Understanding and Using Lithium Rechargeable Batteries

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Today's agenda

- Rechargeable batteries
  - Why use rechargeable batteries?
  - Different battery chemistries
  - 'Horses for courses'
- Lithium rechargeable batteries
  - Are they safe?
  - Different types of Lithium cells
    - Chemistry
    - Size
    - Shape

Today's agenda (continued)

- **Lithium rechargeable batteries** (continued)
  - **Selecting a suitable cell for your project**
  - **Connecting cells together**
  - **Charging and discharging**
  - **Battery management systems**
  - **Longevity**
  - **Disposal and recycling**

- **Share your questions**

Your presenter…

- **Simon Chan**
  - **Born in Hong Kong**
  - **Lived in Australia since ’74**
  - **Raised & educated in Perth**
  - **I love R&D and creating new products**
  - **Have worked 31 years in many awesome companies**
  - **Now working for Australia’s largest 2-way radio integration company**
  - **Started using Lithium batteries for our own energy storage needs**
  - **Now creating unique Lithium battery solutions for industry**

Simon Chan
Chief Engineer at Radlink Communications
Perth, Australia | Telecommunications

Current: Radlink Communications, DTPL
Previous: nearmap.com, Remote Control Technologies Pty Ltd, Memo Communications
Education: The University of Western Australia

For more info about me, see: https://www.linkedin.com/in/simonskchan

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Rechargeable batteries – Why?

- Why use rechargeable batteries?
  - Portable equipment
  - People want low cost, lightweight, long battery life – thanks to smartphones & smart devices
  - Include charger on-board to simplify design
  - 10+ years ago, it was very challenging
  - Design is so much easier now!

  - *Audience participation: Why and where do you use rechargeable batteries?*

Rechargeable batteries – Lead Acid

1900's

- Different battery chemistries
  - Lead Acid
    - Readily available
    - Low cost
    - Tolerant to overcharge
    - Lead is toxic
    - Takes long time to charge
    - Heavy (30-50Wh/kg)
    - Easy to damage
      - Heat
      - Excessive discharge
      - Electrodes become brittle with age
    - Limited cycle life
    - Bulge / crack / leak

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Rechargeable batteries – NiCd

1950's

- Different battery chemistries
  - Nickel Cadmium
    - Readily available
    - Low cost
    - Can be rapidly charged (1 to 2 hours to full charge)
    - High peak discharge current
    - Cadmium is toxic
    - Terrible self-discharge characteristics
    - Charge – discharge memory effect
    - Difficult to charge

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Rechargeable batteries – NiMH

1990's

- Different battery chemistries
  - Nickel Metal Hydride
    - Readily available
    - Low cost
    - Good energy to weight ratio
    - Moderate peak discharge current
    - No charge – discharge memory effect
    - Low toxicity
    - Terrible self-discharge characteristics
    - Limited cycle life
    - Double charge time of NiCd

Useful Summary Slide

Specifications	Lead Acid	NiCd	NiMH	Li-ion[1]		
				Cobalt	Manganese	Phosphate
Specific energy (Wh/kg)	30–50	45–80	60–120	150–250	100–150	90–120
Internal resistance	Very Low	Very low	Low	Moderate	Low	Very low
Cycle life[2] (80% DoD)	200–300	1,000[3]	300–500[3]	500–1,000	500–1,000	1,000–2,000
Charge time[4]	8–16h	1–2h	2–4h	2–4h	1–2h	1–2h
Overcharge tolerance	High	Moderate	Low	Low. No trickle charge		
Self-discharge/ month (room temp)	5%	20%[5]	30%[5]	<5% Protection circuit consumes 3%/month		
Cell voltage (nominal)	2V	1.2V[6]	1.2V[6]	3.6V[7]	3.7V[7]	3.2–3.3V
Charge cutoff voltage (V/cell)	2.40 Float 2.25	Full charge detection by voltage signature		4.20 typical Some go to higher V		3.60
Discharge cutoff voltage (V/cell, 1C)	1.75V	1.00V		2.50–3.00V		2.50V
Peak load current Best result	5C[8] 0.2C	20C 1C	5C 0.5C	2C <1C	>30C <10C	>30C <10C
Charge temperature	–20 to 50°C (–4 to 122°F)	0 to 45°C (32 to 113°F)		0 to 45°C[9] (32 to 113°F)		
Discharge temperature	–20 to 50°C (–4 to °F)	–20 to 65°C (–4 to 49°F)		–20 to 60°C (–4 to 140°F)		
Maintenance requirement	3–6 months[10] (toping chg.)	Full discharge every 90 days when in full use		Maintenance-free		
Safety requirements	Thermally stable	Thermally stable, fuse protection		Protection circuit mandatory[11]		
In use since	Late 1800s	1950	1990	1991	1996	1999
Toxicity	Very high	Very high	Low	Low		
Coulombic efficiency[12]	~90%	~70% slow charge ~90% fast charge		99%		
Cost	Low	Moderate		High[13]		

With thanks to Battery University

http://batteryuniversity.com/learn/article/secondary_batteries

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Rechargeable batteries

- Different battery chemistries
  - A case of ‘Horses for courses’
  - For a long time, not a lot of choice
    - Lead acid for heavy duty products
    - NiMH for portable equipment
  - Has been the status quo for a long time
  - Remember the first ‘Brick’ mobile telephones?

- ***But… science and technology have been improving by leaps and bounds!***

Lithium batteries – Safe?

- Are Lithium batteries safe?
  - Yes and no
  - Early generations of Lithium ion batteries were really difficult to charge
    - Lots of heat being generated leading to fires
  - High energy and power density means one small fault leads to a big mess
    - Lead acid: 30-50Wh/kg
    - Lithium Cobalt Oxide: 150-250Wh/kg
  - Stick to design guidelines = Safe!

1990's

5x - 8x

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Lithium chemistries – $LiCoO_2$

- Lithium Cobalt Oxide – $LiCoO_2$
  - Nominal voltage: 3.6V
  - Capacity: 150-200Wh/kg
  - CC/CV charging
  - Eg 18650 cell: 3.6V 2400mAh
  - Charge up to 1C (2.4A) up to 4.2V
  - Discharge up to 1C (2.4A) – no lower than 2.5V
  - 500-1000 cycles
  - Good for smartphones, tablets, laptops, cameras
  - Beware of thermal runaway at 150°C due to overcurrent
  - Toxicity issues with Cobalt

Lithium chemistries – $LiMn_2O_4$

- Lithium Manganese Oxide – $LiMn_2O_4$
  - Nominal voltage: 3.7V
  - Capacity: 100-150Wh/kg
  - CC/CV charging
  - Charge up to 3C up to 4.2V
  - Discharge up to 10C – no lower than 2.5V
  - 300-700 cycles
  - Inside power tools, medical devices, electric cars
  - Beware of thermal runaway at 250°C

Lithium chemistries – $LiNiMnCoO_2$

- Lithium Nickel Manganese Cobalt Oxide – $LiNiMnCoO_2$ (NMC)
  - Nominal voltage: 3.7V
  - Capacity: 150-250Wh/kg
  - CC/CV charging
  - Charge up to 1C up to 4.2V
  - Discharge up to 2C – no lower than 2.5V
  - 1000-2000 cycles
  - Inside E-bikes, electric cars
  - Beware of thermal runaway at 210°C

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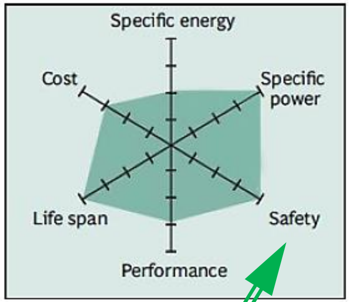
Lithium chemistries – $LiFePO_4$

- Lithium Iron Phosphate – $LiFePO_4$ (aka Lithium Ferro Phosphate or LFP)
  - Nominal voltage: 3.2V
  - Capacity: 90-120Wh/kg (1/3rd weight of lead acid)
  - CC/CV charging
  - Charge up to 1C up to 3.65V
  - Discharge up to 5C – no lower than 2.5V
  - 1000-2000 cycles
  - Good for high load currents and endurance
  - Low risk of thermal runaway (trigger at >270°C)
  - Can tolerate over-charging without damage
  - The 'Safe Lithium battery'
  - Good for Australian conditions & my favourite battery chemistry!



With thanks to Battery University

http://batteryuniversity.com/learn/article/types_of_lithium_ion

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Useful Summary Slide

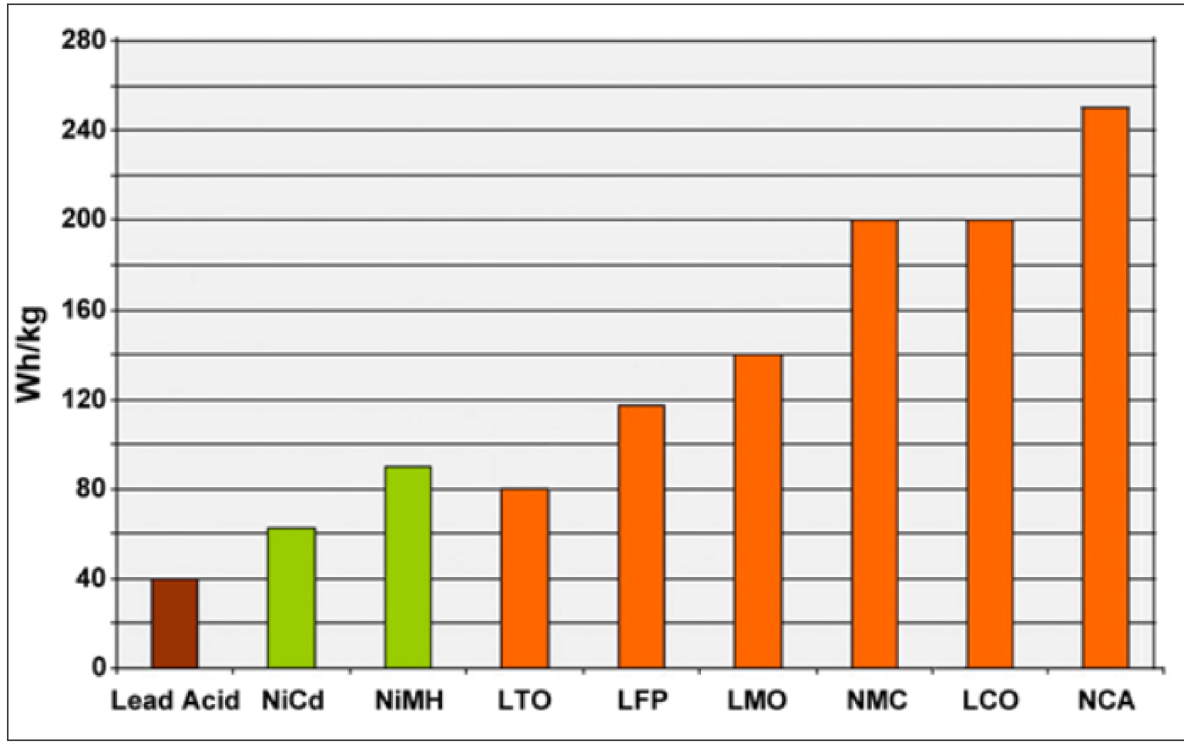

Figure 15: Typical specific energy of lead-, nickel- and lithium-based batteries.

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Useful Summary Slide

12V 22Ah = 260Wh

Lithium Cobalt Oxide
Weight: 1.65kg
Volume: 0.86L

Lithium Ferro Phosphate
Weight: 2.63kg
Volume: 1.48L

Lead Acid
Weight: 7.01kg
Volume: 2.32L

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Useful Summary Slide

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Lithium battery shapes and sizes

- **18650**
  - 18mm diameter
  - 65mm long

Lithium Cobalt Oxide 3.6V 2.2Ah

- **26650**
  - 26mm diameter
  - 65mm long

LFP 3.2V 3.3Ah

- **32650**
  - 32mm diameter
  - 65mm long

LiNMC 3.7V 6.0Ah

Note: Photos not to scale!

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Selecting the right cell for the job

- How will you connect the cells together?

I will focus on LFP but the same technique more or less applies for other Lithium chemistries

  - What is your nominal operating voltage?
    - Divide that by 3.2V to get number of cells in SERIES
  - What is your required Amp-hour capacity?
    - Divide that by cell capacity to give cells in PARALLEL

Selecting the right cell for the job

- Example: we need 36V 90Ah for a scooter

- Nominal operating voltage: 36V
  – Divide 36V by 3.2V = 11.25 cells
  – Can circuit operate at higher or lower voltage?
  – Higher => 12 cells in series
  – Lower => 11 cells in series
  – Since it is a motor, go higher voltage = 12 cells

Selecting the right cell for the job

- Example: we need 36V 90Ah for a scooter
- Require 90Ah
  - 18650 cells come in 1400, 1500 and 1600mAh
  - 26650 cells come in 3000, 3200 and 3300mAh
  - 32650 cells come in 5000mAh only (at this time)
  - Is there a size restriction?
    - No, then select largest cell available = 32650
  - Larger size = higher charging and discharging rate
  - 90Ah divided by 5Ah = 18 cells in parallel

Selecting the right cell for the job

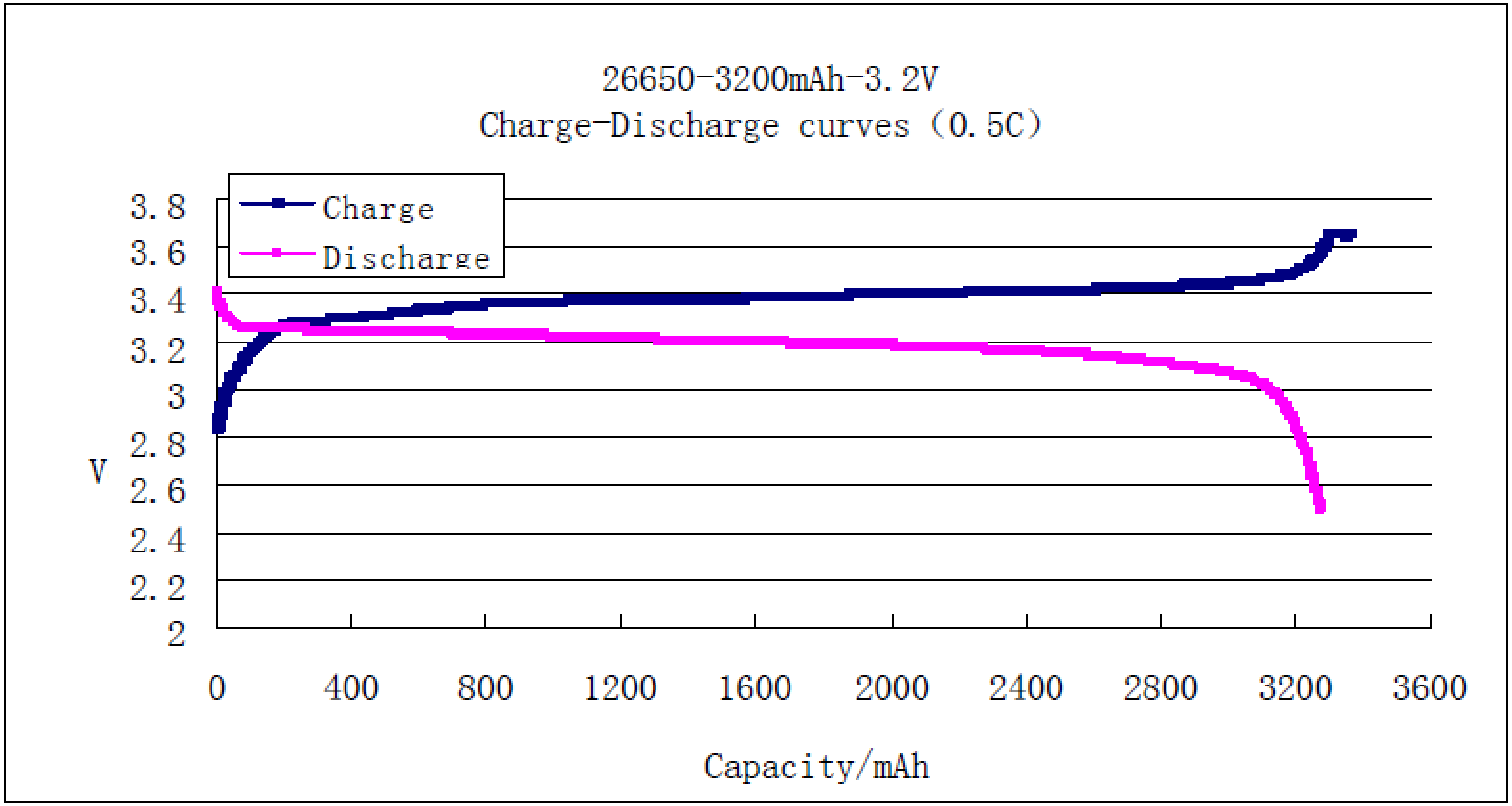
- Example: we need 36V 90Ah for a scooter

- 12 cells in series = 38.4V nominal
  - 12 x 2.5V = 30V minimum (100% DoD)
  - 12 x 3.65V = 43.8V maximum (just charged)
- 18 cells in parallel = 90Ah

- “12S18P 32650 3.2V 5000mAh” battery pack

Selecting the right cell for the job

- Example: we need 36V 90Ah for a scooter



Single cell charge–discharge characteristics

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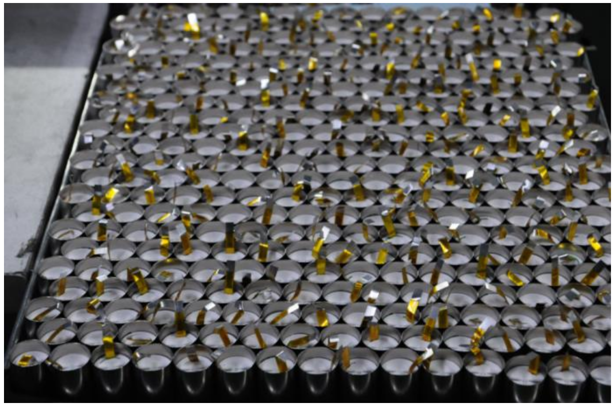
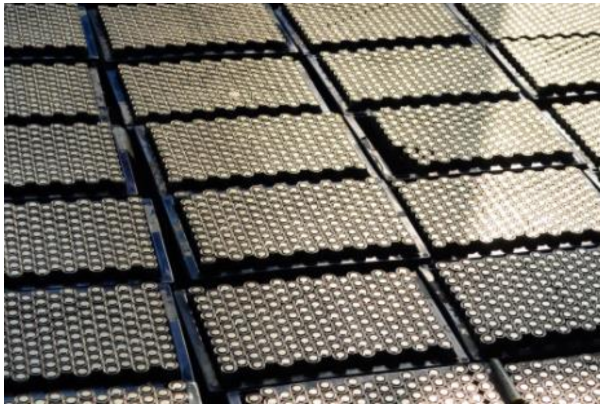
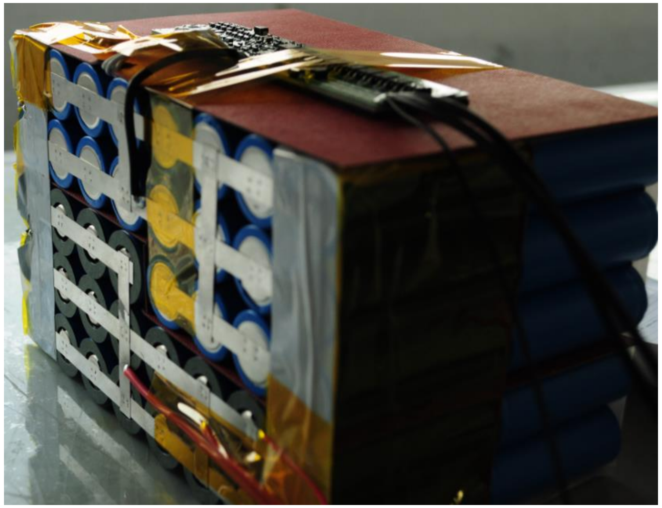
Selecting the right cell for the job







Selecting the right cell for the job

- Example: we need 36V 90Ah for a scooter

- What charging current?
  - 32650 cells can be charged at up to 1C
  - Recommended charge rate C/3 for just over 3 hours
  - 90Ah => CC Charge at 30A for 3.5 hours
    - Or slower at 10A for 10 hours
  - CC/CV => Maximum CV voltage = 43.8V

Selecting the right cell for the job

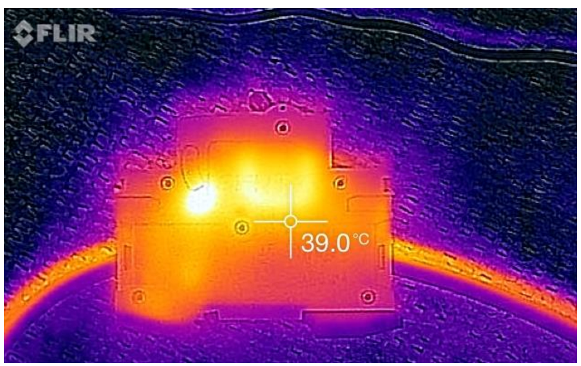
- Example: we need 36V 90Ah for a scooter

- What working current?
  - 32650 cells can be discharged at up to 5C peak
  - 90Ah => 450A starting current
  - Up to 1C operating current => up to 90A for one hour

- Make sure connectors are ‘fit for purpose’!!

Selecting the right cell for the job

- Remember I^2R losses generate a lot of heat!
  - Interconnections between cells
  - Cables to the load
  - Connector pin sizes



- Make sure there is enough space for heat to escape...

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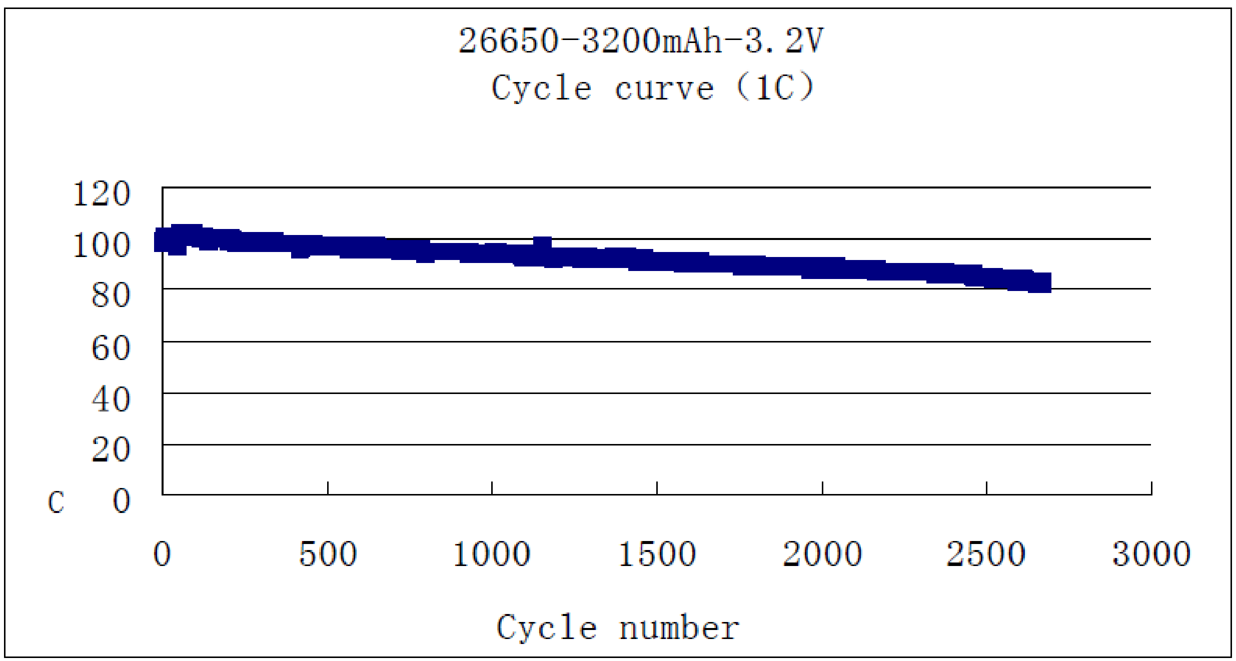
Battery Management System (BMS)

- Insurance policy… protects against misuse and abuse:
  - Over-voltage (ie over-charging)
  - Under-voltage (ie over-discharging)
  - Over-current (ie excessive continuous current)
  - Short-circuit (ie fault generated over-current)
  - Over-temperature (eg incorrect usage)
- Monitors each parallel bank of cells continuously for fault conditions

Anticipated battery life – longevity

- **High quality LFP battery cells have a minimum life of 2000 charge-discharge cycles**

Cycle Characteristic	2000 times	100% DOD, the residual capacity is no less than 80% of rated capacity at 1C rate.



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Anticipated battery life – longevity

- If charge and discharge are managed correctly (eg 70% DoD as with Lead Acid), can expect 6000 cycles of charging and discharging

- That's over 16 years of daily charging and discharging!

Disposal and recycling

- While LFP cells do not contain toxic chemicals, unplanned disposal in Australia is still a concern
- Other Lithium chemistries are even worse
- Recycling batteries in Asia is one option
- Opportunity for Australian business

Summary

- Although Lithium batteries have been around for nearly 20 years, the rate of adoption only took off after smartphones became a commodity
- Proliferation of EV and Solar PV systems are driving new requirements and opportunities
- The demand for lightweight, long life and low cost energy storage solutions is going ‘gangbusters’
- I personally believe smart, networked and managed LFP based battery solutions will have a bright future
- Coupled with correct energy harvesting, conversion and distribution systems, energy storage will change the world

It's your turn now…

- I have had my chance to talk, it is now your turn to share your questions
- Please post your questions in the TEXT MESSAGES box (left side of Electromeet)
- If you have complex questions, or wish to exchange ideas, we can do this after the session or at a later date
- Please Email me at simon.chan@radlink.com.au

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