FARADION
Advanced Energy Storage Solutions

Progress in the Commercialization of Faradion's Na-ion Battery Technology

Jerry Barker, CTO & Founder

www.faradion.co.uk

Faradion Limited: Timeline

FARADION
Advanced Energy Storage Solutions

Finance Yorkshire

Innovate UK
Technology Strategy Board

mercia technologies

HALDOR TOPSOE

2011-2013	2014	2015	2016	2017
• **Founded in 2011** • **Establishes facilities in Sheffield and Oxford, England** • Awarded UK Government grant with Williams Advanced Engineering (WAE) and Oxford University • **Investment from Sharp Corporation**	• **Faradion receives investment from Haldor Topsøe A/S** • Established demonstrator manufacturing facility • 3Ah demonstrator cells available • **Performance ahead of industry requirements**	• **Faradion starts license discussions** • Na-ion technical performance ahead of expectations • **Launch Day: E-bike demonstrator a major success** • Defined safety /abuse performance • Awarded 2 UK Government Grants	• **Signed first licensee option** • Awarded UK Government Grant for EV applications (AGM/WMG) • Cell performance ahead of technology roadmap • Awarded UK Government Grant for temperature study	• **23 patent applications filed – several issued** • License talks with 3 current Li-ion cell manufacturers • **Completed £xM funding round** • 5 kWh production completed • **£xM I-UK Grant for Automotive applications**

WMG
THE UNIVERSITY OF WARWICK

WILLIAMS

UNIVERSITY OF OXFORD

Why Commercialize Na-ion Batteries?

FARADION
Advanced Energy Storage Solutions

1. **Sustainability**. Sodium is abundant, so a Na-ion battery manufacturing facility may be established virtually anywhere. Cobalt-free cell chemistry
2. **Chemistry.** Various aqueous and non-aqueous cell chemistries are available
3. **Performance.** It may be possible to match best Li-ion battery performance in terms of energy density, cycle life, rate etc.
4. **Cost.** Lower cost of precursor materials, use of aluminium cc etc. Faradion predicts a ~30% decrease in $/kWh vs. Li-ion (LFP), at cell level
5. **Safety.** Improved safety, storage and transportation characteristics
6. **Existing Infrastructure.** Uses existing Li-ion cell manufacturing methods – for pouch, prismatic and cylindrical cells
7. **IP Landscape.** By comparison, Li-ion technology is an IP 'minefield' – unique opportunity to secure definitive IP for Na-ion technology.
8. **Business Models.** Licensing and/or Manufacturing Models
9. **TARGET MARKETS** (i) Stationary Energy Storage (ESS); (ii) SLI & 48 V (iii) Power Tools; (iv) Traction Automotive (BEV); (v) Medical Applications

FARADION
Advanced Energy Storage Solutions

Market Opportunities

FARADION
Advanced Energy Storage Solutions

Best Markets for Na-ion?

Best Fit: where can we leverage the clear technical and commercial (cost) advantages of Na-ion batteries over the incumbent technologies i.e. Li-ion (LFP) and Pb-acid? There is also a chance to generate new market opportunities based on these advantages.

Na-ion Key Advantages:

Upfront and Lifetime Costs ($/kWh)
Safety – suitable for large format applications
Storage and Transportation (0 V)
Temperature Range
Non-cobalt technology (sustainability)

Potential Markets:

Stationary (ESS, UPS, Telecoms)
SLI + 48 V Applications (Power and Temperature)
Power Tools
BEV (Automotive)
Forklift
Medical (0 V capability)

Potential Na-ion Battery Markets

FARADION
Advanced Energy Storage Solutions

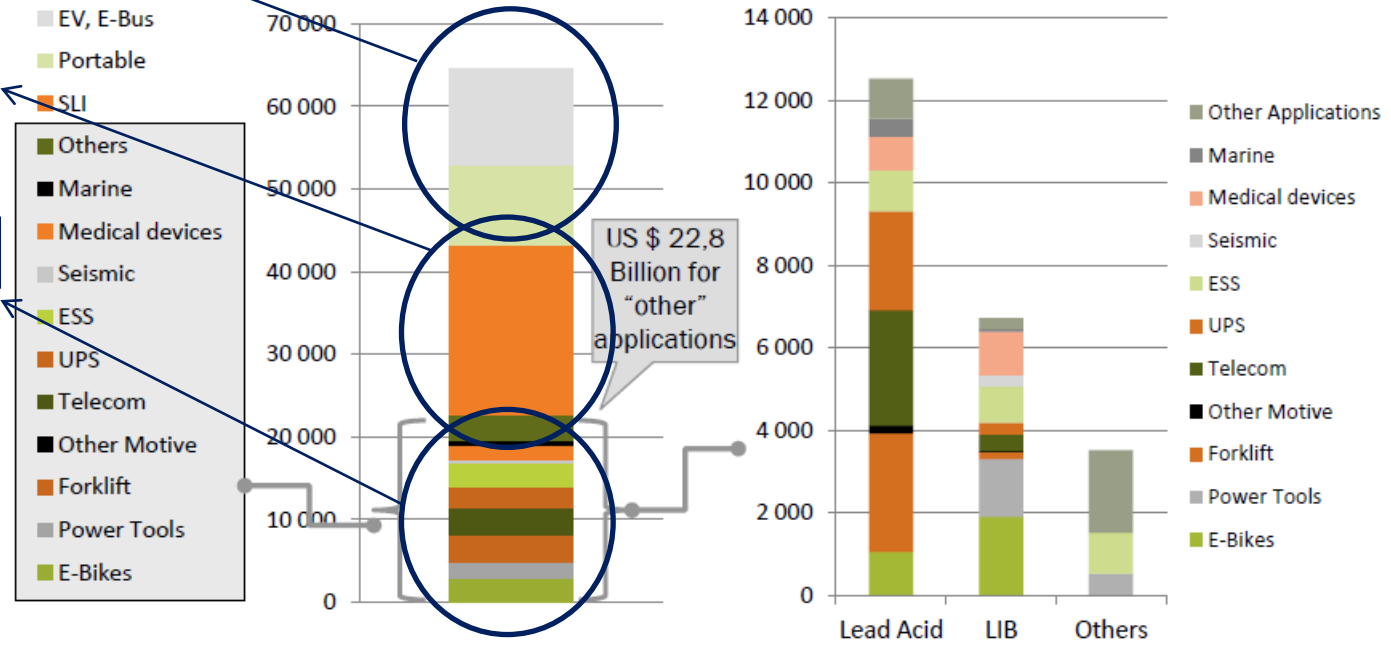
THE WORLDWIDE BATTERY MARKET IN 2016: US $ 65 BILLION

BEV

SLI + 48 V

Other Apps

$20B = Li-ion; $40B = Pb-acid



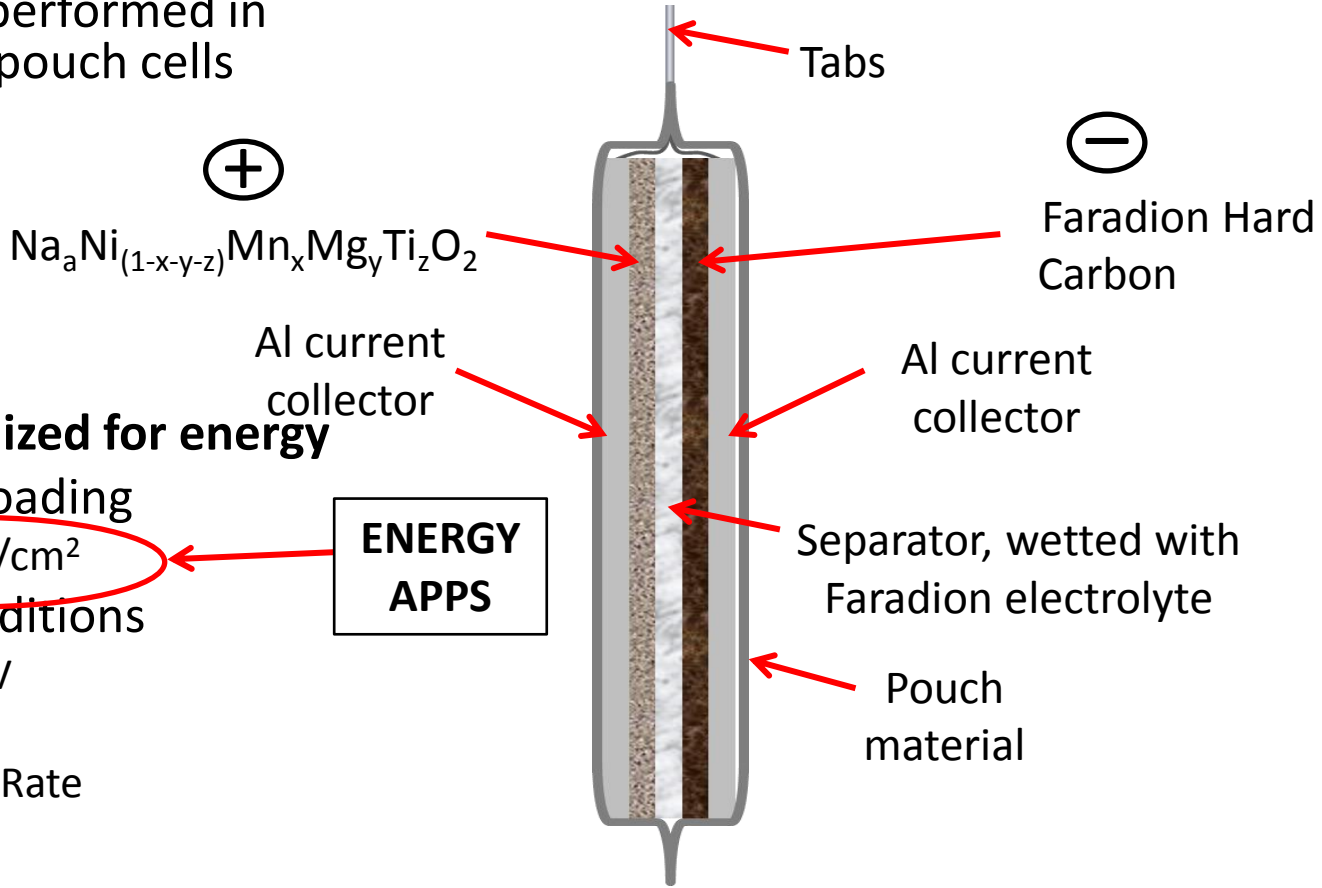
avicenne ENERGY
INFORMATION FOR GROWTH
www.avicenne.com

FARADION
Advanced Energy Storage Solutions

Na-ion Cells: Performance for Energy Applications

Faradion Cell Design

- All testing performed in full Na-ion pouch cells



- **Cells optimized for energy**
- Electrode loading
  - ~ 3+ mAh/cm²
- Cycling conditions
  - 1.0 – 4.3 V
  - CC, CV
  - C/10 to C Rate

ENERGY APPS

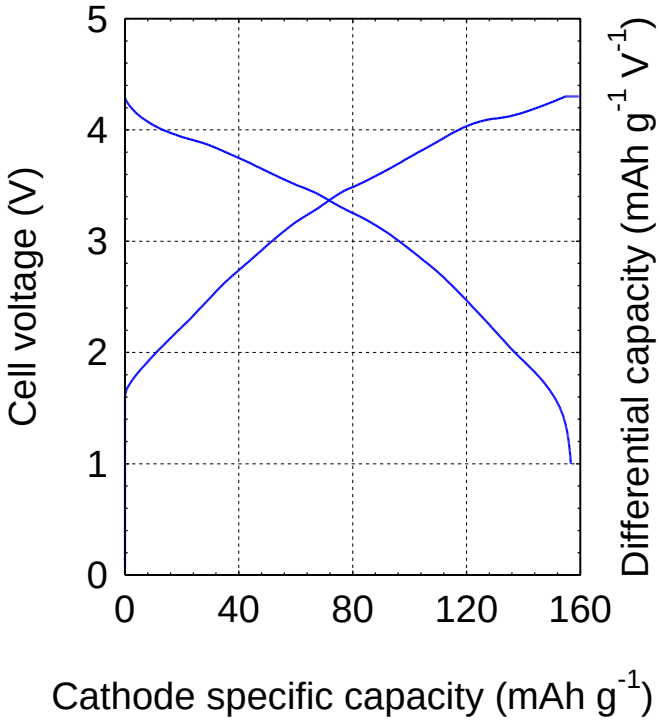
Faradion Prototype Cells

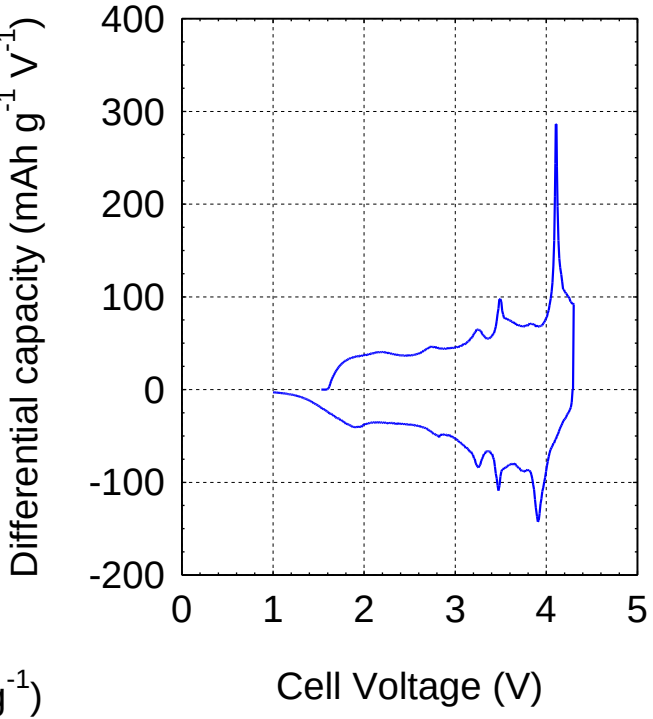
Faradion
Energy Cell
Stacked
A5 Format
14.8 x 21.0 cm
12-13 Ah
36-42 Wh

Faradion
Energy Cell
Power Cell
Stacked
Varying Footprint
1-4 Ah
3-14 Wh

Faradion
Energy Cell
Power Cell
Wound
Varying Footprint
1-3 Ah
3-10 Wh

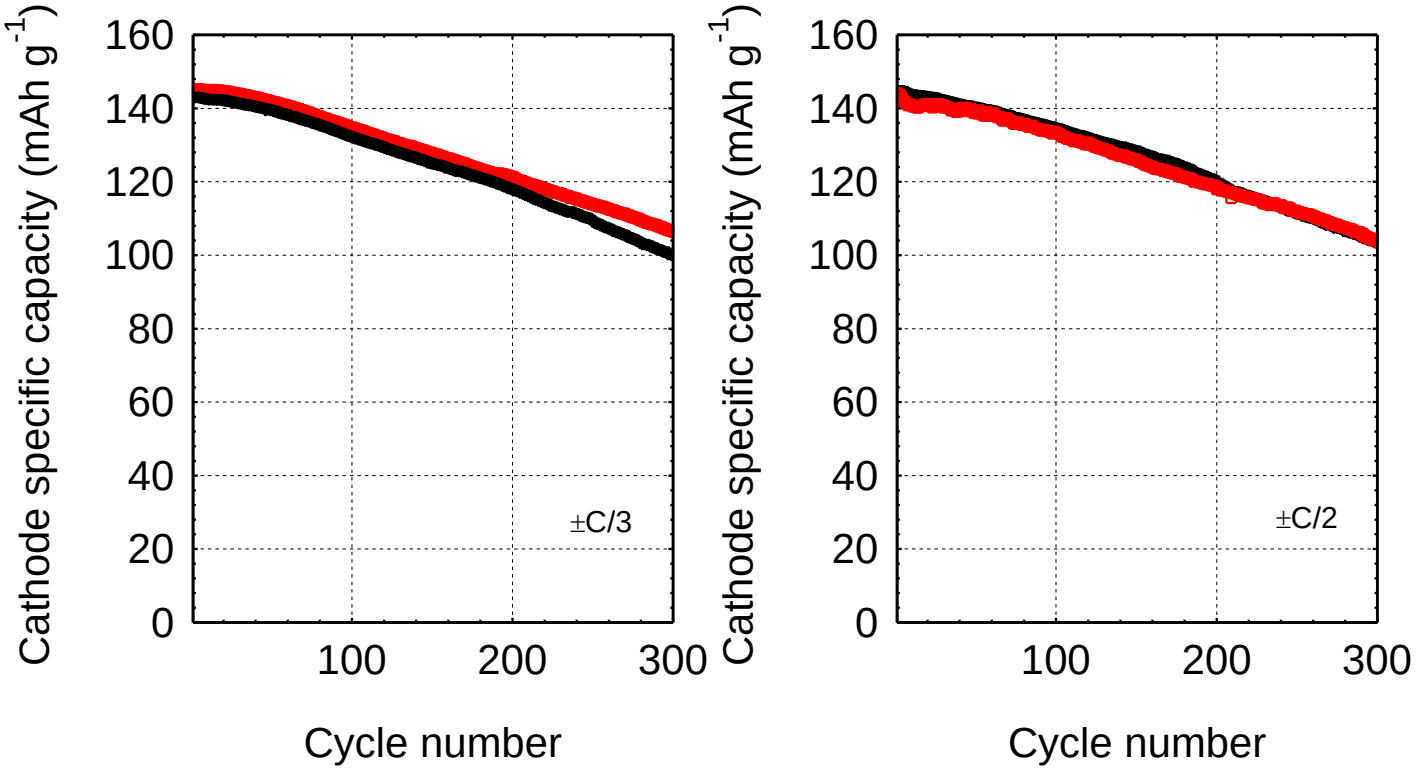
Cycle#2





- Reversible cathode specific capacity = **157 mAh/g**
- Average discharge voltage = **3.20 V**
- Cathode specific energy = **500 Wh/kg**
- Round trip energy efficiency **> 91 %**
- Low polarization

Typical Cycle Life (100% DOD)



Typical: 300-400 Cycles to 80 % of Initial Discharge Capacity

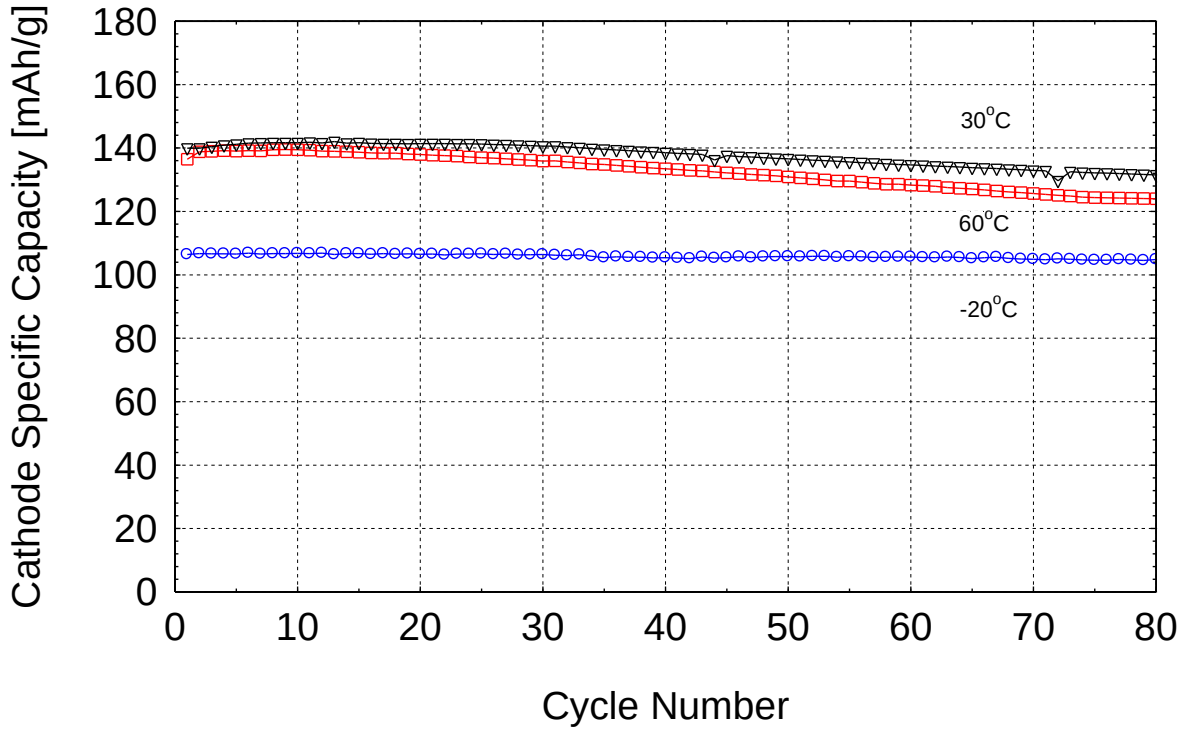
FARADION
Advanced Energy Storage Solutions

Temperature Performance

FARADION
Advanced Energy Storage Solutions

Temperature Performance

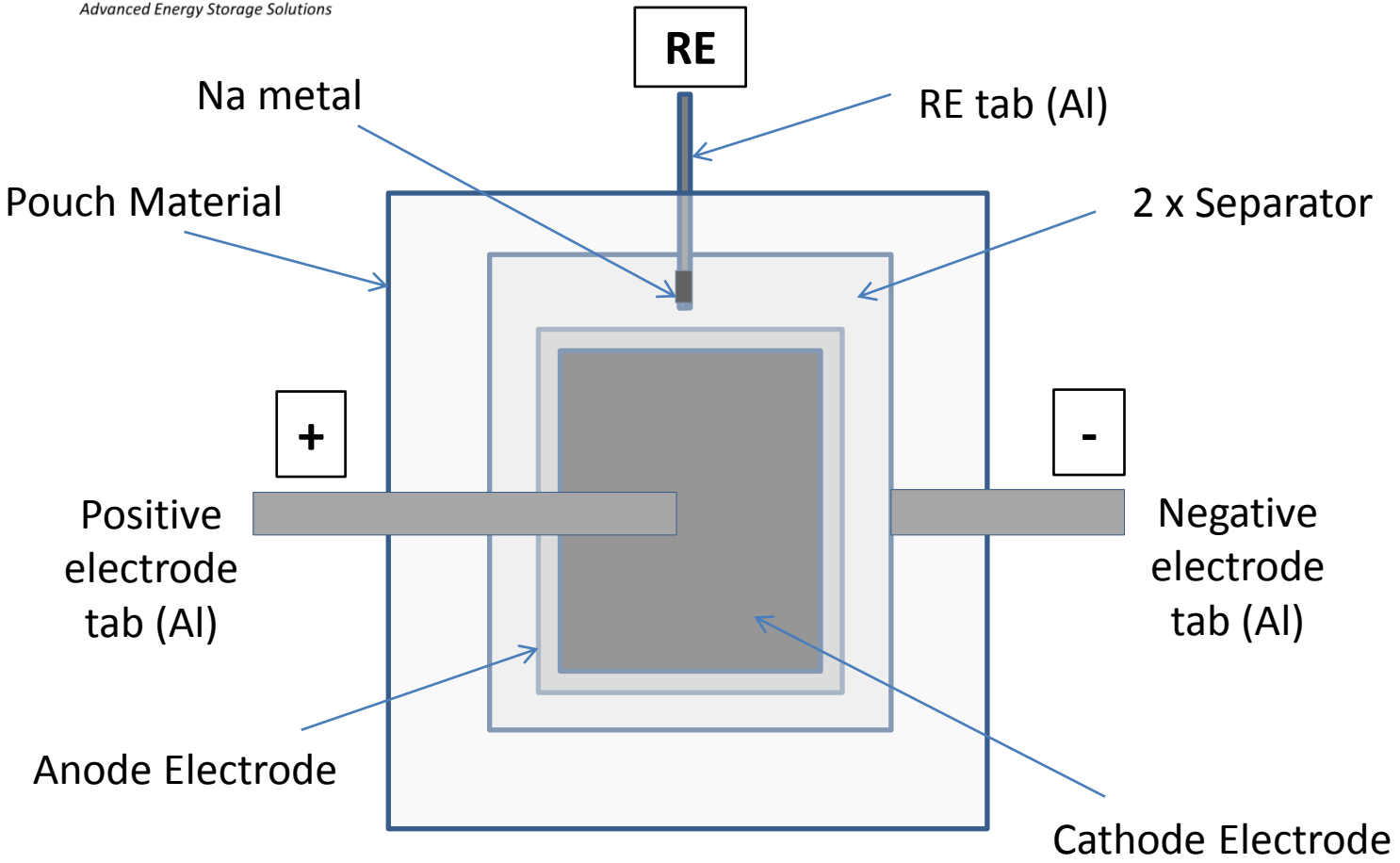
PROTOTYPE CELL CYCLING @ +30ºC, +60ºC and -20ºC



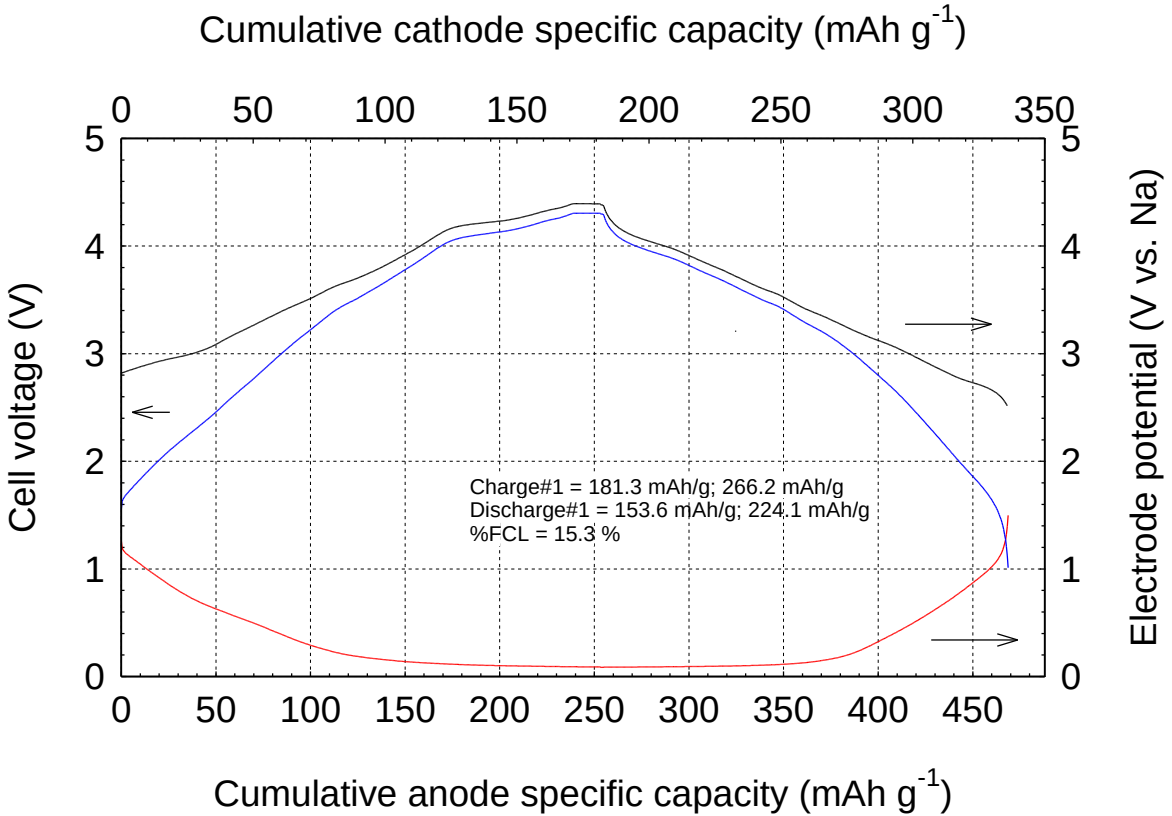
FARADION
Advanced Energy Storage Solutions

3-Electrode Cells

3-Electrode Cell Design



Cycle#1



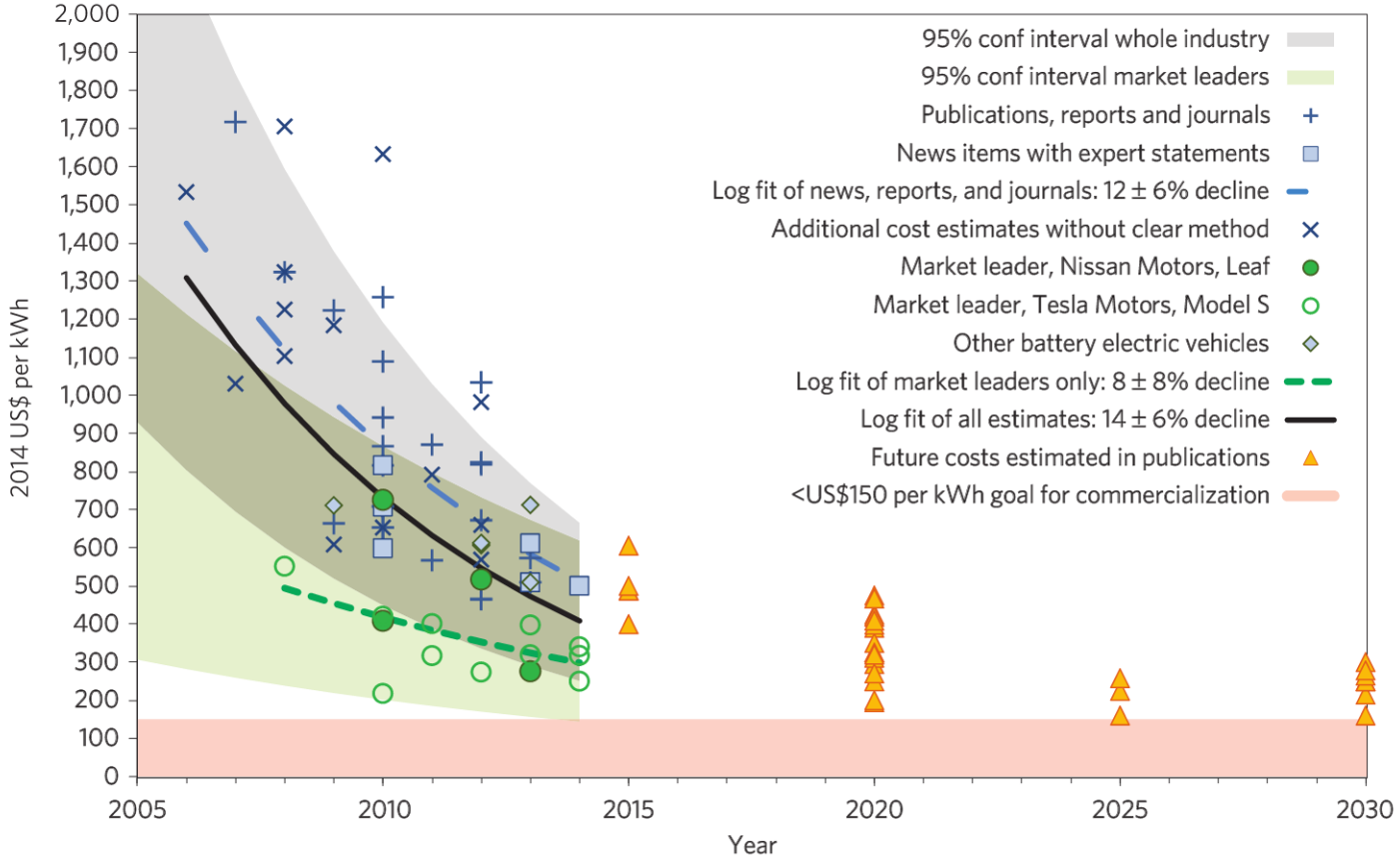
✓ **Very low levels of both cell and electrode polarization at this charge/discharge rate**

FARADION
Advanced Energy Storage Solutions

Na-ion Materials Costings

FARADION
Advanced Energy Storage Solutions

EV: Li-ion Costings

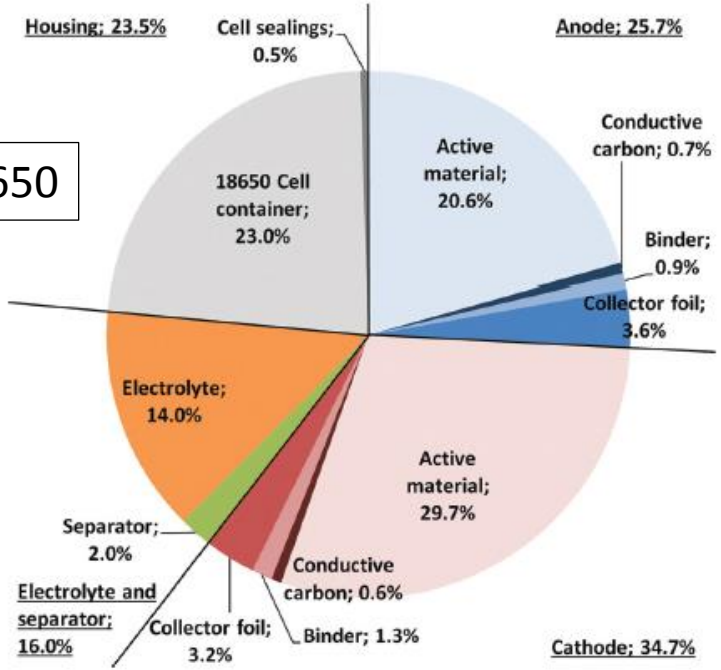


Source: Rapidly falling costs of battery packs for electric vehicles, Nature Climate Change , March 2015

Na-ion Cost Structure

FARADION
Advanced Energy Storage Solutions

18650

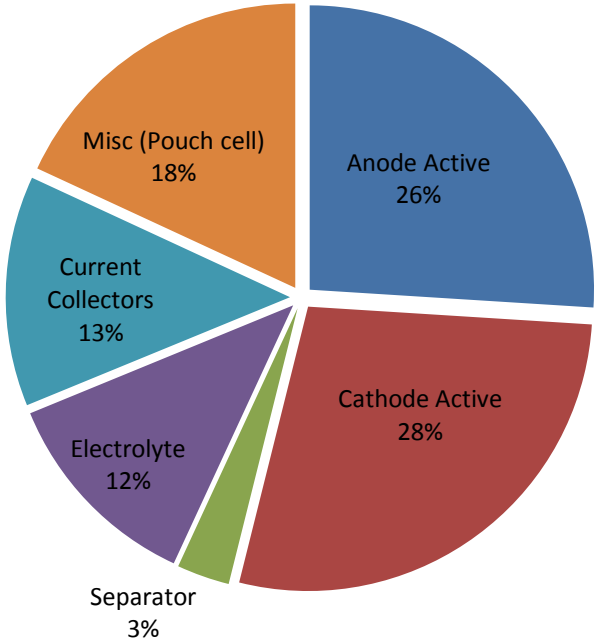


Life cycle assessment of sodium-ion batteries†

Jens Peters,*[ab] Daniel Buchholz,[ab] Stefano Passerini*[ab] and Marcel Weil[abc]

| Energy Environ. Sci., 2016, 9, 1744–1751

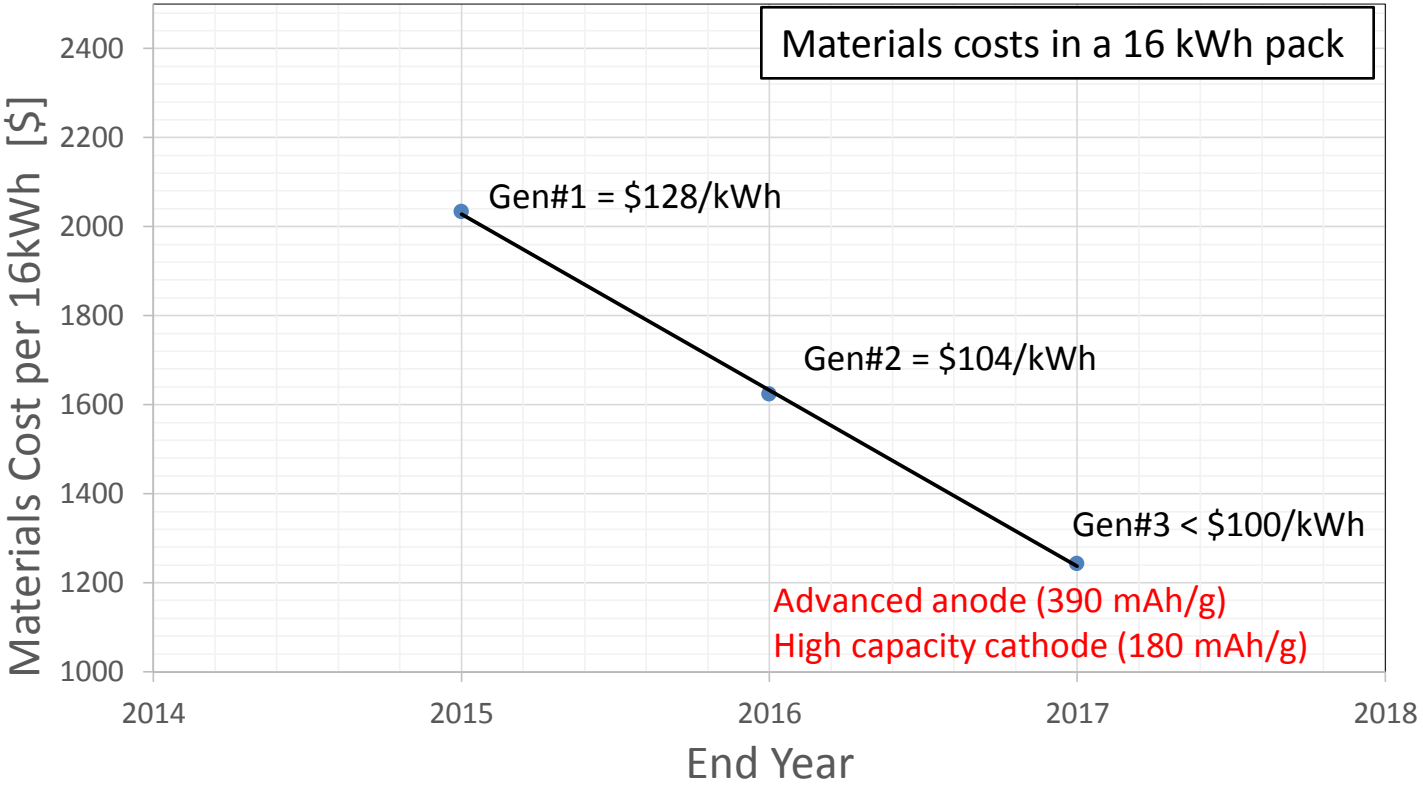
Pouch



* NB: Carbon-coated current collectors

Faradion Limited: Internal Data (2017)

Materials Cost Reduction

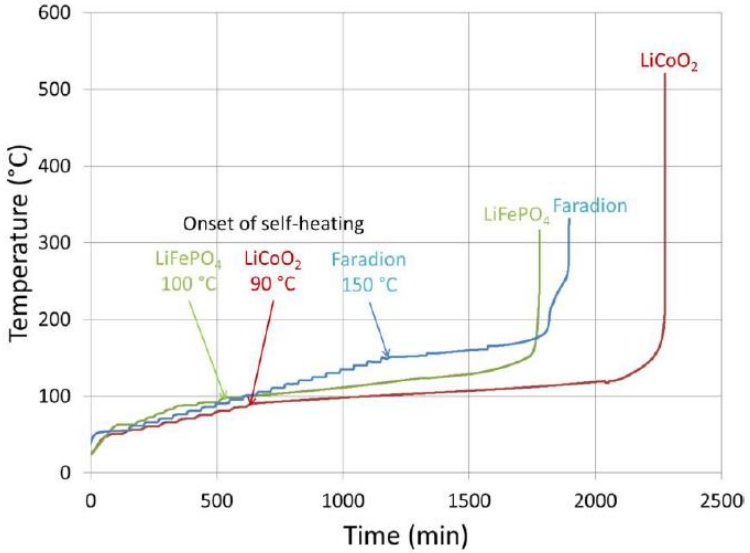


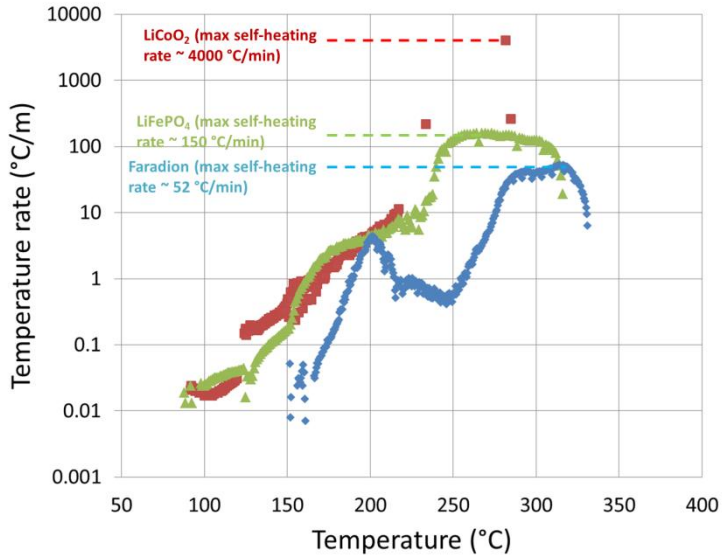
Model: ANL BatPac (2016) – Pouch Cell

FARADION
Advanced Energy Storage Solutions

Safety

ARC: Self-heating Rate





Note: Approx. 10 Ah commercial pouch cells in all cases (fully charged)

Cell Type	Onset T / [°C]	Max. Self Heating Rate / [°C/min]
$LiCoO_2$	90	~ 4000
$LiFePO_4$	100	~ 150
Faradion	150	~ 50

FARADION
Advanced Energy Storage Solutions

Zero Volt Transportation & Storage

Zero Energy Transportation

Transport issues with Lithium-ion

- Transportation of Li-ion batteries is inherently hazardous.
- Li-ion cells have to be stored and transported in a charged state, i.e. a state that is less stable and more prone to fire.
- Numerous incidences of charged Li-ion batteries producing smoke, extreme heat, catching fire or exploding.
- A major concern, particularly to airlines and there are very stringent controls on the bulk air transportation of lithium-based cells
- Controls on both the size as well as the number of batteries allowed in each consignment.

Faradion's solution

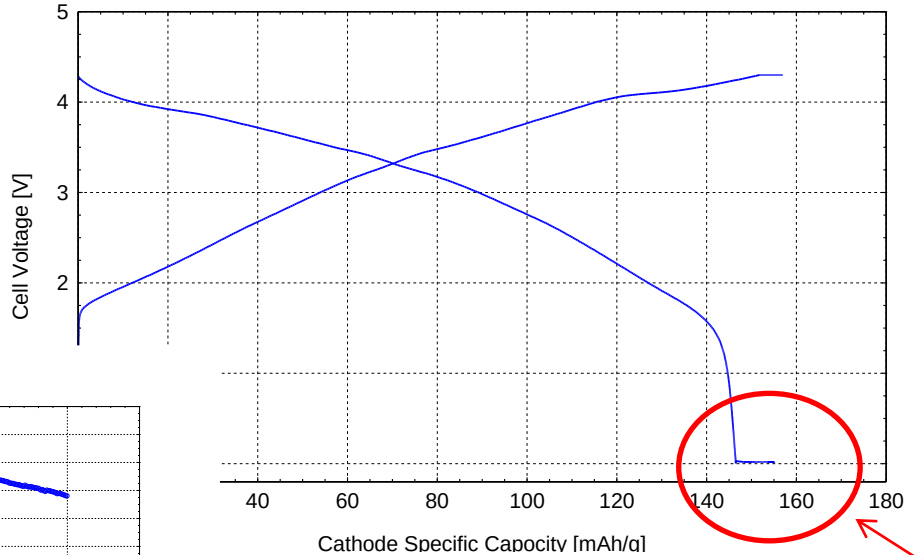
- Faradion's Na-ion batteries solve the problem of air transport.
- Faradion Na-ion cells use safer and lower cost active materials than Li-ion cells and low volatility electrolyte (i.e. high PC fraction).
- Faradion Na-ion batteries can be discharged to 0 V and stored and transported in this discharged state (unlike Li-ion batteries).
- ARC Testing on cells stored at 0 V showed very low reactivity (as expected)

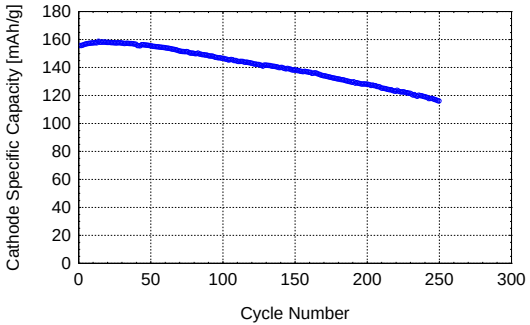
Associated IP

- Faradion has patented a method for the transportation and storage of Na-ion cells

0 V Storage

All prototype cells stored and shipped physically shorted





0 V Voltage hold for 48 h

Max: 6 months at 0 V = No Degradation

UN DOT: White Paper I

FARADION
Advanced Energy Storage Solutions

UN/SCETDG/48/INF.6

Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labelling of Chemicals

23 October 2015

Sub-Committee of Experts on the Transport of Dangerous Goods

Forty-eighth session

Geneva, 30 November – 9 December 2015
Item 3 of the provisional agenda
Listing, classification and packing

Classification procedures related to sodium-ion batteries

Transmitted by the expert from the United Kingdom

Introduction

1. This informal document invites comments on how the Model Regulations should address the carriage requirements for advanced low cost battery materials based on sodium-ion technology.

2. The current classification system does not address the particular circumstances of sodium-ion batteries. The existing entry for batteries containing sodium (UN3292) and Special Provision 239 are relevant to cell chemistries such as sodium sulphur and sodium metal chloride which contain metallic sodium, but do not recognise the lesser risk posed by sodium-ion cell chemistry. This raises the question as to how they should be classified.

Proposal

12. The Sub-Committee is invited to consider the information presented in this paper and offer opinions on how sodium-ion batteries could be classified for carriage. For example, would requirements similar to those for asymmetric capacitors (UN 3508) be appropriate?

Latest News (October 2017):
Faradion has been invited to present to the UN-DOT on Na-ion transportation regulations as part of the UK delegation

FARADION
Advanced Energy Storage Solutions

Scale-up

Press Release: 2016

4 February 2016

Faradion partners with AGM Batteries to commercialise sodium technology

- Joint R&D partnership aims to bring sodium-ion batteries to market
- Innovative Faradion technology will be developed at AGM Batteries' facility in Caithness
- Sodium-ion batteries could cost around 30% less to produce than lithium-ion

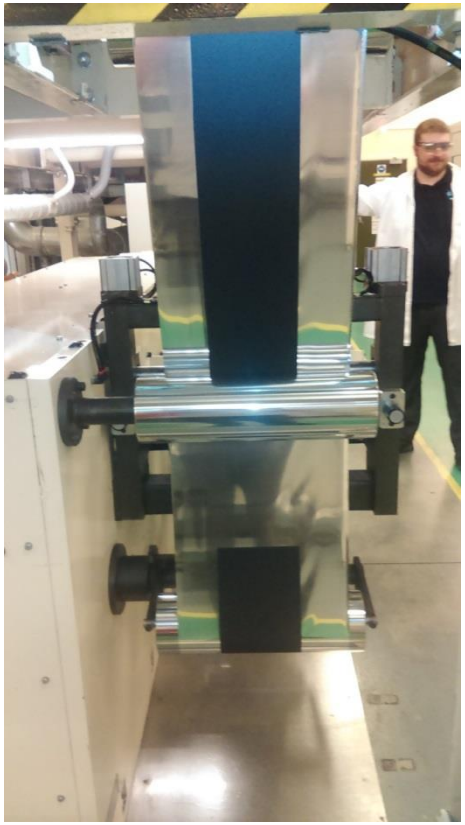
Pioneer of sodium-ion battery technology, Faradion, will partner with UK-based lithium-ion cell developer and manufacturer, AGM Batteries. The research and development partnership will see the two companies scale-up Faradion's sodium-ion technology to make it ready to enter the battery market.

Faradion – AGM 2017

Slurry Mixing

Slurry Transfer

Calender Roll



AGM Batteries Ltd.

http://www.agmbatteries.com/

Faradion – 2 kWh Prototype Run

50 x 40 Wh Stacks = 2 kWh Na-ion Prototype Run – February 2017

FARADION
Advanced Energy Storage Solutions

Summary & Conclusions

FARADION
Advanced Energy Storage Solutions

Summary & Conclusions

- **Faradion's Na-ion scale-up and commercialization plan is underway**. **>5 kWh of product to date.** Uses same infrastructure as current Li-ion technology.
- **Several licensee discussions underway**
- Large global markets. Preferred, early applications centred around **large format applications** (e.g. ESS) and 12V/48V **Pb-acid replacement** (e.g. SLI and M-HEV)
- Key Advantages: **Upfront & Lifetime Costs ($/kWh), Safety and Transportation, Temperature Range**
- Excellent **IP opportunities** still exist
- Faradion Layered Oxide//Hard Carbon = **140 Wh/kg** + upside opportunities to challenge industry best Li-ion technology

FARADION
Advanced Energy Storage Solutions

Thank-you!

E-Bike – Powered by Faradion's Na-ion Battery Technology