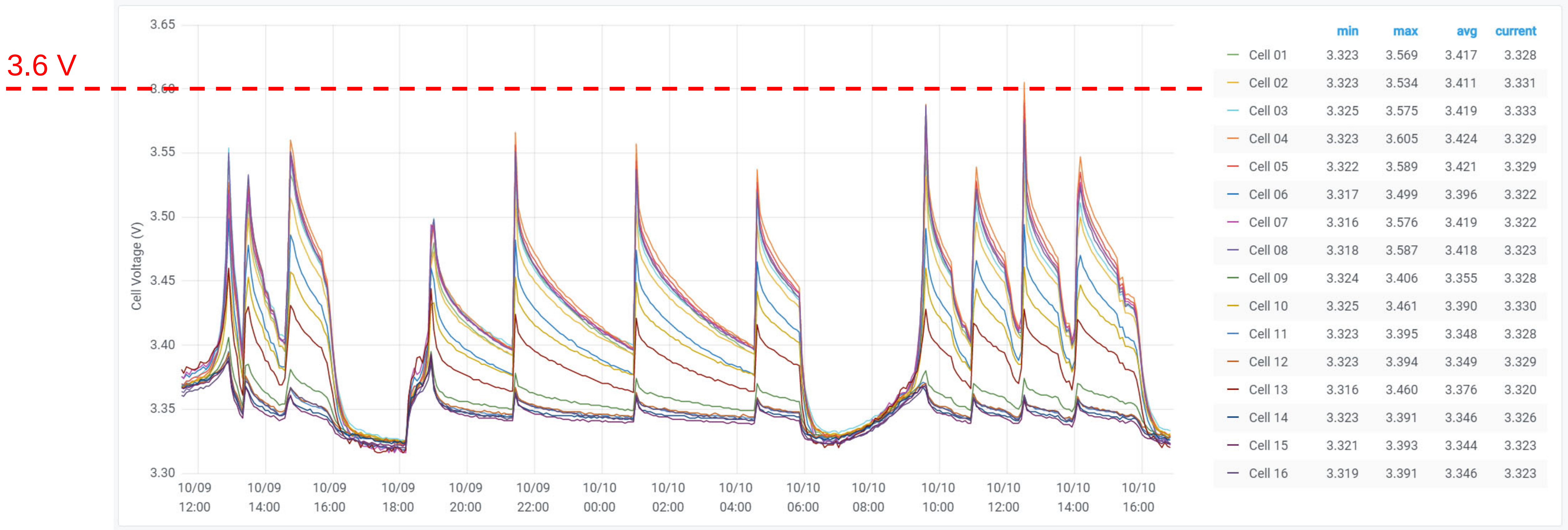
(p) Temperature

(q) SOC

Developed by SDP

Real case - Demonstration of the OCVP

Owing to the OCVP of BMS, the highest cell voltage won't higher than the OCVP value (3.600 V in this case)



Source: SDP

Energy Management system (EMS)

An energy management system (EMS) provides hardware and software to monitor, control, and optimize the energy systems.

BMS manages the battery system
EMS manages the entire energy system encluding the battery.

BMS → Local management
EMS → Global management

Energy Management software (EMSW)

Energy management software plays an important role in the EMS, providing utility bill tracking, real-time metering, building HVAC and lighting control systems, building simulation and modeling, carbon and sustainability reporting, information technology (IT) equipment management, demand response, and/or energy audits.

Real case - Demonstration of the energy management system developed by SDP

EMS for Solar ESS developed by SDP

EMS manages
1. Solar system (Energy generation)
2. ESS (Energy storage)
3. Load system (Energy consumption)

Developed by SDP

Source: SDP

Real case - Demonstration of the energy management software developed by SDP

Basic information about PV in:

(a) Power of PV in displayed by gauge
(b) Power variation of PV in
(c) Voltage variation of PV in
(d) Current variation of PV in

Basic information of ESS:

(e) Total voltage of ESS displayed by gauge
(f) Total voltage variation of ESS
(g) Max cell voltage of ESS
(h) Min cell voltage of ESS
(i) SOC of ESS
(j) Current of ESS

Basic information of AC out:

(k) Power of AC out displayed by gauge
(l) Power variation of AC out
(m) Voltage variation of AC out
(n) Current variation of AC out

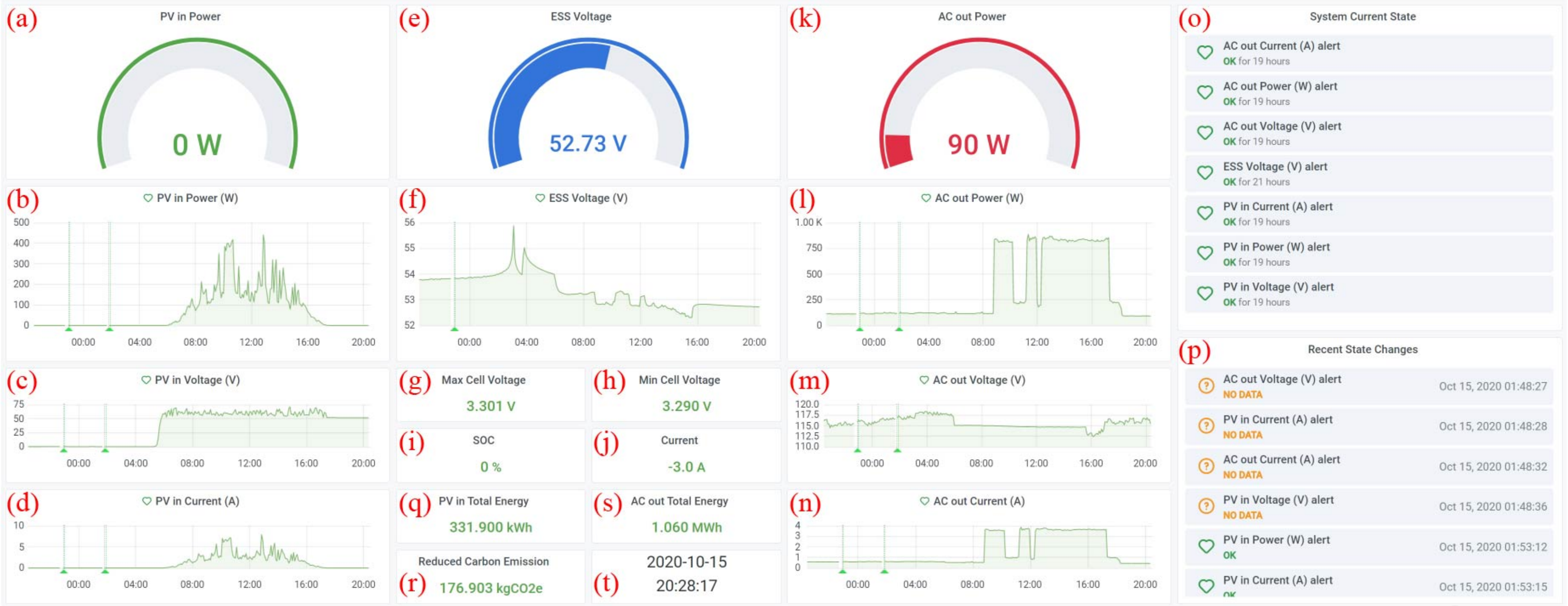
Alert message:

(o) System current state
(p) Recent state change

Statistic information:

(q) Total energy of PV power generation
(r) Reduced carbon emission calculated from the total energy generated by PV
(s) Total energy of AC power consumption
Other information:
(t) Current date and time

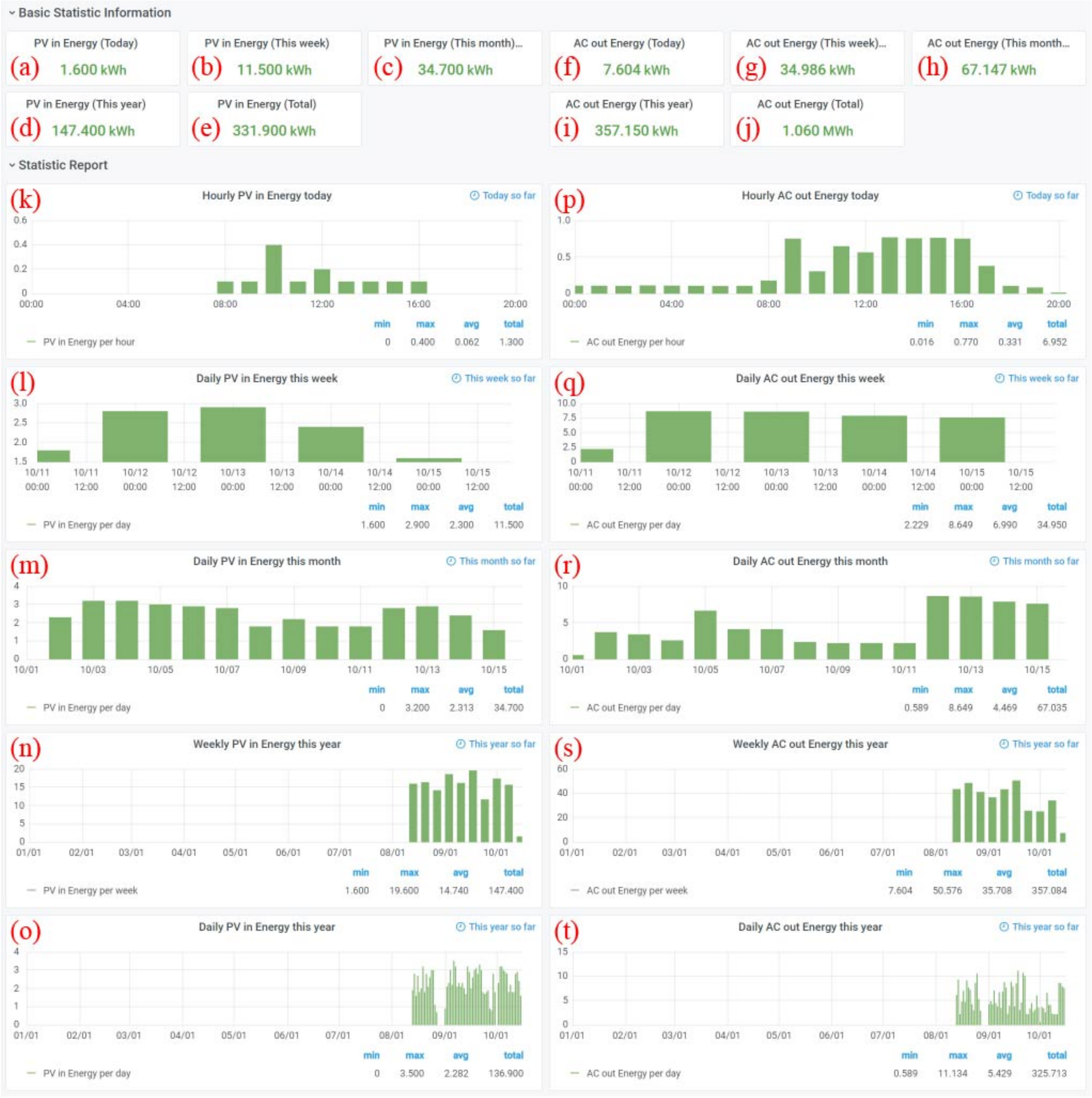
Dashboard of the EMSW of solar ESS



Developed by SDP

Real case - Demonstration of the energy management software developed by SDP

Energy usage analysis of the solar ESS



Basic statistic information about PV in and AC out:

(a) PV energy generation today.
(b) PV energy generation this week.
(c) PV energy generation this month.
(d) PV energy generation this year.
(e) Total PV energy generation.
(f) AC energy consumption today.
(g) AC energy consumption this week.
(h) AC energy consumption this month.
(i) AC energy consumption this year.
(j) Total AC energy consumption.

Statistic report of PV in and AC out:

(k) Hourly energy of PV in today.
(l) Daily energy of PV in this week.
(m) Daily energy of PV in this month.
(n) Weekly energy of PV in this year.
(o) Daily energy of PV in this year.
(p) Hourly energy of AC out today.
(q) Daily energy of AC out this week.
(r) Daily energy of AC out this month.
(s) Weekly energy of AC out this year.
(t) Daily energy of AC out this year.

Developed by SDP

Potential Applications

Potential applications

Power applications

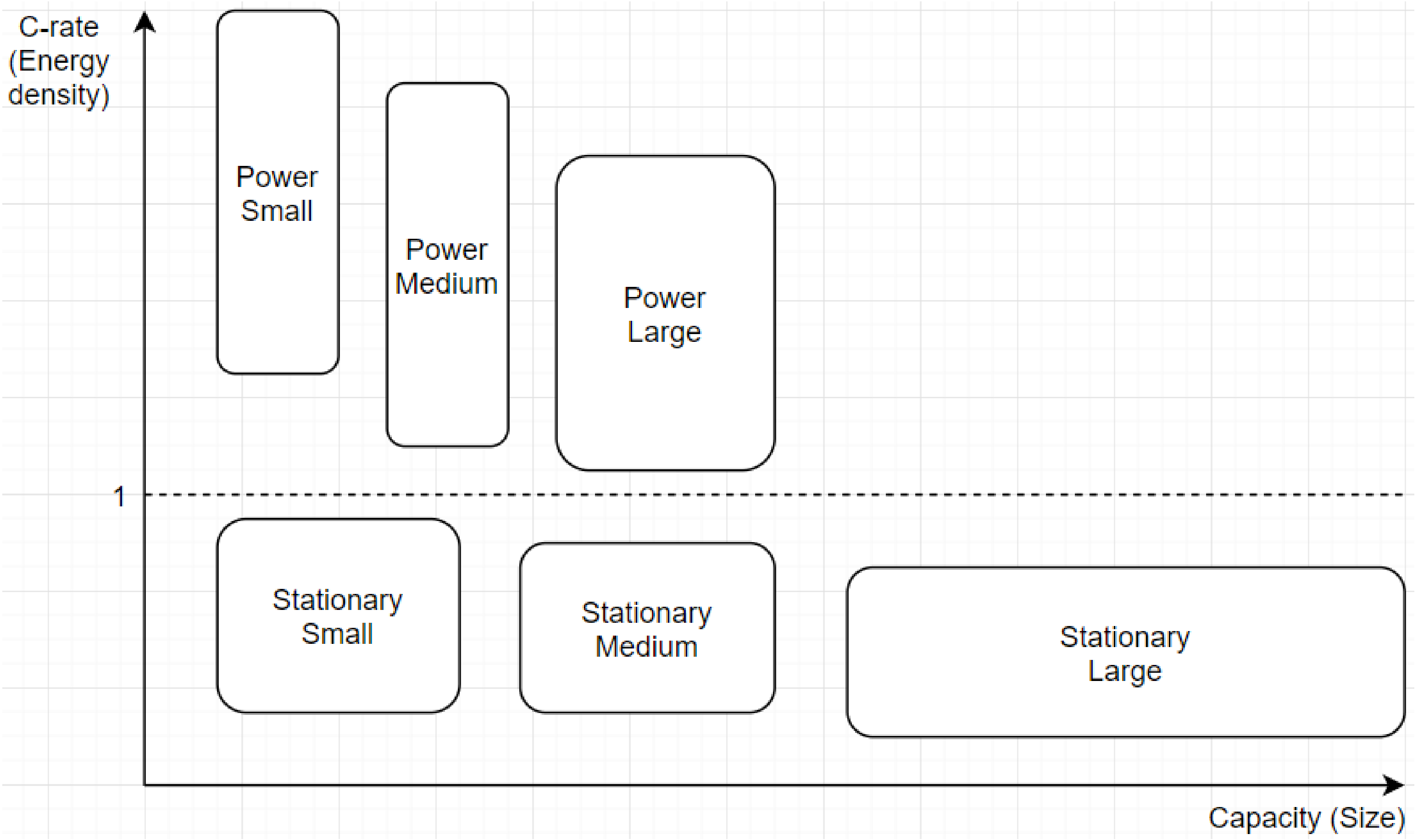
Small/medium/large scale

Feature: high C-rate for short time

Stationary application

Small/medium/large scale

Feature: Low C-rate for long time



Small-scale power applications
Two- and three-wheelers

Gogoro 3 GT

Features:
- Capacity: 3.2 kWh

Source: Gogoro

Gaius Rapide3 concept

Features:
- Capacity: 5.2 kWh LTO

Source: https://electricmotorcycles.news/rapide-3-a-new-advanced-and-electric-way-to-deliver-goods-and-services-to-customers/

Small-scale power applications
Electric car

Tesla Model X

Features:

- Capacity: 75 kWh

Source: Tesla

Several commercial EV and PHEV in 2017 and their key characteristics

Manufacturer	Name	EV/PHEV	Battery Chemistry	Capacity [kWh]	E Engine P [kW]	Vehicle Weight [kg]	B Pack share in weight [%]	Sp. Range [km/kWh]	E. Rang [km]
Tesla	Tesla Model S 75D	EV	NCA	75	245	2108	24	6	405
	Tesla Model S 90D	EV	NCA	90	311	2240	25	5.5	445
	Tesla Model S 100D	EV	NCA	102	451	2390	25	5.5	510
	Tesla Model S P100D	EV	NCA	102	567	2234	26	5.5	505
Toyota	Toyota Prius Prime	PHEV	NMC	8.8	20	1526	7	5.5	40
General Motors	Chevrolet Bolt EV	EV	NMC	60	149	1624	27	7	350
	Chevrolet Volt	PHEV	NMC	18.4	111	1607	11	5.5	85
Volkswagen	VW e-Golf	EV	NMC	35.8	100	1605	22	6.5	195
	VW e-up	EV	NMC	18.7	60	1139	20	7	110
	VW Golf GTE	PHEV	NMC	8.8	75	1520	8	6	45
	VW Passat GTE	PHEV	NMC	9.9	85	1722	8	5.5	45
Audi	Audi A3 Sportback e-tron	PHEV	NMC	8.8	76	1654	7	5	35
	Audi Q7 e-tron	PHEV	NMC	17.3	94	2445	9	4	55
Porsche	Porsche Cayenne S E-Hybrid	PHEV	NMC	10.8	71	2360	6	4	35
	Porsche Panamera 4 E-Hybrid	PHEV	NMC	9.4	100	2170	6	5	40
Nissan	Nissan Leaf	EV	NMC	30	80	1516	20	7	170
Hyundai	Hyundai Ioniq Plug-in	PHEV	NMC	8.9	45	1370	9	6.5	50
	Hyundai Ioniq Electric	EV	NMC	28	88	1420	20	7	165
Ford	Ford Focus Electric	EV	NMC	33.5	107	1651	20	6.5	180
	Ford C-Max Energi	PHEV	NMC	7.6	88	1769	6	5	30
Fiat	Fiat 500e	EV	NMC	24	83	1352	19	7	135
BMW	BMW i3	EV	NMC	33	127	1343	24	6.5	180
Daimler	Mercedes-Benz B-class E Drive	EV	NCA	36	132	1725	17	6	165
	Smart Fortwo Electric Drive	EV	NMC	18	60	995	16	7	120
Kia	Kia Soul EV	EV	NMC	27	82	1554	18	6.5	145
Renault	Renault Zoe	EV	NMC	41	68	1480	26	7	230
Karma	Karma Revero	PHEV	NMC	21.4	106	2450	10	4.5	80
BYD	BYD E6	EV	LFP	82	89	2420	29	5	390
Mitsubishi	Mitsubishi i-MiEV	EV	NMC	16	49	1170	19	7	95
	Mitsubishi Outlander	PHEV	NMC	12	119	1845	10	5	45

For most listed EV and PHEV the maximum DoD for the battery is around 82%, except for the Tesla and Daimler models, where the maximum DoD is 90%. Different values can be found by different sources for the drive range. The values provided herein are based on the battery capacity and the specific range, which must be taken into account as representative for clear weather conditions, reasonable drive practice and no use of air-conditioning or heating.

Ref: Renew. Sustain. Energy Rev. **89** (2018) 292

Small-scale power applications
Electric bus

Great City Life Bus (GCLB)

Features:
- Capacity: 72 kWh

Source: http://www.gdbus.com.tw/service/newbus.htm

KGET K9DA

Features:
- Capacity: 384 kWh

Source: http://www.tw-kget.com/about/KS_about-5-12.html

Real case - Great City Life Bus, Kaohsiung, Taiwan

The proper rate during the operation period reached 99%
Fast charging: 15~30 min

GCLB creating many national firsts in Taiwan:
No. 1 in the country in terms of “number” (68 electric buses)
No. 1 in the country for “operating mileage” (exceeding 300000 km/month)
No. 1 in the country for “carrying capacity” with more than 8 million passengers

Ref: The Liberty Times 2019

Ref:
An Analysis of Operational Benchmarks, Financial Benefits and Development Strategies for Electric Urban Buses
Transp. Plan. J. 46 (2017) 377, W.T. Lai

Small-scale stationary applications
Smartphones, laptops, and tablets

Apple iPhone 12 Pro

Features:
- Capacity: 14 Wh

Source:
https://www.apple.com/tw/iphone-12-pro/specs/

Asus Zephyrus G14

Features:
- Capacity: 76 Wh

Source:
https://rog.asus.com/laptops/rog-zephyrus/rog-zephyrus-g14-series/gallery/

Apple iPad Air

Features:
- Capacity: 28.6 Wh

Source:
https://www.apple.com/ipad-air/

Small-scale stationary applications
Energy storage box for refuge mountain house

(SDP developed)

Features:

- 12 V_{DC}, DC output
- USB charging 5 V_{DC}, DC output
- Multi-function power supply: for radio, lighting and mobile phone charging
- Capacity: 2.5 kWh

山屋專用 12V210Ah 儲能箱

替代鉛酸電池: 可替代 250 Ah 鉛酸電池
工作溫度: -20~60˚C
多工能供電用: 可供無線電、照明及手機充電
鋰鐵電池: 不起火、不燃燒、不爆炸、不漏液
超級耐用: 單電芯循環壽命可達 3500 次

BMS 技術: 電壓平衡、充電保護、放電保護
電源開關: 可關閉電源，節省電力消耗
面板顯示: 顯示電池總電壓，掌握電池狀況
USB 輸出: 支援兩組 USB 輸出，提供 2 A 充電
綠能設備: 可外接太陽能板充電(選配)

規格

型號		12180LiB
DC 輸出	額定電壓	12 Vdc
	工作電壓	11~14.4 Vdc
USB 輸出 (兩組)	額定電壓	5 Vdc
	額定電流	2.1 A
DC 輸入	充電器電壓	14.6 V
	太陽能電壓	14~18 V
電池組	種類	鋰鐵電池
	電池芯循環壽命	≥ 3500 次
	放電深度(DOD)	≥ 80%
	額定容量	210 Ah
	額定能量	2.5 kWh
	連續放電電流	100 A
	瞬間放電電流(30 s)	300 A
	標準充電電流	30 A
	最大充電電流	60 A
	BMS 功能	電壓平衡、過充、過放、短路保護
其他	尺寸	(W) 365 * (D) 150 * (H) 230 mm
	重量	20.5 kg
安規		IEC 62133, IEC 61960, CNS 14857-1, CNS 14857-2

Super Double Power 超倍能科技股份有限公司
SUPER DOUBLE POWER TECHNOLOGY CO., LTD.

地址: 500 彰化縣彰化市彰南路三段 167 號
傳真: 04-7326299
E-mail: sdpcomtw@gmail.com

Developed by SDP

Small-scale stationary applications
Portable energy storage suitcase

(SDP developed)

Features:

- 110 V_{AC}, AC output
- Portable
- Multi-function power supply
- Capacity: 2.4/1.6 kWh

Developed by SDP

SDP 2.4/1.6kWh 行動電源

產品特點

鋰鐵電池: 不起火、不燃燒、不爆炸、不漏液

超級耐用: 單電芯循環壽命可達 2000 次

BMS 技術: 電壓平衡、高低壓保護、充電保護、放電保護

AC 輸出: 正弦波(THD＜3%)

寬廣電壓: 100/110/115/120Vac 適用精密進口設備 (例如: 醫療級設備、實驗室量測儀器等)

逆變保護: 低壓/高壓/短路/過溫/過載、斷開負載、重新啓動

面板顯示: 電壓高低/負載高低/充電模式

綠能設備: 可外接太陽能板充電(選配)

規格

型號		ESS2.4kWh	ESS1.6kWh
輸出	額定電壓	□ 100/110/115/120 Vac	□ 200/220/230/240Vac
	頻率	50/60 Hz (可設定)	
	波型	正弦波 (THD < 3%)	
	功率	1500 W	1000 W
	切換時間	10 ms	
輸入	額定電壓	□ 100/110/115/120 Vac	□ 200/220/230/240Vac
	電池種類	鋰鐵電池	
	電池管理系統(BMS)	電壓平衡、高低壓保護、充電保護、放電保護	
	額定電壓	48 V	
	額定容量	50 Ah	34 Ah
	滿載時，電池可供電時間	1.5 hr	1.5 hr
	電池充飽時間	2.3 hr (for 1000 W charger)	1.5 hr (for 1000 W charger)
其他	尺寸	(W) 230 * (D) 350 * (H) 560 mm	
	重量	35 kg	
	太陽能充電(選配)	75 V / 30 A (max)	
安規		IEC 62133, IEC 61960, CNS 14857-1, CNS 14857-2	

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傳真: 04-7326299
E-mail: sdpcomtw@gmail.com

Small-scale stationary applications Uninterruptible Power System (UPS)

(SDP developed)

Features:

- 110 V_{AC}, AC output
- Capacity: 5/10 kWh

Developed by SDP

SDP 10 度電/5 度電 UPS

產品特點

鋰鐵電池: 不起火、不燃燒、不爆炸、不漏液

超級耐用: 單電芯循環壽命可達 3500 次

BMS 技術: 電壓平衡、高低壓保護、充電保護、放電保護

AC 輸出: 正弦波(THD＜3%)

寬廣電壓: 100/110/115/120Vac 適用精密進口設備 (例如: 醫療級設備、實驗室量測儀器等)

逆變保護: 低壓/高壓/短路/過溫/過載、斷開負載、重新啓動

面板顯示: 電壓高低/負載高低/充電模式

綠能設備: 可外接太陽能板充電(選配)

規格

型號		UPS-10kWh	UPS-5kWh
輸出	額定電壓	☐ 100/110/115/120 Vac ☐ 200/220/230/240Vac	
	頻率	50/60 Hz (可設定)	
	波型	正弦波 (THD＜3%)	
	功率	☐ 1000 W ☐ 1500 W ☐ 3000 W	
	切換時間	10 ms	
輸入	額定電壓	☐ 100/110/115/120 Vac ☐ 200/220/230/240Vac	
	電池管理系統(BMS)	電壓平衡、高低壓保護、充電保護、放電保護	
	額定電壓	48 V	
	額定容量	200 Ah	100 Ah
	滿載時，電池可供電時間	9 hr (for 1000 W output) 6 hr (for 1500 W output) 3 hr (for 3000 W output)	4.5 hr (for 1000 W output) 3.0 hr (for 1500 W output) 1.5 hr (for 3000 W output)
	電池充飽時間	☐ 6 hr (for 1500 W charger) ☐ 10 hr (for 1000 W charger)	☐ 3 hr (for 1500 W charger) ☐ 5 hr (for 1000 W charger)
其他	尺寸	(W) 600 * (D) 600 * (H) 870 mm	
	重量	150 kg	100 kg
	通訊介面	RS485/RS232	
	太陽能充電(選配)	75 V / 30 A (max)	
安規		IEC 62133, IEC 61960, CNS 14857-1, CNS 14857-2	

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Medium-scale stationary applications
Off-grid Solar ESS in Paiyun Lodge in Mt. Jade, Taiwan

(SDP developed)

Features:
- The highest lodge in Taiwan (3402 m above sea level) Yes! We did it!
- Capacity: 72 kWh (can supply electricity for one week without solar power)
- Operation date: 2016

YouTube: https://www.youtube.com/watch?v=70ifcSFFxfc

Medium-scale stationary applications
Off-grid Solar ESS in Tianchi Lodge, Nantou, Taiwan

(SDP developed)

Features:
- The five-star lodge in Taiwan
- Capacity: 75 kWh
- Operation date: 2019

Medium-scale stationary applications
Off-grid ESS in Guishan Island, Taiwan

(SDP developed)

Features:

- Military control zone (Unable to provide details due to intelligence control)
- Capacity: 24 kWh
- Operation date: 2017

Medium-scale stationary applications
Off-grid High-voltage ESS in Mabul Island, Malaysia

(SDP developed)

Features:

- High-voltage: nominal voltage 512 V_{DC} (Unable to provide details due to privacy policy)
- Capacity: 87 kWh
- Operation date: 2018

Medium-scale stationary applications
Off-grid Solar ESS in No. 6 Naphtha Cracker Complex, Taiwan

(SDP developed)

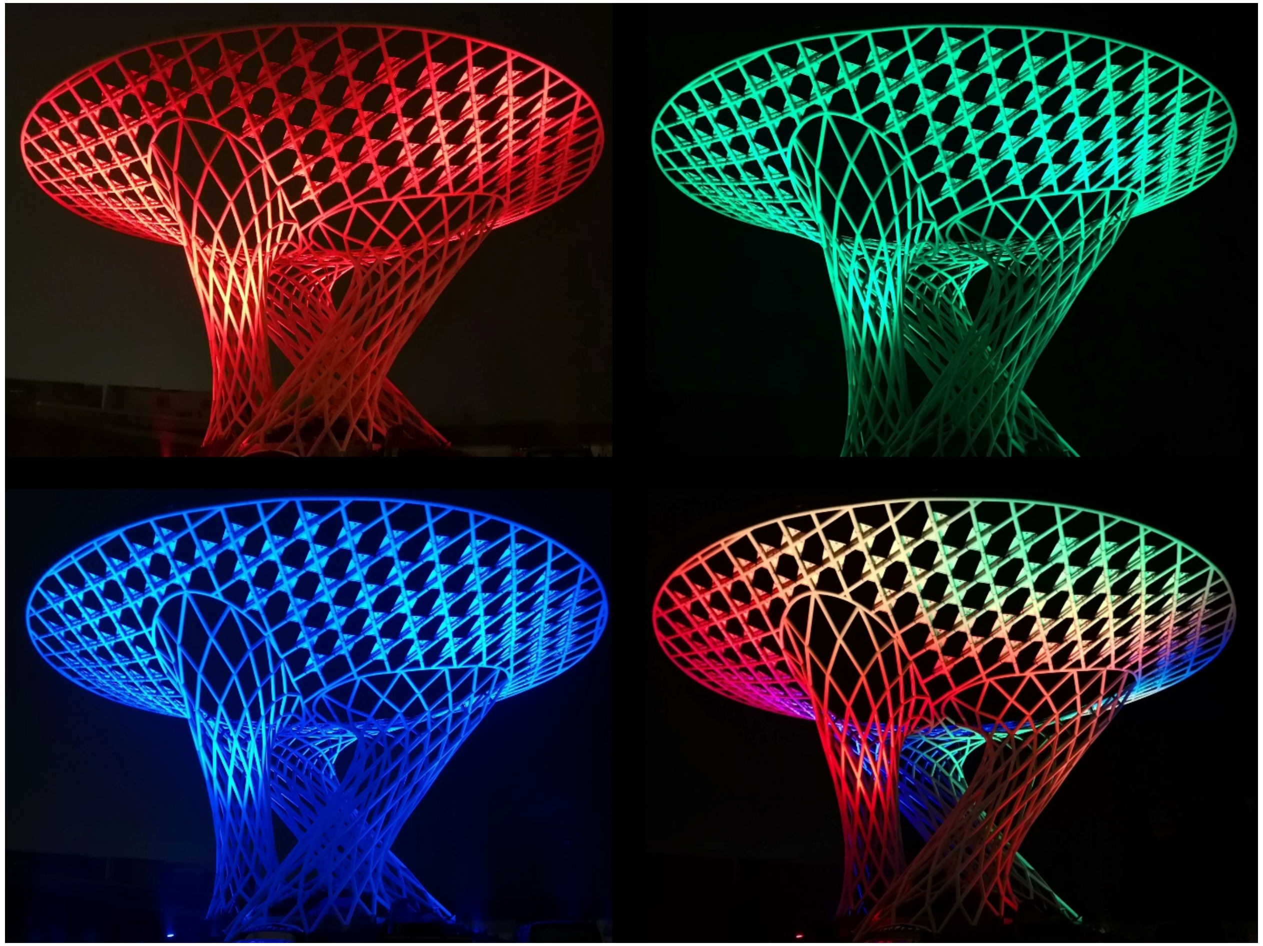
Features:
- Repurposing battery
- Capacity: 24 kWh
- Operation date: 2020

Medium-scale stationary applications
Off-grid Solar ESS of solar tree in SSGESC, Taiwan

(SDP developed)

Features:
- The colorful show with LED lights, brilliant and dazzling, has become the most eye-catching new landmark in Tainan recently.
- Capacity: 15 kWh
- Operation date: 2019

Shalun Smart Green Energy Science City (SSGESC),
the demonstration site is located in a specific high-speed rail (HSR) area, Tainan, Taiwan, covering an area of nearly 7.5 hectares. It is one of the very important topics in Taiwan national project "5 plus 2 industries." It not only emphasizes the demand drives innovation and innovation drives industrial development; but also it will become research, experiment, and development base in the future.



Medium-scale stationary applications
Off-grid Solar ESS of street houses in SSGESC, Taiwan

(SDP developed)

Features:
- Test different type of battery cells
- Capacity:
  - Building 1: 24 kWh (STOBA batteries from Amita Tech. Inc.)
  - Building 1: 24 kWh (LFP batteries from Chang Hong Energy Tech. Co., Ltd.)
  - Building 1: 36 kWh (LFP batteries from Chang Hong Energy Tech. Co., Ltd.)
- Operation date: 2020

STOBA: Self Terminated Olygomers with hyper-Branched Architecture. STOBA is a battery safety material, reduces the fire hazard of lithium-ion batteries.

Ref: ITRI

Large-scale stationary applications
Tesla large battery in South Australia

Features:
- 100 MW/129 MWh
- Usage: support the operation of the grid
- Event: In Dec. 2017, when the Loy Yang coal-fired power plant in Victoria failed, leading to a power shortage, the backup battery connected in and delivered as much as 100 MW into the national electricity grid in 140 ms, responding even more quickly than the coal-fired backups that were supposed to provide emergency power.
- Importance: Large-scale batteries are beginning to show that they have a role in supply electric networks.
- Operation date: 2017

Source:
Tesla Powerpack to Enable Large Scale Sustainable Energy to South Australia
https://www.tesla.com/blog/tesla-powerpack-enable-large-scale-sustainable-energy-south-australia

Ref:
Renew. Sustain. Energy Rev. **111** (2019) 145

Outlook

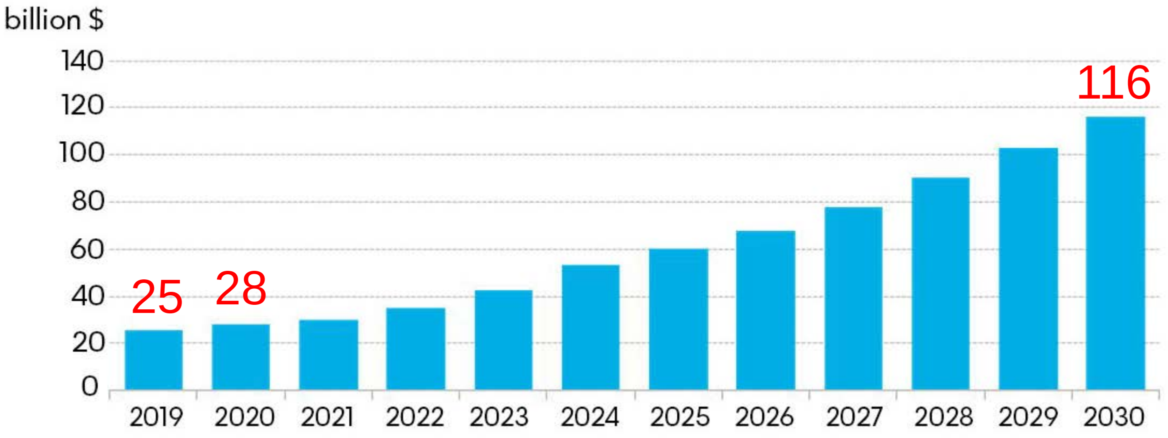
Growing market and falling cost

Growing battery market
2019 USD 25 billion
2020 USD 28 billion (prediction)
2030 USD 116 billion (prediction)

Falling cost of battery pack
2010 USD 1183/kWh
2019 USD 156/kWh (fallen 87%)
2024 USD 100/kWh (prediction, sweet point)
2030 USD 60/kWh (prediction)

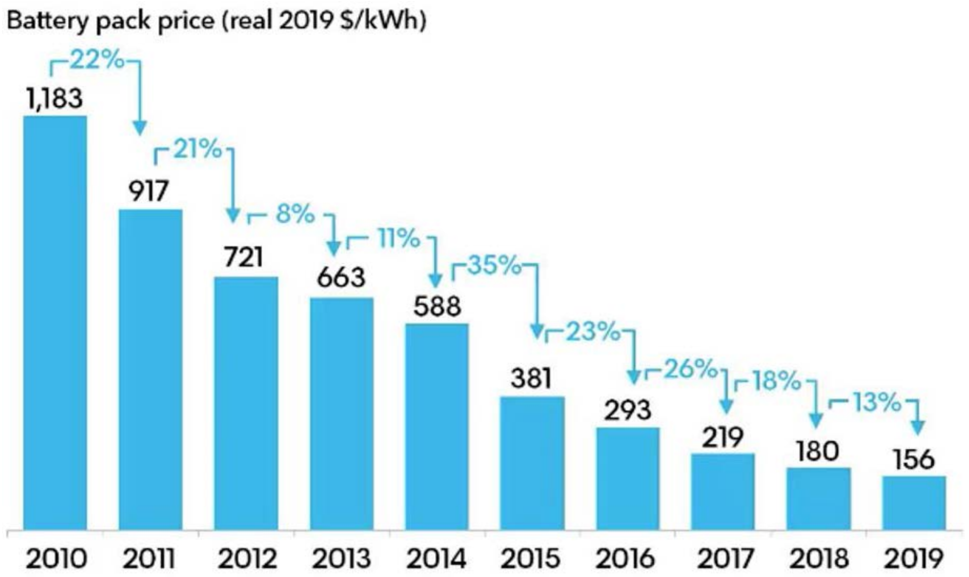
Sweet point
Manufacturers are closing in on a point where EVs will reach cost parity with their fossil fuel-powered cousins at around USD 100/kWh.
That price is widely seen as a sweep point in the sector, where consumers will no longer regard EVs as pricey options.

Annual Li-ion battery market size



Source: BloombergNEF

Li-ion battery price survey results: Volume-weighted average



Source: BloombergNEF

Safety

With the widespread use of Li-ion batteries in recent years, the safety issues of lithium batteries have gradually surfaced.

Brief history

2006~2007 Dell laptop computer battery thermal runaway
2011 Chevrolet Volt battery thermal runaway after a crash testing
2013 Thermal runaway, smoke, and fire onboard the hybrid tugboat Campbell Foss
2013 Boeing Dreamliner battery thermal runaway
2017 Samsung Galaxy Note 7 thermal runaway
2020 ESS fire in Taiwan
2017-present more than 29 ESS fire events in South Korea

The lessons the industry has learned from these incidents is that Li-ion batteries are inherently fragile. Any electrical, thermal, or mechanical abuse, along with internal defects, can potentially initiate cell failure and thermal runaway. The danger of Li-ion batteries is real but can be mitigated and will be as scientists learn more about the reasons for thermal runaways

Source: http://www.e2news.com/news/articleView.html?idxno=200025

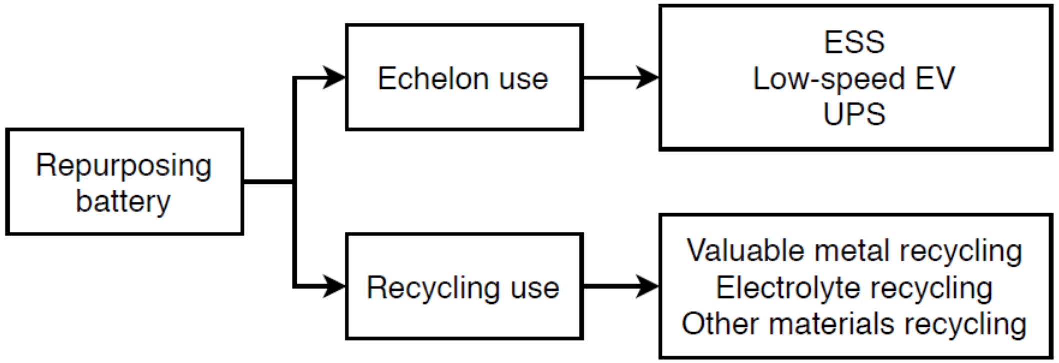
(a) Outside (b) Outside
(c) Side View (d) Inside

Ref: Fire Sci. Eng. **32** (2018) 91

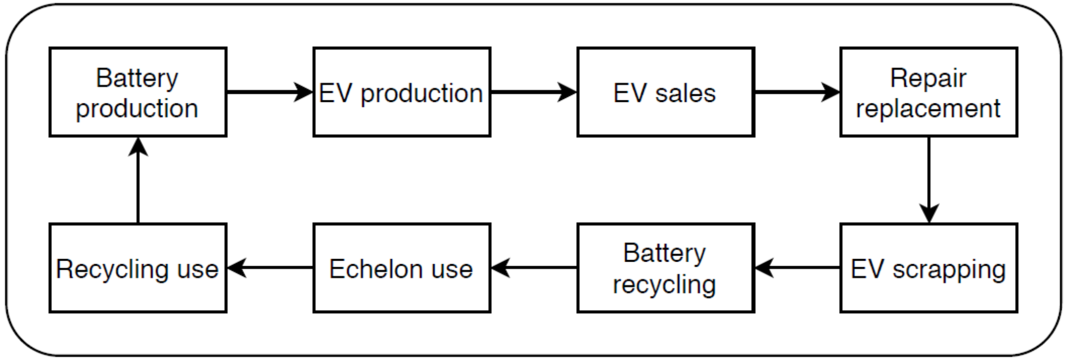
Reuse and recycle of repurposing batteries

1. Too many retired power batteries, causing waste of resources and environmental protection threats.
2. Some of them still possess about 80% initial capacity.

Usage of repurposing batteries



Cycle system of power battery recycling management

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中國汰役電池回收利用的推動現況與分析

鍾獻慶[1*] 鄭耀宗[2**]

摘　要

關鍵詞：鋰離子電池，鋰電池，動力電池，汰役電池，回收利用，梯次利用，法規標準，政策分析

1. 前　言

Action Planning and Situation Analysis of Repurposing Battery Recovery and Application in China
Journal of Taiwan Energy **6** (2019) 425
https://doi.org/10.31224/osf.io/nxv7f

汰役電池安全標準的內容與說明

Summary of Safety Standards for Repurposing Batteries

鍾獻慶 Chung, Hsien-Ching
鄭耀宗 Cheng, Yaw-Chung

摘　要

Abstract

Accompanied by the increase of electric vehicles, repurposing batteries will increase rapidly as well in the future. How to deal with these batteries has become an open-ended question. Some retired power batteries possess about 80% initial capacity. So they can be utilized once again, for example, to serve the batteries in the energy storage system. However, this may cause safety problems. Underwriters Laboratories (UL) published the safety standard for batteries for use in stationary, vehicle auxiliary power, and light electric rail applications in 2013 (UL 1973) to respond to the said issues. To promote wide-ranged applications, UL published the safety standard for repurposing battery evaluation in 2018 (UL 1974). In this paper, we summarize the contents of UL 1973 and UL 1974 as a reference to accelerate the industrial development of battery energy storage system.

關鍵詞(Key Words)：鋰離子電池(Li-ion Battery)、汰役電池(Repurposing Battery)、二次電池(Second-life Battery)、電池儲能系統(Battery Energy Storage System)、二次利用(Second Use)、安全標準(Safety Standard)。

壹、前言

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Summary of Safety Standards for Repurposing Batteries
Monthly Journal of Taipower's Engineering **860** (2020) 35
https://doi.org/10.31224/osf.io/d4n3s

Energy storage as a service (ESaaS)

Energy storage as a service (ESaaS) allows a facility to benefit from the advantages of an ESS by entering into a service agreement without purchasing the system.

ESaaS:
1. Power quality
2. Coincident peak management
3. Demand response
4. Power factor correction
5. Back-up power
6. Peak shaving
7. Energy arbitrage
8. Market ancillary services
9. Transmission support

We use them, but we don't need to own them!

Resemble idea
Cloud services

amazon web services™

Google Cloud

Microsoft Azure

Next-generation energy materials

Currently, the engineers and researchers are still trying to test various types of anode materials, cathode materials, separators, and electrolytes to improve the energy density, power density, and safety of Li-ion battery.

Anode materials

Acta Mater. 175 (2019) 196
J. Power Sources 208 (2012) 74
Energy Environ. Sci. 4 (2011) 2682
J. Am. Chem. Soc. 132 (2010) 13978

Cathode materials

J. Mater. Chem. A 7 (2019) 23770
Appl. Surf. Sci. 507 (2020) 144842
J. Power Sources 278 (2015) 265
J. Power Sources 195 (2010) 939
Adv. Mater. 20 (2008) 2251
Electrochem. Solid State Lett. 4 (2001) A191

Separators

Energy Environ. 7 (2014) 3857
J. Solid State Electrochem. 15 (2011) 649
J. Power Sources 77 (1999) 34

Electrolytes

ACS Omega 5 (2020) 23843
ACS Omega 5 (2020) 13541
Chem. Rev. 116 (2016) 140
Chem. Mater. 25 (2013) 2708
J. Power Sources 162 (2006) 1379
J. Power Sources 77 (1999) 183
Adv. Mater. 10 (1998) 439

Some practices include:

Increasing the silicon-based lithium-ion battery anodes

Small 14 (2018) 1702737
Nano Energy 31 (2017) 113
Nano Energy 27 (2016) 359
Adv. Energy Mater. 4 (2014) 1300882
J. Power Sources 267 (2014) 469
Nat. Commun. 5 (2014) 3217

Nickel content of lithium ternary batteries to more than 80% (for example, NMC 811[1])

ACS Energy Lett. 2 (2017) 196
Energy Stor. Mater. 6 (2017) 125
Angew. Chem. Int. Ed. 54 (2015) 4440
ACS Appl. Mater. Interfaces 7 (2015) 6926

Developing electrode materials that can chemically react with Li-ions (or Li-atoms)

Nat. Energy 4 (2019) 594
Energy Environ. Sci. 10 (2017) 435
J. Chem. Phys. 146 (2017) 064502
J. Chem. Phys. 144 (2016) 034502
Part. Part. Syst. Charact. 31 (2014) 317
ACS Appl. Mater. Interfaces 6 (2014) 10892

Discarding flammable organic solvents in the electrolyte and using non-flammable solid electrolyte materials such as ceramics

Chemsuschem 8 (2015) 3039
J. Power Sources 228 (2013) 250
J. Power Sources 195 (2010) 4554
J. Electrochem. Soc. 152 (2005) A2151

[1]NMC 811 is a cathode composition with 80% nickel, 10% manganese, and 10% cobalt.

In recent years, the rapid progress of nano and low-dimensional materials, e.g., graphene, silicene, and other two-dimensional materials providing many choices for the next generation of Li-ion battery materials.

Graphene

ACS Appl. Mater. Interfaces 12 (2020) 22917
J. Phys. Chem. Solids 146 (2020) 109528
Philos. Mag. 100 (2020) 1834
Physica E 114 (2019) 113572
AIP Adv. 8 (2018) 085123
J. Mater. Chem. A 5 (2017) 4912
Sci. Rep. 7 (2017) 17858
Phys. Chem. Chem. Phys. 18 (2016) 7573
J. Appl. Phys. 119 (2016) 214304
Carbon 109 (2016) 883
RSC Adv. 6 (2016) 24458
Philos. Mag. 94 (2014) 1859
Nat. Commun. 4 (2013) 1687
Phys. Chem. Chem. Phys. 15 (2013) 868
Opt. Express 19 (2011) 23350
J. Phys. Soc. Jpn. 80 (2011) 044602
Physica E 42 (2010) 711
Proc. Natl. Acad. Sci. 102 (2005) 10451
Science 306 (2004) 666

Silicene

ACS Omega 5 (2020) 13760

Other two-dimensional materials

Sci. Rep. 9 (2019) 2332
ACS Nano 9 (2015) 11509
ACS Nano 8 (2014) 4033
Phys. Rev. B 87 (2013) 035438

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Thank you for your attention!

Any questions, please E-mail to me

hsienching.chung@gmail.com

The slide will be published online linking with the project

https://doi.org/10.17605/OSF.IO/7FR9Z

About this talk

Dr. Hsien-Ching Chung was invited to give a talk about "Engineering integrations, potential applications, and outlooks of Li-ion batteries" in the conference, "Taiwan-Vietnam Joint International Conference on Emerging Materials and Batteries (ICMB 2020)." The conference was held at National Cheng Kung University, Tainan, Taiwan on Nov. 26~28, 2020. It's a good opportunity to realize fundamental researches and new technologies in the battery industry and the future of the energy industry.

Dr. Hsien-Ching Chung (鍾獻慶博士)

R&D Manager, Super Double Power Technology Co., Ltd., Changhua City, Changhua County, 500042, Taiwan

- **Education**
  - 2011, Ph. D. degree in physics, National Cheng Kung University (NCKU), Taiwan
  - Research topic: graphene and carbon-related systems
- **Experience**
  - 2020-present, R&D Manager, Super Double Power Technology Co., Ltd., Taiwan
  - 2017-2020, R&D Manager, Masterhold Int'l Co., Ltd., Taiwan
  - 2011-2016, Postdoctoral Fellow, NCKU, Taiwan
- **Membership**
  - IEEE, APS, ACS
- **Recent projects**
  - Development of Cloud-native Energy Management Systems for Medium-scale Energy Storage Systems, Role: PI, Taiwan.
  - Technology development and field verification of innovative home energy storage system, Role: co-PI, Fund: 427,000 USD funded by MOEA, Taiwan.
- **Recent publications**
  - Summary of Safety Standards for Repurposing Batteries, Mon. J. Taipower's Eng. **860**, 35 (2020).
  - Action planning and situation analysis of repurposing battery recovery and application in China, J. Taiwan Energy **6**, 425 (2019).
  - Electronic and optical properties of graphene nanoribbons in external fields, Phys. Chem. Chem. Phys. **18**, 7573 (2016).
  - Magnetoelectronic and optical properties of nonuniform graphene nanoribbons, Carbon **109**, 883 (2016).

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Selected Publications of Dr. Hsien-Ching Chung

Li-ion battery

1. Charge/discharge profiles of $LiFePO_4$ repurposing batteries based on UL 1974. *engrXiv* e6p9w (2020), doi:10.31224/osf.io/e6p9w.
2. Summary of safety standards for repurposing batteries. *Monthly Journal of Taipower's Engineering* **860**, 35 (2020), doi:10.31224/osf.io/d4n3s.
3. Action planning and situation analysis of repurposing battery recovery and application in China. *Journal of Taiwan Energy* **6**, 425 (2019), doi:10.31224/osf.io/nxv7f.

Review article

Electronic and optical properties of graphene nanoribbons in external fields. *Physical Chemistry Chemical Physics* **18**, 7573 (2016), doi:10.1039/c5cp06533j.

Low-dimensional materials

Spin-polarized magneto-electronic properties in buckled monolayer GaAs. *Scientific Reports* **9**, 2332 (2019), doi:10.1038/s41598-018-36516-8.

Graphene-related materials

1. Magnetoelectronic and optical properties of nonuniform graphene nanoribbons. *Carbon* **109**, 883 (2016), doi:10.1016/j.carbon.2016.08.091.
2. Effects of transverse electric fields on Landau subbands in bilayer zigzag graphene nanoribbons. *Philosophical Magazine* **94**, 1859 (2014), doi:10.1080/14786435.2014.897009.
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