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The Lithium Ion Battery Market

Supply and Demand

ARPA E RANGE Conference

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Introduction

Navigant Research provides in-depth analysis of global clean technology markets.

The team's research methodology combines supply-side industry analysis, end-user primary research and demand assessment, and deep examination of technology trends to provide a comprehensive view of the Smart Energy ecosystem.

Sector Focus:

Smart Energy

Smart Utilities

Smart Transportation

Smart Industry

Smart Buildings

Research Offerings:

Research Reports

Subscription Research Services

Custom Market Research

- Go-To-Market Strategy
- Custom Market Analysis
- Market Sizing & Forecasts
- Primary Research
- Technology Evaluation
- Commercial Due Diligence
- Competitive Benchmarking
- Strategic Advisory Sessions

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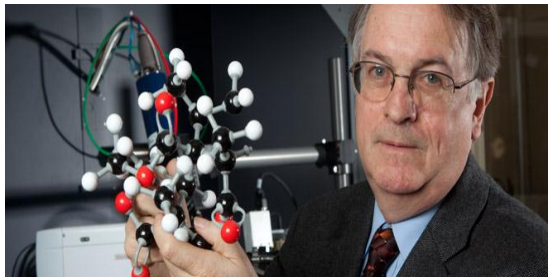
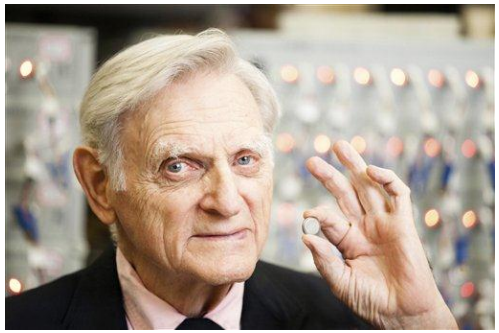
Lithium Ion History

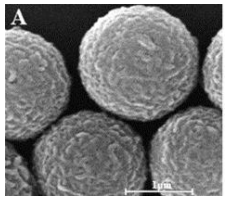
- Secondary lithium ion battery first developed by Dr. Stan Whittingham at Exxon in early 1980s
- Shortly thereafter, Dr. John Goodenough of Texas developed the first lithium cobalt batteries and later patented the first lithium iron phosphate batteries
- Sony launched the first commercial Li-ion battery for consumer electronics in 1991
- Today, Li-ion powers most portable tools and devices, as well as most EVs and stationary storage systems





Lithium Ion Chemistries

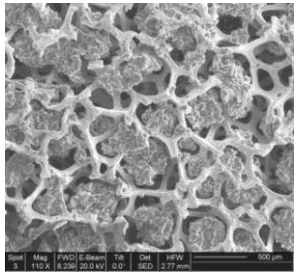
- Lithium Ion Cobalt (LCO)
  - Energy density: 120 Wh/kg to 180 Wh/kg
  - Primary use: consumer electronics
  - Cost range: $250/kWh to $450/kWh
  - Manufacturers: Samsung SDI, Lishen, ATL, Sony
- Lithium Manganese Spinel (LMO)
  - Energy density: 105 Wh/kg to 120 Wh/kg
  - Primary use: automotive, stationary
  - Cost range: $400/kWh to $900/kWh
  - Manufacturers: LG Chem, Samsung SDI



- Lithium Iron Phosphate (LFP)
  - Energy density: 80 Wh/kg to 110 Wh/kg
  - Primary use: automotive, stationary
  - Cost range: $400/kWh to $1,200/kWh
  - Manufacturers: A123, BYD
- Lithium Titanate (LTO)
  - Energy density: 60 Wh/kg to 105 Wh/kg
  - Primary use: bus, automotive
  - Cost range: $800/kWh to $2,000/kWh
  - Manufacturers: ATL, Toshiba, Microvast, LeClanche
- Nickel Manganese Cobalt (NMC)
  - Energy density: 120 Wh/kg to 200 Wh/kg
  - Primary use: automotive, stationary
  - Cost range: $700/kWh to $900/kWh
  - Manufacturers: Dow Kokam, JCI

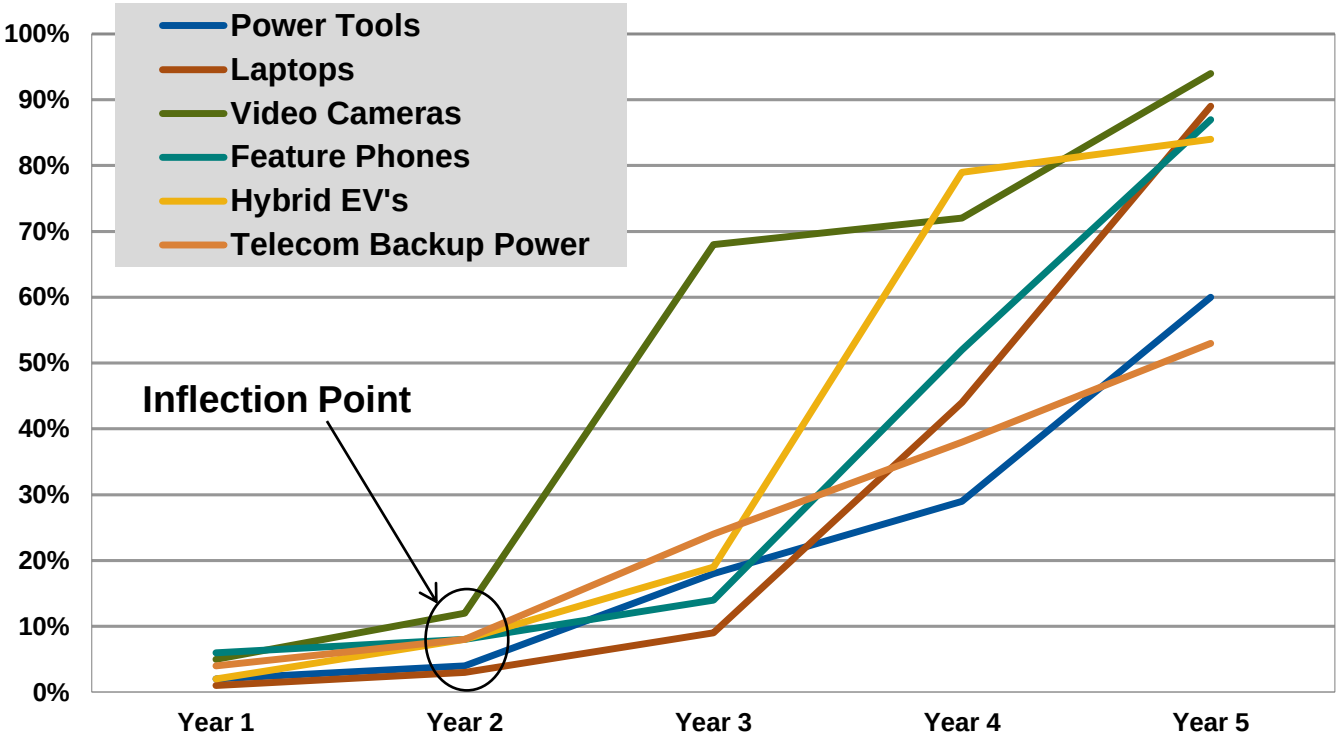
Beyond Lithium Ion Chemistries

- Magnesium Ion
  - Energy density: 80 Wh/kg to 120 Wh/kg
  - Primary use: automotive, consumer electronics
  - Cost range: $800/kWh to $1,000/kWh
  - Strengths: Cycle life durability, low-cost inputs
  - Companies: Toyota, Apple, Pellion
- Lithium Sulfur (LiS)
  - Energy density: 220Wh/kg to 500 Wh/kg
  - Primary use: consumer electronics, aerospace
  - Cost range: $1,400/kWh to $2,000/kWh
  - Strengths: best proven energy density in non-hypothetical cells, low-cost inputs
  - Companies: Nohms, Amprius, Polyplus, Oxis, Sion
- Lithium Air (LO)
  - Energy density: 500 Wh/kg to 4,000 Wh/kg
  - Primary use: all applications
  - Cost range: N/A (experimental)
  - Strength: Highest potential energy density
  - Companies: IBM, Toyota, Samsung
- Lithium Capacitor (LiC)
  - Energy density: 15 Wh/kg to 35 Wh/kg
  - Primary use: SSVs, forklifts
  - Cost range: $2,500/kWh to $3,500/kWh
  - Strengths: Cycle life longevity and power burst capabilities
  - Companies: JSR, Hitachi



Lithium Ion Inflection Point

Lithium Ion Market Share by Segment, World Markets: First Five Years



(Source: Navigant Research)

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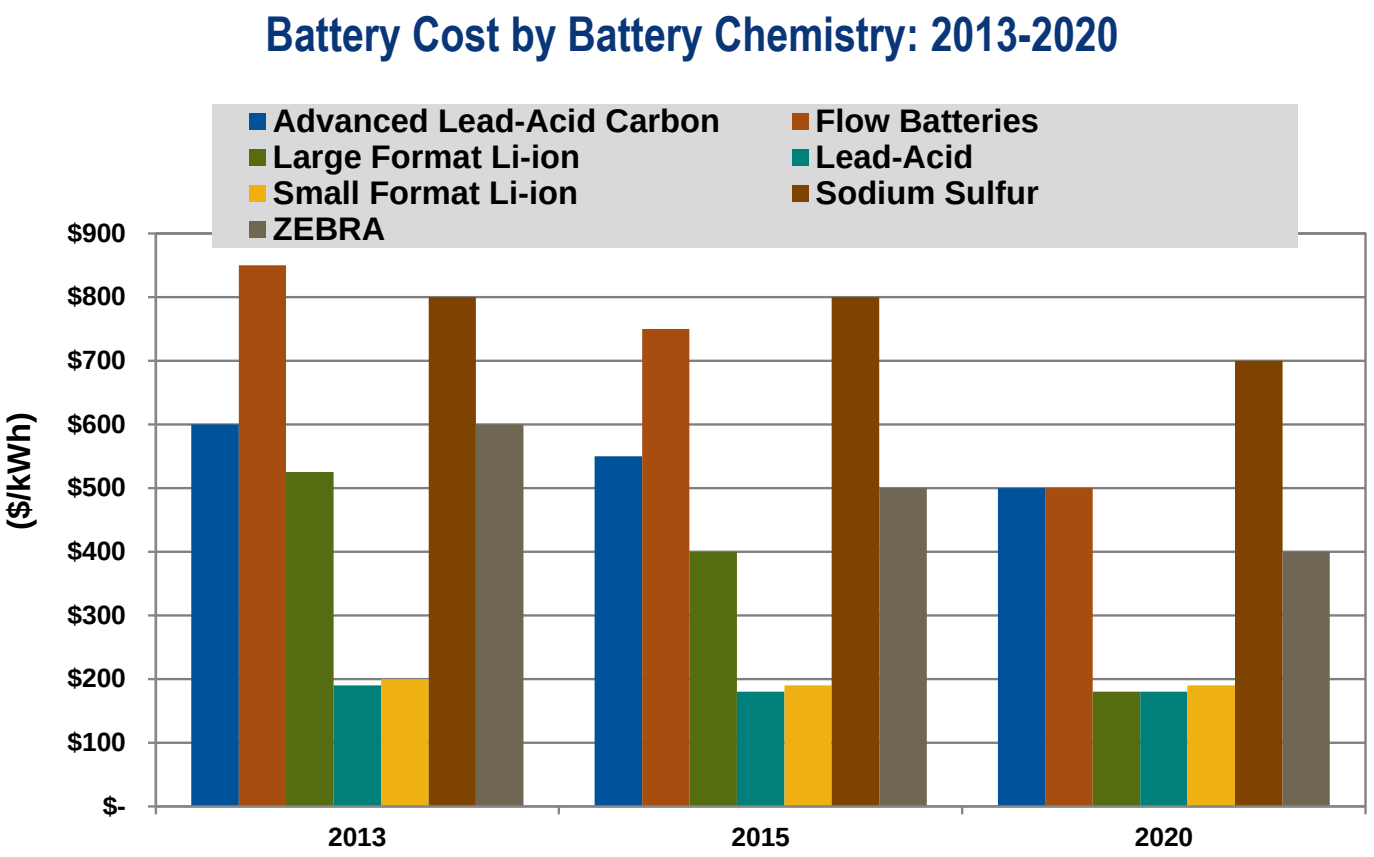
Comparison to Other Batteries



(Source: Navigant Research)

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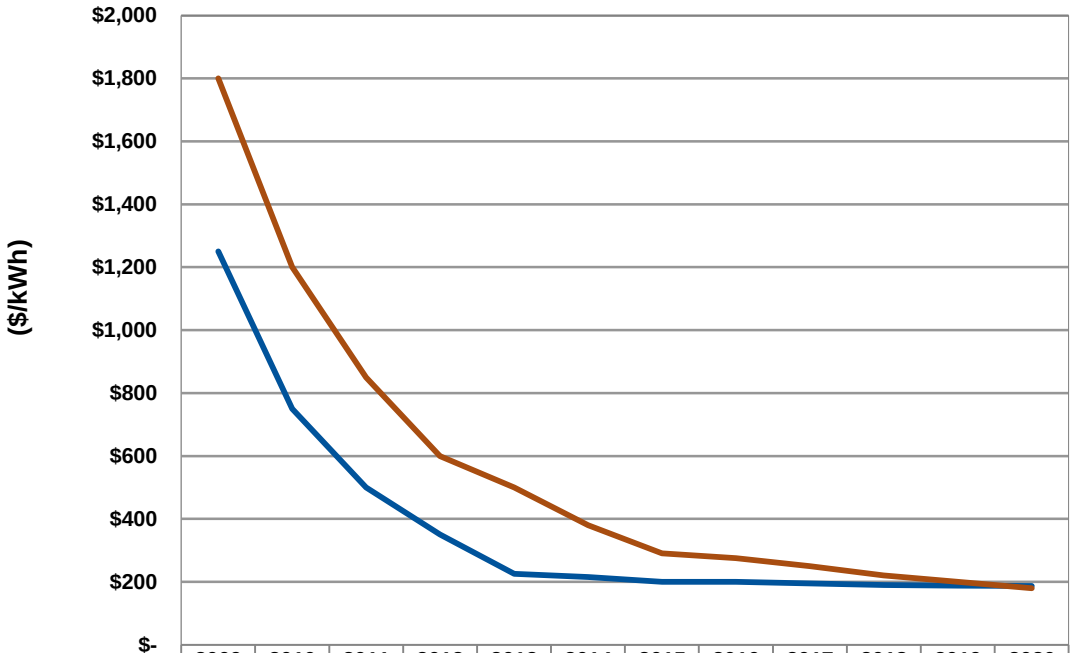
Lithium Ion Cell Pricing Forecast

Lithium Ion Battery Pricing by Cell Type: 2009-2020



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Consumer Electronics Li-ion	1,250	750	500	350	225	215	200	200	195	190	188	187
Large Format Li-ion	1,800	1,200	850	600	500	380	290	275	250	220	200	180

(Source: Navigant Research)

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EV Battery Pack Trends

- Tesla Model S
  - 65 kWh
  - Nickel cobalt aluminum (NCA) 18650 cells by Panasonic
  - Estimated cost of cells: $25,000
  - Estimated cost of pack: $40,000
- Nissan LEAF
  - 25 kWh
  - LMO cells by AESC
  - Estimated cost of cells: $11,000
  - Estimated cost of pack: $16,000
- Chevrolet Volt
  - 16 kWh
  - LMO by LG Chem
  - Estimated cost of cells: $9,600
  - Estimated cost of pack: $17,000
- Toyota Plug-in Prius
  - 4.4 kWh
  - NCA cells by Panasonic
  - Estimated cost of cells: $3,500
  - Estimated cost of pack: $8,000

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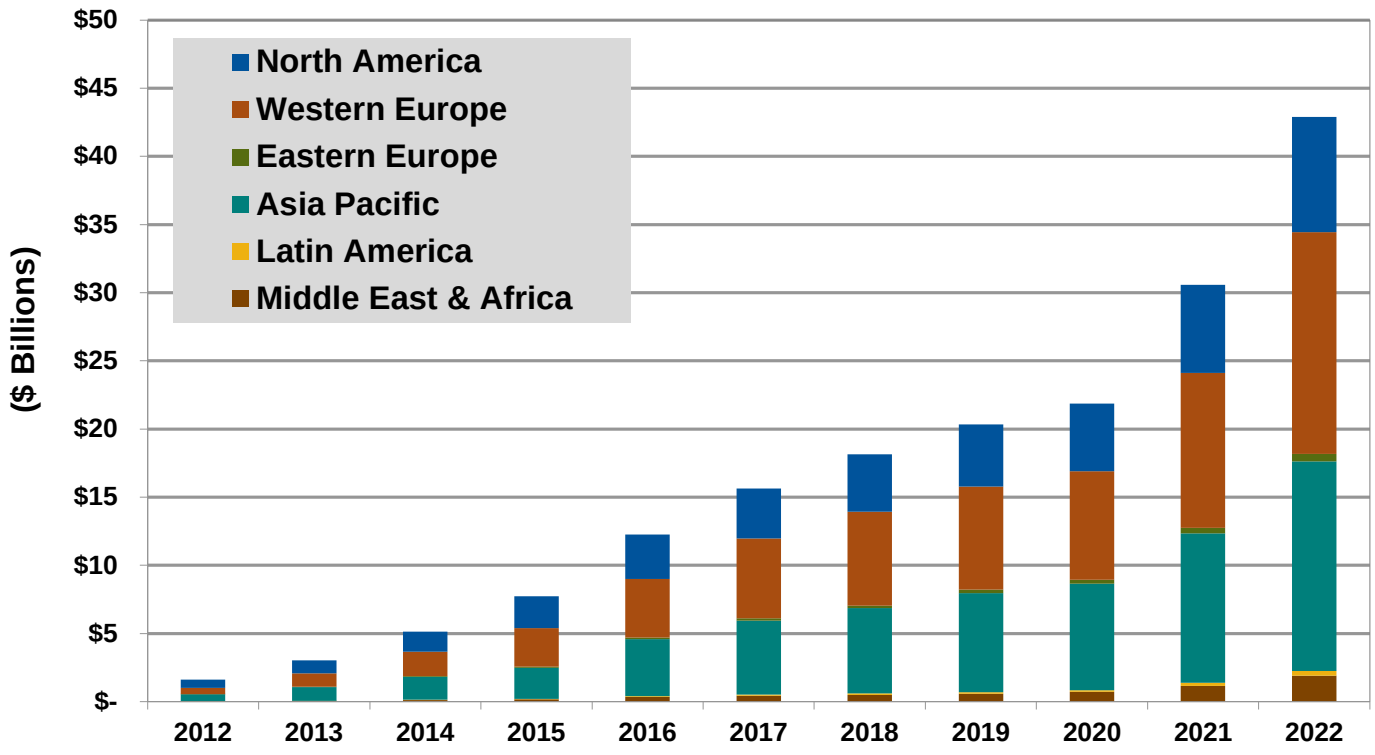
Lithium Ion EV Battery Forecast

Lithium Ion Transportation Battery Revenue by Region, World Markets: 2012-2022



(Source: Navigant Research)

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End-Use Applications for Stationary Storage

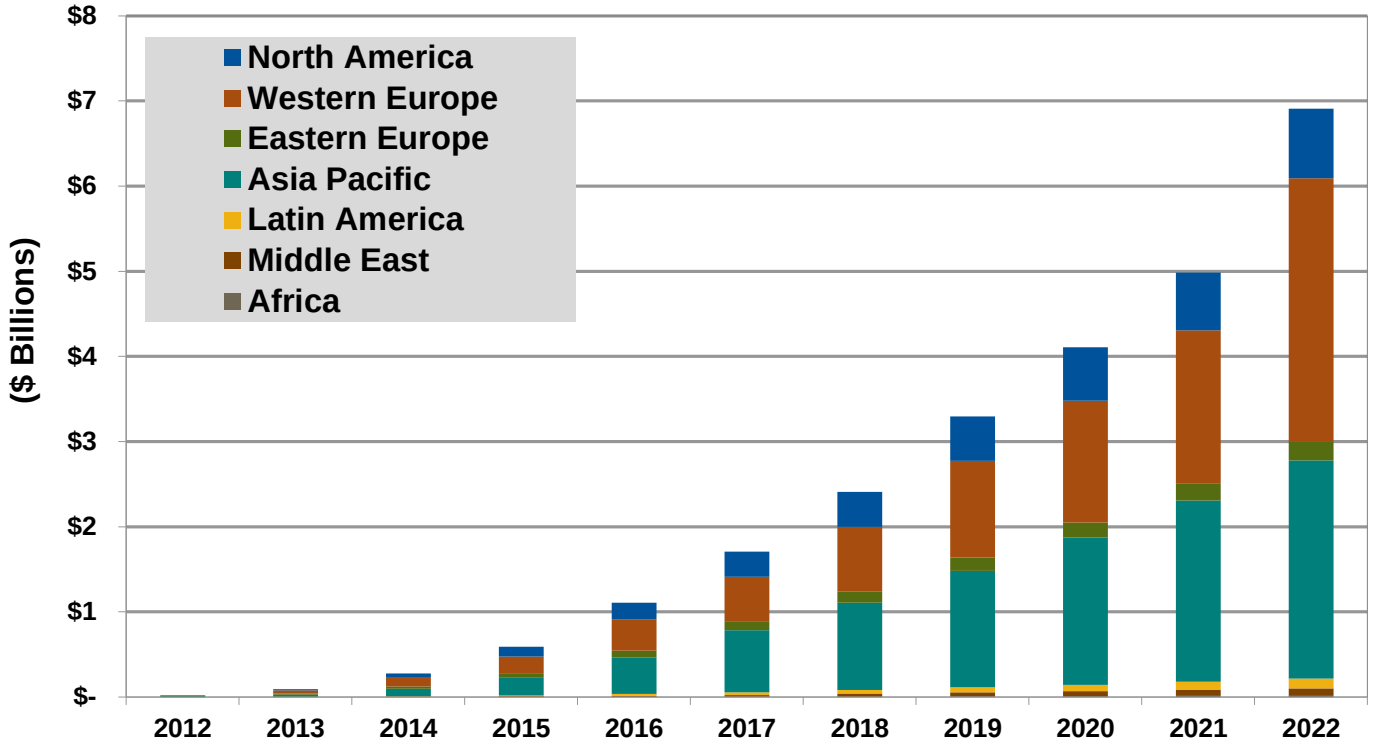
- Frequency regulation
  - Primary chemistry in use: LFP
  - Approximate global capacity: 88 MW, 22 MWh
- Renewables integration
  - Primary chemistry in use: LMO
  - Approximate global capacity: 160 MW, 960 MWh
- Spinning reserves
  - Primary chemistry in use: LFP
  - Approximate global capacity: 18 MW, 14 MWh
- Peak shaving
  - Primary chemistry in use: LFP
  - Approximate global capacity: 40 MW, 40 MWh
- Load shifting
  - Primary chemistry in use: N/A
  - Approximate global capacity: 0 kW, 0 kWh

Tehachapi Energy Storage Project Rendering

(Source: Southern California Edison)

Lithium Ion Stationary Storage Forecast

Lithium Ion Stationary Storage Revenue by Region, World Markets: 2012-2022



(Source: Navigant Research)

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Trends in Portable Application Batteries

- The thirst for more battery power
  - Power tools require bursts of large amounts of power
  - Cordless devices are more common on work sites than corded
  - Smartphones replaced tablets which replaced laptops which replaced desktops
- The thirst for more battery energy
  - Battery life is the single most desired specification in consumer electronics devices
  - Next-generation devices are being designed around the battery cell, not the CPU
- The downsizing of energy needs in portable devices
  - At the same time that batteries are getting larger and more powerful, applications (like GPS apps, video compression, and screen management) are reducing their energy requirements

Motorola RAZR:
32-Hour Battery Life in 2006

Motorola Droid RAZR Maxx HD:
5-Day Battery Life in 2013

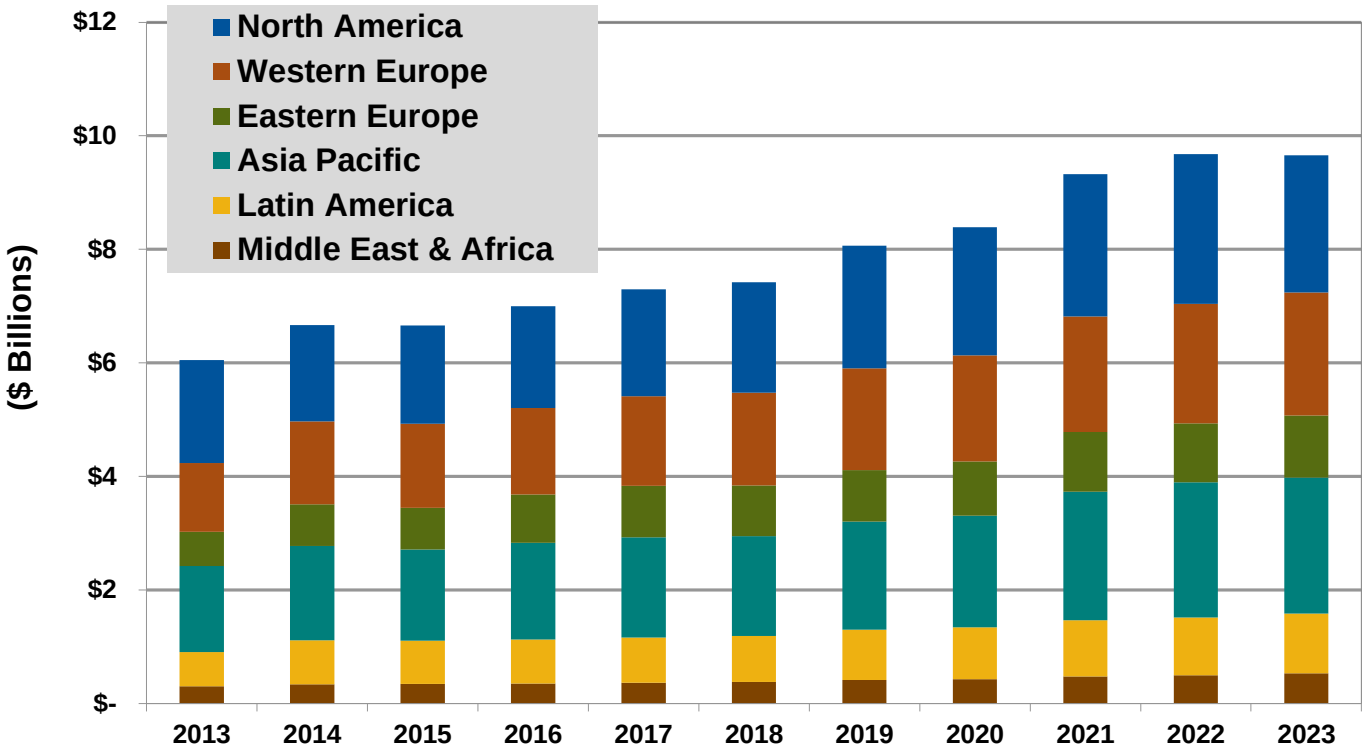
(Source: Motorola)

Portable Application Markets

- Consumer electronics
  - Current chemistry leader: LCO
  - Potential future chemistry leader: LiS
  - Most important specifications: energy density
- Power tools
  - Current chemistry leader: LCO
  - Potential future chemistry leader: NMC
  - Most important specifications: power density, safety
- Defense
  - Current chemistry leader: LCO
  - Potential future chemistry leader: LiS
  - Most important specifications: energy density, cycle life
- Medical
  - Current chemistry leader: Lithium thionyl chloride (primary)
  - Potential future chemistry leader: NMC
  - Most important specifications: safety, cycle life, calendar life

Lithium Ion Consumer Electronics Forecast

Lithium Ion for Consumer Electronics Revenue by Region, World Markets: 2013-2023



(Source: Navigant Research)

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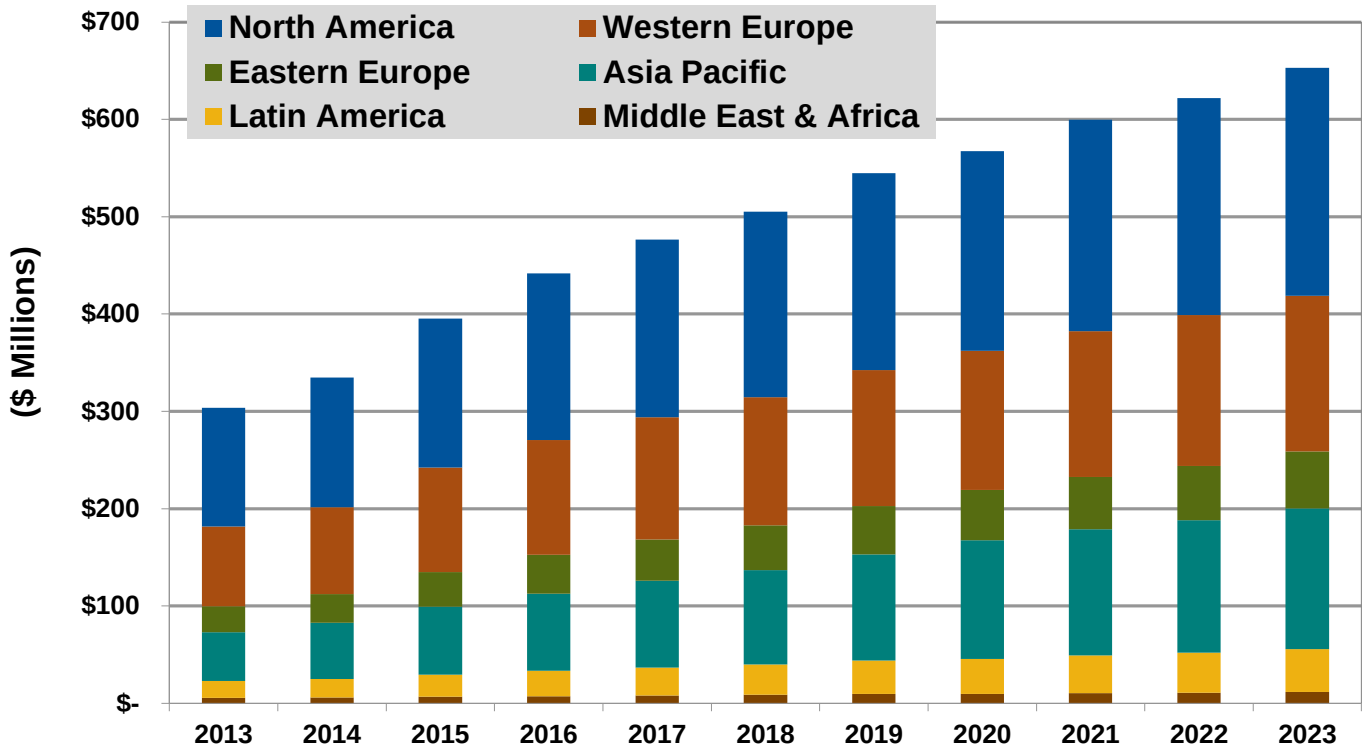
Lithium Ion Power Tool Battery Forecast

Lithium Ion for Power Tools Revenue by Region, World Markets: 2013-2023



(Source: Navigant Research)

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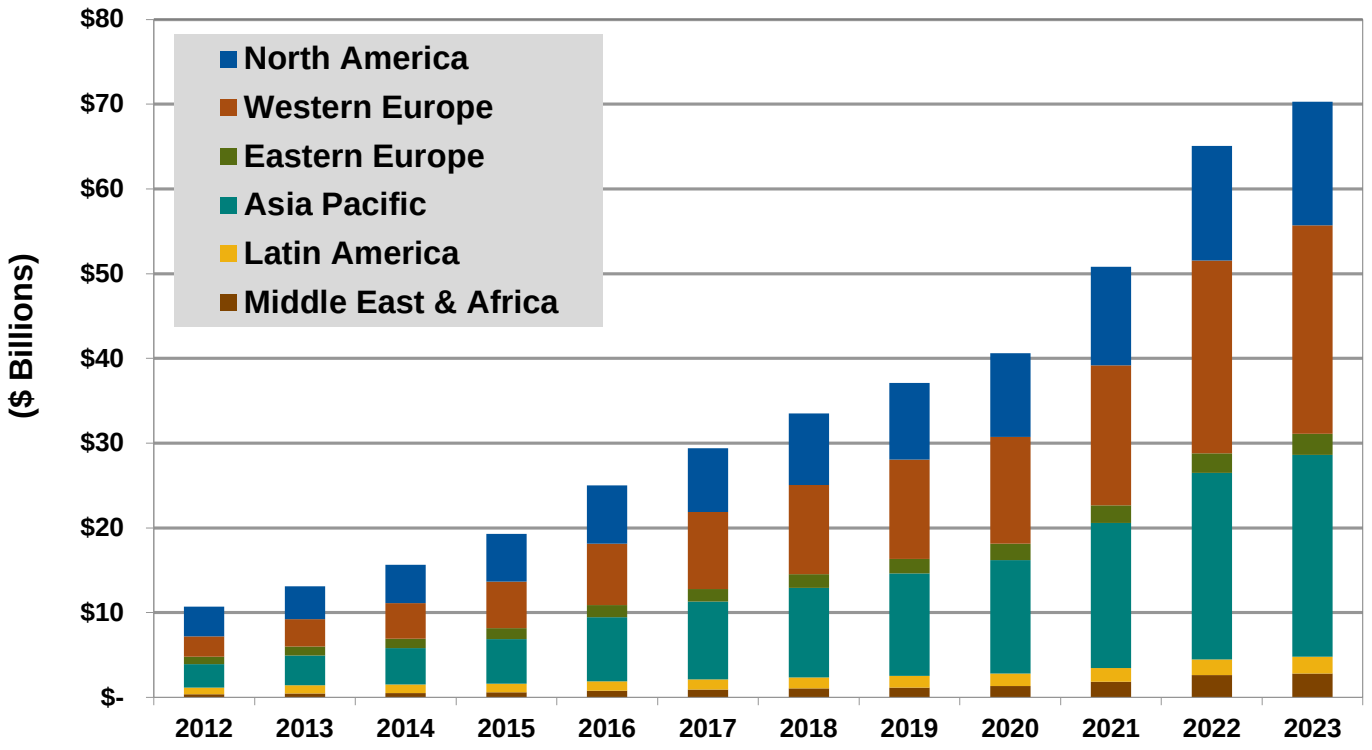
Global Forecast for All Lithium Ion Shipments

Lithium Ion Revenue by Region, All Segments, World Markets: 2012-2023



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