I. xEV Market Trends

1. Overview
   • Recent EV-Market Boosters
   • Market Drivers
   • In 2010 to 2016, most automakers introduced ‘Compliance Cars’
   • Battery-EVs: Main Development and Direction
   • PHEVs: Main Development and Direction
   • Strong HEVs: Main Development and Direction
   • Mild to Advanced Micro-HEVs (MHEVs): Main Development and Direction
   • Powertrain Electrification and Impact on CO2 Emissions
   • xEV Market Drivers and Market Share by Category

2. Vehicles Markets by Region
   • Worldwide Sales of Top Electric Vehicles (2018)
   • Worldwide Sales of Top Plug-In Electric Vehicles (2018)
   • Current Chinese xEV Market Trends: Market Drivers – Government
   • China NEV Subsidy 2018 versus 2017
   • Current Chinese xEV Market Trends: Market Drivers – Automakers
   • Chinese Sales of Top Electric Vehicles (2018)
   • Chinese Sales of Top Plug-In Electric Vehicles (2018)
   • Chinese “Logistic EVs”
   • Chinese NEV (PHEV + EV) Market, 000 units
   • Current European xEV Market Trends – Market Drivers
   • European Sales of Top Electric Vehicles (2018)
   • European Sales of Top Plug-In Electric Vehicles (2018)
   • Current European xEV Market Trends – EVs
   • Current European xEV Market Trends – PHEVs
   • Current European xEV Market Trends – Strong Hybrids (HEVs)
   • Current European xEV Market Trends – Mild Hybrids (MHEVs)
   • Current European xEV Market Trends – Micro Hybrids (μHEVs)
   • Current U.S. xEV Market Trends – Market Drivers
   • 2018 EV US Sales
   • Current U.S. xEV Market Trends – EVs
   • 2018 PHEV US Sales
   • Current U.S. xEV Market Trends – PHEVs
   • Current U.S. xEV Market Trends – Strong HEVs
   • Current U.S. xEV Market Trends – MHEVs
   • Current Japanese xEV Market Trends – Hybrids
   • Current Japanese xEV Market Trends – PHEVs/ EVs
   • Current xEV Market Trends – Rest of the World (ROW)

3. Vehicle Market Forecast to 2020
   • HEV Market by Vehicle Producer 2010 – 2020
   • HEV Market by Hybrid Category
   • EV Market Forecast
   • EV Market Forecast – Excluding Chinese Automakers
   • PHEV Market by Producer
   • EV Market (Forecast) by World Region
   • EV Market Growth by World Region
   • PHEV Market Forecast by World Region

4. Vehicle Market Forecast Beyond 2020
   • EV Market Development to 2025 and Beyond
   • Market Growth Beyond 2015 – Customer Pull?
   • xEV Market Driver and Share by Category
   • 2025 xEV Market Share Forecast by Region: Our Baseline Estimate
   • 2025 xEV Market Forecast by Region
   • 2030 xEV Market Share Forecast by Region: Our Baseline Estimate
   • 2030 xEV Market Forecast by Region

5. Directions of Individual Carmakers
   • Direction of Key European Carmakers
   • Direction of International Carmakers
   • Direction of Japanese Carmakers
   • Toyota / Lexus
   • 2001-17 Toyota HEV Family
II. Lithium-Ion Battery Technology for xEVs

1. Key Battery Design Parameters
   - Historical xEV Battery Development
   - xEV Battery Technology Overview
   - The Lithium-Ion Cell
   - Li-Ion Cell Stack
   - Cell Design & Casing: Pouch, Cylindrical, or Prismatic
   - Cell Casing: Cylindrical
   - Cell Casing: Prismatic and Pouch
   - Cathode Chemistry: Ni-Based
   - Cathode: NMC is the Focus for Large-Cell EV Batteries
   - Cathode Chemistry: Other
   - Anode: Graphite-Based
   - Status of Graphite
   - Si-Blend Anode
   - Electrolytes
   - Separator
   - Solid Electrolyte/Separator?
   - xEV Battery Power and Energy Level vs. Applications
   - xEV Battery Pack Energy Density vs. Power Level

2. Mild and Strong Hybrid Batteries
   - Requirements
     - Batteries for Strong Hybrids
     - 2001-17 Toyota HEV NiMH: Battery Pack Parameters
     - HEV Li-Ion Cell Current Design Matrix
     - Li-Ion Prismatic Metal-Can Cells Involved in Production HEVs
     - Li-Ion HEV Cell Materials Cost
     - Li-Ion HEV 5-Ah Cell Price
     - Li-Ion HEV: Key Cost Components
   - Cell and Pack Design, and Cost
     - 48V Mild Hybrids: Battery Requirements and Selection
     - 48V Battery Solutions
     - Audi 48V Battery System Requirements
     - 48V, 0.37-kWh Liquid-Cooled SDI Pack for Jeep Wrangler
     - LG Chem 9.8-Ah Pouch Cell for Mild Hybrids
     - 10-Ah MHEV Cell Price 2020
     - 48V MHEV, 2025 Cell Materials Cost
     - 48V MHEV, 2025 Cell Price
     - 48V Cell and Battery Design Evolution
     - Audi’s 48V Battery System Requirement Evolution Forecast
     - 14V Micro-2 Hybrids: Energy-Storage Solutions
     - Micro-2 Hybrids: Energy-Storage Solutions (2)
     - Micro-2 Hybrids: Energy-Storage Solutions (3)
     - Low-Voltage Hybrid Li-Ion Cell Design

3. EV & PHEV Battery Technology
   - PHEV Battery Technology Evolution
     - Battery Pack Capacity for PHEVs
     - PHEV Battery Pack – Specific Energy
     - PHEV Battery Pack – Capacity vs. Launch Year
     - PHEV Battery Pack – Specific Energy vs. Launch Year
     - PHEV Cell and Pack – 2017 Market
     - Mercedes PHEV Battery-Pack Parameters
     - PHEV-2 Roadmap
   - EV Cell and Battery Design, Energy & Power Density
     - EV Pack Key Characteristics since 1996
     - Battery Packs for EVs vs. Launch Year
     - Li-Ion Cells Employed in EVs 2008-2017
     - Key Characteristics of EV Cells Utilized in EV Packs 2017
     - Battery Packs for EVs – Specific Energy vs. Launch Year
     - Specific Energy of EV Battery Packs
     - Cells Delivering 600Wh/liter are Being Qualified
     - VW’s Aggressive Technology Roadmap
     - Li-Ion Cell Energy Density Evolution
     - Where is the improvement in energy density coming from?
• **Life and Safety**
  - EV & PHEV Battery Life
  - Tesla Battery Capacity versus Driven km (as published by Tesla Drivers Club)
  - Li-Ion Battery Safety
  - Safety at Module and Pack Levels
  - Safety: Key Issues
  - Safety Enhancement and its Cost
  - Fast Charge & Battery Design
  - Impact of Fast Charge on Cost and Energy Density
  - Fast-Charge Tesla Batteries: about 50% in 30 minutes

4. **EV and PHEV Battery Cost**
• **Cost of Materials**
  - Nickel Pricing
  - Class 1 Nickel Supply and Demand
  - Cobalt Pricing $/kg
  - Lithium Pricing
  - NMC (6,2,2) Cost Estimate
  - NCA (90,6,4) Cost 2018-2020
  - NCA (90, 06, 04) Cost 2025
  - 37-Ah PHEV Cell Materials Cost
  - 3.4-Ah 18650 Cell Materials Cost
  - 21700 Cell Materials Cost – 2020
  - 56-Ah EV Pouch Cell Materials Cost

• **Cell and Battery Cost**
  - 37-Ah PHEV Cell Price
  - Cell Price for a 44 Ah Prismatic PHEV cell (2020)
  - 3.4-Ah 18650 Cell Price, 2016
  - 56-Ah EV Pouch Cell Price, 2018
  - 21700 Cell Price, 2020
  - 65Ah Pouch Cell Price, 2020
  - 78Ah EV Pouch Cell Price Estimate, 2025

• **Cost Reduction Trajectory**
  - PHEV Battery Price Trends
  - VW’s Aggressive (unrealistic?) Price Target for Cells and Packs
  - GM’s Roadmap for EV Cell Pricing, Chevy Bolt
  - EV Battery Price Trends
  - Cost-Reduction Roadmaps—Issues
  - EV Battery Cost Estimate
  - xEV Battery Cost Estimate

III. **Battery Technology: Is there a Future Beyond Lithium Ion?**

1. **xEV Batteries’ Desired Attributes and Characteristics of 2025 Li-Ion Batteries**
  - Automakers’ Expectations for Key Performance Values of Battery-EV Li-Ion Cells
  - Automakers’ Expectations of 2025 Li-ion BEVs
  - Fast-Pace Expansion History of Li-Ion Batteries
  - Future Automotive Cell Requirements - Other Applications
  - Direction of Automotive Li-Ion Battery Development

• **So What is the BEV Cell Development Matrix?**
• **Automakers’ EV-Battery Needs for Faster BEV Expansion Beyond 2028**

2. **Anode Opportunities: Silicon and Metallic Lithium**
• Silicon-based Anodes
• Silicon Anode Pre-Lithiation
• Metallic Lithium Anode
• 1975-1977, Li/TiS2 and LiAl/TiS2 Rechargeable Cells - EXXON
• 1986-1990: Li/MoS2 Rechargeable Cells – Moli Energy
• Valence Technology 1994 Li/’Wet’ Polymer/VOx Cell Phone Cells
• Li-Metal Rechargeable Batteries
• Li-Metal Anode Cost and Processing
• Lithium Foil Pricing
• Metallic Li Anode – The Electrolyte Challenge

3. **Solid Electrolyte: Promise and Challenges**
• Solid Electrolyte for Lithium-Metal Rechargeable Batteries
• Solid Electrolytes – High-Level View
• Challenges of Solid Electrolytes in all Solid-State Li-Metal Cells
• Solid-State Batteries: Overview
• Many Electrolyte Families Under Development
• Limitations of Solid Electrolytes
• Key Characteristics of Contending Solid Electrolytes
• Solid Polymer Electrolytes ‘Dry’ (SPE) and ‘Gels’
• Ionic Conductivity of Inorganic Solid Electrolytes
• The Lithium Protective Layer: Status and Challenges
• The Lithium Protective-Layer Approach
• Protected Li Metal Anodes

4. **Li/SE versus C-Gr/LE; Energy Density and Cost**
• Li-NMC: the Most Promising of the ‘Future Technologies’
• Volumetric Energy Density – Li-NMC versus Gr-NMC Cell Design Matrix
• Volumetric Energy Density – Li/NMC versus Gr-NMC Cells
• Li-NMC: Can we achieve cost parity with Gr-NMC?
• Li/NMC versus Gr-Si/NMC

5. **Cathode Development: Is There a Future Beyond High-Nickel NMC?**
• Li/Air or Li/Sulfur Chemistries – Volumetric Energy Density
• Li Ion versus Li/S – Battery Requirement Spider Diagram
• New Cathodes

6. **Future EV Battery Technology Synopsis**
• Beyond Li Ion before 2030?
• CONCLUSIONS: Beyond Li Ion for Mass-Market EVs?
• Conclusions: Post-Li-Ion Opportunity
• What is the Automakers’ True Evaluation of Post Li Ion for EVs? Hype or Real Promise?
IV. xEV Battery Market Forecast to 2025

1. xEV Battery Market Overview
   - xEV Battery Market Overview
   - 2017 Automotive Li-Ion Battery Market
   - 2018 Automotive Li-Ion Battery Market
   - xEV Battery Pack Business
   - 2020 Automotive Li-Ion Battery Market
   - xEV Li-Ion Battery Market 2020
   - 2025 Automotive Li-Ion Battery Market

2. Mild and Strong Hybrids
   - Strong HEV OEM/Supplier Relationships
   - Mild HEV OEM/Supplier Relationships
   - HEV Battery-Pack Market
   - Li-Ion HEV Battery Module Market

3. EVs and PHEV
   - PHEV OEM/Supplier Relationships
   - PHEV Battery Cell Market by Producer
   - EV OEM/Supplier Relationships
   - EV Battery Cell Market by Producer
   - Combined EV & PHEV Cell Market by Producer
   - xEV Battery Shipments by Chinese Producer, MWh
   - Automotive Li-Ion Battery Business – 2025 Base Case
   - 2030 xEV Battery Business – Base Case

4. Demand for Materials
   - HEV Cell Materials Demand 2020
   - PHEV-EV Cell Materials Demand 2020
   - xEV 2020 Key Cell Materials
   - 2025 xEV Battery Materials Demand
   - xEV 2025 Key Raw Materials Demand Forecast

5. Directions of Individual Cell Makers
   - Panasonic
   - LG Chem Key Product
   - LG Chem Cells and Packs
   - LG Chem EV Cells
   - LG Chem Cells and Pack – 2017 Chrysler Pacifica PHEV
   - LG Chem Cells and Packs for Volvo PHEVs
   - LG Chem – PHEV Battery Cells
   - LG Chem – Other
   - Samsung SDI
   - CATL
   - BYD
   - Chinese Market – Battery Makers
   - SK Innovation
   - AESC Advanced Energy Supply Corporation
   - GS Yuasa Group
   - Toshiba
   - Hitachi Vehicle Energy
   - A123 Systems
   - Johnson Controls

V. Appendix

1. Levels of Vehicle Hybridization/Electrification
   - Key Hybrid Functions
   - Which level of electrification?
   - Micro-1 Hybrids (Stop/Start)
   - Micro-2 Hybrids
   - 48V Mild Hybrids
   - 100-140V Mild Hybrids
   - Strong Hybrids
   - Plug-in Hybrids
   - History of EV Battery Development
   - Electric Vehicles
   - Fuel-Cell Vehicles
   - Heavy-Duty Vehicles

2. Lead-Acid and NiMH HEV Batteries and Ultracapacitors
   - Enhanced Flooded Lead-Acid Battery Design (Exide)
   - Valve-Regulated Lead Acid
   - Lead Acid in Future Automotive
   - EC Capacitors
   - Nickel Metal Hydride HEV Cells
   - Commercial Status of NiMH
   - Lead Acid Producers – U.S. & Europe
   - Lead Acid Producers – Japan
   - NiMH producers Primearth EV Energy

3. Levels of Vehicle Hybridization
   - EVs
   - PHEVs
   - HEVs
   - Mild HEVs
   - Strong HEVs
   - Plug-in HEVs
   - Heavy-Duty Vehicles