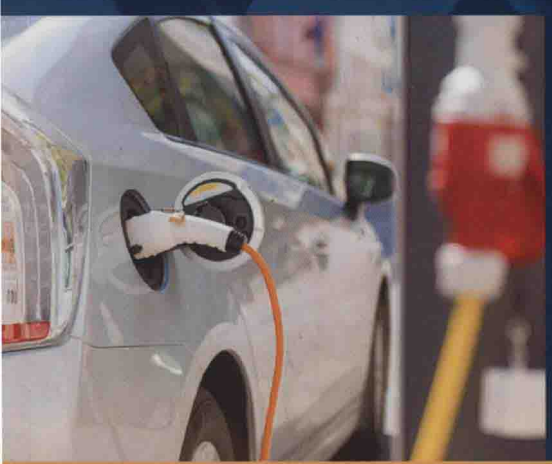
John Warner



The Handbook of Lithium-Ion Battery Pack Design

Chemistry, Components, Types and Terminology

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Preface

In early 2009 as the US automotive industry was in the midst of its restructuring, I took advantage of the changing industry to join a new energy start-up and enter into the lithium-ion battery space. As I worked to make the transition from a major OEM to the lithium-ion battery industry, I purchased pretty much every book I could find on lithium-ion batteries looking for one that gave me the basic information, which I would need to be successful. However, I found that while there were some good books on the market, they were either very technical and targeted at engineers or focused on different markets such as laptops or on different technologies such as Nickel-Metal Hydride batteries. Over the following years I spent a lot of time working with chemists, engineers, and battery scientists to learn as much as I could.

However, about 18 months ago I was speaking to a colleague who was asked a simple question as we were coming out of a meeting—how do you know all of this stuff? And it occurred to me that there may be a need for a tool to help people, who are working in the lithium-ion battery industry but are not battery experts but who still need to gain a better understanding of the industry and the products in order to do their jobs better. In other words, I decided to write the book that I wish I had when I started in the industry. I spent a lot of time thinking back to that time and the types of questions that I had. As someone who had spent a career in engineering organizations but was not an engineer, I had to ask a lot of questions and made a lot of crib notes but I could not find a single source for everything I was trying to learn.

This book is the realization of that knowledge gap in the industry. This book is intended for everyone; you do not have to be an engineer in order to gain an understanding of batteries. In fact, as the battery industry has grown so much over the past 10 years, there have been a lot of new people coming into the battery world from other industries. That means a lot of people with great experience in their various specialties who now need to learn about lithium-ion batteries. Maybe you are a student in one of the new energy storage system programs that are beginning to sprout up in universities across the world, or perhaps you are a purchasing manager who is now tasked with buying a whole new set of components and have no idea what it is they are, or what if you are a thermal engineer who has now moved into the battery world—this book is for you!

In this book you will first begin by gaining an understanding of the history of batteries, as we do not want to repeat any of the mistakes of the past; it is important to understand what has come before us. The next most challenging part of moving into a new industry is understanding the lingo; this book will also help to give you that basic understanding. You will also be able to gain an understanding of the basic math that can be used in doing the first run sizing of a battery—this section is the result of 7 years of taking notes and back calculating some of the work I had seen engineers do over the years. This is followed by chapters that will introduce you to the different parts of the battery, the industry organizations that are out there, and a wide range of different applications that are being powered by batteries—some lithium-ion and some with other technologies.

So whether you are looking to learn something about one aspect of lithium-ion batteries to bolster your knowledge or are entirely new and are looking to learn all about the basics, this book will be a good tool to add to your toolbox.

I have come to believe that, after nearly 2 years of writing and editing this book, it is an ongoing project that will continue to evolve as the industry and technologies themselves evolve. Lithium-ion battery technology is not fixed; it is a constantly evolving field with new innovations, inventions, and chemistries emerging almost daily. This book will give you a great basis to continue your education. So charge up and get started!

Acknowledgments

I would like to begin by thanking my wife Amy and my children Erika and Lukas for their support and encouragement while I have undertaken this project. Without your patience and support over the many weekends and evenings, this book would not have been possible.

I also wish to thank the following people for their contributions to my inspiration and knowledge and other help in creating this book: Bob Purcell, whose background in the automotive electrification field proved very helpful in offering direction and insights as the project was being outlined; Bob Galyen, who has spent his career as a leader in the battery-energy storage industry who provided constant encouragement and support as well as providing direction when needed; Dr Per Onnerud and Dr Christina Lampe-Onnerud, who both became early mentors to me in the lithium-ion battery world; Dr JR Lina, who took me under his wing early in my battery career and taught me many of the basic and key concepts around which this book is based; Subhash Dhar, who has led more energy storage companies over the past 20+ years than anyone else I know; Jon Bereisa, who has been involved in electrification throughout many aspects of his career and is perhaps one of the best resources I have known who can speak on just about any topic. And I need to include a special thanks to some of the people who were initial reviewers of the idea for this book, which helped me to guide the direction and scope of it including Bob Kruse, Dell Crouch, Lori Hutton, Oliver Gross, and many others.

I apologize if I missed anyone, but everyone I have worked with and had interactions with over the past 7 years or more have all been the inspiration for this book and I thank you!

Acronyms List

A	Ampere
AC	Alternating Current
AGM	Absorbed Glass Mat
Ah	Ampere hour
AIAG	The Automotive Industry Action Group
ALBAC	Advanced Lead Acid Battery Council
ARB	Air Resource Board
ASIC	Application Specific Integrated Circuit
ASQ	American Society for Quality
AUV	Autonomous Underwater Vehicle
BCI	Battery Council International
BDU	Battery Disconnect Unit
BEV	Battery Electric Vehicle
BMS	Battery Management System
BOL	Beginning of Life
CAD	Computer-aided Design
CAE	Computer-aided Engineering
CAEBAT	Computer-aided Engineering for Electric-Drive Vehicle Batteries
CAFE	Corporate Average Fuel Economy
CARB	California Air Resource Board
CATARC	China Automotive Technology and Research Center
CES	Community Energy Storage
CFD	Computational Fluid Dynamics
CID	Current Interrupt Device
CSC	Cell Supervision Circuit
DC	Direct Current
DEC	Diethyl Carbonate
DES	Distributed Energy Storage
DFMEA	Design Failure Modes Effect Analysis
DFR	Design for Reliability
DFS	Design for Service

DFSS	Design for Six Sigma
DMC	Dimethyl Carbonate
DOD	Depth of Discharge
DOE	U.S. Department of Energy
DOE	Design of Experiments
DVP&R	Design, Validation Plan & Report
EC	Ethylene Carbonate
ECSS	Electrochemical Storage System
eMPG	Electric Miles per Gallon
EDV	Electric Drive Vehicles
EES	Electrochemical Energy Storage
EMC	Ethylmethyl Carbonate
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMS	Energy Management System
EOL	End of Life
EREV	Extended Range Electric Vehicle
ESS	Energy Storage System
EUCAR	European Council for Automotive Research and Development
EV	Electric Vehicle
EVAA	Electric Vehicle Association of America
FCEV	Fuel Cell Electric Vehicle
FEA	Finite Element Analysis
FMEA	Failure Modes Effect Analysis
GEO	Geosynchronous Earth Orbit
GEV	Grid-tied Electric Vehicle
HC	Hydrocarbon
HEO	High Earth Orbit
HEV	Hybrid Electric Vehicle
HD	Heavy Duty
HIL	Hardware in the Loop
HPDC	High Pressure Die Cast
HPPC	Hybrid Power Pulse Characterization
HV	High Voltage
HVAC	Heating Ventilation Air Conditioning
HVFE	High Voltage Front End
HVIL	High Voltage Interlock Loop
IBESA	International Battery and Energy Storage Alliance
ICB	Interconnect Board
ICE	Internal Combustion Engine

IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
INL	Idaho National Laboratory
IP	International Protection
IP	Ingress Protection
IPVEA	International Photovoltaic Equipment Association
ISO	International Organization on Standardization
kWh	kilo-watt hour
LAB	Lead Acid Battery
LCO	Lithium-ion Cobalt Oxide
LD	Light Duty
LEO	Low Earth Orbit
LEV	Low Emissions Vehicle
LEV	Light Electric Vehicle
LEVA	Light Electric Vehicle Association
LFP	Lithium-ion Iron Phosphate
LIB	Lithium-ion Battery
LIP	Lithium-Ion Polymer
LiPo	Lithium-Ion Polymer
LI-Poly	Lithium-Ion Polymer
LMO	Lithium-ion Manganese Oxide
LPG	Liquid Propane Gas
LTO	Lithium-ion Titanate Oxide
LV	Low Voltage
MEO	Medium Earth Orbit
μHEV	Micro Hybrid Electric Vehicle
MPG	Miles per Gallon
MSD	Manual Service Disconnect
MTBF	Mean Time between Failures
MTTF	Mean Time to Failure
MY	Model Year
MWh	Mega-watt hour
NAATBatt	National Association for Advanced Technology Batteries
NCA	Lithium-ion Cobalt Aluminum
NEMA	National Electrical Manufacturers Association
NEV	Neighborhood Electric Vehicle
NEV	New Energy Vehicle (China)
NHTSA	National Highway Transportation Safety Administration
NiCd	Nickel Cadmium
NiMh	Nickel Metal Hydride

NMC	Lithium-ion Nickel Manganese Cobalt
NREL	National Renewables Energy Laboratory
NTC	Negative Thermal Coefficient
NTCAS	National Technical Committee on Automotive Standardization (China)
OEM	Original Equipment Manufacturer
ORNL	Oak Ridge National Laboratory
OSV	Off-Shore Vessel
PbA	Lead Acid
PCB	Printed Circuit Board
PCM	Phase Change Material
PE	Polyethylene
PFMEA	Process Failure Modes Effect Analysis
PHEV	Plug-In Hybrid Electric Vehicle
PMS	Power Management System
PNNL	Pacific Northwest National Laboratory
PP	Polypropylene
PRBA	Portable Rechargeable Battery Association
PSV	Platform Supply Vessel
PTC	Positive Thermal Coefficient
PV	Photovoltaic
PVDF	Polyvinylidene Fluoride
PZEV	Partial Zero Emissions Vehicle
REEV	Range Extended Electric Vehicle
RESS	Rechargeable Energy Storage System
REX	Range Extender
SAC	Standardization Administration of China
SAE	Society of Automotive Engineers
SEI	Solid Electrolyte Interphase
SIL	Software in the Loop
SLA	Standard Lead Acid
SLI	Starting, Lighting, Ignition
SNL	Sandia National Lab
SOC	State of Charge
SOH	State of Health
SOL	State of Life
SRU	Smallest Replaceable Unit
S/S	Stop/Start
T&D	Transmission & Distribution
TMS	Thermal Management System
TTF	Test to Failure

UAV	Unmanned Aerial Vehicles
UL	Underwriter's Laboratory
UN	United Nations
UPS	Uninterruptible Power Supply
USABC	U.S. Advanced Battery Consortium
USCAR	United States Center for Automotive Research
UUV	Unmanned Underwater Vehicles
VDA	Verband der Automobilindustrie
VRLA	Valve Regulated Lead Acid
VOC	Voice of the Customer
VTB	Voltage, Temperature monitoring Board
VTM	Voltage, Temperature Monitoring
W	Watt
W/kg	Watt per kilogram
W/L	Watt per liter
Wh	Watt-hour
Wh/kg	Watt-hour per kilogram
Wh/L	Watt-hour per liter
ZEV	Zero Emissions Vehicle

Contents