Li-Ion Tech Trends
Lunch & Learn

We will begin in a few moments. We encourage you to use a separate phone to dial-in for the audio and use your computer for the presentation material only.

Participants are automatically muted but may ask questions via your control panel.

If there are problems with the audio, please try dialing an alternate (US dial-in is 213-929-4221).

We will be taking questions at the end but feel free to submit questions at any time.

All past & future webinars listed at: www.varta-storage.com/webinars

VARTA Lunch & Learn Series
Past & Future Topics

Upcoming Webinars

Jul 09, 2020	Tech Trends for Li-Ion: NMC, NCA, LFP, LCO - Learn what it all means
Jul 17, 2020	Batteries and Big Data - Multiply Your Business with One Design Change
Jul 23, 2020	Factory Tour: Automated Battery Pack Assembly Plant

www.varta-storage.com/webinars

Past Webinars

Jun 19, 2020	Transportation Regulations for Li-Ion Batteries
Jun 11, 2020	Batteries 101 - Just the Basics
Jun 05, 2020	Standard Lithium-Ion Batteries for Floor Cleaners
May 29, 2020	10 Things to Know when Choosing a Battery Supplier
May 22, 2020	Logistics AGV / AMR - Powering and Charging
May 15, 2020	Custom Battery Design Tips
May 07, 2020	Spotlight on Innovative Agricultural Robotics Solutions – Powering and Charging
May 01, 2020	Application Specific Standard Battery Workshop
Apr 24, 2020	VARTA Battery Solutions for Robotics (Agriculture and Logistics)
Apr 17, 2020	Custom or Standard – Which Battery is Best for You?
Mar 27, 2020	Learn what VARTA has to offer the mobile robotics industry...

Li-Ion Tech Trends

"Lithium-Ion" is a catch-all for a variety of battery chemistry variants - and they are not all the same. Join us for a webinar to explain the differences and recent industry trends in Li-Ion technology.

Attend this webinar to:

- Learn what chemistry and cell size options are available for Li-Ion
- See application examples for different requirements
- Learn how to select the right Li-Ion solution for your device

Presenter: Dan Friel, National Business Development Manager, VARTA

Linked-In: Dan Friel: https://www.linkedin.com/in/dan-friel-2004

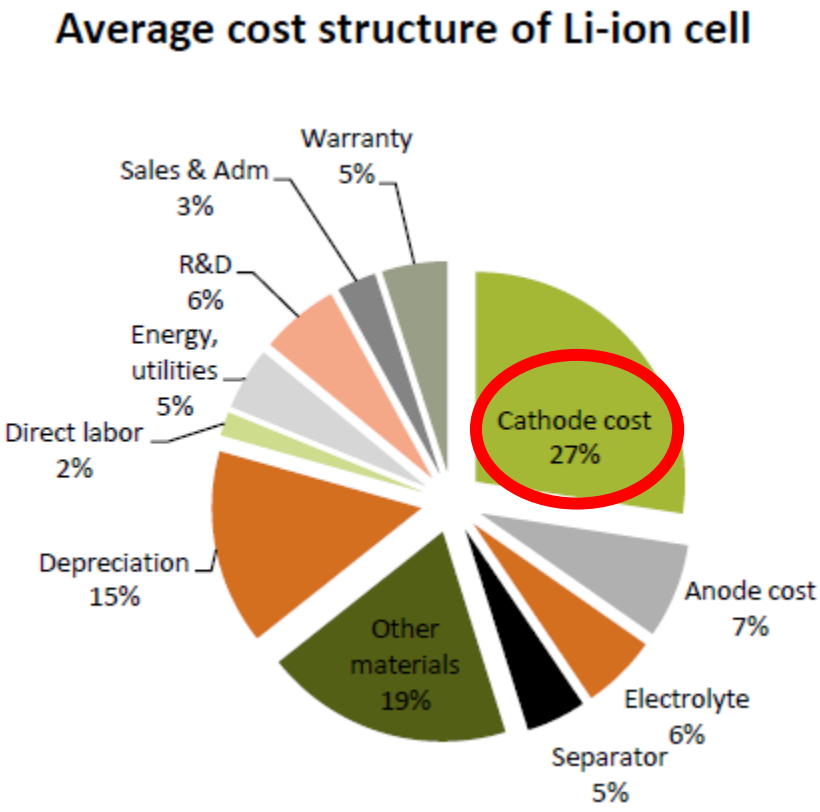
Email: dan.friel@varta-microbattery.com

Li-Ion Tech Trends

History: Changes in Cell Suppliers & Costs

- Sony commercialized Li-Ion in 1990‘s
- Panasonic & Sanyo (Japanese) dominated batteries until 2000‘s
- Panasonic buys Sanyo in 2009
- Sony sell battery business to Murata in 2018
- Korean players now dominate: Samsung SDI and LG Chem
- China continues to improve: CATL, BYD, Lishen

- Costs dominated by Cathode (~1/3)
  - Cobalt is the highest-cost Cathode



Sources: VARTA, cell manufacturers, Avicenne

Li-Ion Tech Trends

History: Consumer Electronics driving Li-Ion Cell Market

Now: EV Market is literally driving the Market

Ex: Reuters: Car makers investing $300B in EVs (2019)

What does this mean for supply?

- Pushes up component pricing (Cobalt 2x in 2018)
- Reduces choice – cell sizes being discontinued

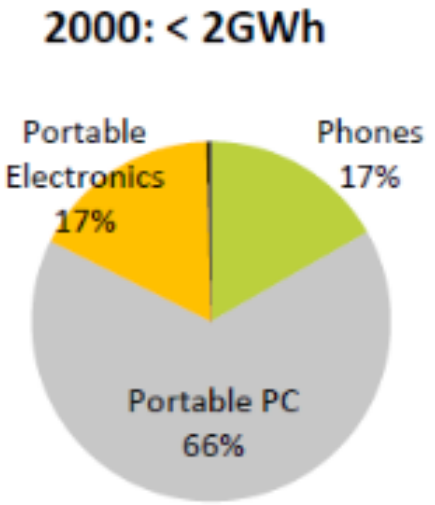
Market Still Small, But Growing

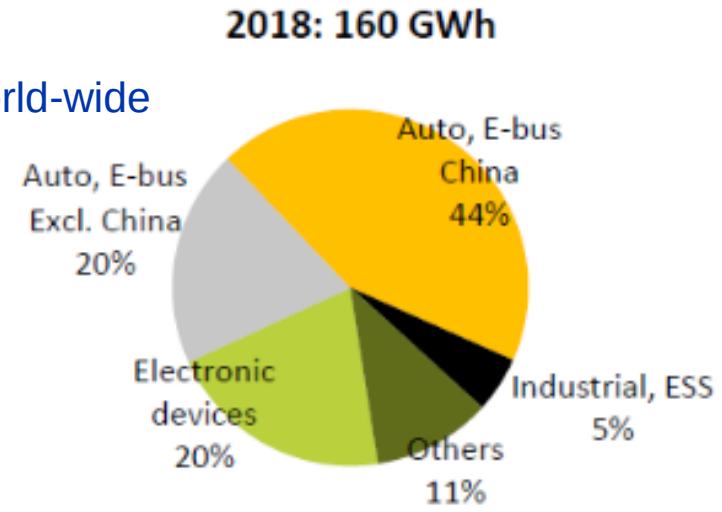
- Even a small number of EVs requires a large number of cells
- (Tesla uses ~7000 cells per vehicle)

Est. ~2M EVs sold world-wide; 17M+ total vehicles sold world-wide

All the Major Players are Shifting Focus

- Panasonic supplies Tesla (Cylindrical)
- LG Chem supplies GM (Pouch)



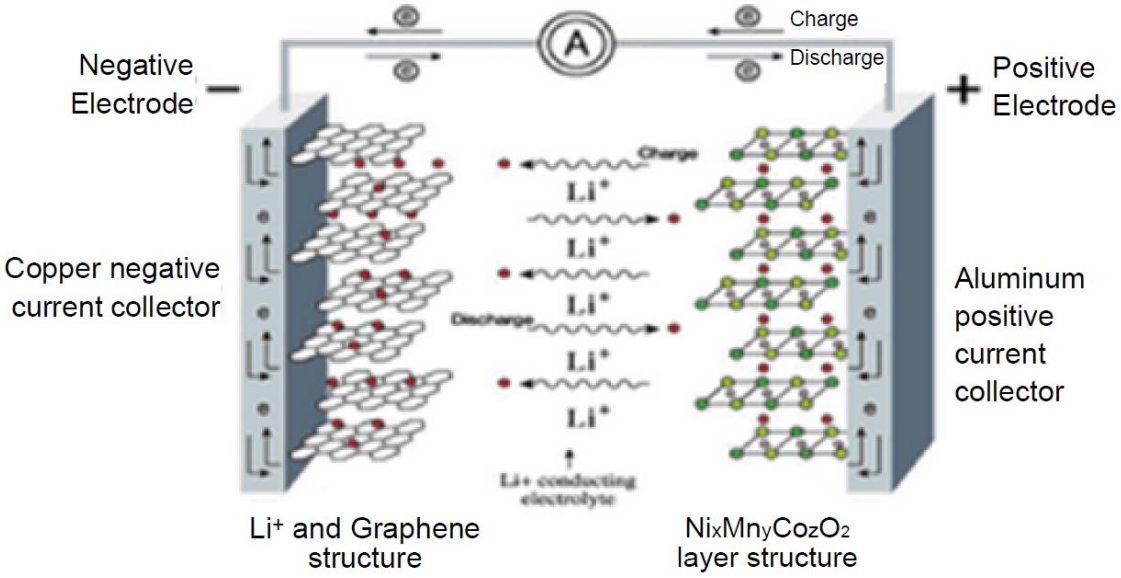


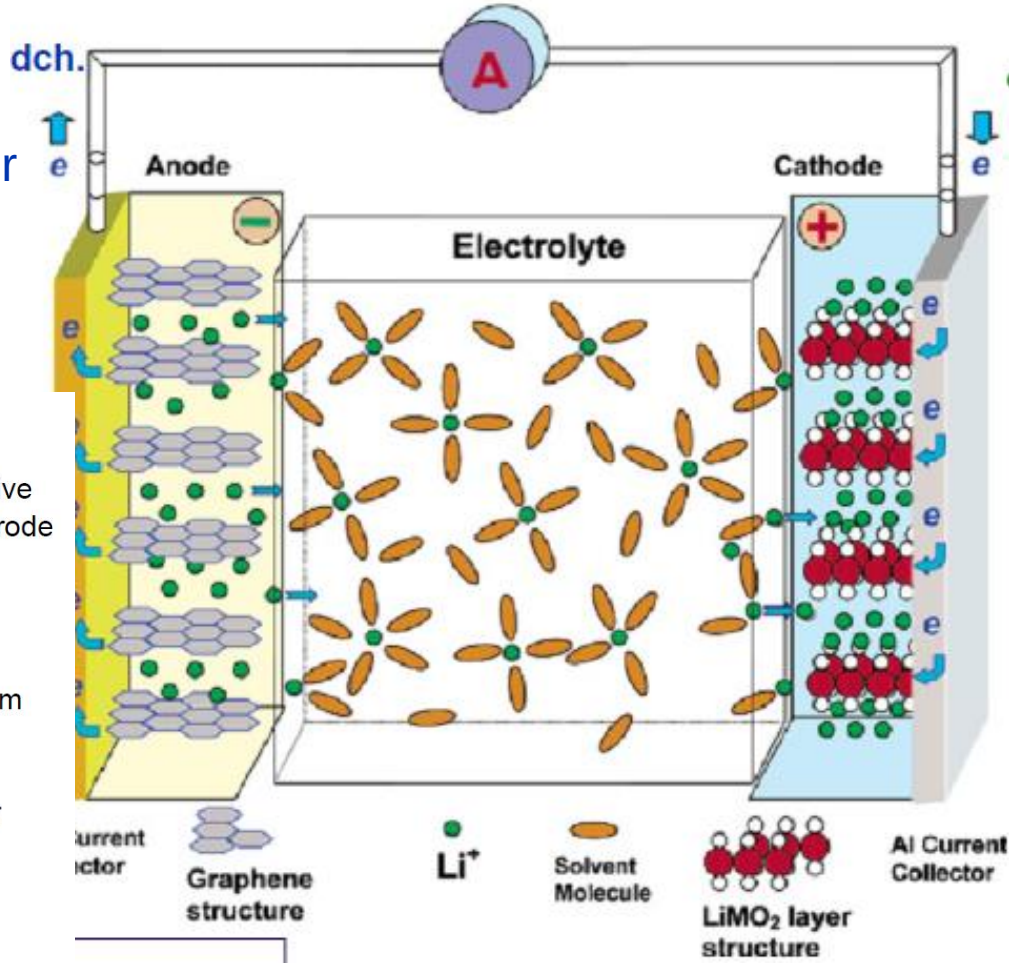
Sources: Wall Street Journal, Reuters, VARTA; Avicenne

Li-Ion Tech Trends

What's Inside: Chemistry 101

- Anode, Cathode, Electrolyte, Separator
- Same for Rechargeable or Primary

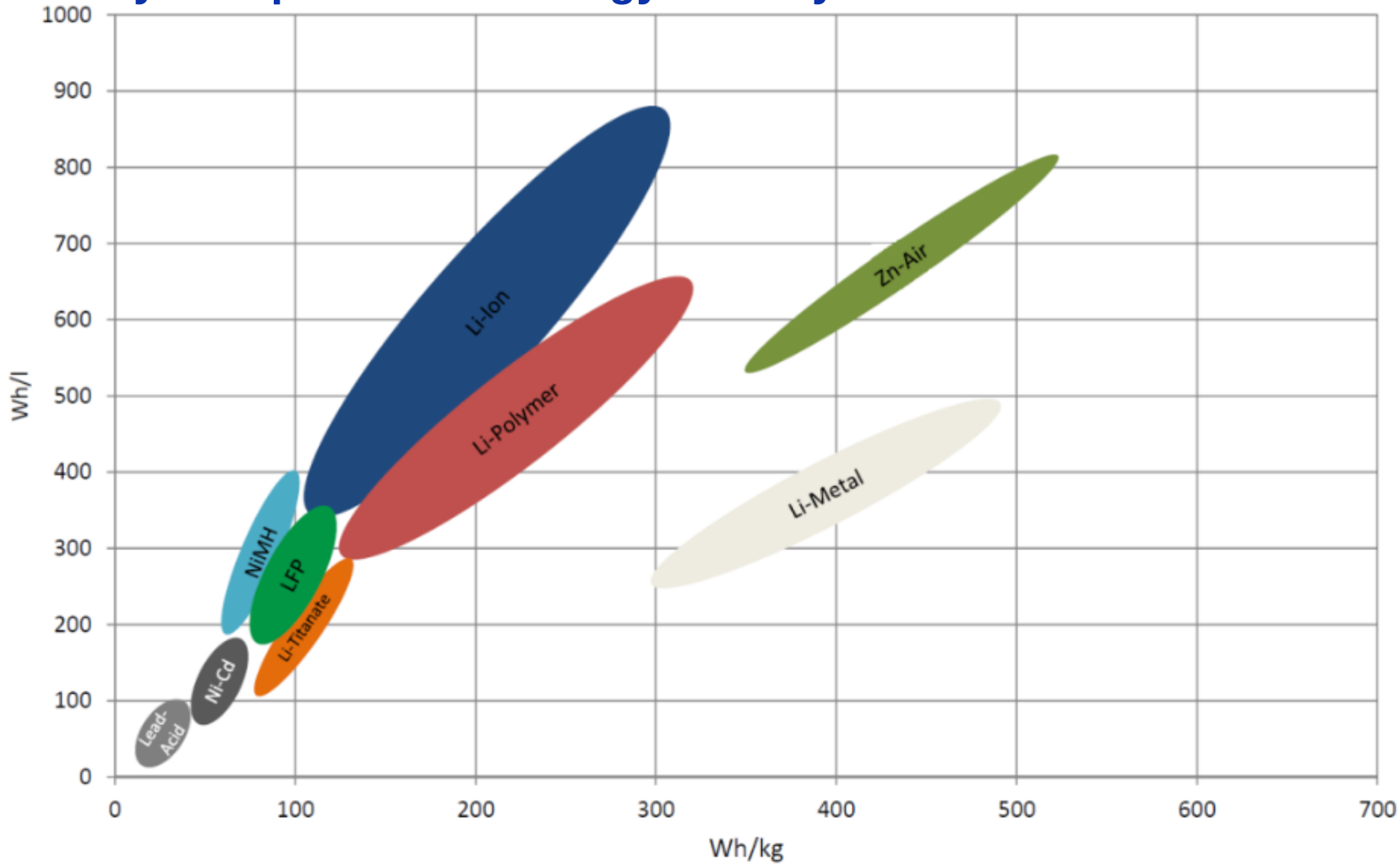




Sources: VARTA, Linden's Handbook of Batteries

Li-Ion Tech Trends

Cell Chemistry Comparisons – Energy Density



Sources: VARTA

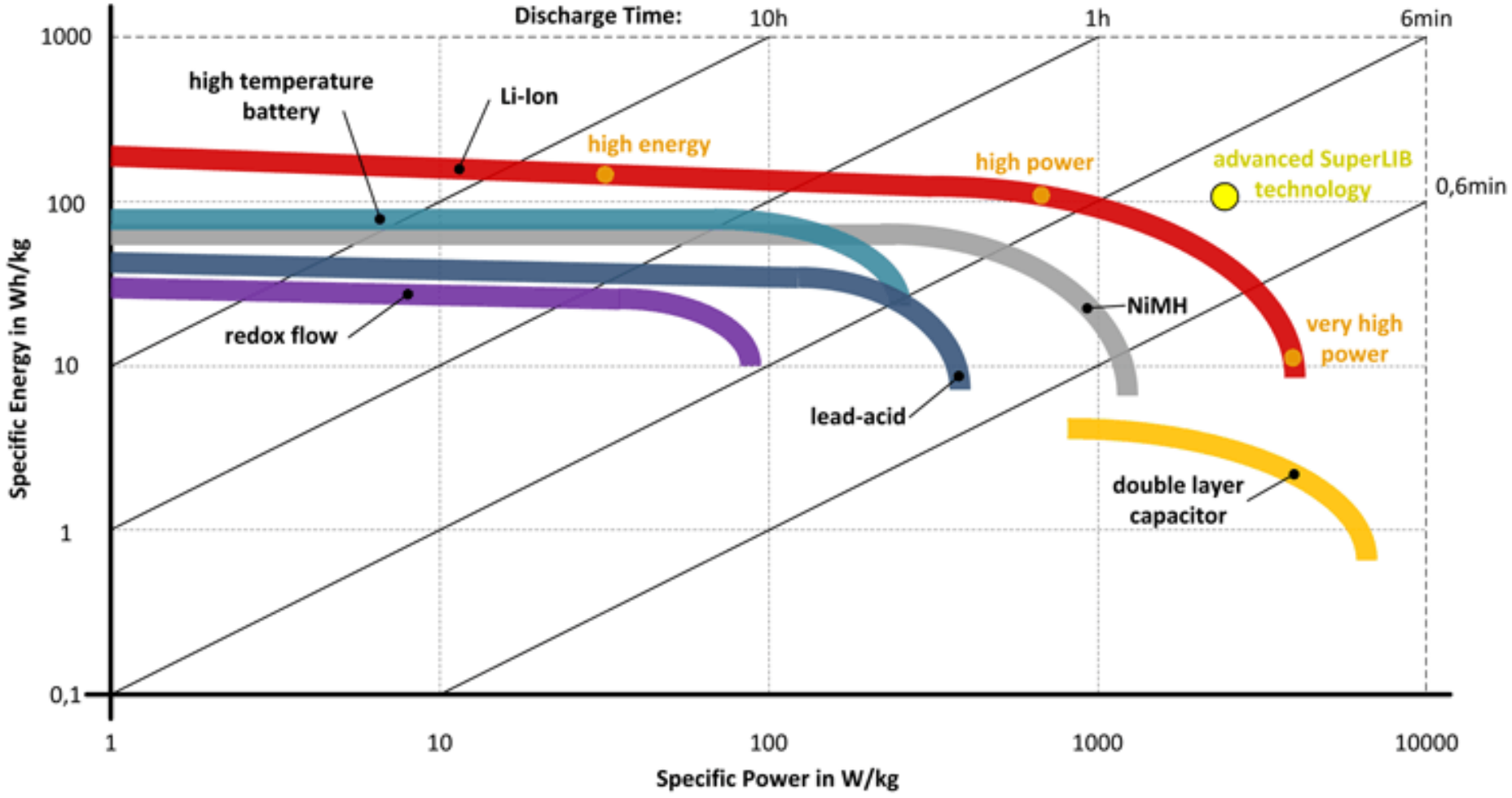
Li-Ion Tech Trends

Power vs. Energy

- Power = High Current, Short Duration
  - Power is rate of current: Usually in Watts = Volts x Amps
- Energy = Low/Medium Current, Long Duration
  - Energy is duration of Power: Has a time component, i.e. Amp-Hours, Watt-Hours

Li-Ion Tech Trends

Cell Chemistry Comparisons: Energy (Run-time) vs. Power (Peak)

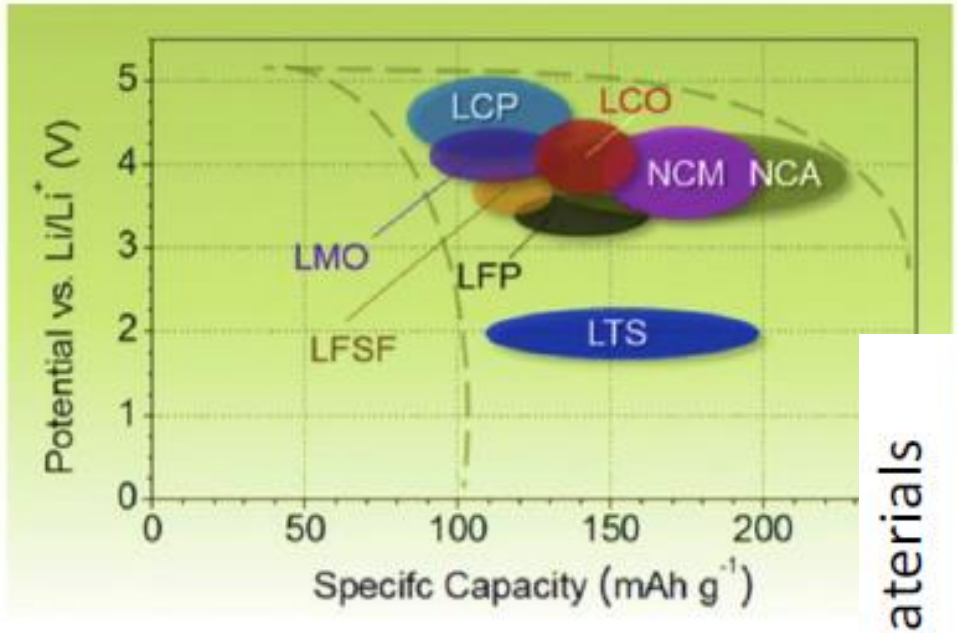


Sources: Avicenne

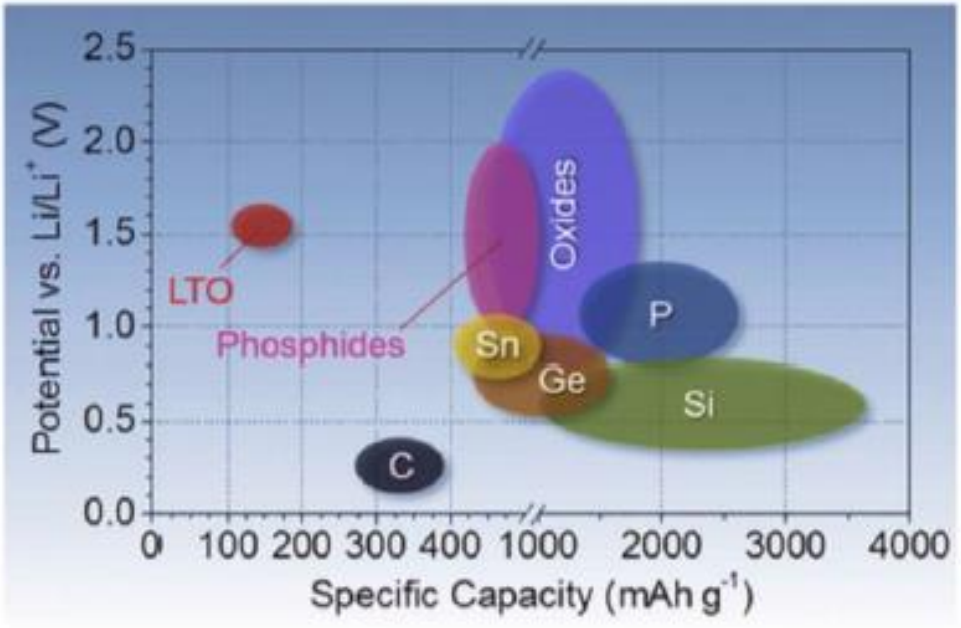
Li-Ion Tech Trends

Cell Chemistry Comparisons

Cathode Materials



Anode Materials



Li-Ion Tech Trends

Alphabet Soup

Positive Electrode Material (Cathode)

- Lithium Cobalt Oxide: LCO
- Lithium Nickel Manganese Cobalt: NMC or NCM
- Lithium Nickel Cobalt Aluminum Oxide: NCA
- Lithium Manganese Oxide: LMO
- Lithium Iron Phosphate: LFP

(Negative Electrode – Anode – is Graphite Carbon, perhaps with Silicon)

And the "mix" – Examples for NMC

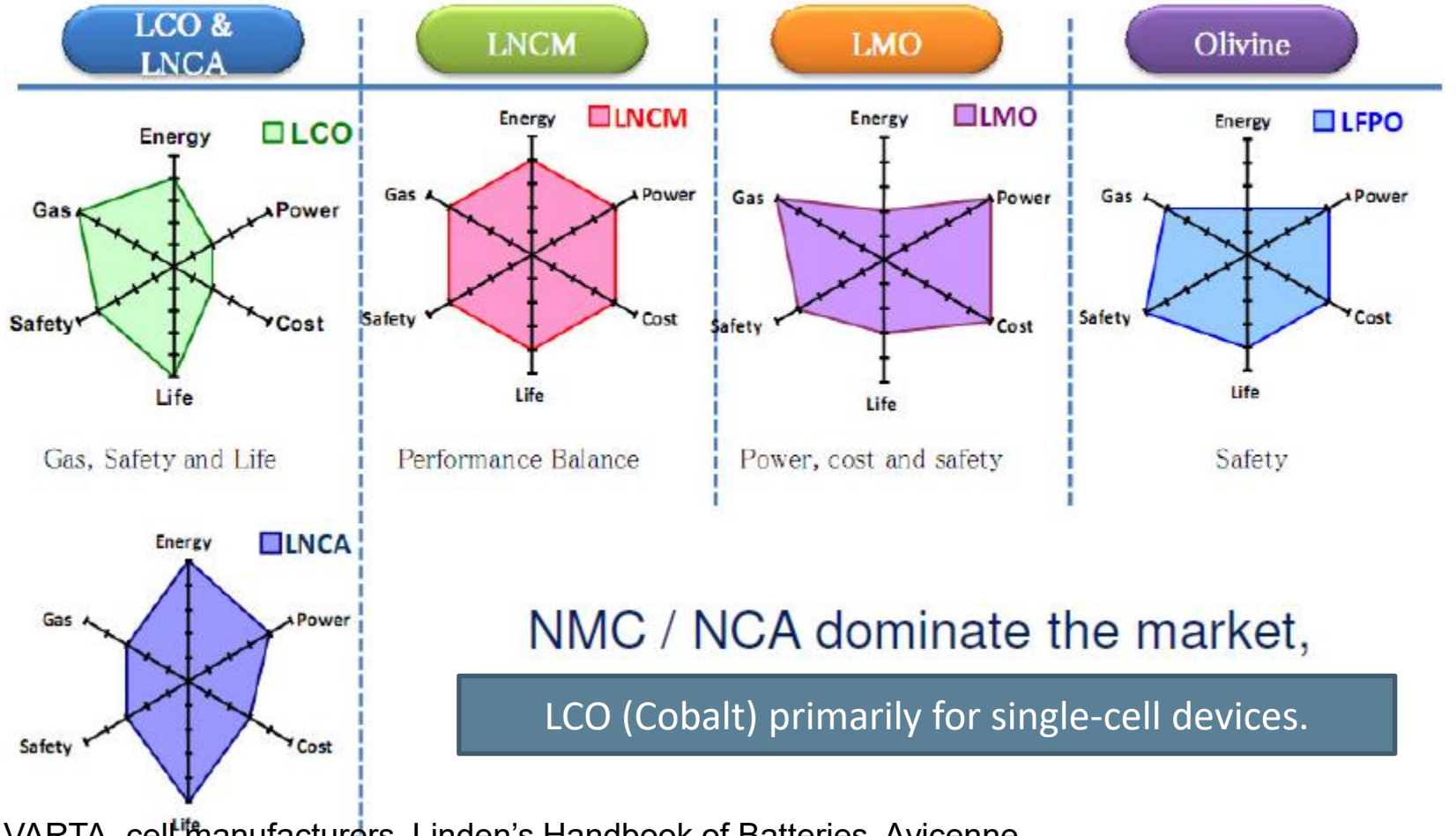
- NMC 111: Ni, Mn, & Co in equal ratios: High Capacity & Temp Stability
- NMC 532: Ni 0.5, Manganese 0.3, Cobalt 0.2:
- NMC 622: Ni 0.5, Mn 0.2, Co 0.2: Good Capacity, Good Temp Stability
- NMC 811: Ni 0.8, Mn 0.1, Co 0.1: Low Capacity, Low Temp Stability, Low Cobalt

Sources: Linden's Handbook of Batteries, Fifth Edition, McGraw-Hill, 2019

Li-Ion Tech Trends

Cell Chemistry Comparisons – Top Level

Comparison of cathode materials



NMC / NCA dominate the market,

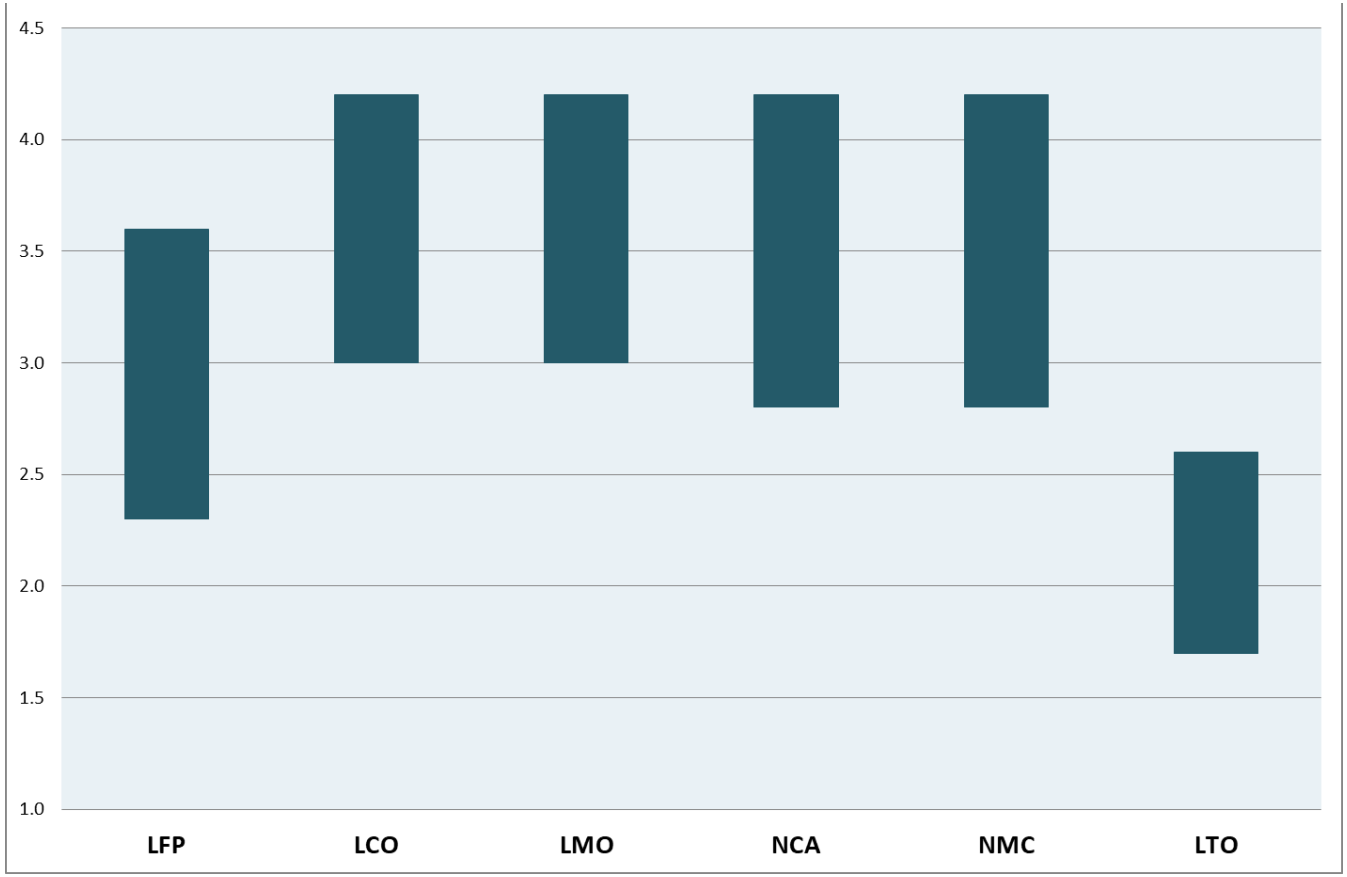
LCO (Cobalt) primarily for single-cell devices.

Sources: VARTA, cell manufacturers, Linden's Handbook of Batteries, Avicenne

Li-Ion Tech Trends

Voltage Variation by Chemistry

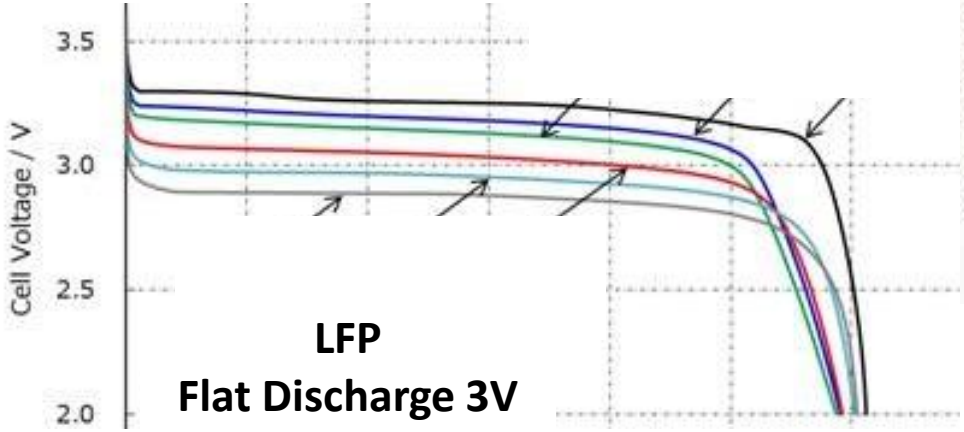
- Each Chemistry has a unique voltage range

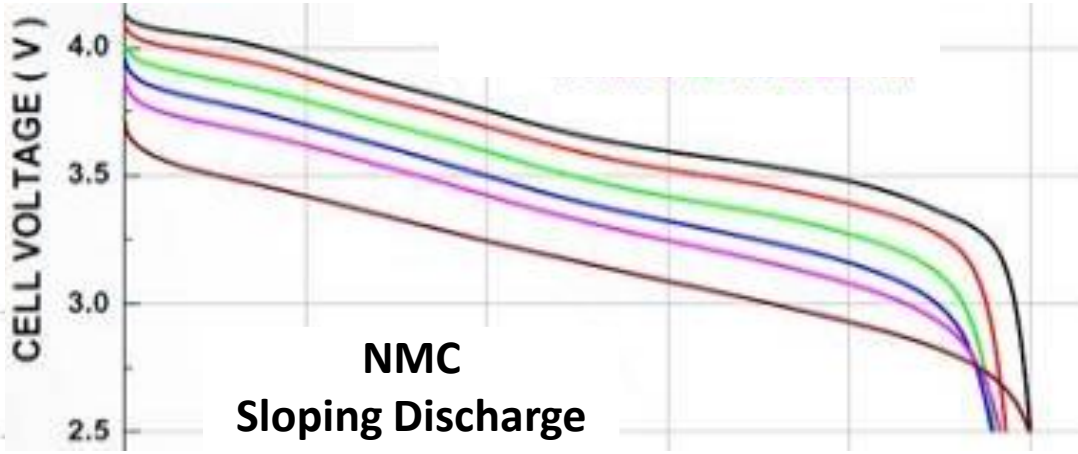


Li-Ion Tech Trends

Voltage Variation by Chemistry

- Battery is NOT a constant voltage output device
  - Chemistry has a unique discharge voltage profile
  - Altered by magnitude of discharge (load) Current

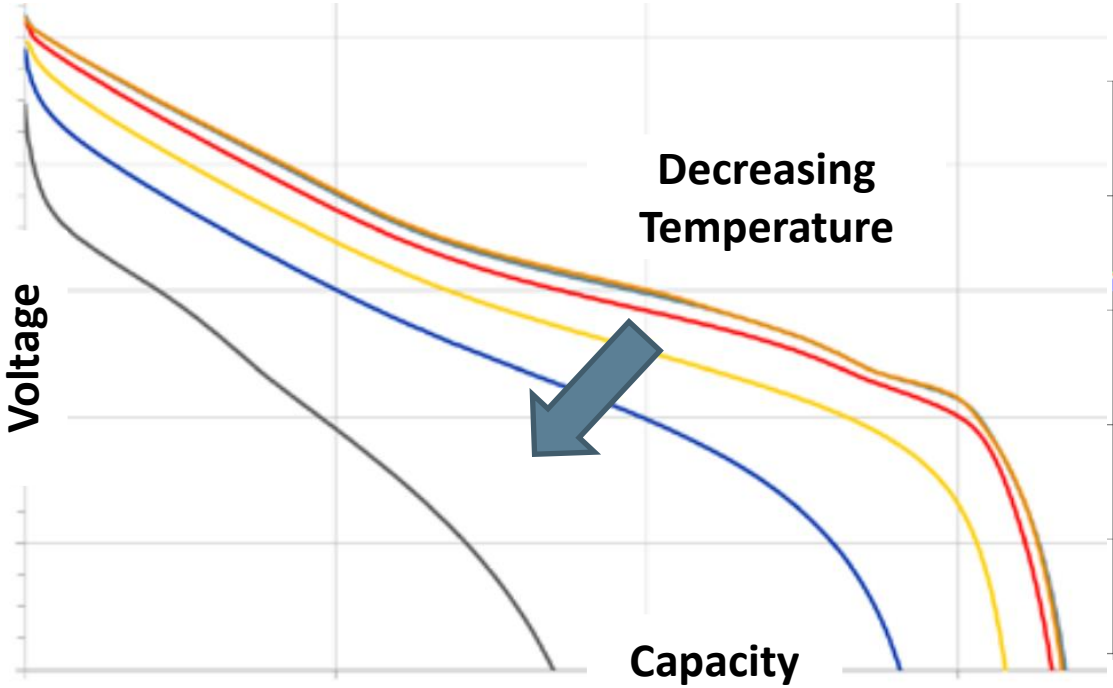


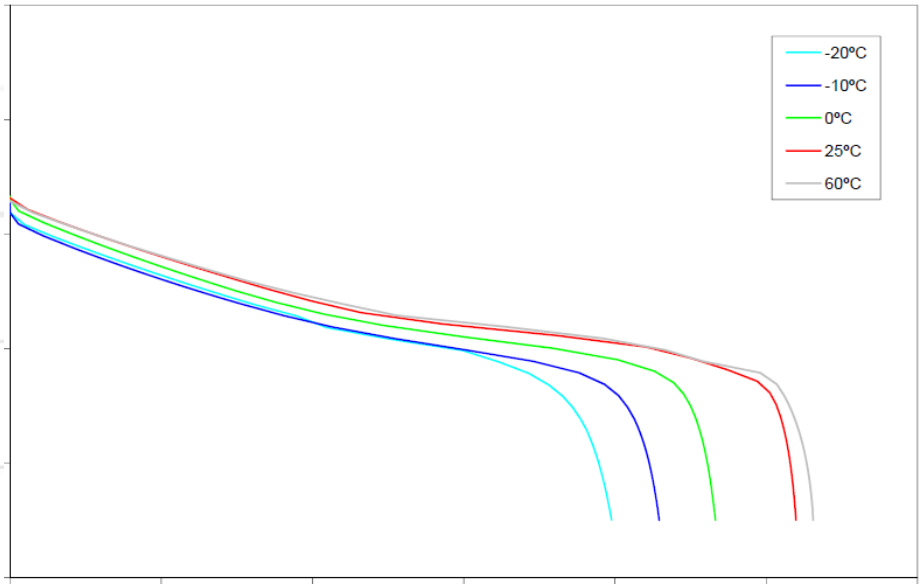


Li-Ion Tech Trends

Voltage Variation by Chemistry

- Significantly altered by Temperature



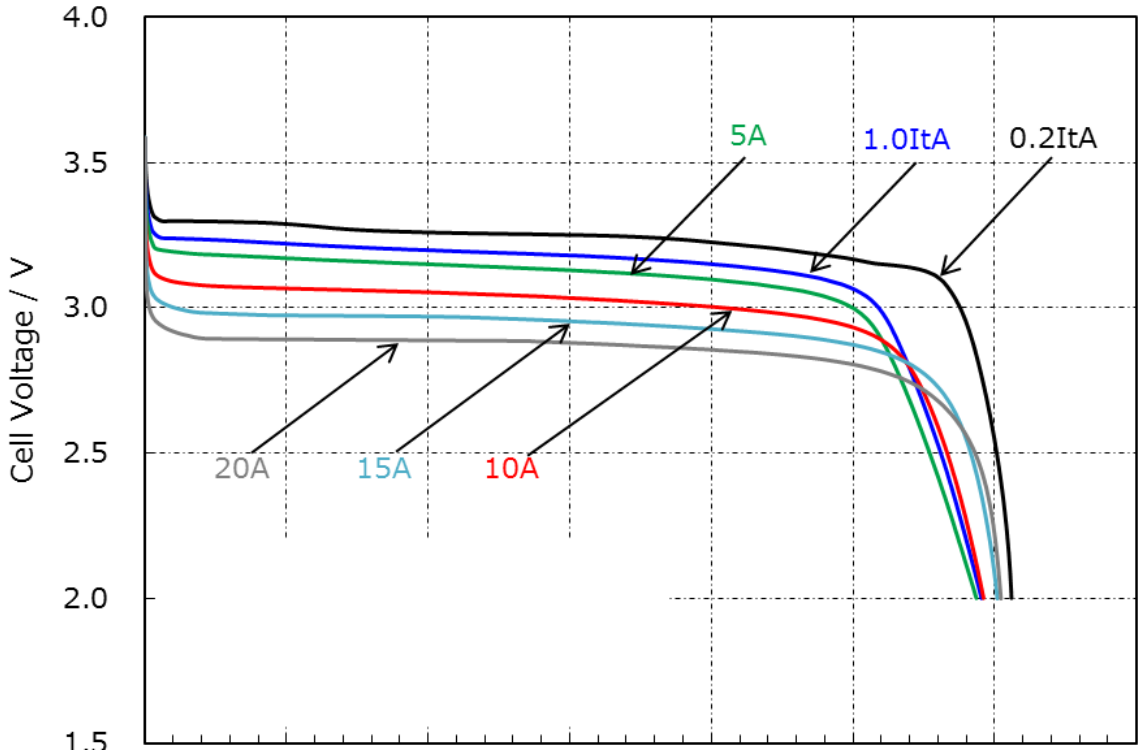


Li-Ion Tech Trends

Voltage Variation by Chemistry

LFP Discharge Cell Voltage

Limited impact from Discharge Current

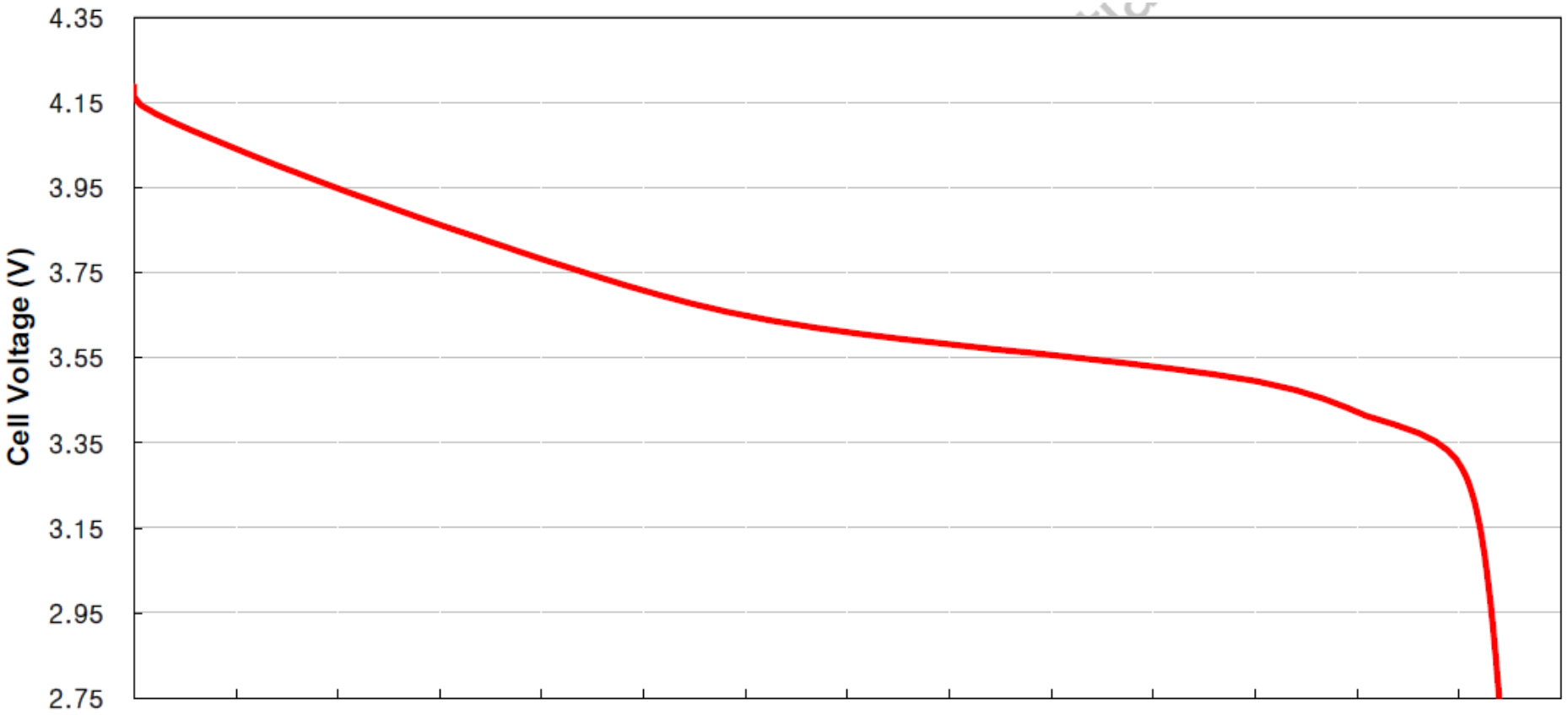


Sources: VARTA & cell manufacturers

Li-Ion Tech Trends

Voltage Discharge Profiles

NMC Cell Voltage during Discharge



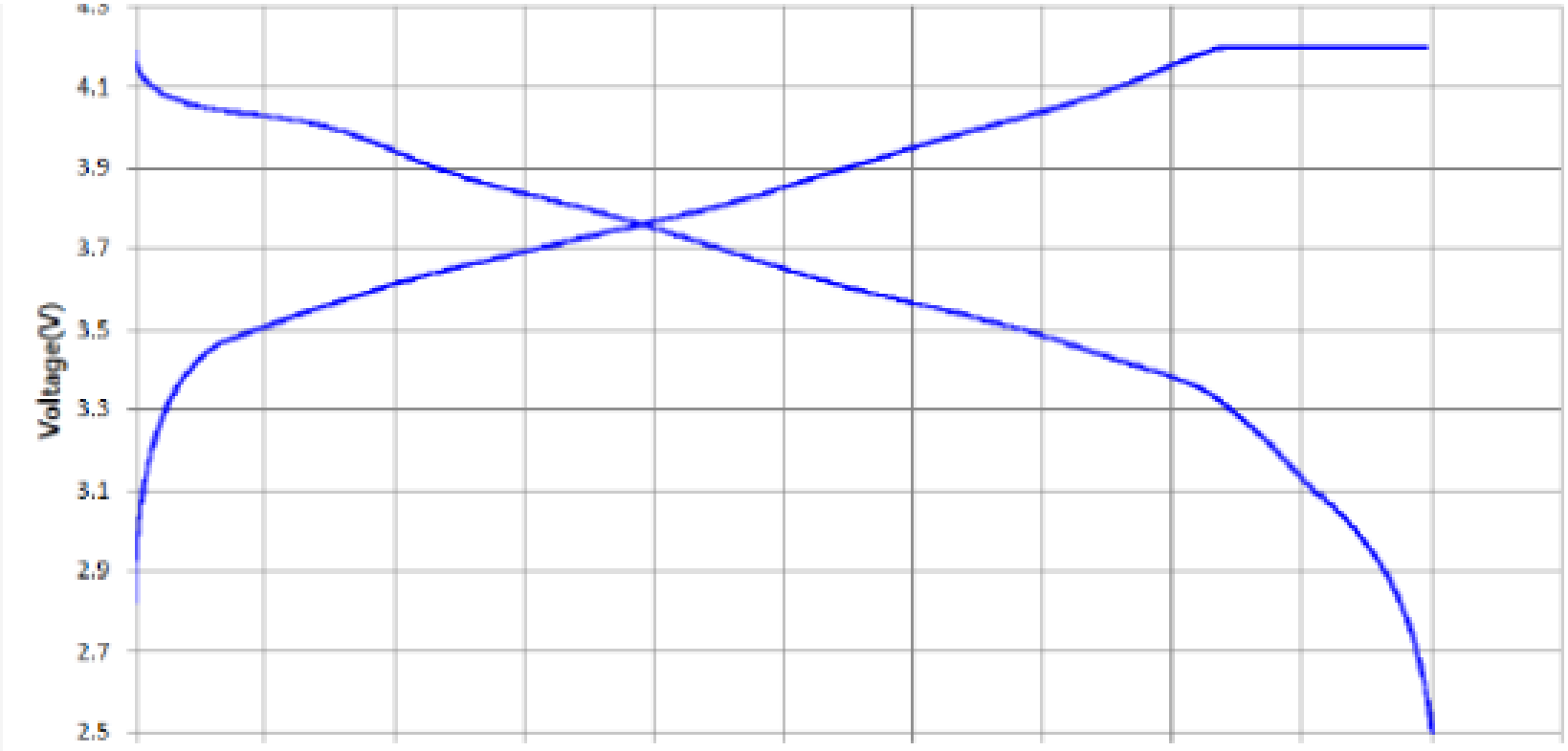
Sources: VARTA & cell manufacturers

Li-Ion Tech Trends

Voltage Discharge Profiles

NCA Cell Voltage during Discharge and Charge

Generally higher during Discharge

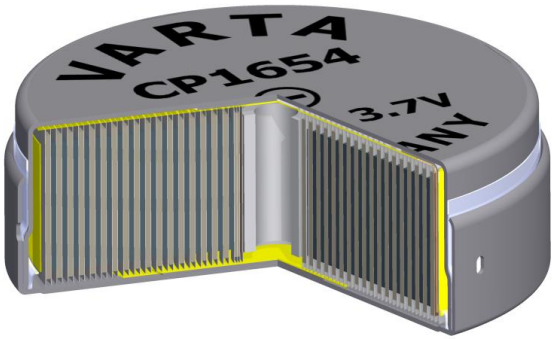


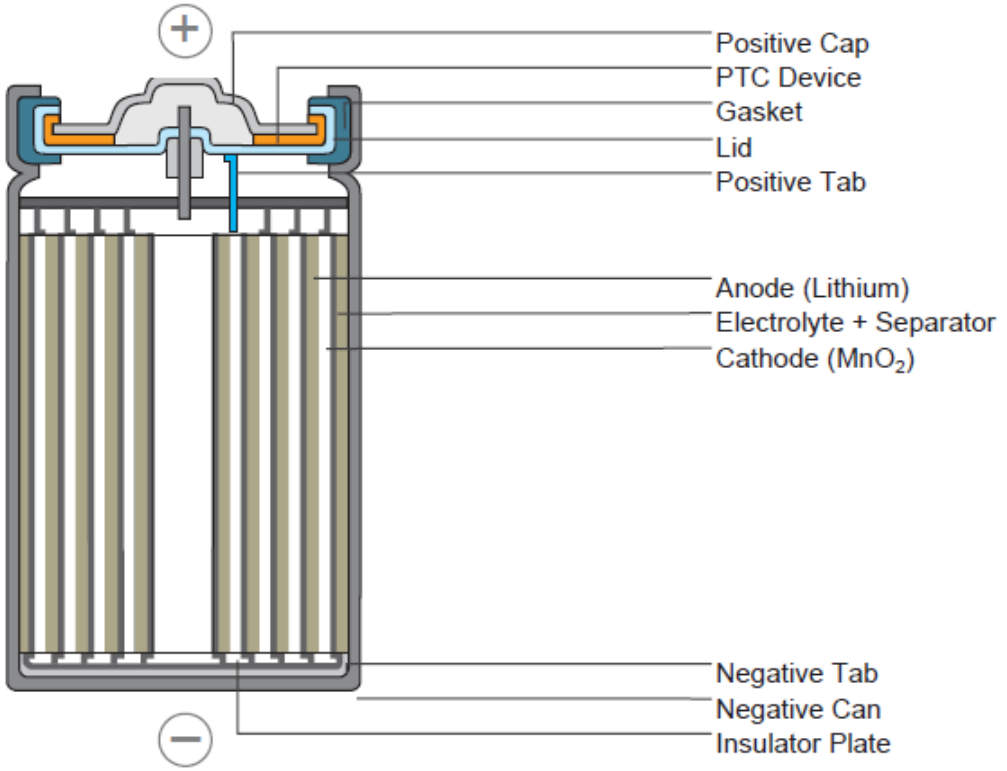
Sources: VARTA & cell manufacturers

Li-Ion Tech Trends

Cell Construction:

- Construction determines many criteria:
  - Capacity, Power, Safety … & Cost





Li-Ion Tech Trends

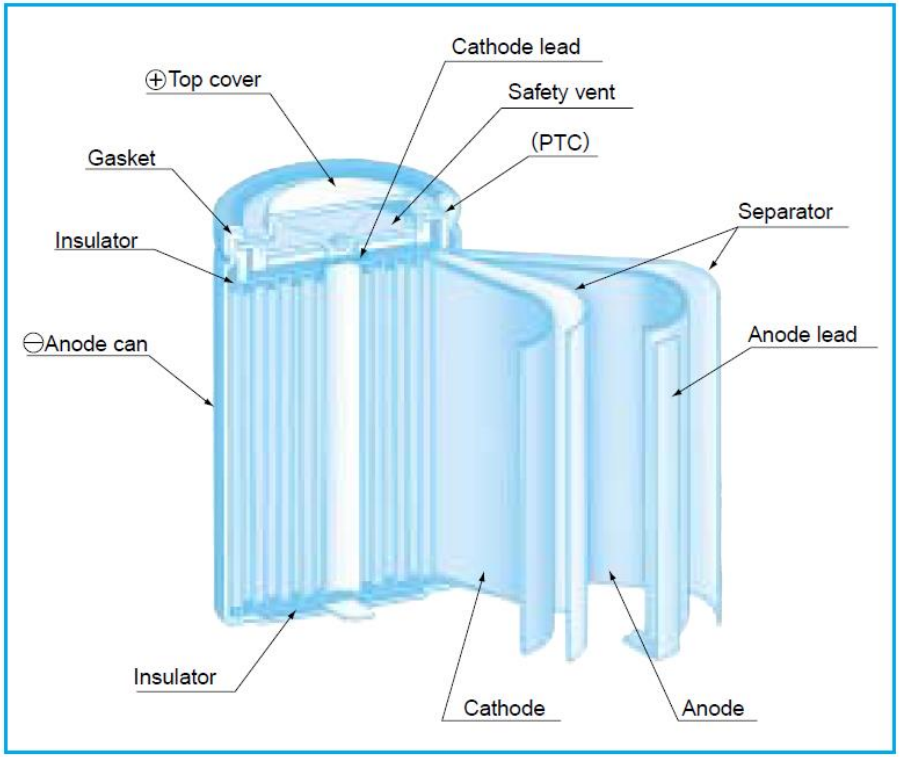
- **Cell Construction for Application:**
  - Power vs. Energy

Type	Energy Cell	Energy & Power Cell	High Power Cell
Cathode			
Anode			
J/R			

Li-Ion Tech Trends

Cell Types: Rechargeable Li-Ion

- Cylindrical:
  - 18650, 21700, 26650 & others
  - Best Rate Capability: Fast Charge & Discharge
  - Lowest Cost & Highest Energy Density
  - Other sizes exist: 18500, 14500, etc.

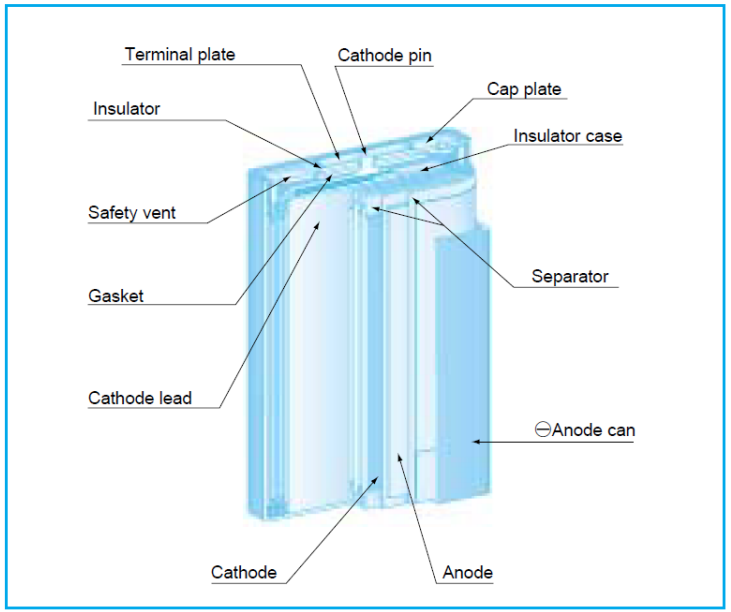


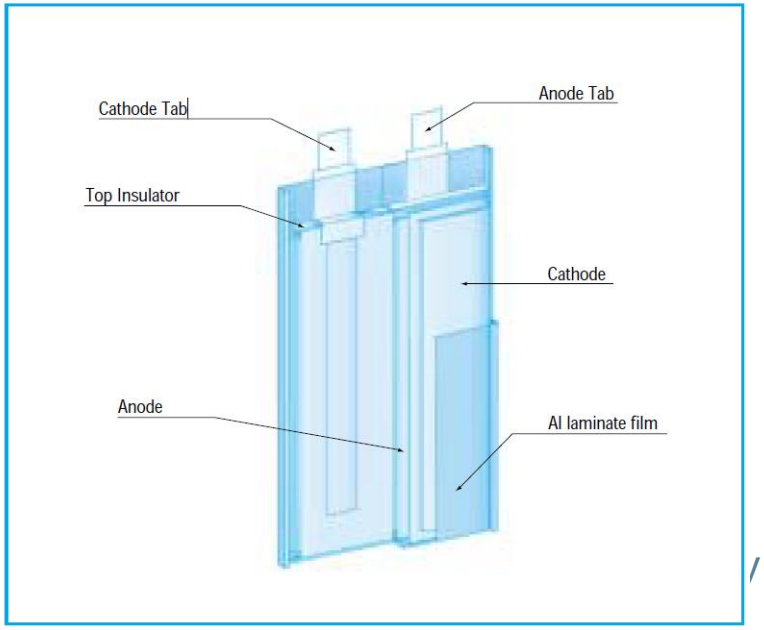
Images courtesy of Sony (now Murata)

Li-Ion Tech Trends

Cell Types: Rechargeable Li-Ion

- Prismatic: 103450 = 10 x 34 x 50 mm
  - Good Energy Density; Good Charge & Discharge
  - Limited Sizes (z x 34 x 50mm most common & available)
- Pouch/Polymer: Various sizes – Usually thinner than 10mm
  - Lower Energy Density (due to thin size); Reasonable Charge & Discharge
  - Thinnest options available; but more X-Y-Z size options – has swelling issues



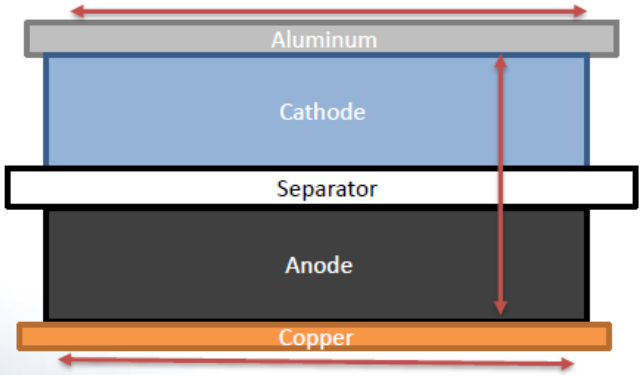


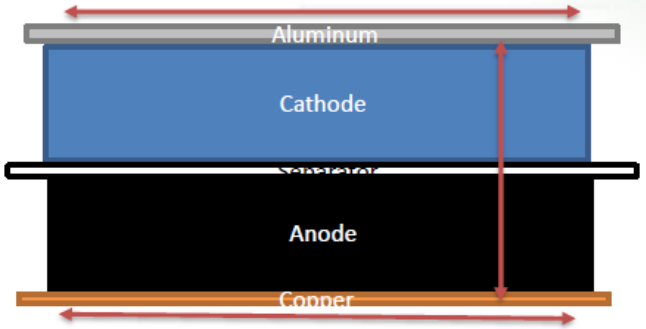
Images courtesy of Sony (now Murata)

Li-Ion Tech Trends
Future

Cells

- Push for Energy Density (Capacity) via cell construction techniques





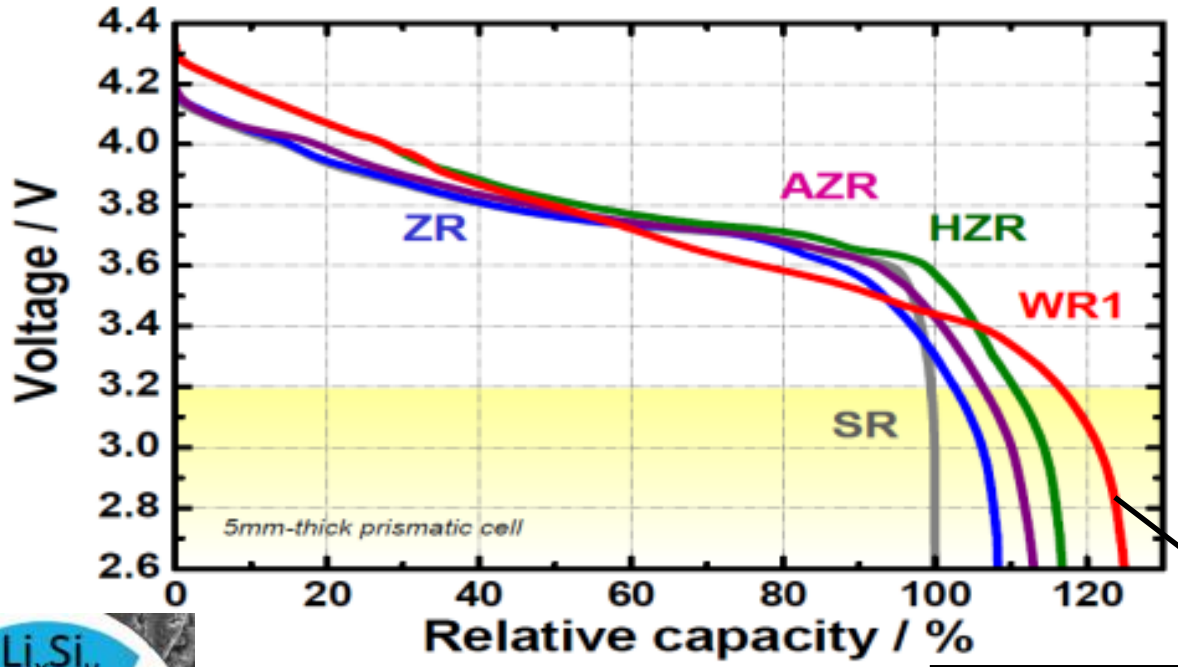
- 2010
  - Thick separator, current collectors
  - Relatively low energy density electrodes
  - 150 Wh/kg
- 2017
  - Separators, current collectors much thinner
  - Higher energy density electrodes
  - 300 Wh/kg

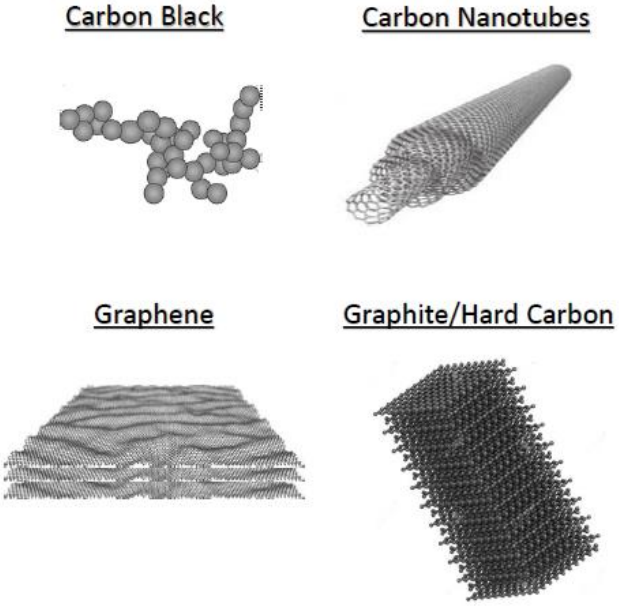
Sources: Dreamweaver International, VARTA

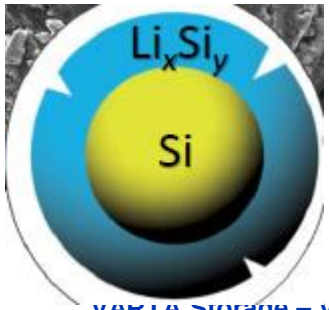
Li-Ion Tech Trends
Future Trends

New Chemistry Formulations

- Silicon in Anode – already occurring (and lots of development upside)







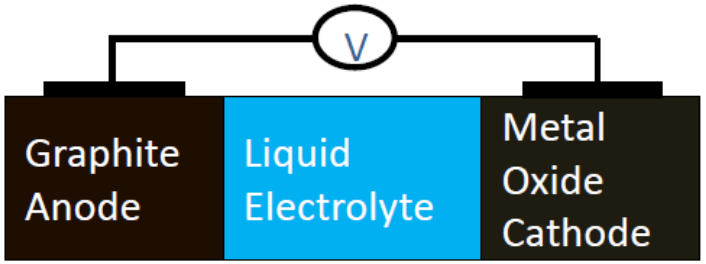
- Increased Si-content increases capacity
- Most increase happens at low voltages <3.2V

Sources: Black Diamond Structures, TI

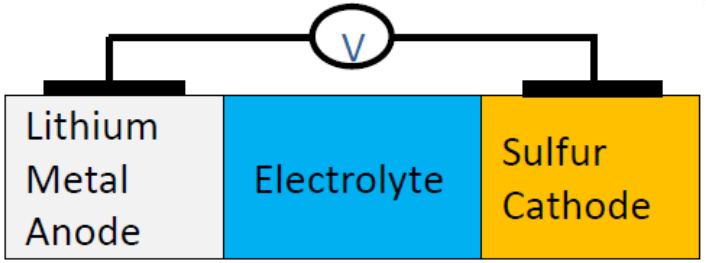
Li-Ion Tech Trends
Future Trends

Capacity Increases via New Chemistry Formulations

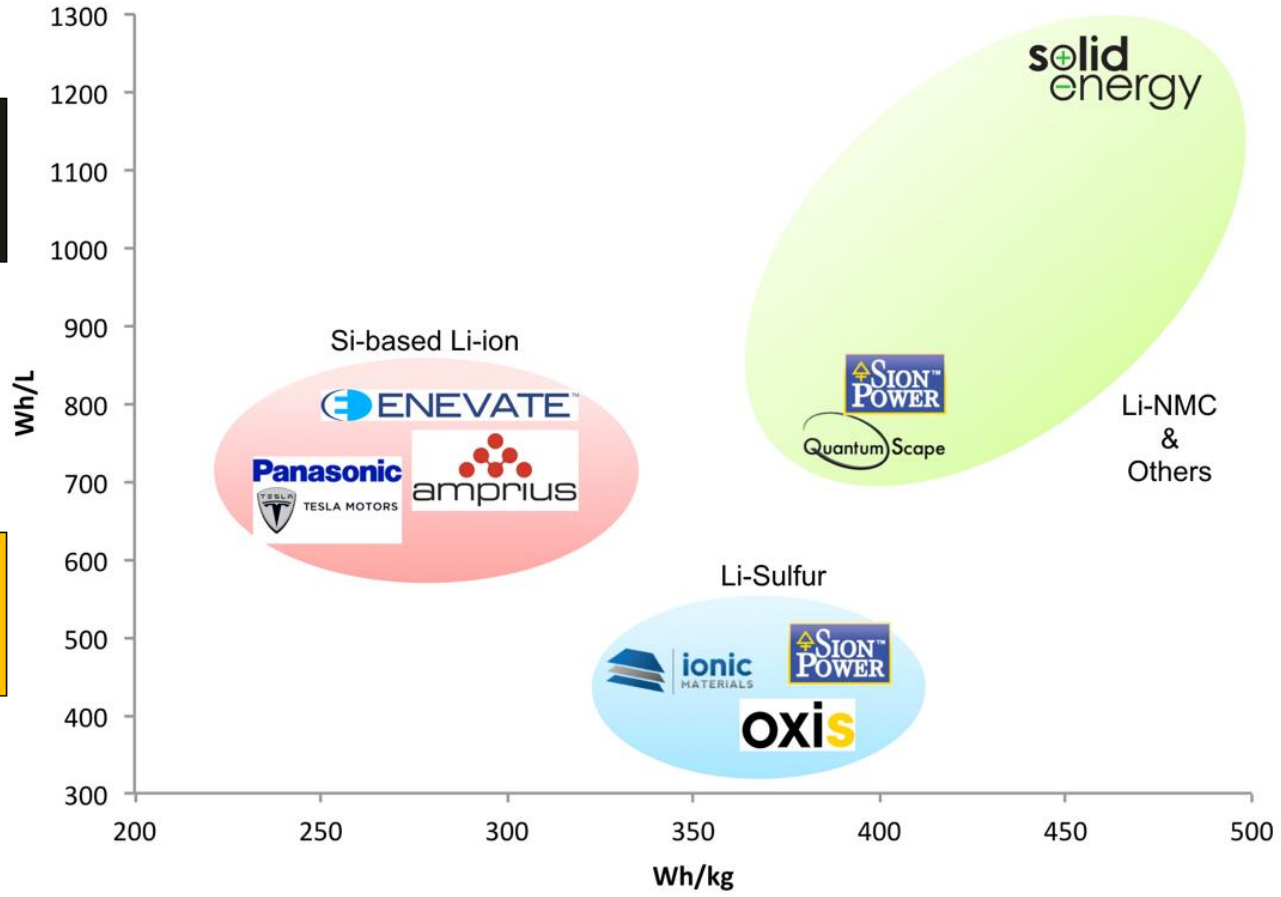
- Li-Sulfur, Others



Lithium Ion Battery



Lithium-Sulfur Battery

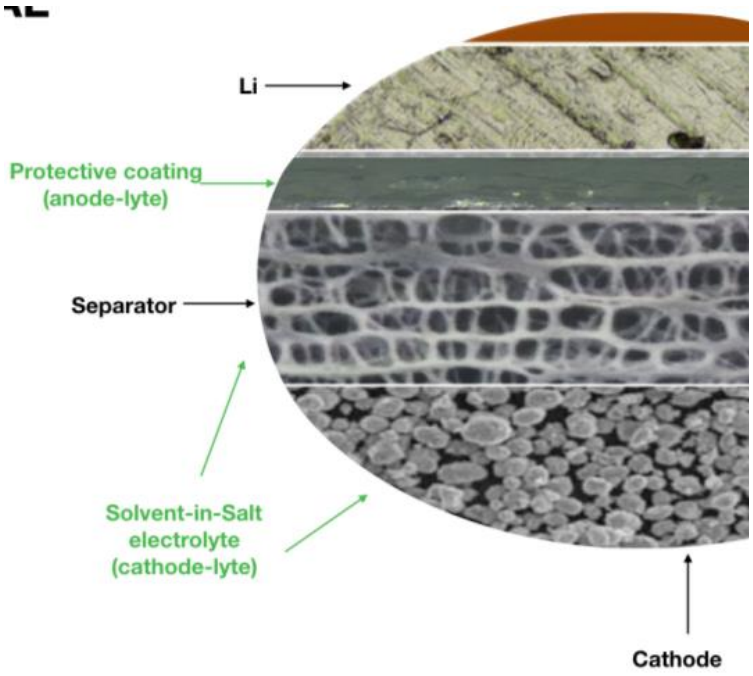


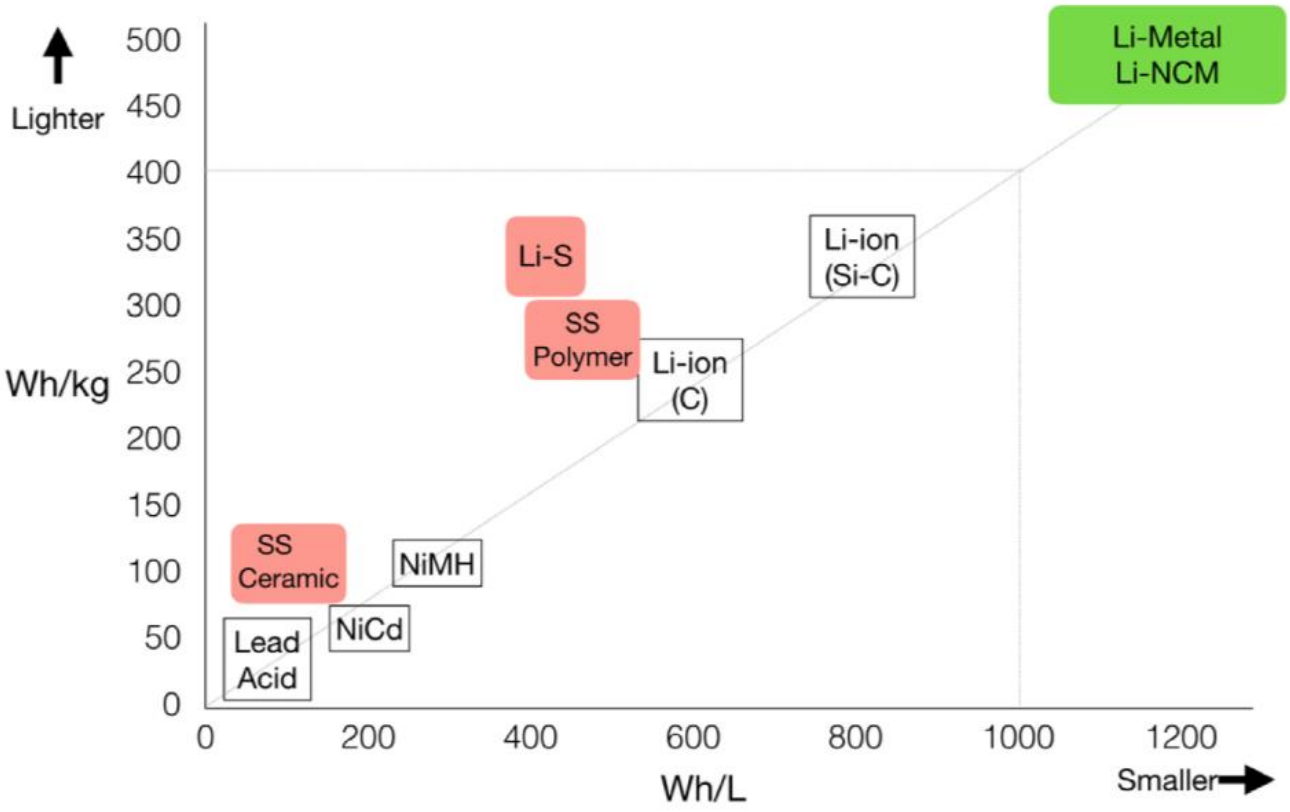
Sources: Battery Show, 2019

Li-Ion Tech Trends
Future

„New“ Chemistries:

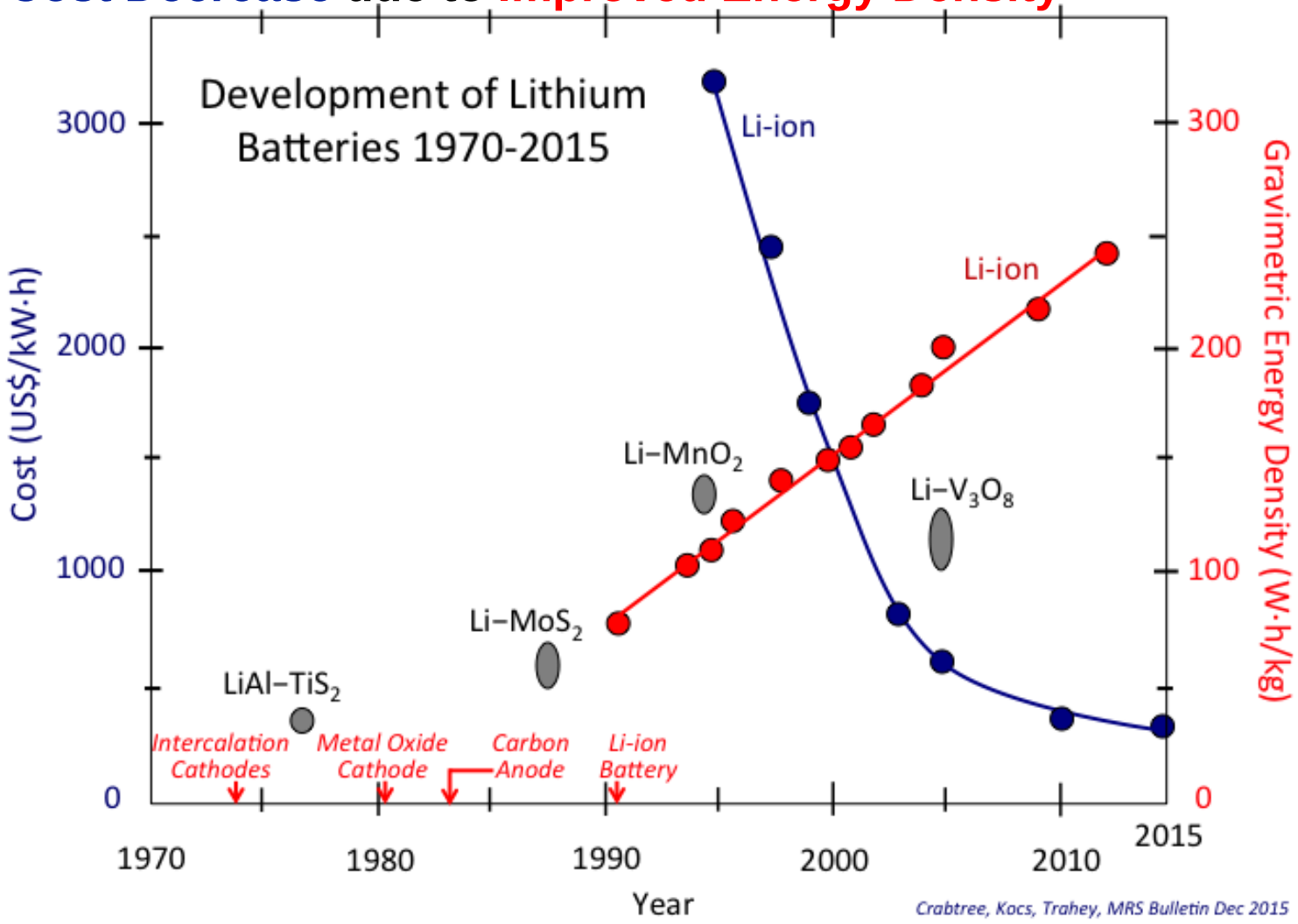
- Lithium-Metal Hybrids – Semi-solid, others





Li-Ion Tech Trends
Future Trends

Li-Ion Cost Decrease due to Improved Energy Density

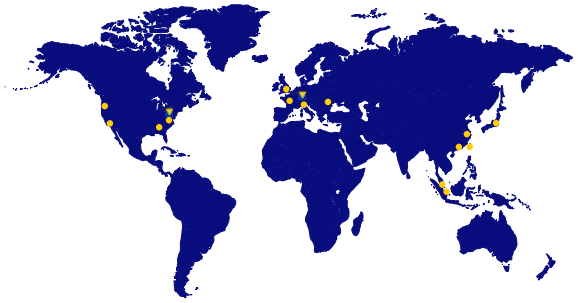


Crabtree, Kocs, Trahey, MRS Bulletin Dec 2015

Li-Ion Tech Trends

Finding the Right Battery Partner:

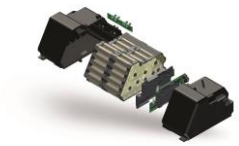
- Technology Leader
- Well known in the Industry
- Standard line of products in a variety of sizes
- Previous Custom designs with well known customers
- History and Industry Experience in Battery systems
- High-volume Manufacturing Expertise (not just a Design House)
- Worldwide Reach & Support
- Multiple Manufacturing & Design locations
- Reputable firm – ideally a public company
- Financially Stable & Reliable



VARTA Worldwide

VARTA AG

MICROBATTERIES & SOLUTIONS

Healthcare	Entertainment	Solutions
		

Largest Manufacturer of Hearing Aid Cells (1B/yr)

www.VARTA-Microbattery.com

HOUSEHOLD BATTERIES

Consumer Batteries	Energy Storage
	

Standard & Custom Battery Packs and Energy Storage

www.VARTA-Storage.com

Consumer Coin & Cylindrical Cells; Home Energy Storage

www.VARTA-Consumer.com

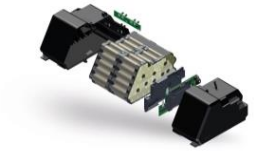
More than 130 years of innovation

1990
VARTA Lithium Cells

1995
VARTA Primary Lithium Cell assembly
+
Wire connector

2000
VARTA Customized Lithium-Polymer Pouch
+
Safety Electronic

2010
VARTA PowerPack Solutions
+
Mechanical and Electrical Design



2011
VW VARTA Joint Venture
+
New material technologies

2012
VARTA Storage Residential Energy Solutions
+
Cell and charge balancing, Power interface

2014
VARTA CoinPower Series
+
Innovative Cell-Design for highest Performance & Safety

2016
VARTA Storage Commercial Storage Solution
+
Adressing multiple energy management functionalites

2018
New VARTA CoinPower types
+
form factors

2019
Production
+
Massive Investments in production in lithium ion cells in Ellwangen and Noerdlingen

VARTA has a long history in research, development, and mass production of a variety of electro-chemistry and battery systems.

VARTA Solution Options

VARTA's Family Cells & Batteries:

- Voltages 1.5V to 48V
- Capacities 10mAh to >1500Ah
- Multiple Chemistry Options
- Coin & Cylindrical Sizes
- Pouch & Prismatic Sizes
- Embedded Battery Packs
- Consumer Removable Packs
- Industrial, Mobile Robotics Batteries
- Custom Designed Batteries
- Application Specific Standard Batteries

Cells

Easy Block/Blade/Pro

CellPac LITE

EasyPack

All past & future webinars listed at:

www.varta-storage.com/webinars

Presenter: Dan Friel, National Business Development Manager, VARTA

Linked-In: Dan Friel: https://www.linkedin.com/in/dan-friel-2004

Email: dan.friel@varta-microbattery.com

Batteries 101: Battery B-I-N-G-O

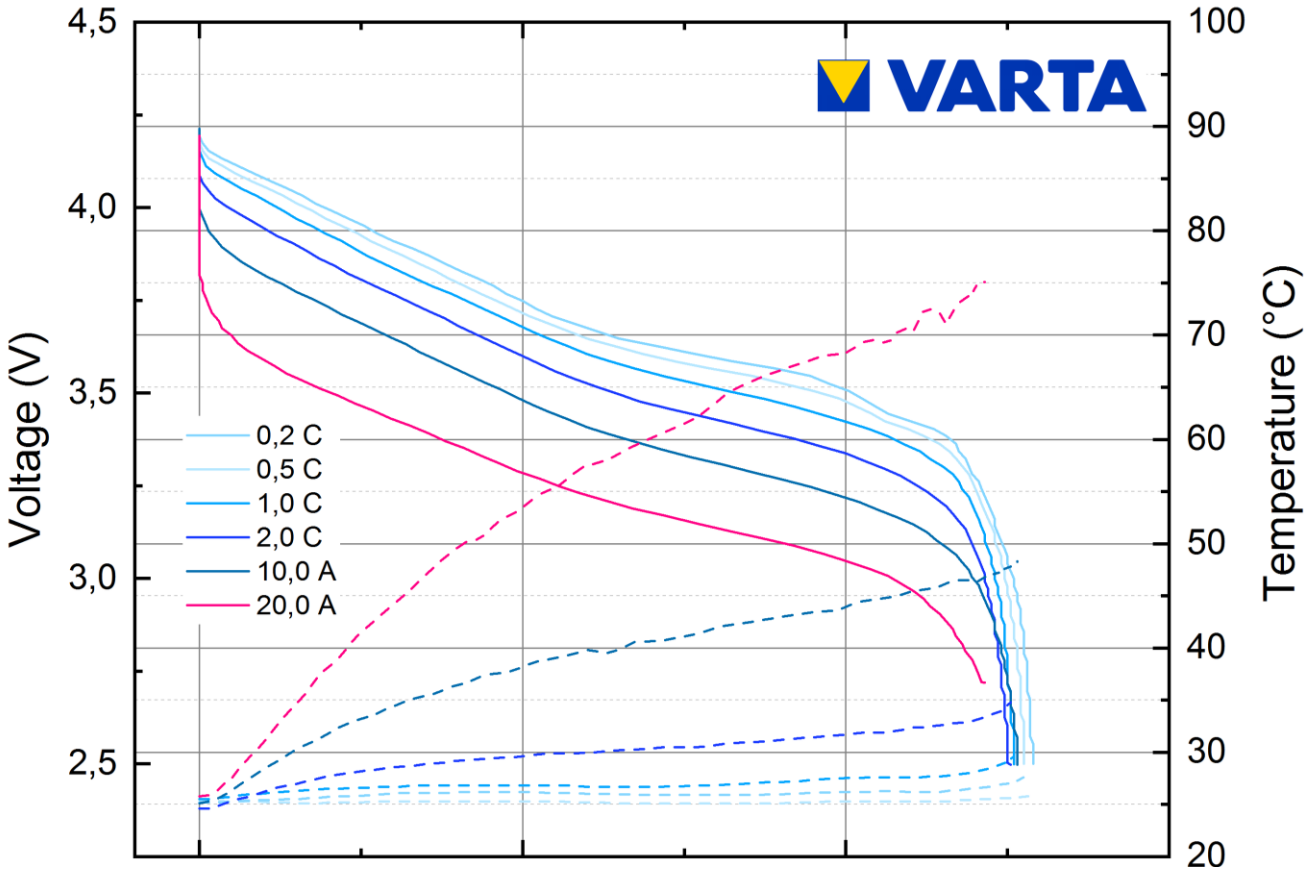
B Battery	I Innovations	N Never	G Get	O Old
BMS Battery Management System	**18650** 18 mm x 65 mm Cell	**Cathode** Positive side of Cell	**Pb-A** Lead-Acid	**IEC 62133** Battery Certification
C-Rate 1 Hour Discharge Rate	**LCO** Lithium Cobalt Oxide (Li-Ion)	**Anode** Negative side of Cell	**NCA** Nickel Cobalt Aluminum (Li-Ion)	**26650** 26 mm x 65 mm Cell
Si-A Silicon Anode	**EODV** End-of-Discharge Voltage	VARTA	**Whrs** Watt-hours (V x Ah)	**UN38.3** Air Shipment Regulation
1642 UL Standard (Cell)	**NMC** Nickel Manganese Cobalt (Li-Ion)	**CC-CV** Constant-Current, Constant Voltage	**PCM/PCB** Printed Circuit Module/Board	**LFP** Lithium Iron Phosphate
103450 10 x 34 x 50mm Cell	**1Sx2P** 1 Series Cell & 2 Parallel Cells	**NiMH** Nickel Metal Hydride	**21700** 21mm x 70mm Cell	**BLE** Bluetooth Low Energy

Li-Ion Tech Trends

Voltage Variation by Chemistry

High-Rate NMC Cells: Meant to be discharged at 10A+

But temperature rise must be considered

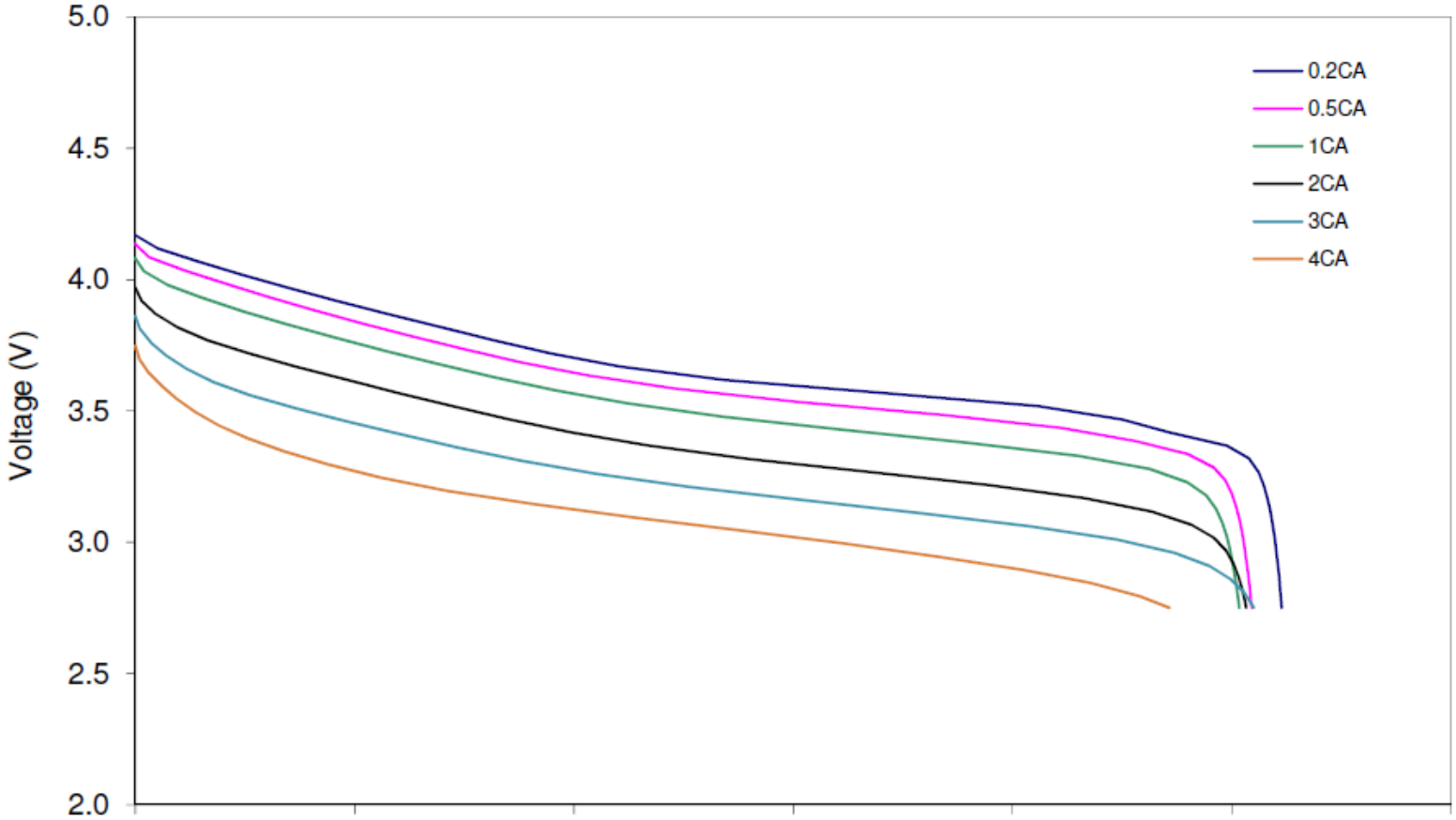


Sources: VARTA & cell manufacturers

Li-Ion Tech Trends

Cells

Mid-Rate NMC Cell



Sources: VARTA & cell manufacturers

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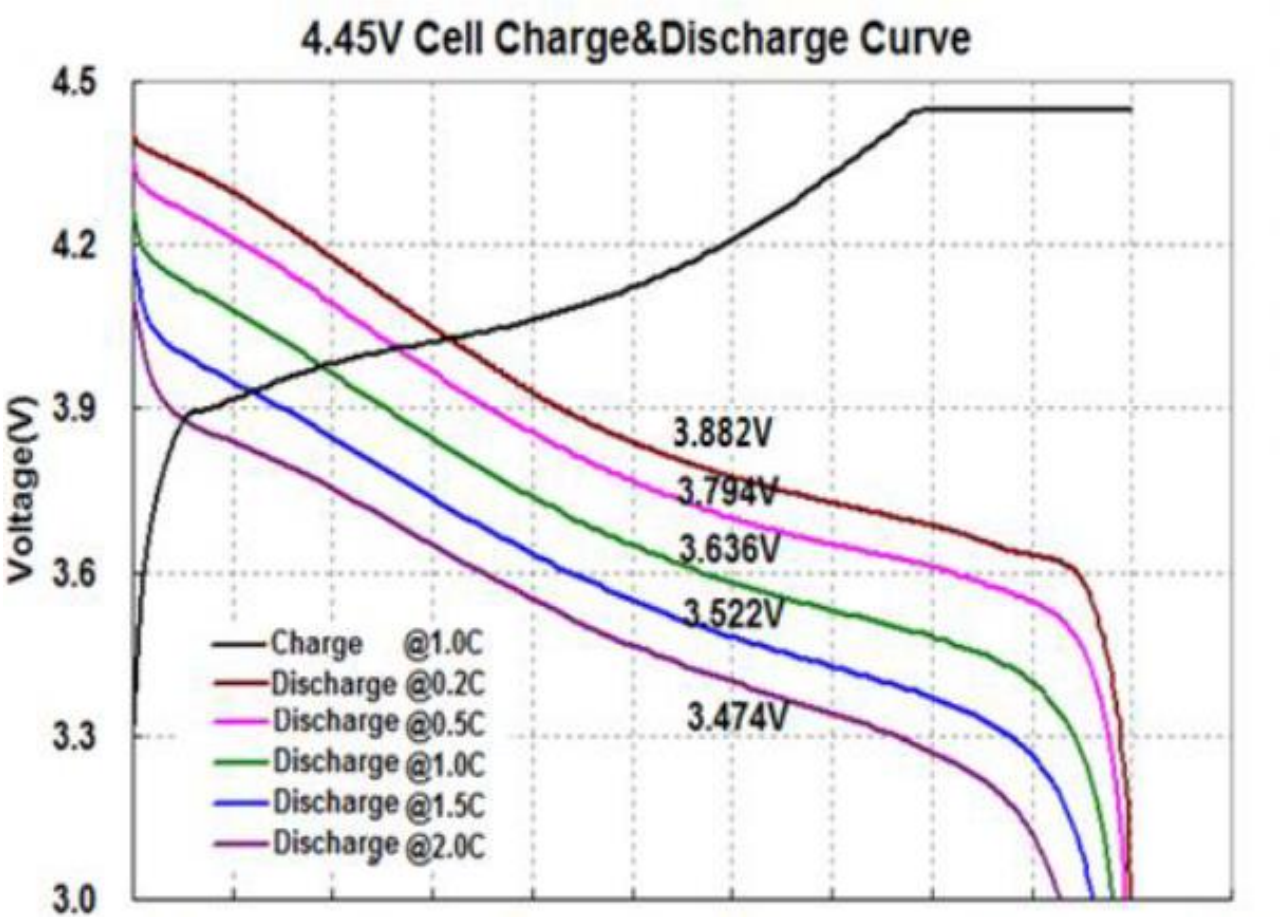
High Voltage Cells (>4.2V Charging)

Challenges: All components must tolerate higher voltage



Sources: VARTA analysis of various cell manufacturers