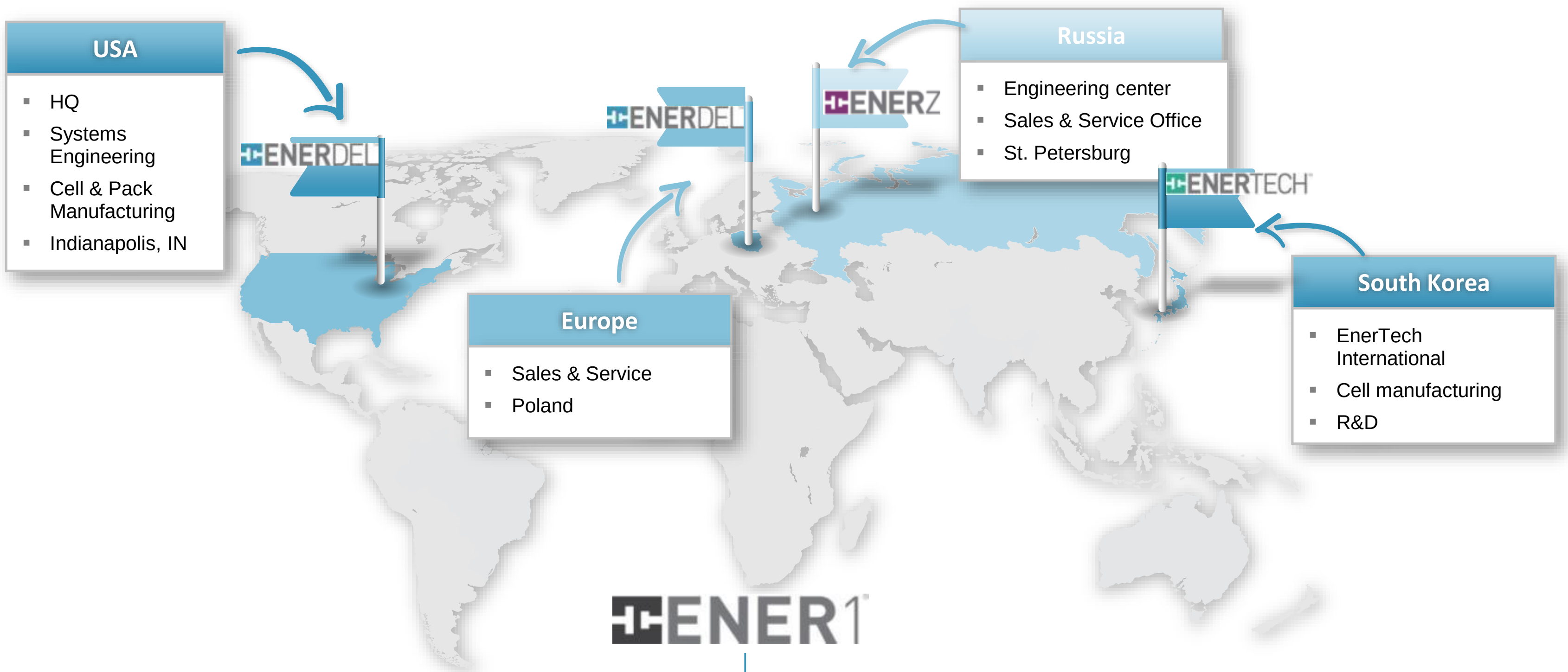
Batteries market landscape and sources for improvement

Skoltech conference September 2017

About company

Integrated Family of Companies with a Global Footprint



ENER1

ENERDEL

- Indianapolis HQ & manufacturing facility
- Cell manufacturing and module / pack assembly
- Large format for transportation, industrial and grid applications

ENERZ

- Engineering center
- Sales & Service Office
- St. Petersburg

ENERTECH

- Chungju manufacturing
- Korean supplier of large and small format Li-ion cells

ENERZ™

Электромобили | Грузовой транспорт | Автобусы | Троллейбусы | Трамваи | Поезда | ВИЭ | Домохозяйства | Общ. накопитель & MicroGrid | Телеком | Накопители энергии

Manufacturing Facilities

ENERDEL™

- **Manufacturing Facilities**
  - Indianapolis ~ 98,000 ft^2

- **Significant Capital Investment Allocated for Production Readiness**
  - Mixers, Proprietary Coating Line, Custom Cutting, Custom Automated Cell Assembly, Automated Formation (12,000 channels)

- **Main Product**
  - Large format, prismatic cells, modules, packs and systems for transportation and grid energy storage applications

- **Annual capacity:**
  - 1.6MM EV cells, 106 MWh
  - >200MWh module and packs

Manufacturing Facilities

ENERTECH™

- **Acquired in 2008**
- **Manufacturing Facility:**
  - Chungju (factory) ~200,000ft^2
- **Products**:
  - Electrode fabrication, Li-ion Cells (small, medium, large format)
  - Custom Packs (mobile phone, scanners, 2 way radio etc.), EV, PHEV
- **Annual capacity:**
  - 1.7MM EV cells, 107 MWh

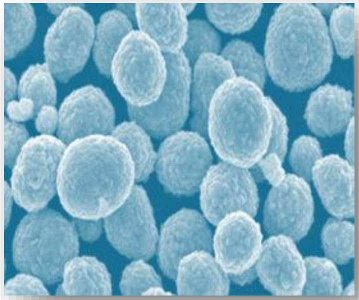





Engineering and R&D Capabilities

The Ener team includes some of the best battery researchers and engineers in the world with a wide range of knowledge and expertise

- **Cathode & Anode development**
- **Product design and development**
  - Cell, module, pack and system engineering
    - Mechanical
    - Electrical
    - BMS Software & Hardware
    - Test & Validation
    - Reliability & Compliance Engineering
- **Manufacturing engineering support**
- **Quality engineering support**



Analytical Capabilities

- **Dry Rooms**
  - Separate R&D and production dry rooms with dew point in the range -60°F (summer) to -110°F (winter)

- **Analytical Laboratory Instrumentation**
  - Differential scanning calorimeter
  - Microscopes
    - *Scanning electron, metallographic, optical*
  - Spectrometers
    - *Gas chromatograph – mass, inductively coupled plasma, Fourier transform infrared, X-ray diffraction, Raman*
  - Analyzers
    - *Electrochemical, thermogravimetric, energy dispersive spectroscopic, tap density, particle size, surface area, true density*
  - Misc
    - *Polishers, water analysis titrators, pull strength tester, balances, wet chemistry glassware, glove boxes, ovens, caliper, multimeters, viscometers*

- **Cell Cyclers**
  - 300+ channels of battery cyclers (10mA to 10A)
  - Environmental chambers with chilling and heating capability

Test & Validation Capabilities

- **Cell Level Testing**
  - Cell Cyclers
    - *768 channels (10A max. charge / 30A max discharge, 0 to 5 volts, 30°C to 55°C)*
    - *200 test circuits (100A max. charge / discharge, 0 to 18 volts, -40°C to 85°C*)

- **Module / Pack / System Level Testing**
  - Module Cyclers – 12 channels (30kW)
  - Pack/System Cyclers – 19 channels (80kW – 135kW)
  - Temperature & Humidity – 31 chambers (-68°C to +180°C, 0 to 100% R.H.)

- **Safety & Abuse Test Capabilities**
  - Drop, Penetration, Roll Over, Immersion, Crush, Radiant Heat, Partial Short Circuit, Overcharge, Over Discharge, and Thermal Stability (*USABC 2.2, 2.3, 2.4, 2.5, 2.6, 3.1, 3.2, 4.2, 4.3, 4.4*)
  - Altitude, Thermal Shock, Vibration, Mechanical Shock, Short Circuit, Impact, Overcharge, Forced Discharge, Immersion (*UNDOT UN-T1 through T-8, IPX7*)

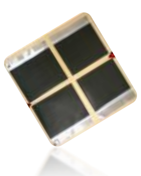
- **External Testing Sources**
  - Raytheon Analysis & Test Laboratory
  - Naval Surface Warfare Center, Crane Division
  - SafetyTech Protection Systems
  - MGA Research Corporation
  - TÜV SÜD America, Inc.
  - Detroit Testing Laboratory, Inc.
  - Dayton T. Brown, Inc.

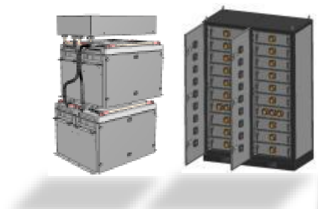
Value Chain Strategy

Battery Management Systems

Stationary and Modular Energy Storage Systems

Electrodes → **Cells** → **Modules** → **Packs** → **DC** + **AC**





We develop and manufacture 80% of the value chain for large-format, prismatic lithium-ion powered energy storage solutions

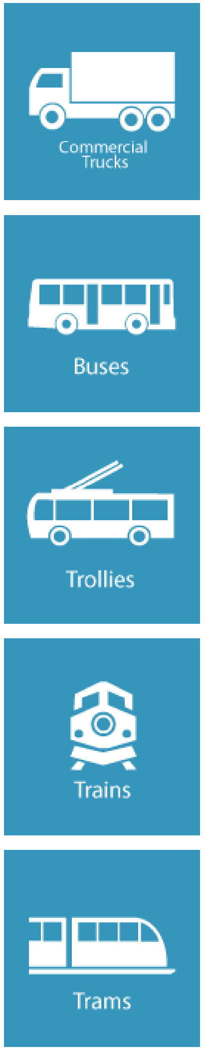
Partnerships with local and global Integrators

About product

Cells GEN 2

NEW PRODUCT

Item		Specification	
		EV	PHEV
Capacity	Nominal	22 Ah	20Ah
Energy Density	Volumetric	327Wh/L	297Wh/L
	Gravimetric	172Wh/kg	161Wh/kg
Weight		≤ 480 g	≤ 465 g
Nominal Voltage		3.75V	3.75V
Operating Voltage Range	Max.	4.20V	4.20V
	Min.	3.00V	3.00V
Standard Current	Charge	0.5C (11A)	0.5C (10A)
	Discharge	0.5C (11A)	0.5C (10A)
Maximum Current	Charge	3.0C (66A)	5.0C (100A)
	Discharge	5.0C (110A)	7.0C (140A)
	Pulse Discharge	7.0C(154A)	10.0C(200A)
Internal Resistance		< 2.0mΩ	< 1.5mΩ
Operating Temperature	Charge	0℃ ~ 55℃	
	Discharge	-20℃ ~ 55℃	
Storage Temperature	Range	-20℃ ~ 55℃	
	Recommend	25±3℃	
Storage Humidity		45 ~ 85%RH	
Cell size	Thickness	5.8mm	+0.2 -0.4
	Width	253mm	± 1
	Length	172mm	± 1

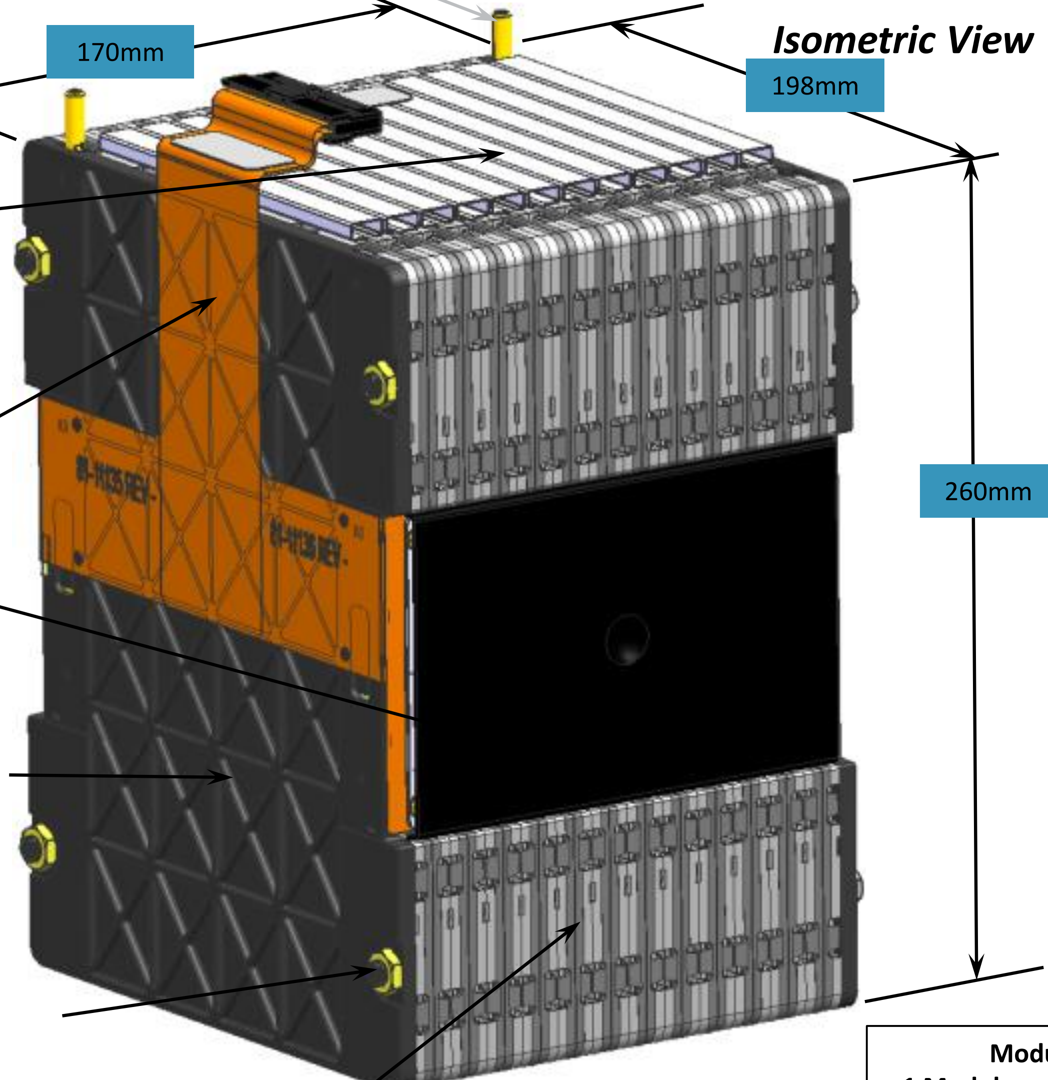


ENERZ™

Module Assembly

Isometric View

Power Buss Terminals
-<50 volts for safe assembly and service
-Cable lug hardware also available



Aluminum Heat-Sinks
-Co-planar surface for cold plate / heater element interface, or air cooling

Flexible Circuit
- Discrete copper traces sense individual cell voltage
-Thermistors sense zone temperature
-Electrolyte and chemical resistant
-Low volume / low mass vs discrete wire

Side Shields
- Protects power bussing connections
- Provides electrical insulation

Endplates
- Promotes module retention / ionic conductivity
- Provides electrical insulation

Tie-Rods
-External threads for module compression
- Internal threads for sub-pack mounting

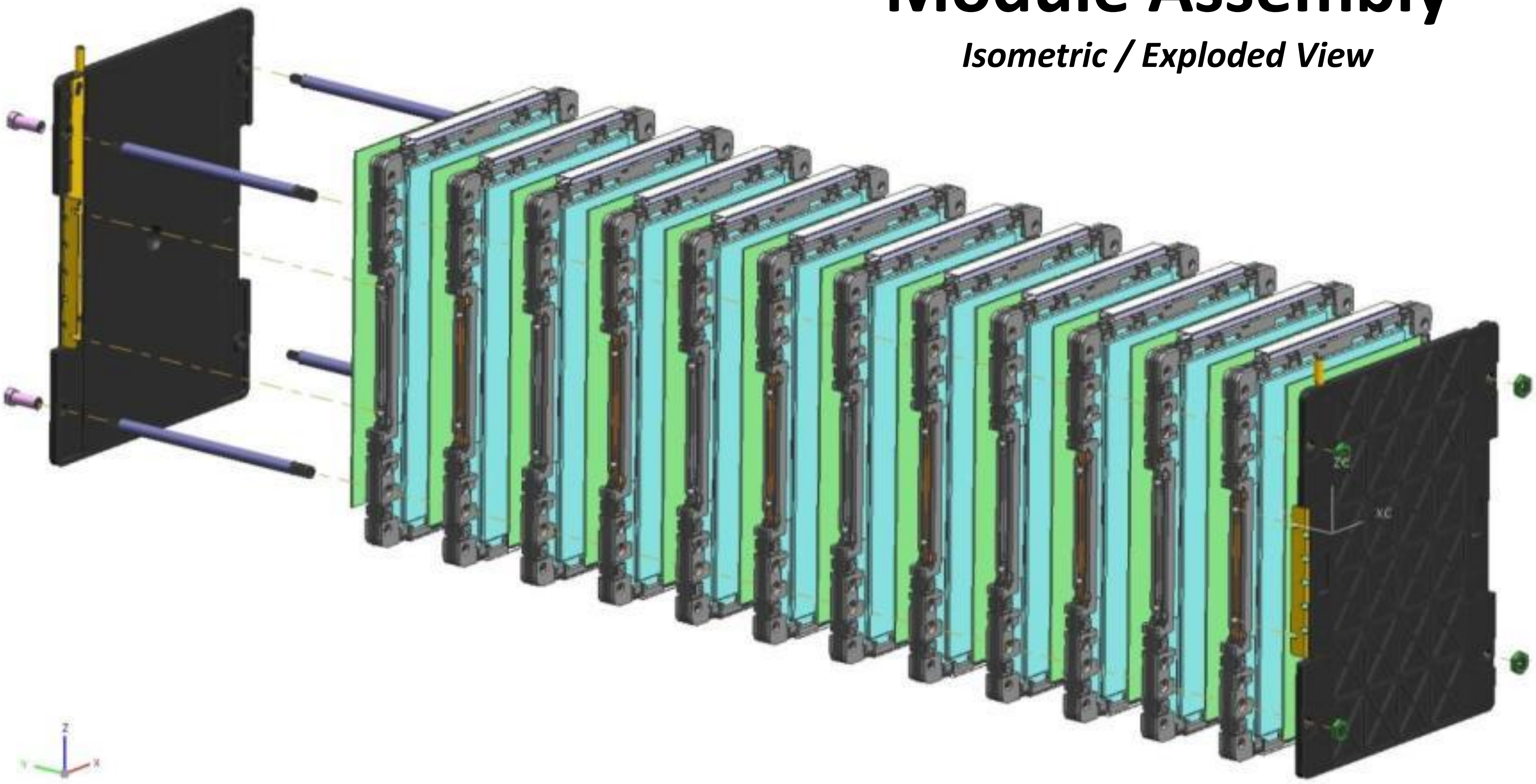
Cell Element Frames
- Cell / heat sink / interconnect hardware retention
-Electrically insulates seal edge perimeter

Module Details
- 1 Module = 12 Elements
- 1 Element = 2 Cells
- TOTAL CELL COUNT = 24 CELLS

Safety Features - Pack

Module Assembly

Isometric / Exploded View



Module Attributes

-**Mechanical interconnects allow disassembly down to cell level for first time quality repair, service, or end of life recyclability and Guaranteed Residual Value (GRV)**

Mechanical Architecture

Cell

Module

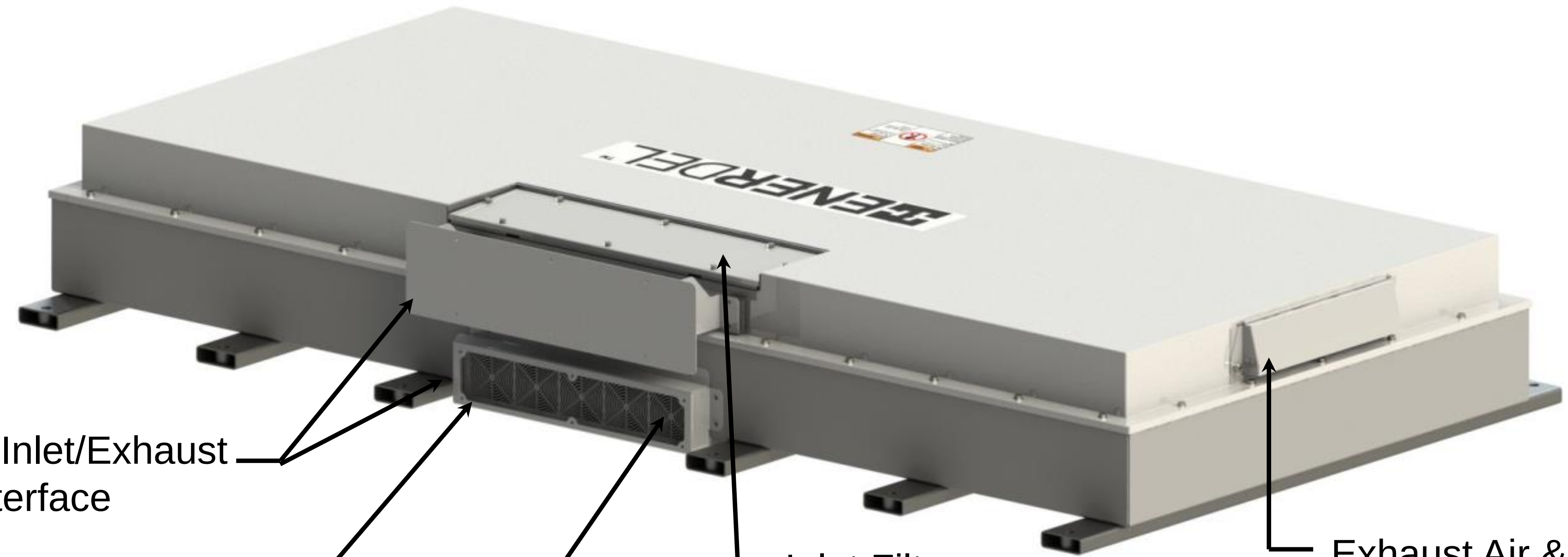
Sub-Pack w/o Case

Integrated Sub-packs and BMS Components

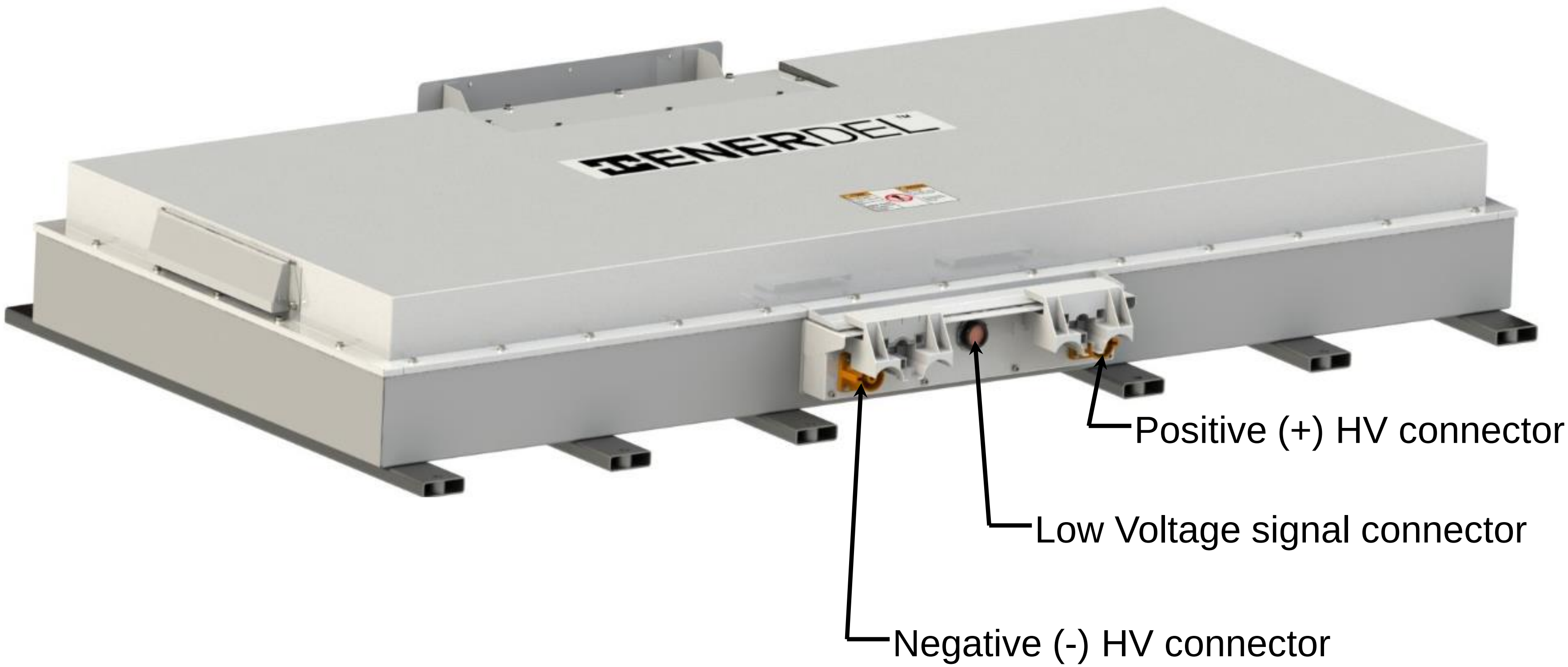
Assembled System

		***EnerDel* - Pack Arrangement - Quantity**						
		Cell	Element	Module	Sub Pack	Pack	Cells in Series	Cells in Parallel
Assy Level	Cell	1						
	Element	2	1					
	Module	24	12	1				
	Sub pack	48	24	2	1			
	Pack	384	192	16	8	1	96	4

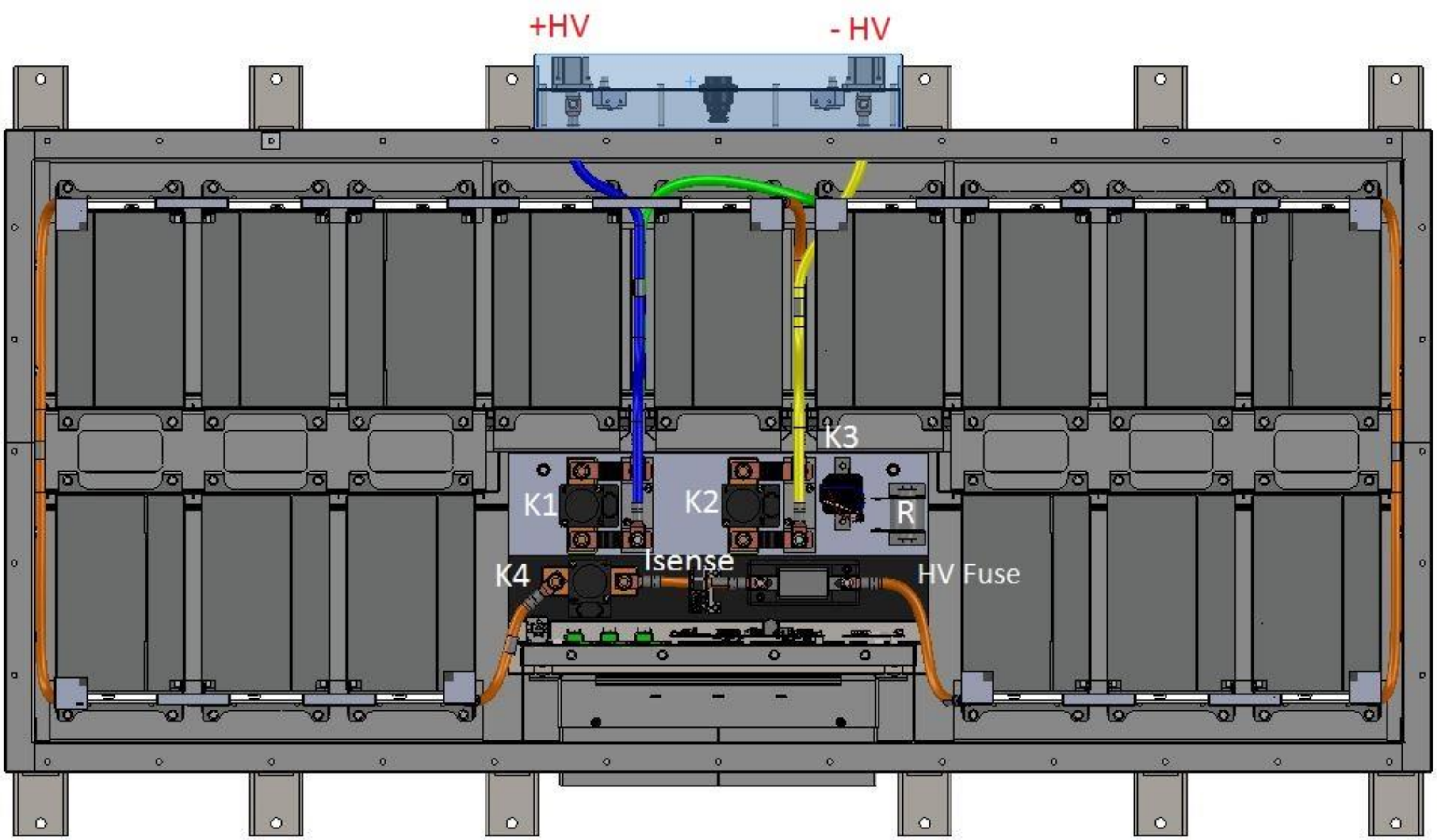
PP320-737-LP *Vigor+ ESS*



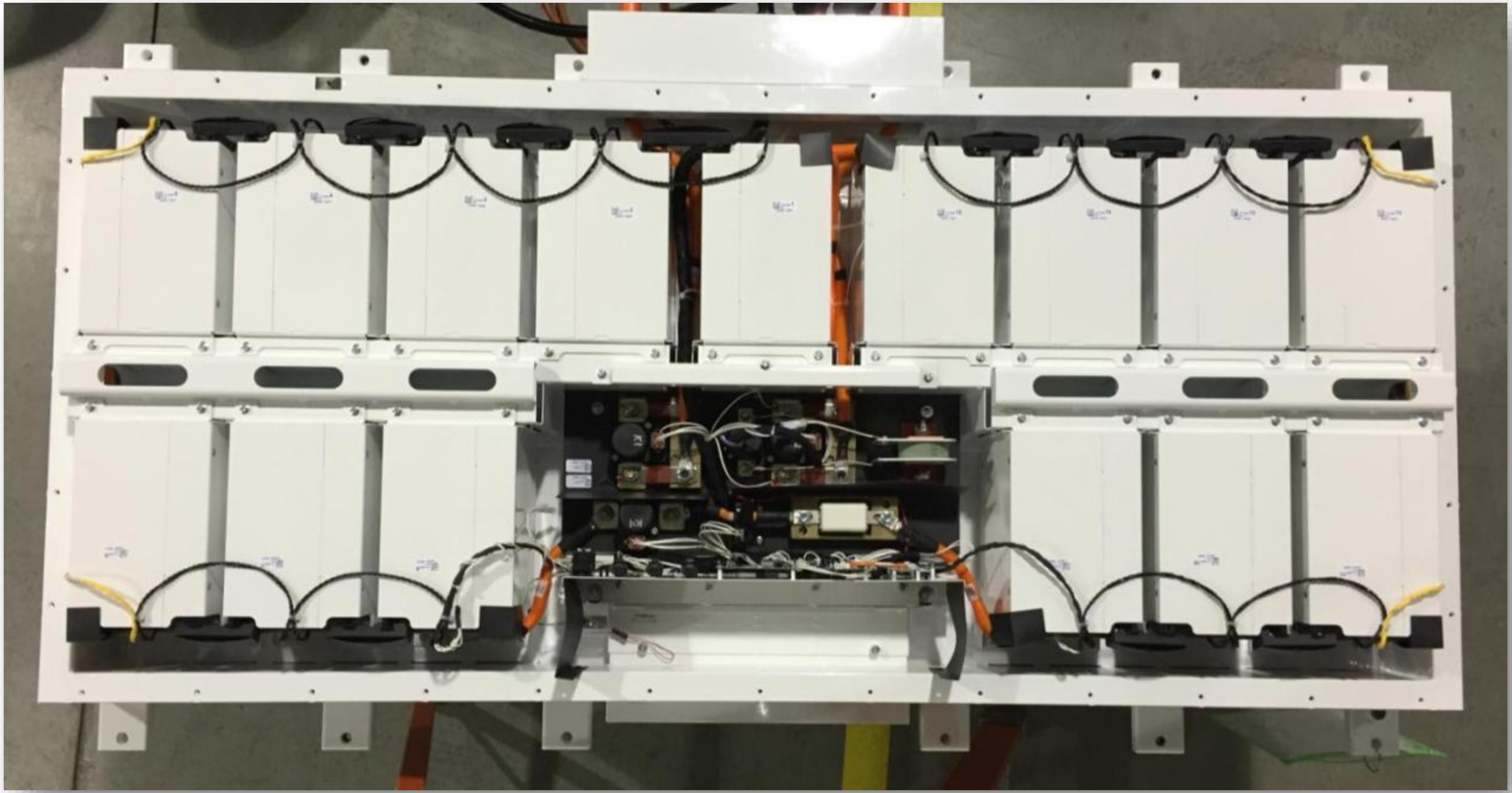
PP320-737-LP *Vigor+ ESS*



PP320-737-LP *Vigor+ ESS*



PP320-737-LP *Vigor+ ESS*



Design compatible with air-cooled module

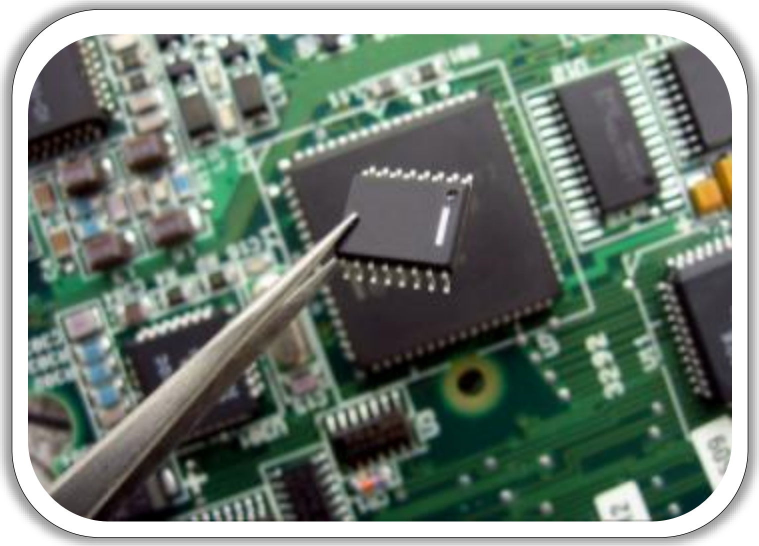
Battery Management System

High-speed battery control system

- Temperature
- State of Charge
- Voltage
- State of Health

Cell monitoring and control

- Optimizes capacity
- Maintains precise state of balance
- Ensures safe and efficient operation of the pack
- Achieves optimal performance and life expectancy

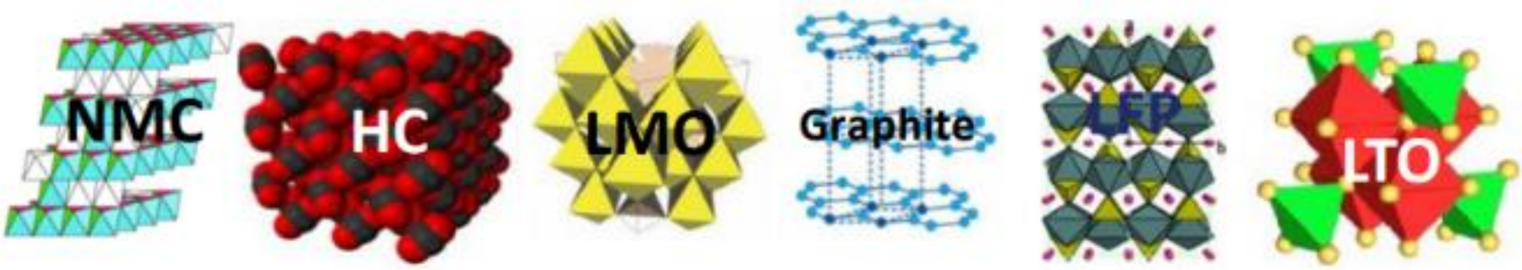


BMS system controls

- Pre-charge
- Closing sequence of contactors
- Opening sequence of contactors
- Online DC response: immediate
- Offline DC response: < 2 Seconds possible

Chemistry choice

Electrode production experience with more than 10 different kinds of chemistry



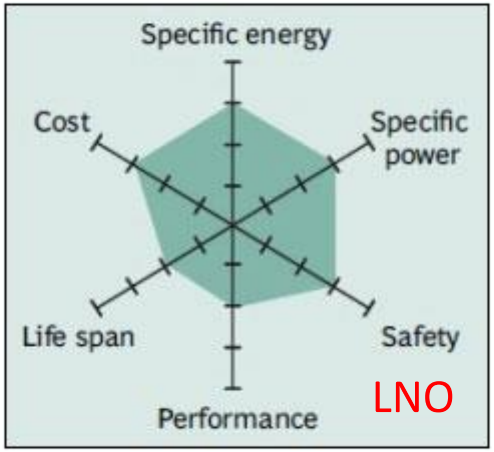
318 patents, including LTO

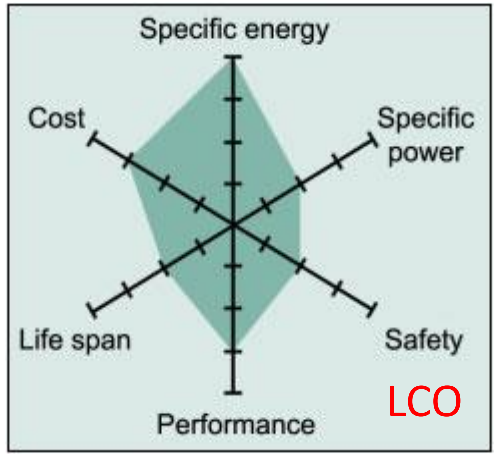
and current choice is NMC+Graphite

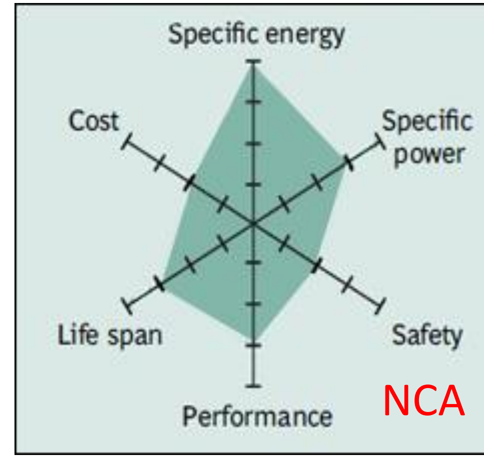
Comparative analysis

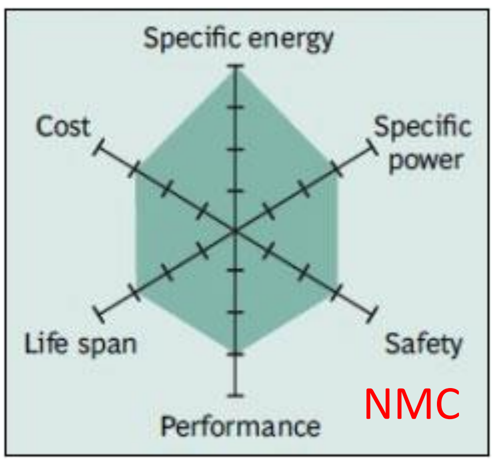
Cell Chemistry	Chemistry Name	Max. Charge Voltage	Nominal Voltage	Min. Discharge Voltage	Energy Density (Wh/kg)	Cycles	Advantages	Disadvantages
Nickel Manganese Cobalt	NMC	4.2	3.7	2.5	150-240	1,000-2,000 **(EnerDel >3,500)**	Highest energy density, Good balance of power and energy	Cost
Nickel Cobalt Aluminum	NCA	4.2	3.6	3.0	200-260	500	Very high specific energy	Not fast charge capable, limited specific power, Cobalt is expensive
Iron Phosphate	LFP	3.6	2.3	2.0	90-120	1,000-2,000	Safer than NMC? High power	More cells in series for application
Manganese Oxide	LMO	4.2	3.7	2.5	100-150	300-700	High power, Least expensive	Short Life
Titanium Oxide (Anode)	LTO	2.8	2.25	1.8	70-80	3,000-7,000	High Cycle Life, High Power	More cells in series for application, expensive
Cobalt Oxide	LCO	4.2	3.6	2.5	150-200	500-1,000	Very high specific energy	Not fast charge capable, limited specific power, Cobalt is expensive

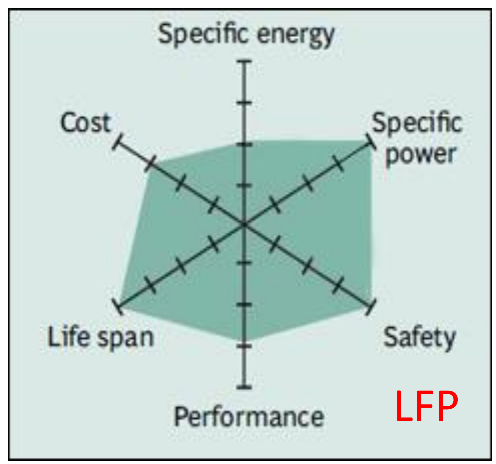
Balanced characteristics of NMC

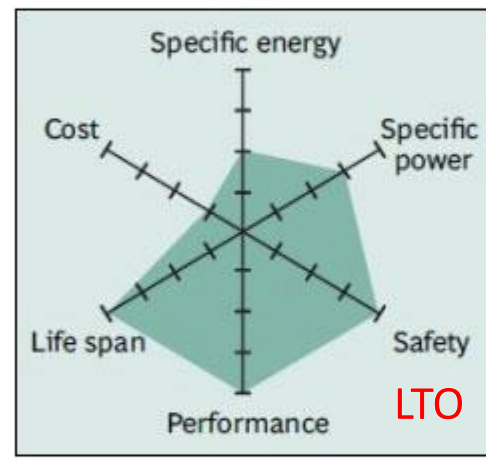




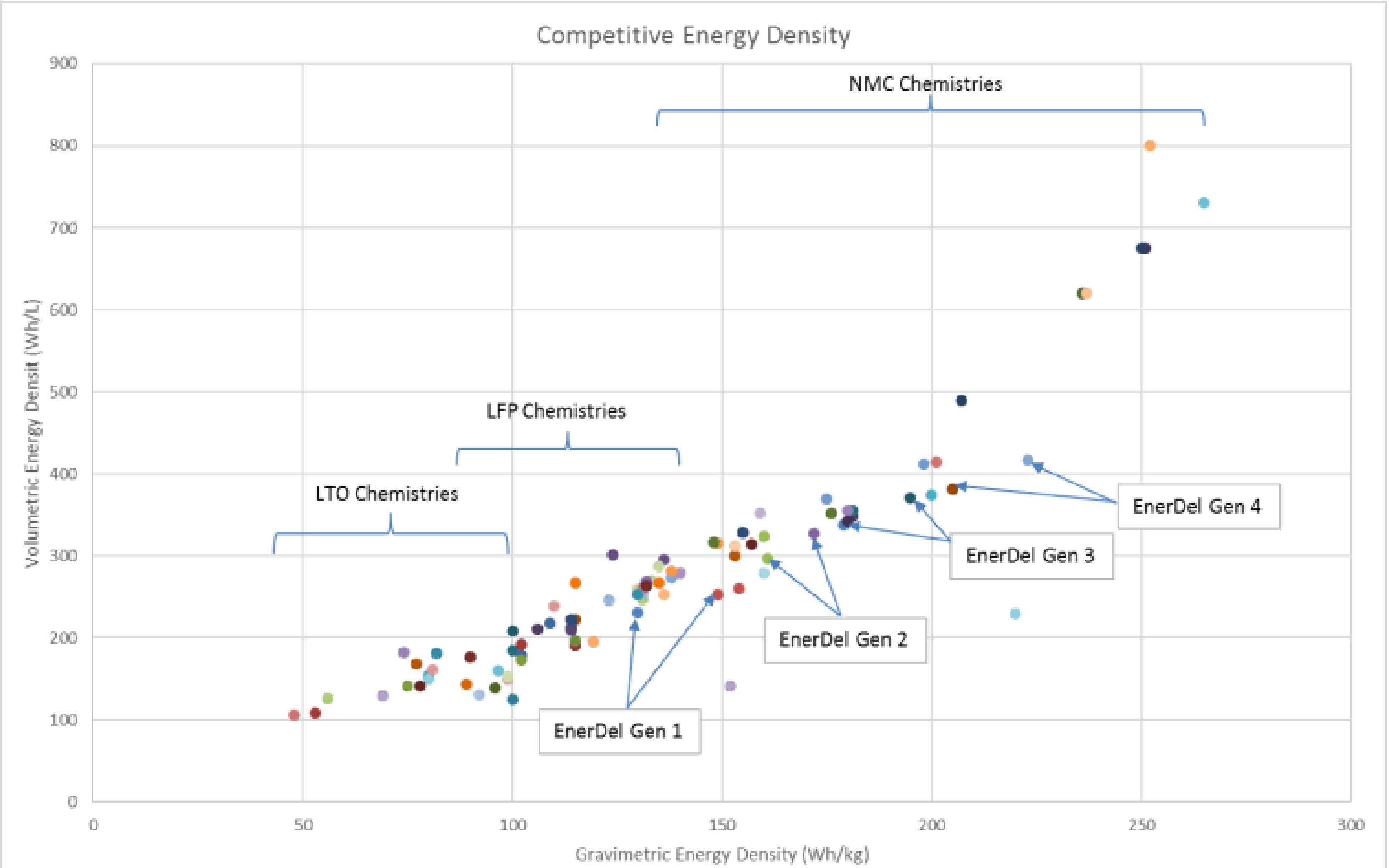








Competitive Cell Analysis
All Chemistries



Higher Energy and higher progress dynamics of NMC.

Evolution of cells

Gen 2 launched in 2017, Gen launch – beginning of 2018

		Gen1		Gen2	Gen3	Gen4	
		EV	PHEV	Energy	Energy	Energy	Power
Capacity (Ah)		17.5	16	20	25	28	26
Energy density	Wh/kg	149	130	158	195	223	205
	Wh/L	253	227	297	371	416	381
Chemistry		NCM(333)/HC		NCM(622)/HC	NCM(622)/GP	NCM(811)/SiC	
Availability		2010		2016	2018 Q1	2019 Q2	

+14% +43% +60%

About customers

Our customers

Grid Energy Storage

FGC UES

ITOCHU

WANXIANG

PGE
Portland General Electric

United States Air Force

UDRI
University of Dayton Research Institute

U.S. Army Corps of Engineers®

Transportation & Industrial

HYUNDAI
HEAVY INDUSTRIES CO., LTD.

FUSO

ГАЗ

VOLVO

JOHN DEERE

TORO.

VANHOOL

THINK

BROOKVILLE

SOLARIS

Nordco

Allison Transmission

GAZ Group: electro bus 6274

Trial operation from January till July 2017 in M2 route, Moscow
Metro Kitay-gorod – Park Pobedy
Next destination for trial is a regional city

SpethAutoInginiring holding: Gazel NEXT Electro

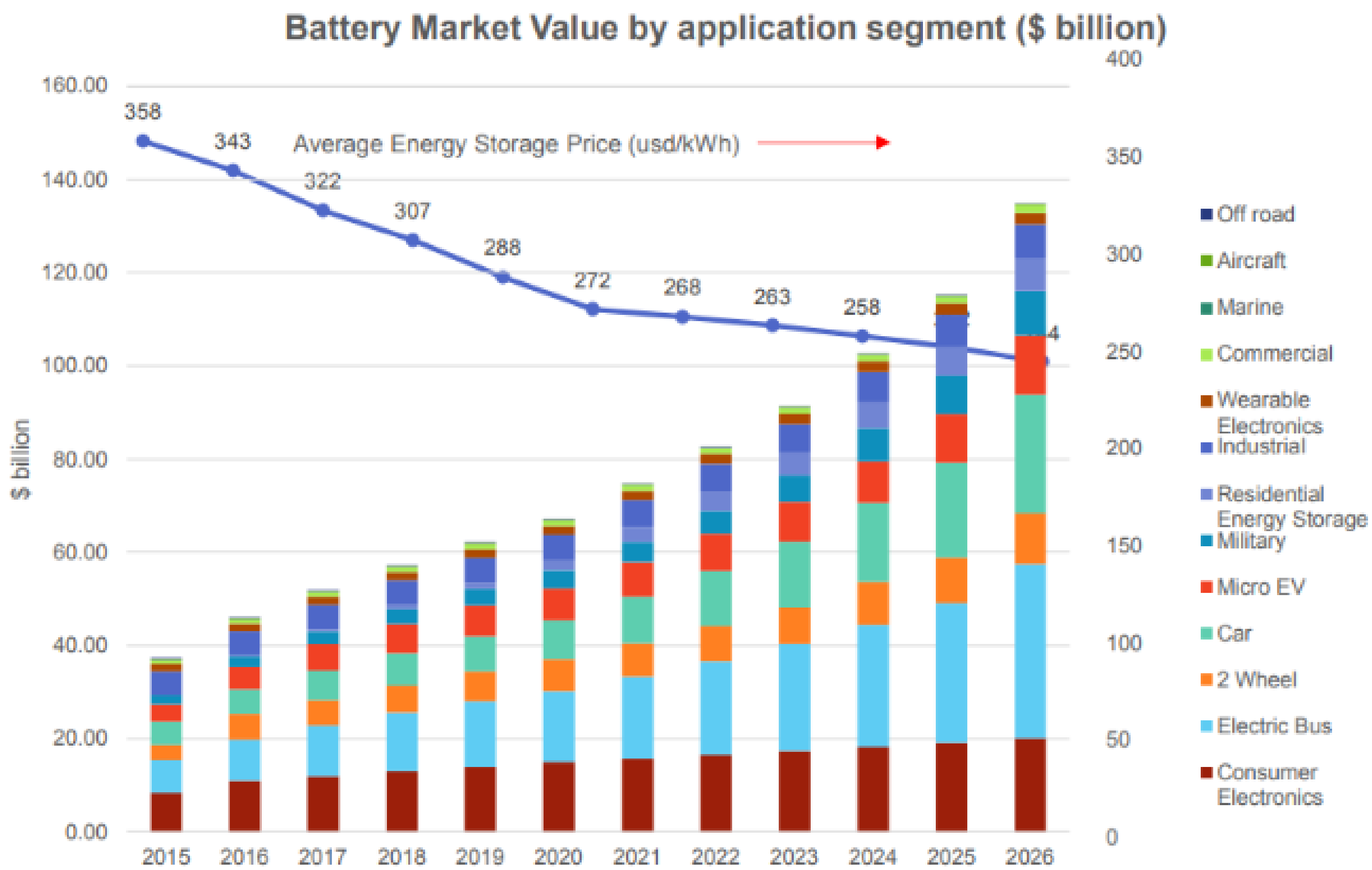
ENERZ™

Электромобили | Грузовой транспорт | Автобусы | Троллейбусы | Трамваи | Поезда | ВИЭ | Домохозяйства | Общ. накопитель & MicroGrid | Телеком | Накопители энергии

Electro buses in Korea since 2010

About market

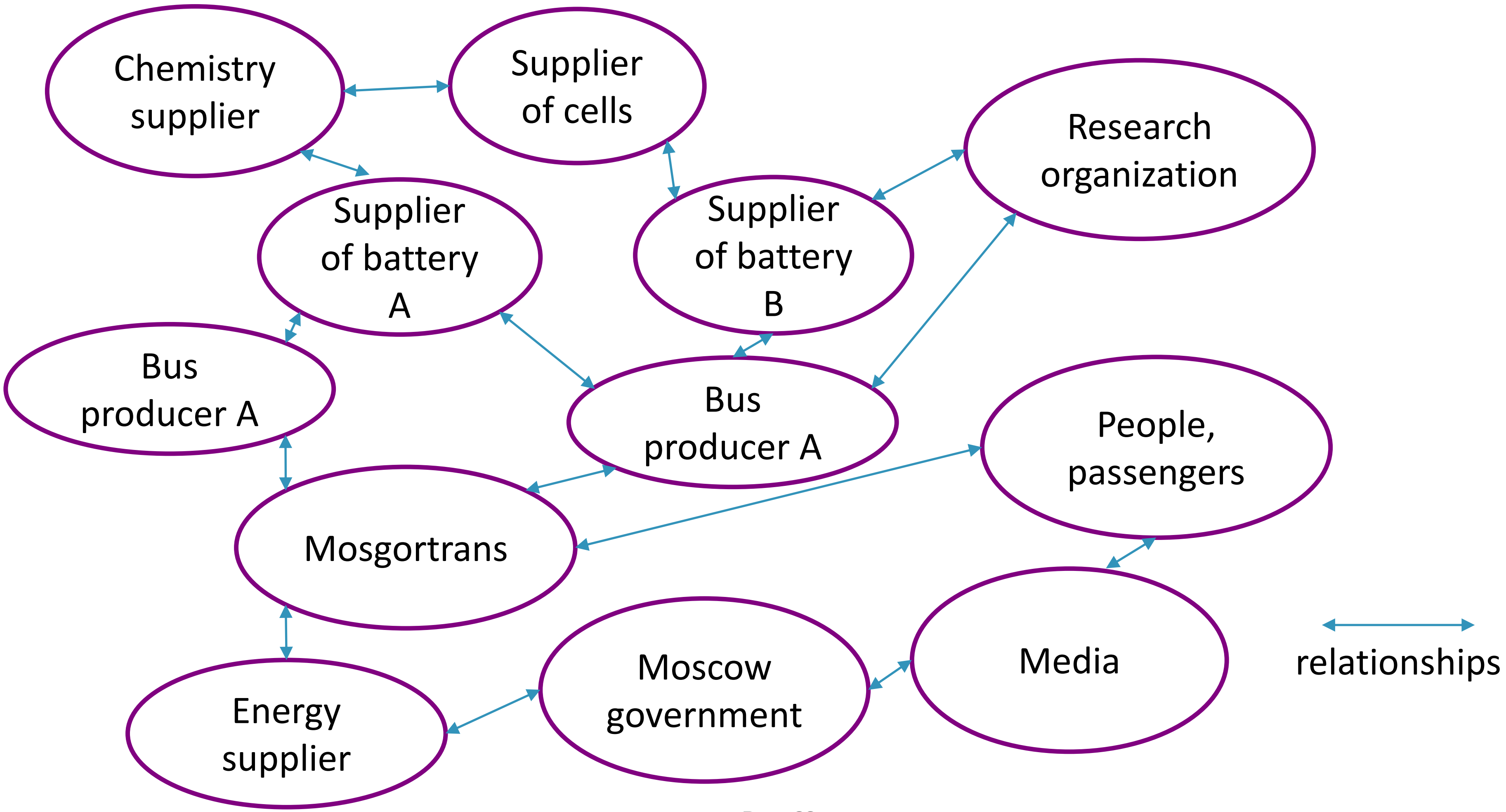
Expected growth of market segments



Source: IDTechEx

ENERZ™

Electrobus market from Market as Network prospective



Comments and conclusion, MAN analysis

- Market as Network is not a hierarchical view
- Every element of market network could be important source of improvement or risk.

Performanse of the industry = $P_{chemistry} * P_{engineering} * P_{assembling} * P_{infrastructure} * P_{users} * P_{recyclers} * P_{other}$

Recycling issue

- “The main challenge of batteries recycling is a high diversity of them. We have to use manual sorting prior to processing”. Vladimir Mathsuk, General manager of Megapolis recourse.

- Environmental concern is the major driver of demand. Economic concern currently is less applicable. For instance, electric buses are more expensive then diesel by several times now.

Uncertainty issue

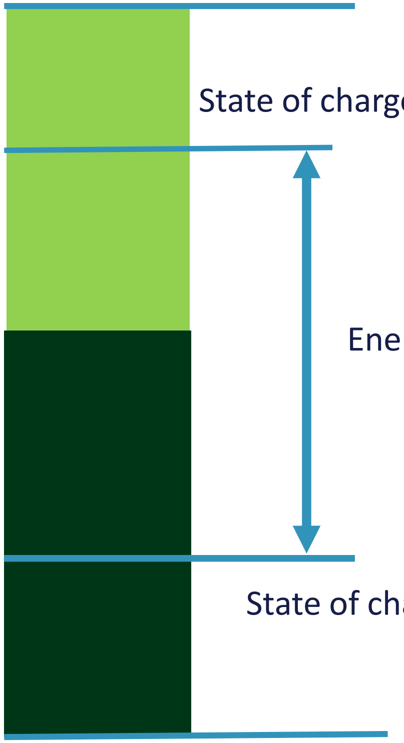
- High level of uncertainty about batteries useful lifetime, safety, reliability and other features diminishes ability of decision makers to adopt new technology.

Batteries parameters

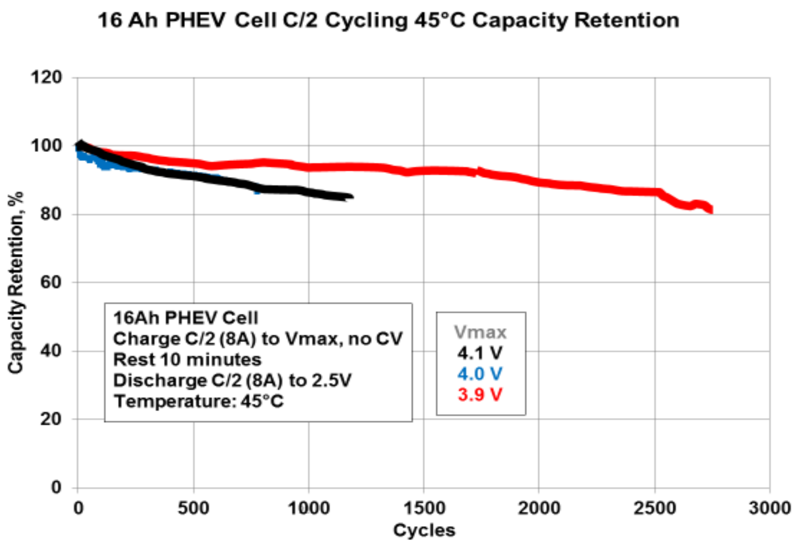
- Energy Density
- Power
- Cost
- Useful life

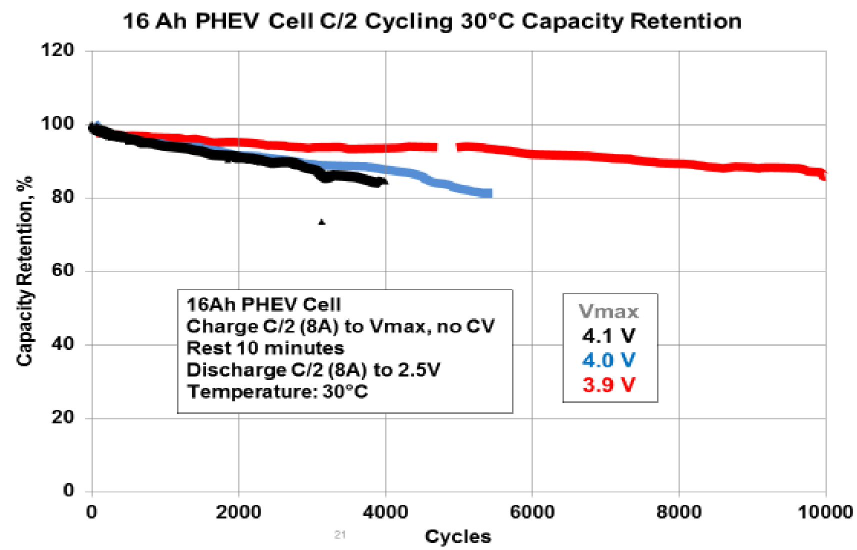
Useful life depends on chemistry and character of cycling.

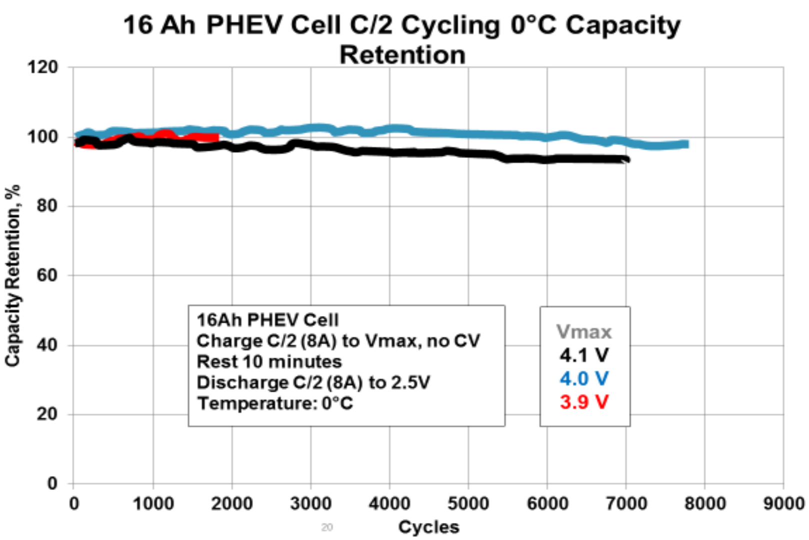
The narrow the lag in between max charge and min charge, the longer useful life, but how longer exactly?



Cycling results experimental

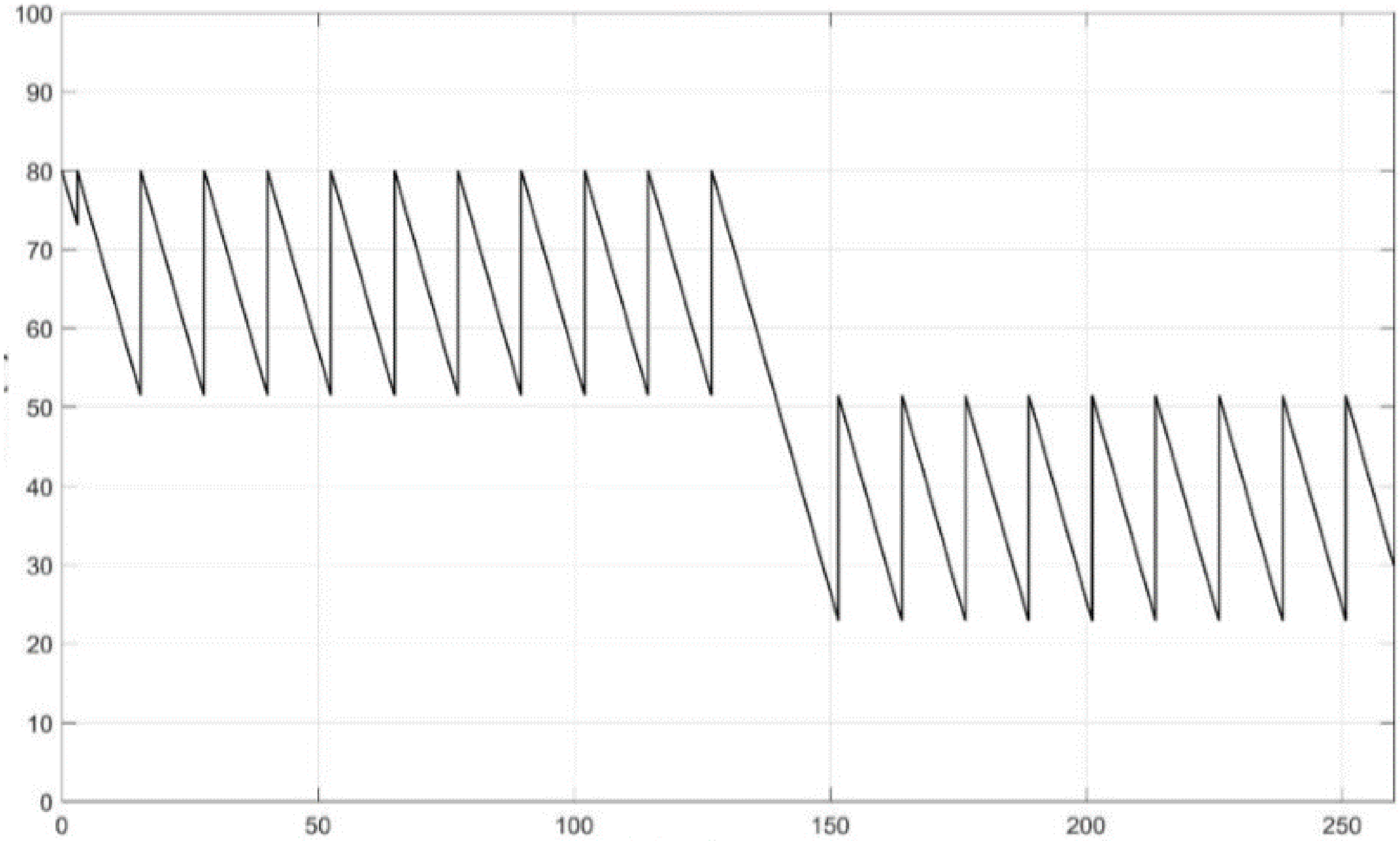






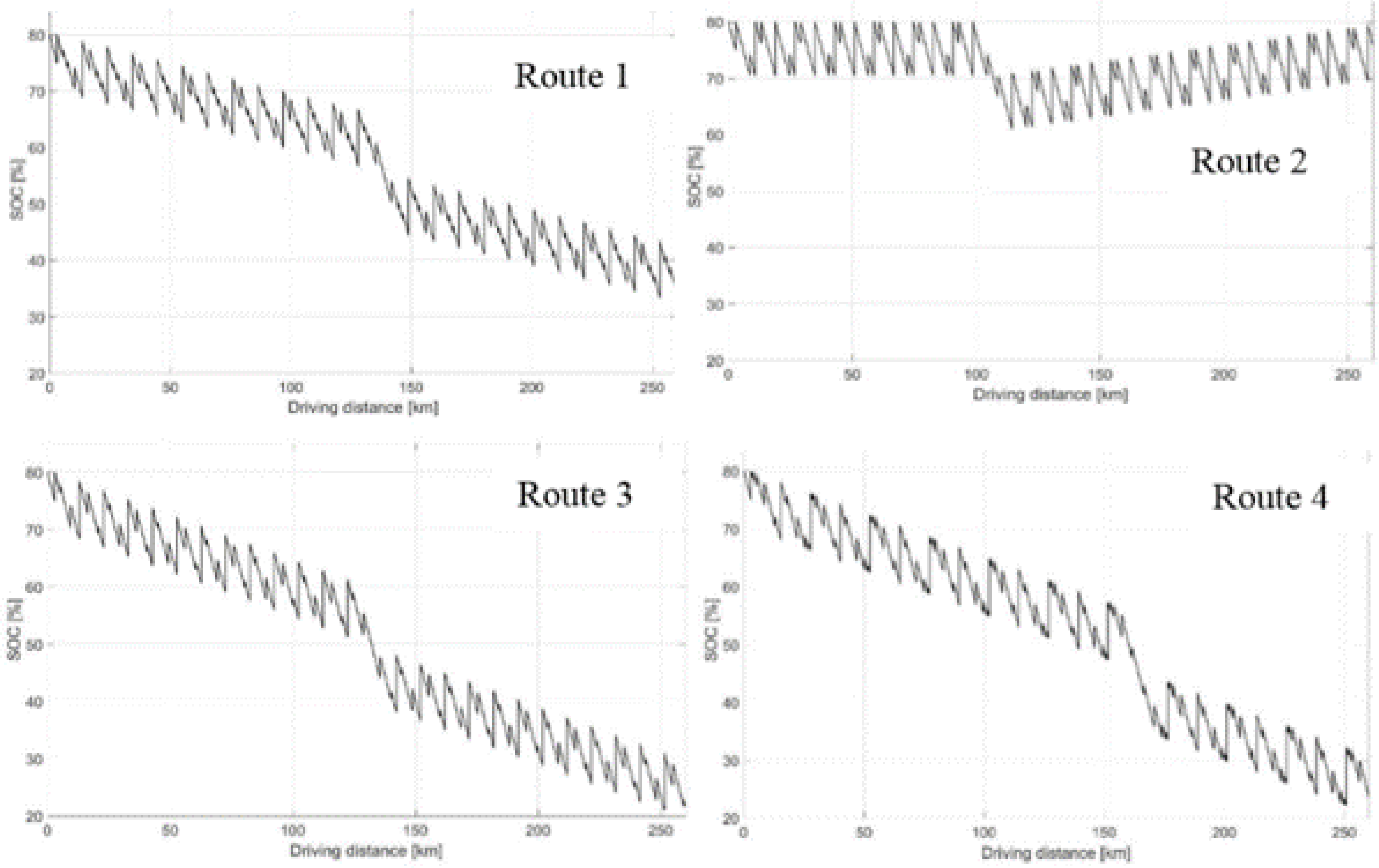
Daily cycling plan for bus

Level of charge, %



Distance, km

More complex depending the route



Even more complex in reality

- Traffic jams
- Whether conditions
- Number of passengers

As result of deviations of conditions, energy spent per km of route may be different from 1.2 to 3.7 kWt*h/km

Mosgortrans has narrowed the task by defining conditions wich need to be provided by supplier

70 kWt*h – available energy, maximum energy spent 2.7

And how to estimate lifetime?

- Testing is the first answer but what about theory?
- A lack of papers about cycling depending various condition

Performance and reliability assessment of NMC lithium ion batteries for stationary application

Yi Li[1,2,*], Noshin Omar[1], Elise Nanini-Maury[2], Peter Van den Bossche[1], Joeri Van Mierlo[1]
[1] Vrije Universiteit Brussel, MOBI Research Group, Pleinlaan 2, 1050, Brussels, Belgium
[2]ENGIE LAB Laborelec, Rodestraat 125, B-1630 Linkebeek, Belgium
*liyi@vub.ac.be

Abstract— **One of the main barriers to increasing the market size of lithium ion batteries for stationary applications is their lifetime. In order to select the optimal cells for integrating into grids, battery performance characterization and lifetime analysis need to be carried out to assess the battery performance and reliability under various operating conditions. In this work, a comprehensive investigation has been carried out to address these issues for a lithium nickel manganese cobalt oxide battery type. Moreover, an empirical ageing model for the lifetime prediction is presented.**

Keywords—Lithium ion battery; NMC; stationary application;

different operating conditions, battery characterization and lifetime tests need to be carried out. Moreover, developing accurate performance models is an economical and effective way to predict the battery performance, ageing status and lifetime, which is a key enabler for the reliable integration of batteries in power grids[9]. Empirical models are often used for battery ageing and lifetime estimation due to their convenience and simplicity. The battery parameters in different ageing stages can be accessed by experimental data and used as input for ageing models. According to the experimental decay tendency the battery lifetime can be

Data from the article

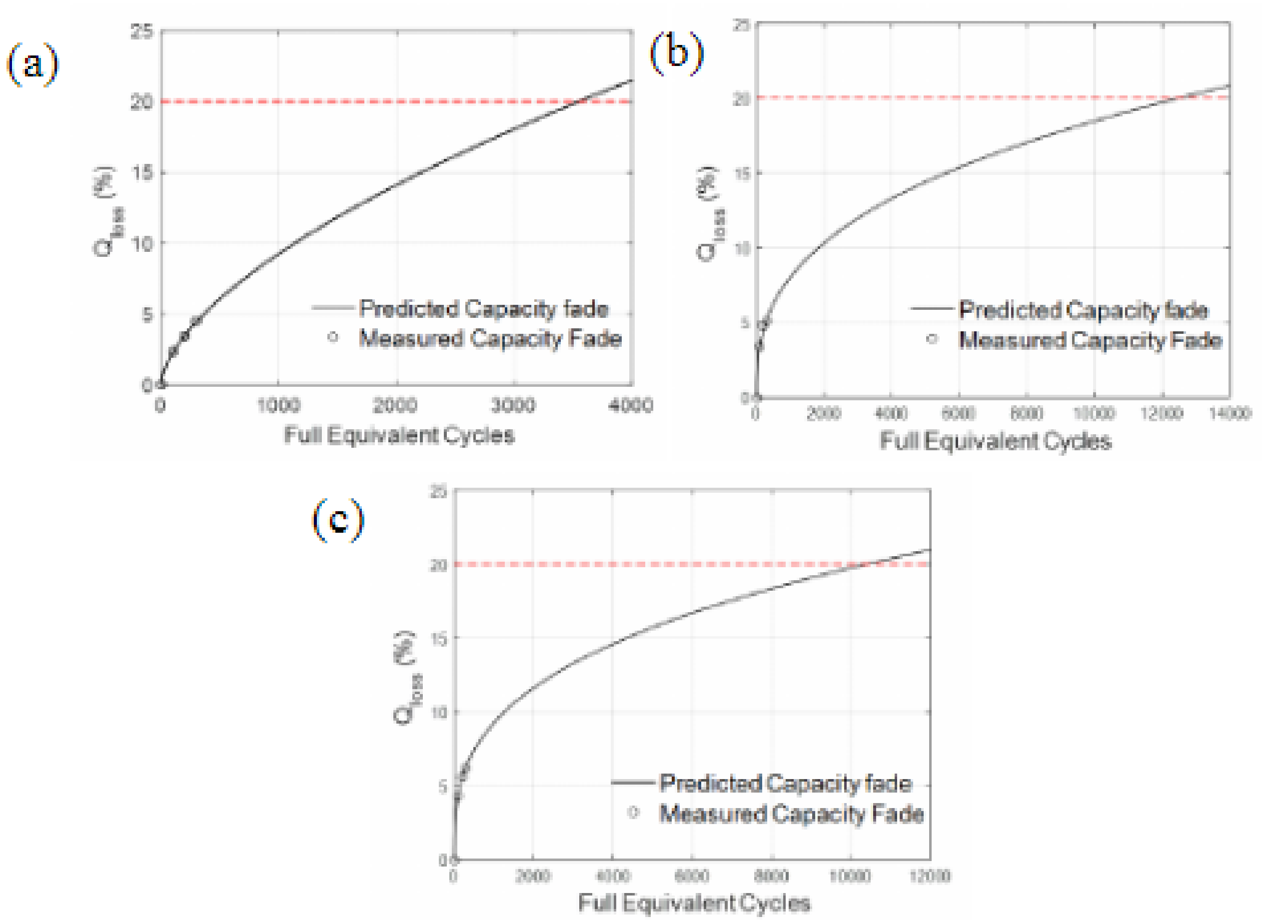


Figure 10. Capacity loss data at different cycling DoD levels (solid color markers) and fitted cycle ageing model (solid line) for cycling at 0.5C at (a) 100% DoD; (b) 80% DoD; (c) 60% DOD until EOL criterion

What would you suggest?

Thank you for your attention!

Viktor Moskalev

Marketing Director

v.moskalev@enerz.ru,

cell: +7 916 103 1486

www.enerz.ru

Address for CV – info@enerz.ru