



TOTAL BATTERY CONSULTING REPORTS

The xEV Industry Insider Report

AN INSIDER'S VIEW OF THE FUTURE XEV MARKET AND THE BATTERY TECHNOLOGY THAT WILL POWER IT

Dr. Menahem Anderman

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A SYSTEMATIC ACCOUNT OF WHY BATTERY SAFETY INCIDENTS OCCUR AND HOW TO AVOID THEM

Dr. Daniel Doughty

The xEV Industry Insider Report

AN INSIDER'S VIEW OF THE FUTURE XEV MARKET AND THE BATTERY TECHNOLOGY THAT WILL POWER IT

Author: Dr. Menahem Anderman

An assessment of the pace of xEV market expansion based on global conditions and the cost/benefit ratios of emerging vehicles and battery technologies

BENEFITS

Automakers:

Benefit from the report's balanced analysis of the future cost, performance, and durability of advanced automotive batteries.

Battery producers:

Gain insights into the directions of both the advanced automotive market and individual carmakers.

Materials producers:

Learn about the prospects of battery materials in the xEV market.

Corporate and financial investors:

Use this comprehensive assessment of the technology and market challenges to better guide your investment decisions.

KEY TOPICS

- China is leading the way
- European, North American, and Japanese markets
- Tesla and other specialty-EV firms
- Will expansion accelerate after 2021?
- Vehicle-market projections to 2025
- Li-Ion battery-market projections to 2025
- Li-Ion cell design and performance trajectory
- Li-Ion cell and battery cost
- Materials: demand, cost, and supply
- Solid electrolyte: Is there a path to mass market?
- Directions of individual carmakers
- Strengths of individual battery makers
- 48V mild-hybrids: challenges, opportunities, and energy-storage selection
- Status and future of Pb-Acid and NiMH batteries and ultracapacitors

2018 REPORT OUTLINE

I. xEV Market Trends

1. Global Market Drivers: Directions & Challenges
2. China, Europe, North America, and Japan
3. Vehicle Market Forecast to 2025
4. Directions of Individual Automakers

II. Lithium-Ion Battery Technology for HEV-PHEV-EV

1. Chemistry
2. Cell Design
3. Pack Design
4. Materials and Manufacturing Costs

III. xEV Battery Market 2010 to 2025

1. Mild and Strong Hybrids
2. PHEVs & EVs
3. Buses and Specialty Vehicles
4. Materials: Demand and Pricing

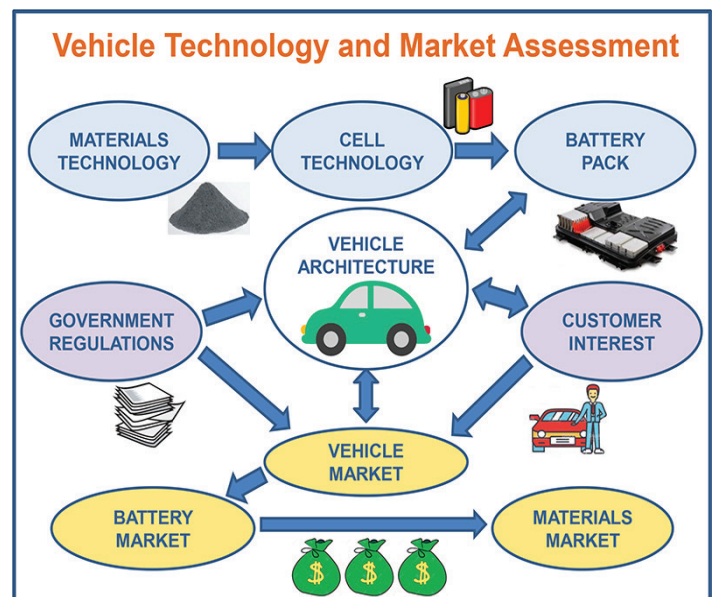
IV. Technology Development to 2030

1. Traditional Lithium Ion
2. Solid Electrolyte: Is it Coming?
3. Assessment of Other Contenders

V. Directions of Individual Battery Makers

VI. Appendix

1. Levels of Vehicle Hybridization
2. Lead-Acid and NiMH Batteries
3. Ultracapacitors



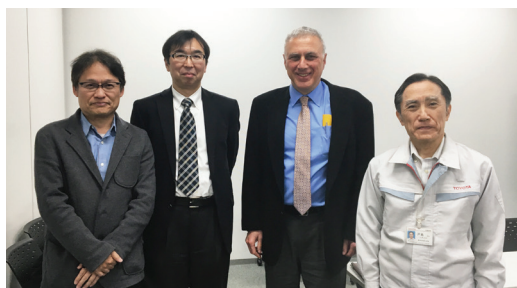
"There is certain data that you just cannot get elsewhere and we rely on the Report's analysis - especially cost information; so it is very valuable to us. It is worth the money - absolutely."

— William J. Wallace, General Motors

"Dr. Anderman and TBC are a very valuable, independent source for automotive battery technology and market insights."

— Soeren Striepe, Senior Manager, Magna International

THE VISITS AND DISCUSSIONS BEHIND THE REPORT



With Toyota's solid-electrolyte development team



At LG Chem's facility in Nanjing, China



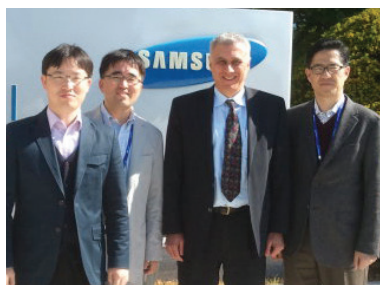
At CATL's new headquarters and production facility in Ningde



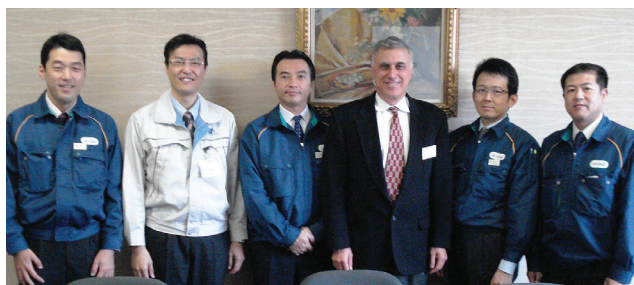
With BJEV Battery technology executives



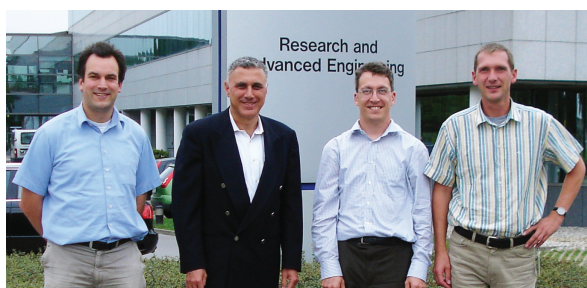
With Gotion's R&D team in Heifi



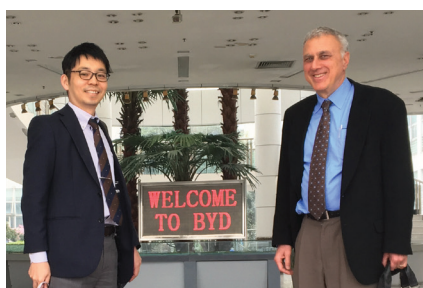
At SDI plant in Korea



After discussion with GS Yuasa and Li Energy Japan



Dr. Anderman at Ford R&D in Aachen Germany



At BYD's battery technology center

COMPANIES VISITED 2016-2018

Automakers/Automotive Systems:

- Audi
- AVL
- BJEV
- BMW
- Chery Automobile
- Fiat-Chrysler
- Daimler
- Ford
- General Motors
- Honda
- Hyundai
- Mitsubishi Motors
- Nissan
- Opel AG
- Renault
- Toyota
- Valeo
- Volkswagen

Battery Producers:

- A123 Systems
- AESC
- BYD
- CATL
- Farasis
- Gotion
- GS Yuasa
- Hitachi
- LG Chem
- Li Energy Japan
- Lishen
- Panasonic
- Polyplus
- Samsung
- SK Innovation
- Toshiba

Other Participants:

- California Air Resources Board
- Mitsubishi Chemical
- Umicore

Battery Packs of Modern xEVs

A COMPREHENSIVE ENGINEERING ASSESSMENT

Authors: Kevin Konecky and Dr. Menahem Anderman

TABLE OF CONTENTS

I. xEV Battery System Key Design Attributes

- a. ESS Definition
- b. ESS Requirements
- c. ESS Design
- d. ESS Validation
- e. ESS Integration
- f. ESS Battery Life
- g. ESS Cell Safety
- h. ESS Safety
- i. ESS Product Development

II. Battery Packs for EVs

- a. EVs discussed in this section
- b. Battery packs for EVs – Analysis
- c. Vehicle-specific review for production EVs
 - US/EU/JP/KR vehicles
 - Chinese vehicles

III. Battery Packs for PHEVs

- a. PHEVs discussed in this section
- b. Battery packs for PHEVs – Analysis
- c. Vehicle-specific review for production PHEVs
 - US/EU/JP/KR vehicles
 - Chinese vehicles

IV. Battery Packs for HEVs

- a. HEVs discussed in this section
- b. Battery packs for HEVs – Analysis
- c. Vehicle-specific review for production HEVs

V. Charging Systems of EV/PHEVs

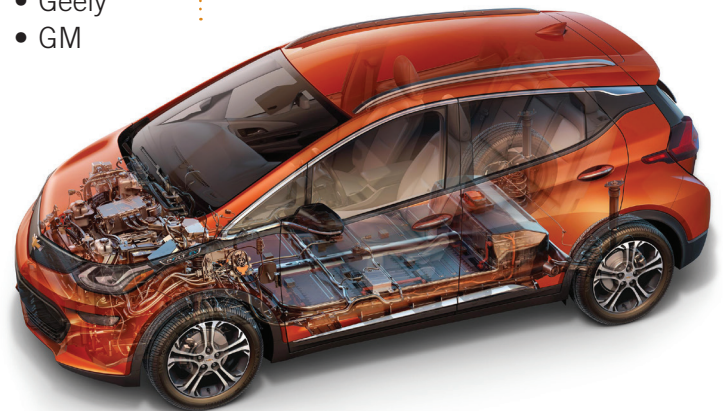
- a. Charging systems overview
- b. Charging standards
- c. Application usage of charging
- d. Vehicle trends for production EVs

An analysis of the battery-pack technology—cells, modules, and subsystems—used in 135 of the most recent xEVs.

A reference book for professionals in this industry.

Pack technology of the following OEMs:

- | | | |
|-----------|--------------|--------------|
| • Audi | • Hawtai | • Nissan |
| • BAIC | • Honda | • Renault |
| • BJEV | • Hyundai | • SAIC |
| • BMW | • JAC | • Subaru |
| • BYD | • JLR | • Tesla |
| • Chery | • JMC | • Toyota |
| • Daimler | • Kia | • Volkswagen |
| • Denza | • NIO | • Volvo |
| • FCA | • Porsche | • Zhidou |
| • Fisker | • Mazda | • Zotye |
| • Ford | • Mitsubishi | |
| • Geely | | |
| • GM | | |



BENEFITS

Automakers:

Consult this review of the battery-pack technologies used in current xEVs to guide your future work.

Battery producers:

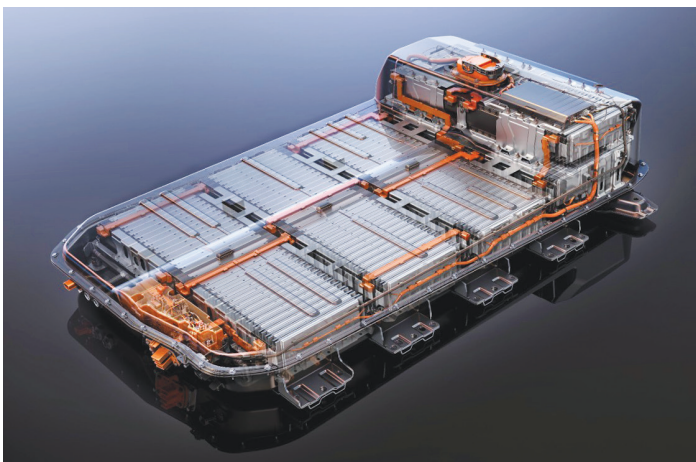
Gain insights into the trends of automotive battery-pack technology.

Component and subsystem producers:

Learn about automotive energy-storage system and subsystem design trends and individual cell and pack producers.

Corporate and financial investors:

Use this all-inclusive assessment of battery-pack technology to sharpen your investment decisions.



Li Ion Batteries & Beyond

CRITICAL INSIGHTS INTO FUTURE CELL CHEMISTRY AND MATERIALS

Author: Prof. Martin Winter

TABLE OF CONTENTS

I. Introduction

1. General principles
2. Li-metal chemistry—the ancestor of Li-Ion
3. Li-Ion design overview
4. Battery design trade-offs and limitations

II. Anodes

1. Introduction to Li-Ion battery materials
2. Carbonaceous and graphitic anodes
3. Alternatives to carbonaceous and graphitic anodes
4. Pre-lithiation and other measures to compensate for C_{irr}

III. Cathodes

1. Introduction: cathode materials classification
2. Synthesis of cathode materials
3. Cathode vs. anode: capacity balancing
4. Layered cathode materials
5. Other cathode materials
6. Composite cathodes & summary
7. Mutual anode-cathode influence

IV. Electrolytes

1. Composition of liquid organic-solvent-based electrolytes
2. Conductivity and transport mechanism
3. Electrolyte stability and interphase (SEI, CEI) formation
4. SEI and CEI analysis
5. SEI forming solvents and electrolyte additives
6. The electrolyte salt: $LiPF_6$
7. Ionic Liquids (ILs)

V. Inactive Materials

1. Overview of active and inactive materials
2. Separators
3. Current collectors
4. Binders
5. Conductive electrode additives

VI. Beyond Li-Ion Batteries

1. Beyond Li-Ion, before Li-Ion, parallel to Li-Ion
2. How to make high-energy-density (“super”) batteries?
3. Specific energy vs. energy density: A necessary look at new cell chemistries
4. Lithium/sulfur chemistry
5. Lithium/air chemistry
6. Solid electrolytes: polymeric and ceramic
7. Alternative chemistries: Na, Na-Ion, Mg, Al, Dual-Ion

This unique report evaluates advanced battery R&D work across the globe and highlights the most promising materials and cell technologies that will enable advances in battery technology and, with it, market expansion.

BENEFITS

Automakers, utility / industrial system integrators:

Consult the report’s critical review of future cell chemistry and material R&D to advance your planning and roadmaps.

Battery producers:

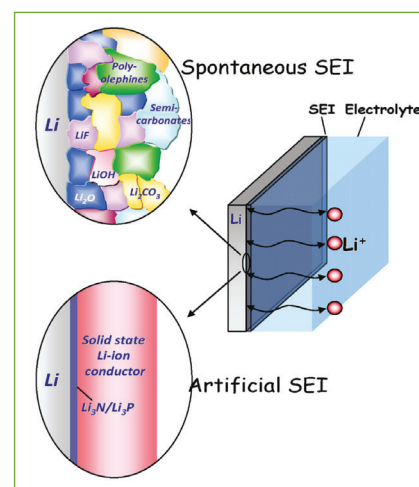
Use this all-inclusive assessment of the challenges associated with new cell chemistries and materials to better calibrate your development work.

Material developers / producers:

Benefit from this unbiased expert assessment of what is in the pipeline to sharpen your development strategy and funnel your R&D investment into the most promising technologies.

Corporate and financial investors:

Gain insights into the future of battery cell materials and chemistry to guide your investment decisions.



A critical assessment of what is in the research labs, what is likely to make it to the market, and why.

“Prof. Winter handles this complex topic with professionalism and authority.”
— Jeff Oren, *Primet Precision Materials*

“Prof. Winter’s presentation is impressive, structured, high content! Fascinating how much he covers in short time! A good presentation to explain science to engineers!”
— Roland Matthe, *General Motors*

“This was the 4th time listening to Prof. Winter’s presentations, and I am looking forward to the 5th time. Very good!”
— Kai Vuorilehto, *Skeleton Technologies*

Li Ion Battery Safety & Abuse Tolerance

A SYSTEMATIC ACCOUNT OF WHY BATTERY SAFETY INCIDENTS OCCUR AND HOW TO AVOID THEM

Author: Dr. Daniel Doughty

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1. Background and Fundamentals of Battery Safety

- Battery Safety Fundamentals
- Examples of Recent Safety Recalls
- Hazards & Thermal Runaway
- Cell Failures
- Safety Devices

2. Understanding Battery Failure Modes

- Understanding Battery Failures
- Li-Ion Battery Safety & Abuse Characterization Tests
- Propagation of Thermal Runaway of Single Cell
- Abuse Tolerance Simulation
- Effect of Cell and Pack Design on Abuse Response

3. Safety Validation: Abuse Testing Methods & Procedures

- General
- Shipping Procedures
- Pass/Fail vs. Safety Characterization Tests
- Test Procedure Comparisons
- Functional Safety
- What's Missing

Summary and Conclusions

Appendix: Organizations that Publish Safety Test Standards

Safety concerns arise when batteries are abused, used outside the design's operational space, poorly designed, or beyond useful life. Heat generation and gas generation are the most common responses of batteries to abusive conditions--the most serious consequences occur when the stored energy is rapidly released in an unintended manner, triggering thermal runaway. This report presents the fundamentals of battery safety and abuse tolerance. It discusses materials, cells, and battery system design, manufacturing, applications, and validation, as well as the lessons learned from recent failures.



BENEFITS

Automakers, utility / industrial system integrators:

Consult the report's critical review of cell, battery, and system safety to calibrate your own work in the field.

Battery producers:

Use this all-inclusive assessment of cell, battery, and system safety and the challenges associated with abuse tolerance and safety validation. Enhance your understanding of this crucial aspect of the technology and its role in your development work.

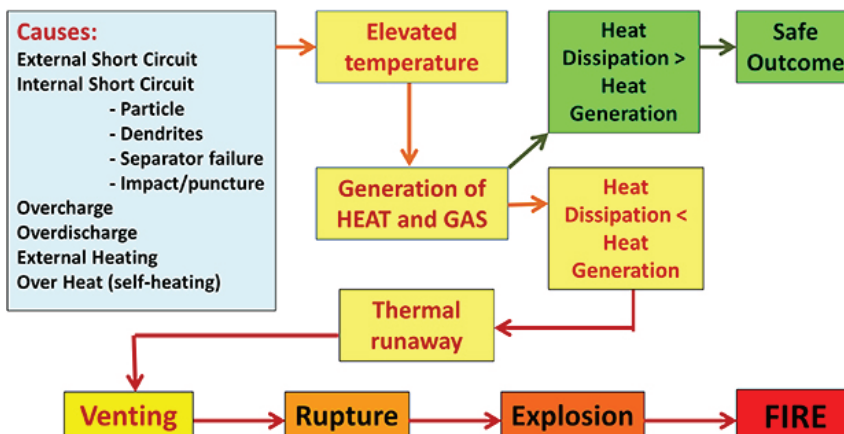
Material developers / producers:

Benefit from this unbiased expert assessment of materials, cell, and battery safety to sharpen your development strategy and funnel your R&D investment into the most promising technologies.

Corporate and financial investors:

Gain insights into the single largest risk associated with advances in battery technology and the financial exposure related to any investment in the field, to hone your investment choices.

Anatomy of Cell Failure



THE AUTHORS



Dr. Menahem Anderman,

President, Total Battery Consulting, Inc.

As the world's leading independent expert on advanced automotive batteries, Dr. Anderman provides technological assessments to companies worldwide. His client list includes most major auto-

makers, leading international battery developers and suppliers, financial institutions, and government agencies. His access to automakers and battery companies gives Dr. Anderman insight into the latest trends in the advanced-vehicle market as reflected in his 2002 and 2007 Advanced Automotive Battery Industry Reports, 2005 Ultracapacitor Opportunity Report, 2010 / 2011 EV-PHEV Opportunity Reports, and his current reports, the xEV Industry Insider Report and The Tesla Battery Report.



Kevin R. Konecky

Mr. Konecky has 15 years of experience as engineering manager for Energy Storage Systems, predominantly for xEVs. He is skilled in component and subsystems design, integration, and testing. Mr. Konecky has worked on HEV packs as

senior engineer or engineering manager for GM Allison, GM Tahoe, Cobasys - GM Saturn Vue, on EV packs for EnerDel -Volvo; and on PHEV packs for Fisker. As a consultant he has helped automakers and battery developers active in the U.S. and Chinese markets develop and validate xEV packs ranging from low-voltage HEVs to large EV battery systems.



Dr. Daniel Doughty,

President, Battery Safety Consulting, Inc.

Dr. Doughty founded his consulting firm in 2008 to provide independent expert consulting services for a wide range of battery safety issues, including failure analysis, test method development,

interpretation of test results, expert witness and forensic consulting. In this capacity, he works with battery developers and integrators to secure and validate battery system safety under all foreseeable abuse conditions; he also assists standard and test organizations in establishing battery safety test standards.



Prof. Martin Winter,

Prof. Winter is the Founding Scientific Director of the MEET Battery Research Center as well as the Founding Director of the Helmholtz Institute "Ionics in Energy Storage", WWU Muenster, Germany. He oversees one of the largest

battery R&D groups in the world with ca. 150 technical staff. Prof. Winter provides consulting to the automotive battery and materials industries and is the chairman of the advisory board of the Batterieforum as well as the spokesperson of the program Batterie2020 for the BMBF (Germany's Ministry of Education and Research). Prof. Winter was awarded the Research and Technology Awards of the Electrochemical Society (ECS) and the International Battery Materials Association (IBA) and the Carl Wagner Memorial Award of the ECS.

ORDERING INFORMATION

xEV Industry Insider Report (April 2019 edition)	Full report	\$3,900
	Partial report, any two chapters	\$2,800
Battery Packs for Modern xEVs Report (April 2019 edition)		\$3,500
Li Ion Battery Safety & Abuse Tolerance Report (December 2017 edition)		\$2,500
Li Ion Batteries & Beyond Report (published February 2017)		\$3,500
Corporate license for each report		\$1,500
Additional copies (only available with report purchase)		\$150
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- Varta Batteries
- Vulcan

OTHER

- Andreas STIHL AG & Co KG
- Andrews Kurth LLP
- Argonne National Laboratory
- ATS Armor LLC
- Battery Design Company
- Boeing / Hughes Space & Communications
- BTU International
- California Air Resources Board

- Copper Development Association
- CRA International
- CRI Advantage
- E-Motion Mobility
- Electric Power Research Institute
- EnBW Energie Baden-Wuerttemberg AG
- Exponent
- Field Support Services
- Fraunhofer Institute for Systems and Innovation Research
- Hon Hai Precision Ind. Co., Ltd.
- ICCT
- Idaho National Engineering and Environmental Laboratory
- IFP Energies Nouvelles
- Illinois Tool Works
- Instituto de Tecnologia Edson Mororo Moura
- ITRI
- National Research Council Canada
- New York University
- Nickel Institute
- Philips Research Laboratories
- Roland Berger Strategy Consultants GmbH
- SunEdison
- SVP Japan Co.
- Taiwan Industrial Technology Research Institute (ITRI)
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- TUM CREATE, Ltd.
- University of California, Davis
- VTT Technical Research
- US Department Of Energy

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- Arkema
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- Brueckner Maschinenbau GmbH & Co. KG
- Cabot Corporation
- Celgard
- Chemetall
- ConocoPhillips Company
- Corning
- Degussa
- Dow Chemical Company
- DuPont Company

- Engelhard Corporation
- Entegris
- Freudenberg & Co.
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- Hollingsworth & Vose
- Honeywell
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- INCO Special Products
- Kimberly-Clark
- MeadWestvaco Corporation
- Merck KGaA
- Michelin
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- Mitsui Mining & Smelting Co., Ltd.
- Momentive
- Morgan Crucible
- Nanogram
- NGK-Locke, Inc.
- Nippon Shokubai Co.
- Occidental Material Group (OMG)
- Orion
- POSCO
- Primet Precision Materials
- Procter & Gamble
- Rogers Corporation
- Rohm and Haas Chemicals
- Sabic Innovative Plastics
- Schott AG
- SciMAT
- SGL Carbon
- Showa Denko
- Solvay
- SQM S.A.
- Süd Chemie
- Sumitomo Bakelite North America
- Sumitomo Corporation
- Ticona
- Toda
- Tonen Chemical
- Toray Battery Separator Film
- Umicore
- W.L. Gore & Associates
- Zeon Corporation

OIL COMPANIES

- BP America Production Company
- Chevron Texaco Corporation
- Exxon Mobil Chemical Co.
- Nippon Oil (U.S.A.)
- Nippon Shokubai Co.
- Shell Oil
- SK Corporation

Since 1996, Total Battery Consulting (TBC) has provided consulting and multi-client industry reports in the field of energy-storage development, application, and market, with particular emphasis on the advanced automotive battery market. In 2000, TBC's founder and President Dr. Menahem Anderman also founded the premier international event in the industry: the Advanced Automotive Battery Conference (AABC), which he has chaired ever since. The objective of Total Battery Consulting is to make information available to industry professionals around the world to help them focus their financial and human resources on the most technologically viable and economically affordable solutions for the needs of the automotive energy-storage industry. Supporting Dr. Anderman at TBC as consultants are Prof. Martin Winter of Muenster Electrochemical Energy Technology, Dr. Robert Spotnitz, President of Battery Design, LLC, and Mr. Kevin Konecky.



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