CEMAC
Clean Energy Manufacturing Analysis Center

Automotive Lithium-ion Battery (LIB) Supply Chain and U.S. Competitiveness Considerations

Donald Chung, Emma Elgqvist, Shriram Santhanagopalan, CEMAC

With contributions from experts at the U.S. Department of Energy, Argonne National Laboratory, the National Renewable Energy Laboratory, and Industry Partners

June 2015

NREL/PR-6A50-63354
Contract No. DE-AC36-08GO28308

DISCLAIMER AGREEMENT

These manufacturing cost model results ("Data") are provided by the National Renewable Energy Laboratory ("CEMAC"), which is operated by the Alliance for Sustainable Energy LLC ("Alliance") for the U.S. Department of Energy (the "DOE").

It is recognized that disclosure of these Data is provided under the following conditions and warnings: (1) these Data have been prepared for reference purposes only; (2) these Data consist of forecasts, estimates or assumptions made on a best-efforts basis, based upon present expectations; and (3) these Data were prepared with existing information and are subject to change without notice.

The names DOE/CEMAC/ALLIANCE shall not be used in any representation, advertising, publicity or other manner whatsoever to endorse or promote any entity that adopts or uses these Data. DOE/CEMAC/ALLIANCE shall not provide any support, consulting, training or assistance of any kind with regard to the use of these Data or any updates, revisions or new versions of these Data.

YOU AGREE TO INDEMNIFY DOE/CEMAC/ALLIANCE, AND ITS AFFILIATES, OFFICERS, AGENTS, AND EMPLOYEES AGAINST ANY CLAIM OR DEMAND, INCLUDING REASONABLE ATTORNEYS' FEES, RELATED TO YOUR USE, RELIANCE, OR ADOPTION OF THESE DATA FOR ANY PURPOSE WHATSOEVER. THESE DATA ARE PROVIDED BY DOE/CEMAC/ALLIANCE "AS IS" AND ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE EXPRESSLY DISCLAIMED. IN NO EVENT SHALL DOE/CEMAC/ALLIANCE BE LIABLE FOR ANY SPECIAL, INDIRECT OR CONSEQUENTIAL DAMAGES OR ANY DAMAGES WHATSOEVER, INCLUDING BUT NOT LIMITED TO CLAIMS ASSOCIATED WITH THE LOSS OF DATA OR PROFITS, WHICH MAY RESULT FROM AN ACTION IN CONTRACT, NEGLIGENCE OR OTHER TORTIOUS CLAIM THAT ARISES OUT OF OR IN CONNECTION WITH THE USE OR PERFORMANCE OF THESE DATA.

CEMAC Clean Energy Manufacturing Analysis Center

Operated by the Joint Institute for Strategic Energy Analysis

The Clean Energy Manufacturing Analysis Center (CEMAC) provides unique and high-impact analysis, benchmarking, and insights of supply chains and manufacturing for clean energy technologies that can be leveraged by decision makers to inform research and development strategies, and other policy and investment decisions. Housed at the National Renewable Energy Laboratory and operated by the Joint Institute for Strategic Energy Analysis, CEMAC engages the DOE national lab complex, DOE offices, U.S. federal agencies, universities, and industry to promote economic growth and competitiveness in the transition to a clean energy economy.

CEMAC was established in 2015 by the U.S. Department of Energy's Clean Energy Manufacturing Initiative.

ManufacturingCleanEnergy.org

Introduction, Objectives and Methodology

- This report is intended to provide credible, objective analysis regarding the regional competitiveness contexts of manufacturing lithium-ion batteries (LIB) for the automotive industry by identifying key trends, cost considerations, and other market and policy developments that inform current competitiveness considerations for LIB production. The report includes:
  - An assessment of published market studies
  - An overview of qualitative factors that can influence factory location decisions
  - Findings from a detailed bottom-up cost modeling of regional cell production scenarios.

- The CEMAC cost model is based upon a detailed, bottom-up accounting of the total costs that a manufacturer incurs in the high-volume production of LIB cells.
  - Costs captured include all capital, fixed, and variable costs incurred in each country scenario explored
  - A minimum sustainable price (MSP) is then determined by analyzing capital expense, COGS, operating expenses, taxes, free cash flows, and required rates of return.

Executive Summary

- Competitive locations and opportunities for automotive lithium-ion battery (LIB) cell manufacturing are mostly created, as opposed to being tied to factors that are inherent to specific regions.
  - Established LIB competitors are advantaged due to production expertise, supply chains optimization, and partnerships initially developed to serve consumer electronics applications.
  - Many advantages among LIB incumbents are transferrable to the LIB automotive sector.
- Asia currently dominates automotive LIB cell production with a robust upstream supply chain, from processed materials to complete cells.
  - Cost modeling indicates that the United States and especially Mexico may be competitive under certain conditions.
- LIB pack production may remain proximal to original equipment manufacturer (OEM) end-product manufacturing, but materials and cell production could locate globally, in areas where competitive opportunities are strong.
  - LIB components are not commoditized: each is particularly important to overall battery performance, and technical/quality differentiation is possible.

Table of Contents

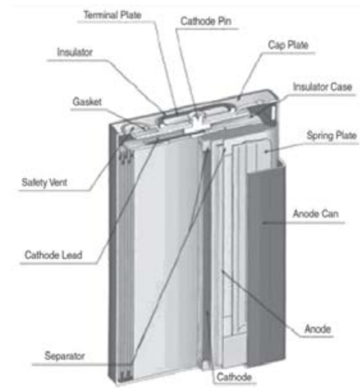
I

Overview of Global LIB Markets and Supply Chain

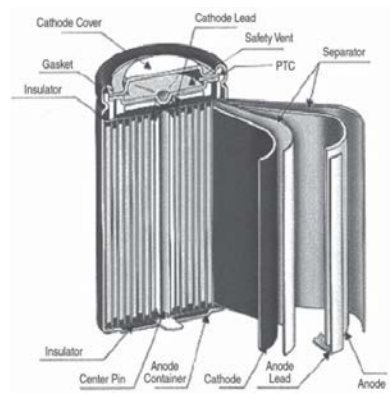
Lithium-Ion Battery Introduction

- Lithium-Ion Battery (LIB) is a generic term for batteries whose electric and chemical properties depend on lithium.
- LIB cells are comprised of four main components—cathodes, anodes, separators, and electrolytes—inserted into various container types (cylindrical and prismatic containers shown).
- Cathodes, anodes, and separators take the form of sheets, and are either wound or stacked to form alternating layers of cathode–separator–anode, with ions flowing between the cathode and anode sheets via an electrolyte solution.
- LIBs are primarily utilized in consumer electronics (CE) applications due to their high energy density and lifecycle. Their high potential power output also makes them well-suited to particular automotive applications.

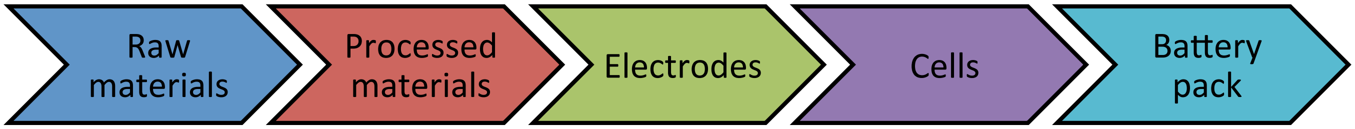
Prismatic LIB Cell Schematic



Cylindrical LIB Cell Schematic



Simplified Automotive LIB Manufacturing Value Chain



- Battery manufacturing is made up of several steps, currently performed in separate, specialized facilities
  - Raw materials such as lithium and graphite are mined, then processed for purity or specific composition
  - Processed materials are used to manufacture electrodes, which are key components of battery cells. Electrodes and cells are typically produced in the same facility
  - Cells, along with other components, are assembled into a complete battery pack

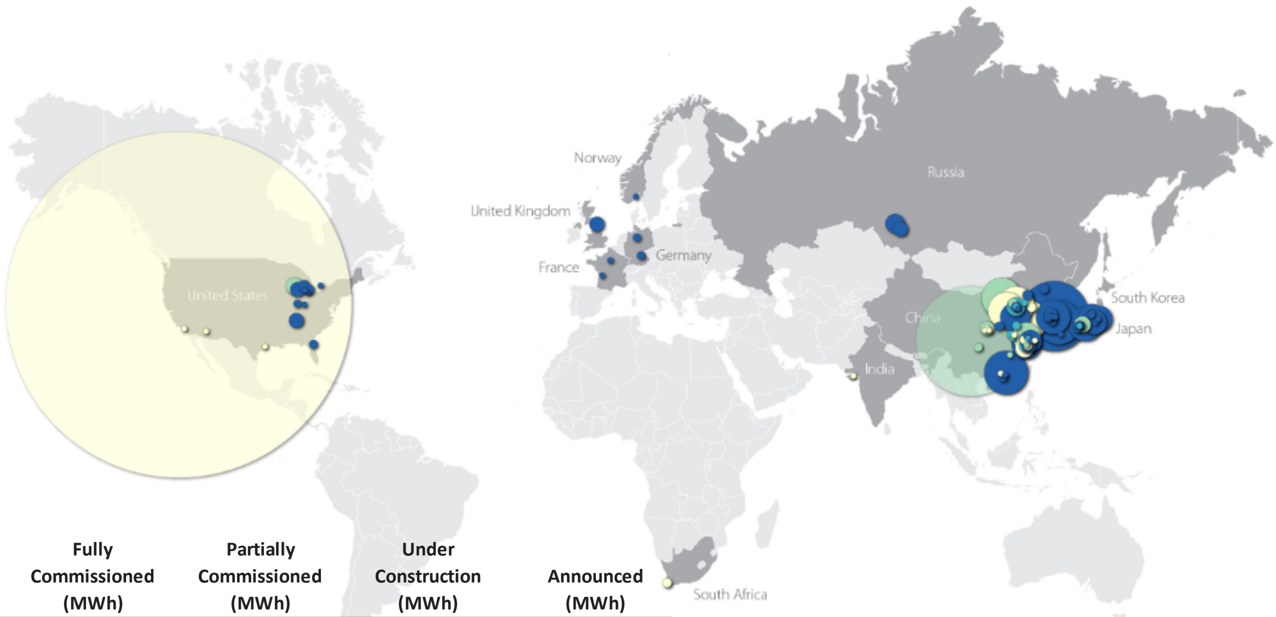
LIB Configurations Vary Significantly Across Auto Applications

AUTOMOTIVE APPLICATIONS	LIB SPECIFICATIONS: Capacity	Power	Operating Voltage	Main Attribute	Example
Hybrid Electric Vehicles (HEV)	1.1-1.4 kWh	25-60 kW	150-350 V	Power assist and limited electric drive	Toyota Prius, VW Jetta Hybrid
Plug-in Hybrid Electric Vehicles (PHEV)	7-16 kWh	40-110 kW	150-600 V	Power assist and extended electric drive	Ford C-Max Energi, Chevy Volt
Full Battery Electric Vehicle (BEV)	20-24 kWh	70-130 kW	200-360 V	Full electric drive	Nissan Leaf, Ford Focus EV
Full Battery Electric Vehicle (BEV)	40-85 kWh	310 kW	375 V	Full electric drive	Tesla Model S*

*The Tesla battery pack is comprised of 18650 battery cells typically used in CE applications instead of larger format cells typically used in automotive applications

Sources: AAB (2014); Roland Berger (2012).

Today, LIB Cell Manufacturing Is Heavily Concentrated in Asia…



	Fully Commissioned (MWh)	Partially Commissioned (MWh)	Under Construction (MWh)	Announced (MWh)
China	16,704	3,576	18,730	12,847
Japan	10,778	0	1,200	0
Korea	16,059	0	0	0
U.S.	3,770	0	1,200	35,000
EU	1,798	0	0	0
Rest of World	2,440	0	0	564
TOTAL	**51,549**	**3,576**	**21,130**	**48,412**

Cartographer: Billy J. Roberts
February 13, 2014

CEMAC

Note: This map includes factories that are fully and partially commissioned, under construction, and announced. Capacity is not disclosed for all factories.
Source: Corporate reporting. Bloomberg New Energy Finance BNEF (2015).

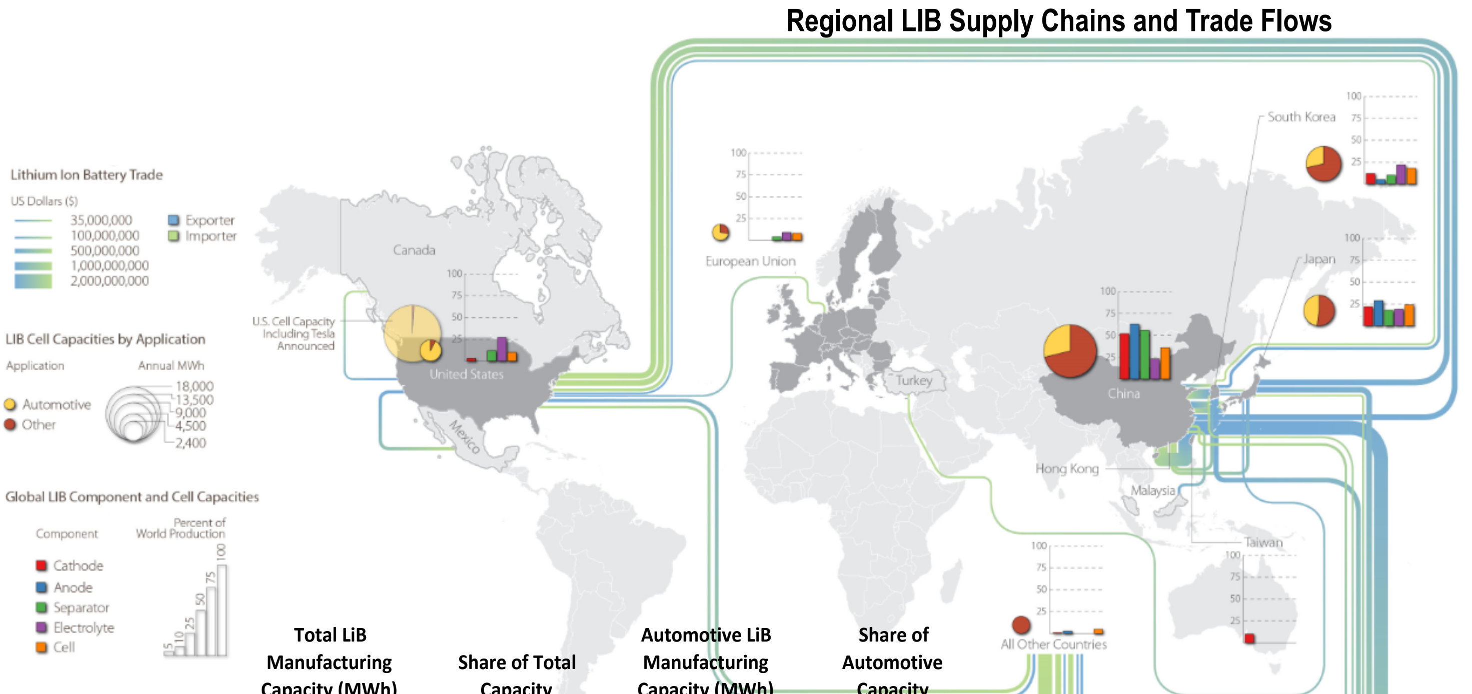
LIB manufacturing capacity (serving all end market applications) is primarily located in China, Japan, and Korea. Together, these countries constitute 85% of global fully commissioned LIB production capacity for all end-use applications.

Japan's LIB cluster grew from sustained investments in LIB technology by consumer electronics companies in the 1990s. The Japanese government bolstered private sector investments with R&D funding and low cost capital to establish manufacturing plants. Japan made these investments despite the long commercialization cycle of LIB technologies and the low returns on the LIB business because the technology enabled competitive advantages in portable consumer electronics end applications (Brodd 2012). Korea and China followed Japan's lead in investing in LIB cell and pack production for consumer electronics.

Korea's LIB cluster is a result of government and industry efforts, started in the 2000s, to build up this portion of the supply chain within Korea (Pike 2011 and 2013). China, too, has fortified its LIB cluster development through various government R&D, tax, investment incentives (Patil 2008), domestic content requirements, and export restraints (Haley 2012, Stewart et al. 2012). While Korean and Chinese cell manufacturers initially relied heavily on Japanese suppliers, their national efforts to build LIB clusters have resulted in less dependence on Japanese suppliers, and may contribute to advantageous pricing on key materials for fully scaled, co-located Korean and Chinese cell producers (Pike 2011 and 2013).

Historically the U.S. has not been a leader in LIB production, and currently hosts 7% of global LIB capacity. However, Tesla's recent announcement to build a 35 GWh LIB manufacturing facility in Sparks, NV would significantly increase the U.S. share. While the factory is set to begin initial production as early as 2017, the schedule for full production remains unknown.

…As Is Upstream Materials Manufacturing



	Total LiB Manufacturing Capacity (MWh)	Share of Total Capacity	Automotive LiB Manufacturing Capacity (MWh)	Share of Automotive Capacity
China	39,010	51%	11,240	41%
Japan	11,978	16%	5,750	21%
Korea	16,059	21%	4,600	17%
U.S.	4,970	7%	4,600	17%
EU	1,798	2%	1,300	5%
Rest of World	2,440	3%	0	0%
TOTAL	**76,255**	**100%**	**27,490**	**100%**

Sources: Corporate reporting; Bloomberg New Energy Finance BNEF (2015); 2013 International Trade Centre www.trademap.org accessed January 2015.

China, Japan, and Korea also control the majority of automotive LIB production, comprising 79% of total automotive LIB production (not including announced facilities). The United States has established a foothold in automotive LIB production. The United States hosts 17% of global automotive LIB capacity, the same market share as Korea.

In Japan, Korea, and China there is also a significant population of key, LIB-specific upstream materials suppliers (for electrodes, separators, electrolytes, etc.) that together constitute supply chain "clusters" focused upon LIB production. Such clusters may contribute to regional supply chain advantages (Pisano and Shih 2009) and cost benefits not available to cell manufactures located outside of such clusters. Finally, some degree of vertical integration exists across Asian electrode materials and cell production, which may also contribute to lower input costs for certain manufacturers. The United States, in contrast, hosts a relatively immature supply chain, and most U.S. cell and battery plant operators are relatively new to the industry. Nearly all U.S. LIB capacity is targeted at serving the emerging automotive market.

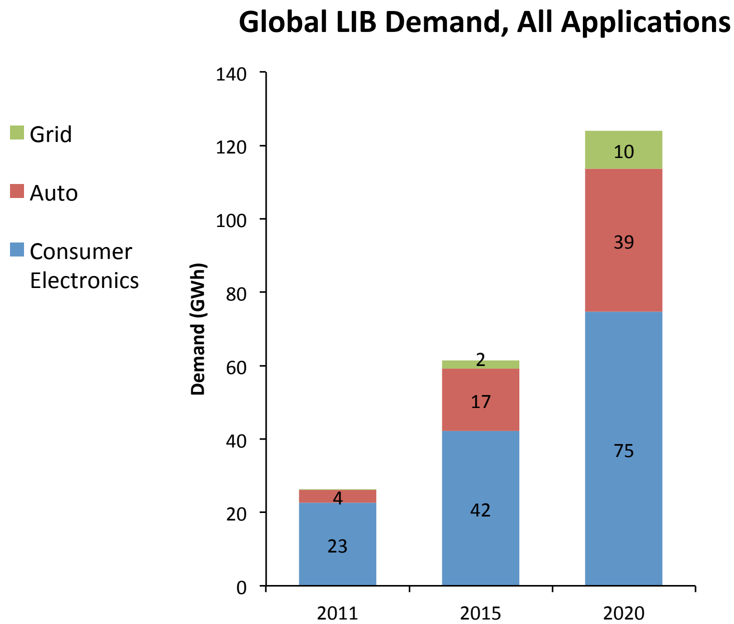
As indicated by the trade flows, SE Asian LIB production capacity was built not only to serve domestic consumption but for export markets as well.

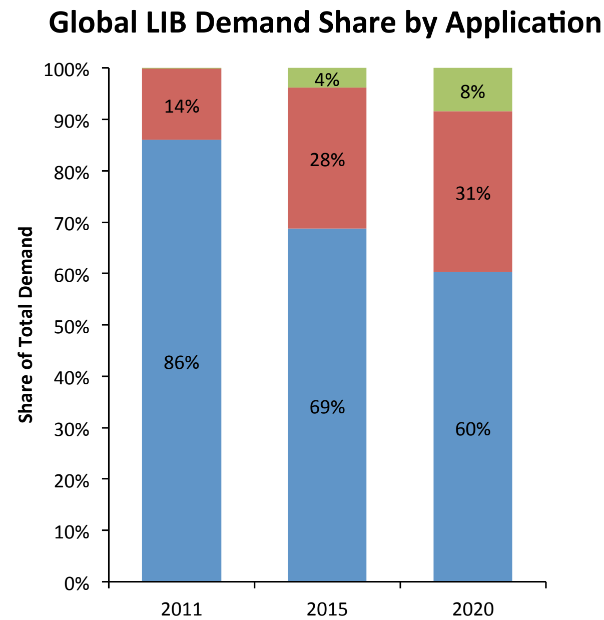
Most current LIB production knowledge and experience was developed by firms serving consumer electronics markets. These incumbent firms have created robust supply chains and accumulated significant production experience, much of which is transferrable to the production of large format LIB cells for automotive end-markets. Compared to LIB startups and newer competitors focused solely on automotive markets, incumbent LIB producers generally enjoy many advantages:

- Processing expertise gained through much higher cumulative production, especially with respect to small format batteries (manifested by higher yields)
- Lower total overhead and fixed costs because costs can be amortized across sales to multiple end application markets
- Stronger purchasing power
- More established regional supply chain clusters and relationships
- Potentially increased utilization as facilitiesmay produce more diversified products for larger end-markets.

While it is possible for newer industry entrants to succeed, new entrants will likely face challenges in establishing cost-competitive, high-volume production. Another potential barrier to entry in automotive markets is the relatively high performance, safety, and reliability requirements of customer automotive original equipment manufacturers (OEMs). OEM quality requirements, as well as their desire for financially stable suppliers, may tilt the playing field in favor of established competitors with strong production track records and proven product performance.

Consumer Electronics Represent the Majority of Demand for LIBs

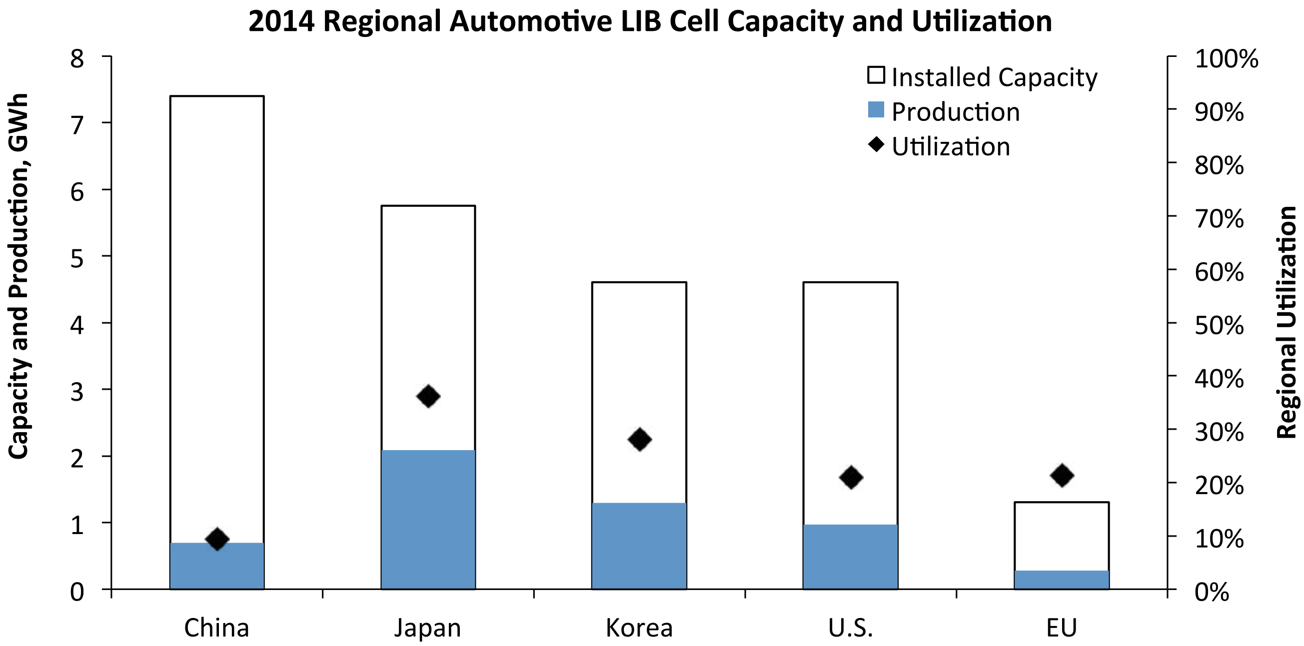




- Competitive advantages for automotive LIB producers emerged from incumbent firms supplying consumer electronics (CE) applications; these advantages may persist, at least in the near-term.
- While automotive demand is expected to grow, the majority of demand for LIBs may continue to be driven by CE applications.

Sources: Roland Berger (2012); Pike Research (2013); AAB (2013); CEMAC analysis

Significant Overcapacity in the Automotive LIB Supply Chain



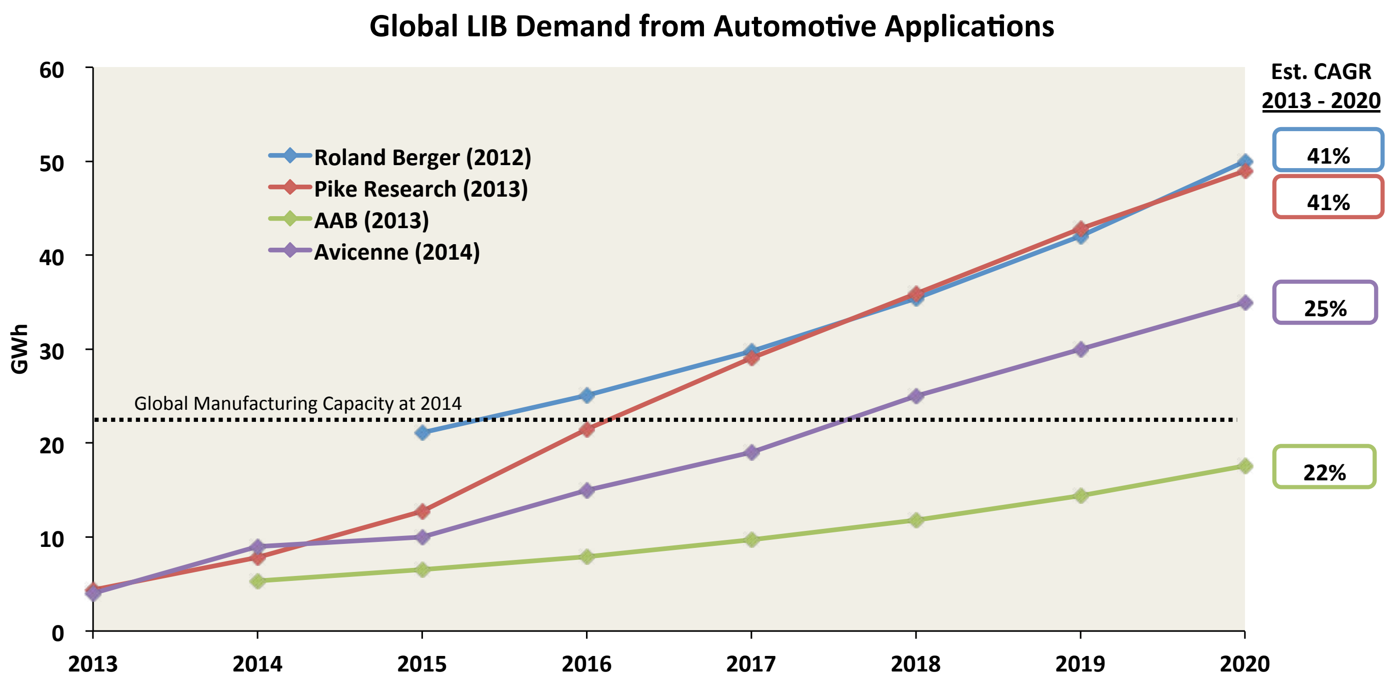
- Across regions, automotive LIB production capacity far exceeds production. Global average utilization was estimated at 22% at the beginning of 2014.
- Corporate restructurings and the postponement of announced capacity may help rationalize capacities going forward.

Source: Bloomberg New Energy Finance (2014); Pike Research (2013); Advanced Automotive Batteries (AAB) (2013); Roland Berger (2012); IEA (2011); CEMAC estimates.

Initial overly optimistic assumptions regarding xEV demand (and BEV/PHEV demand particularly) contributed to an overbuild of large format LIB cell production capacity for automotive markets. Supply-side governmental supports have also been made available for capacity expansions in recent years. In the United States, the American Reinvestment and Recovery Act of 2009 (ARRA) provided $1.5B to support the expansion of U.S.-based advanced battery manufacturing. The governments of China, Japan, and Korea have also long supported aggressive goals for domestic LIB production through tax and other investment incentives, and have more recently supported consumer xEV adoption (Patil 2008, Pike 2013).

However, while industry-wide utilization is low, it is likely that on a firm-specific and even plant-specific level, utilization is higher, especially for more established competitors.

Moderate to Strong Demand Growth Forecasted for Automotive LIBs



- Forecasted compound annual growth rates (CAGR) in LIB demand range from 22% to 41% through 2020.
- If moderate demand estimates are met, today's manufacturing capacity (and commensurate underutilization) may rationalize by 2017-2018.

Sources: Roland Berger (2012); Pike Research (2013); AAB (2013); Avicenne Energy (2014).

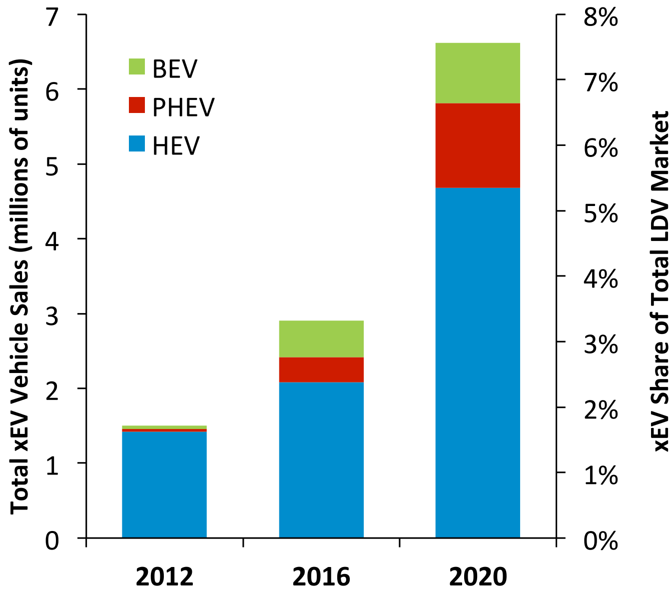
A comparison of multiple estimates of automotive demand for LIBs through 2020 demonstrates wide-ranging expectations for market growth. However, the demand outlook is reasonably strong even in the lowest growth scenario at 22% CAGR.

Each xEV type requires different amounts of battery storage, and thus certain xEVs affect LIB demand more than others. Generally, we assume that BEVs require battery packs with 25kWh or more of storage, PHEVs require 10kWh, and HEVs require 1kWh. Thus, even though HEVs constitute the bulk of xEV unit demand, PHEVs and BEVs sales will be larger drivers of automotive LIB demand.

Assuming the moderate xEV sales forecasts are realized and current manufacturing capacity remains unchanged, the underutilization of automotive LIB capacity may rationalize by 2017–2018. However, future capacity, such as Tesla's announced plans for a large LIB manufacturing facility (the "gigafactory") in the United States, targeting 35 GWh of LIB cell production to come online by 2017, is not included and may further impact overall utilization rates.

Moderate Sales Growth is Forecasted for Electric and Hybrid Vehicles

Global xEV Sales and Share of Total Light Duty Vehicle Sales



- Forecasted xEV sales growth is strong at 20% CAGR.
- However, xEV share of the total light duty vehicle (LDV) market will remain small, potentially reaching just over 7% of all LDV unit sales in 2020.
- While HEVs constitute a large portion of the xEV mix, BEV and PHEV sales may drive the LIB market due to their much larger battery pack capacities
- Currently most HEVs utilize NiMH batteries, not LIB, though this is beginning to change.
- Japan and the United States account for 46% and 34% of the global xEV demand, respectively.

Note: **xEV** is inclusive of all advanced vehicles using LIB (BEVs, PHEVs, HEVs). BEV – Battery electric vehicle; PHEV – Plug-in hybrid electric vehicle; HEV – Hybrid electric vehicle.

Source: Pike Research (2013); Advanced Automotive Batteries (AAB) (2013); Roland Berger (2012).

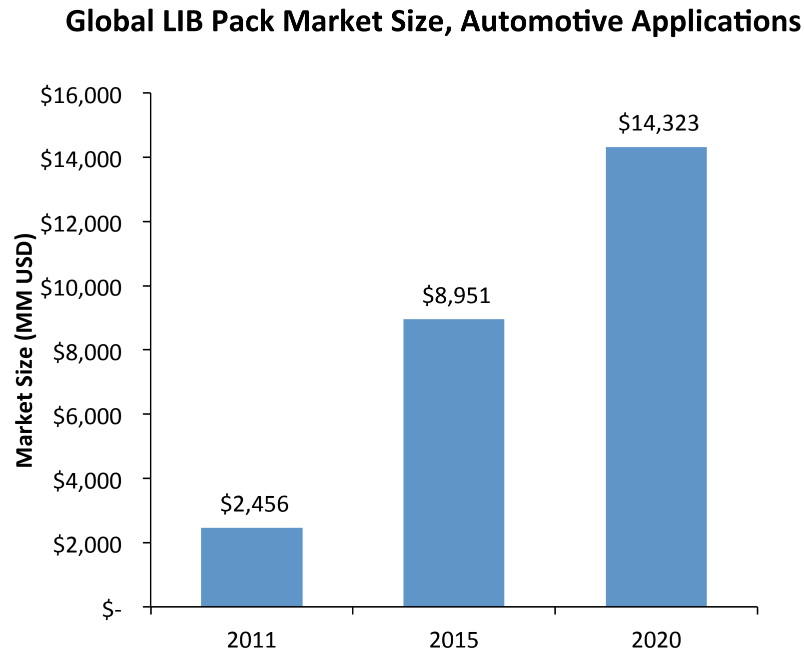
In the automotive industry, demand for LIBs is driven by production of battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV). LIBs have begun to displace nickel metal hydride (NiMH) batteries in hybrid electric vehicles (HEV). Whereas initial (pre-2013) market demand was tepid, sales of all BEVs, PHEVs, and HEVs (collectively referred to as xEVs) are expected to grow over the next few years. Demand for xEVs in all geographic markets is sensitive to several key factors, namely governmental requirements for fuel economy and/or emissions, governmental demand- and supply-side subsidies, the cost of xEV drivetrain technology, charging infrastructures, and the prices of gasoline and diesel. Differing assumptions about these factors across multiple markets contribute to the variation in forecasted demand volumes; shown here is the average of multiple forecasts.

Strong compound annual growth rates (CAGRs) for xEVs are expected, estimated at 20% through 2020. This compares to a 2.3% CAGR for the overall LDV market for the same time period (Pike 2013). However, xEVs are expected to continue to comprise a small percentage of the total global light duty vehicle (LDV) market between 2014 and 2020.

Japan and the United States are currently the largest markets for xEVs, comprising 46% and 34% of global xEV demand, respectively. While their share of the global market will likely moderate in time, Japan and the United States are expected to remain the largest markets for xEVs in 2020 (Pike 2013).

U.S. domestic demand for xEVs is driven by a combination of corporate average fuel economy (CAFE) standards, tax credits, rebates, fossil fuel prices, and consumer preference. In the United States, governmental incentives are administered at the federal, state, and local levels.

Automotive LIB Pack Markets Expected to Reach $14.3B by 2020



- Strong growth is expected in automotive LIB pack markets on a revenue basis.
- Markets expected to grow at 22% CAGR, from $2.5B in 2011 to $14.3B in 2020.

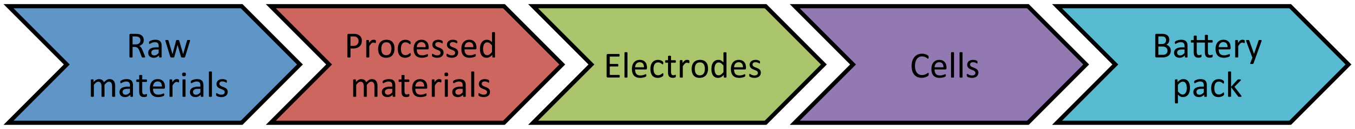
Sources: Roland Berger (2012); Pike Research (2013); AAB (2013); CEMAC analysis

LIB Market and Supply Chain Summary

- Moderate to strong demand growth for automotive LIBs is expected.
  - Minimum 22% CAGR through 2020 – the United States and Japan are currently the largest single country markets for xEVs, and are expected to remain so through 2020.
  - Current auto-specific LIB cell capacity underutilization may moderate by 2018 if moderate demand growth forecasts are met.
- LIB production is dominated by incumbent manufacturers in Asia.
  - Incumbents have gained significant experience building batteries for consumer electronics applications.
  - Incumbent experience and their advantageous supply chain relationships can be applied to automotive-specific LIB production.
- Although the United States has a foothold in automotive LIB production, the majority of global production is concentrated in Asia.
  - China, Korea, and Japan comprise 79% of global production capacity.
  - U.S.-based manufacturers comprise 17% of global production capacity.

II Regional Comparison of Cell Manufacturing Costs

The Automotive LIB Manufacturing Value Chain



Raw materials

- Basic input materials (e.g. lithium, nickel, cobalt, graphite, etc.).

Processed materials

- Purified input materials ready for transformation into cell components.
- Processed materials are considered Critical to Quality (CTQ), meaning the materials' purity greatly influences overall cell performance and production yields.

Electrodes

- Cathode and anode materials.
- CTQ, cathode materials quality especially contributes to cell capacity and overall performance.

Cells

- Fundamental functional, charge-retaining battery unit comprised of cathode, anode, separator, electrolyte, and housing.
- CTQ.

Battery pack

- Full battery pack comprised of multiple cells, controls, thermal management, and physical protection.

Sources: Pike Research (2013); CEMAC cost analysis (May 2014).

Value chain elements noted as "critical to quality" (CTQ) are of particular interest as they represent areas where IP and trade secrets may confer competitive advantage and the basis for competition beyond price. Further, advantages gained in these CTQ elements are generally transferrable across end-applications. For example, intellectual property developed for electrodes used in consumer electronics LIBs could also be applied to electrodes used in automotive LIBs.

Generally, cells are semi-custom and thus somewhat specific to the end application in which they will be utilized. Automotive cells in particular are non-standardized and specific to the particular xEV in which they will be installed. The automotive exception is Tesla, which to date has utilized 18650 cells, a standardized form factor cell originally developed for consumer electronics applications

Packs are bespoke to their particular applications, and are typically designed in close collaboration with the end application OEM. This is especially so in automotive applications, where many OEMs design and manufacture their own packs. Automotive OEMs have strict performance, life cycle, thermal management, weight, and physical packaging and protection requirements given the duty cycle, operating environments, and life expectancy of automobiles.

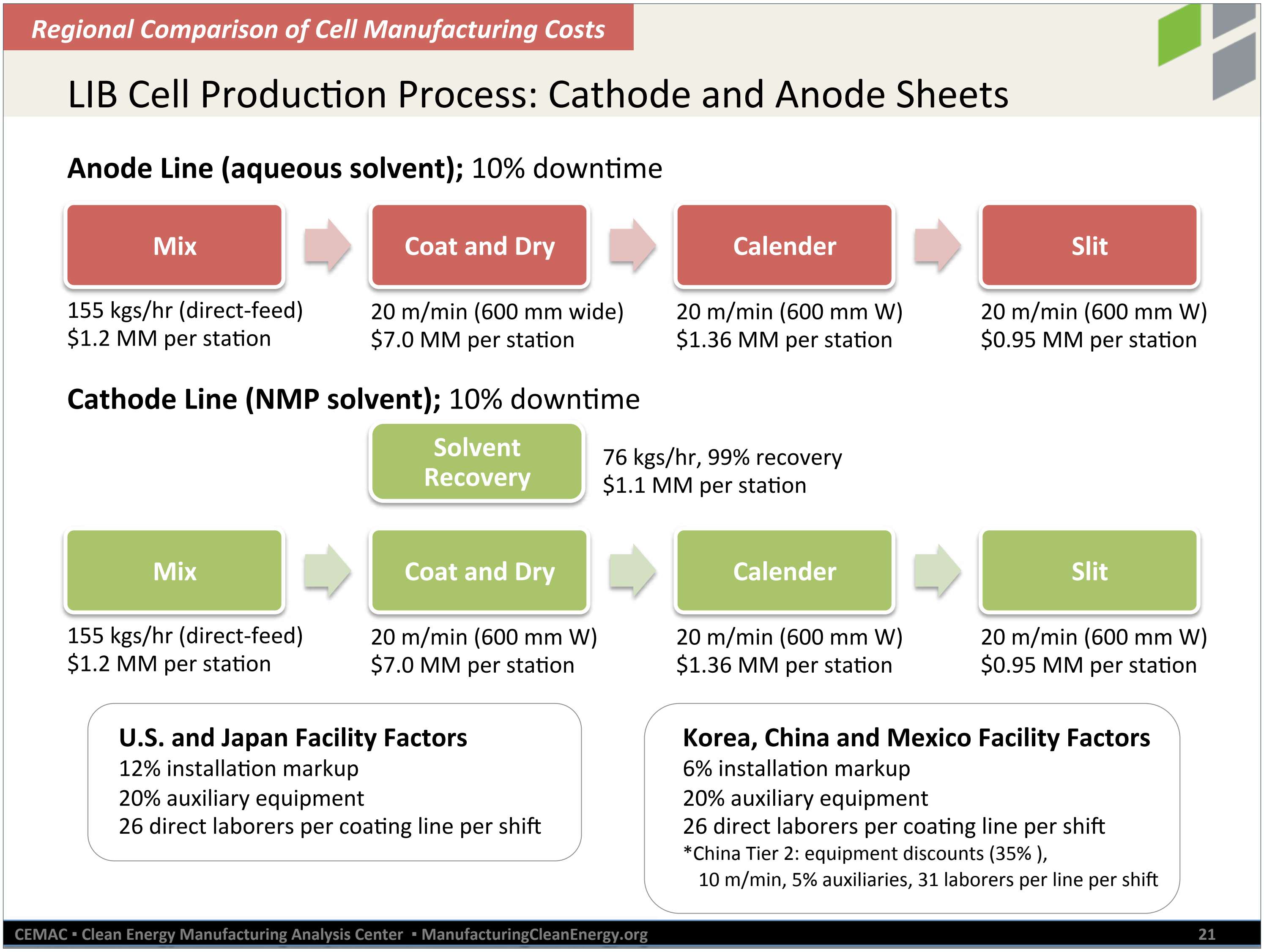
The following modeling and analysis is focused on cell manufacturing – other portions of the value chain are not modeled.

CEMAC Cost Model Overview

- The CEMAC cost model quantifies all costs, throughputs, and yields associated with each LIB cell manufacturing process step
  - Bottom-up look at every step in the process
  - Identifies all equipment, tooling, materials, labor, energy, facilities needed
  - Considers all material flows (input scrap, yields)
  - Considers throughputs and capacities (process, setup/change times)
  - Incorporates more than 30 independent variables associated with each country scenario, and over 240 independent variables associated with the production processes.

- Assigns costs to each process step
  - Assigns variable and fixed costs to each step
    - Variable: input materials, labor, utilities
    - Fixed: equipment, tooling, facilities, maintenance, financing, labor burdens
  - Aggregates costs across all process steps.

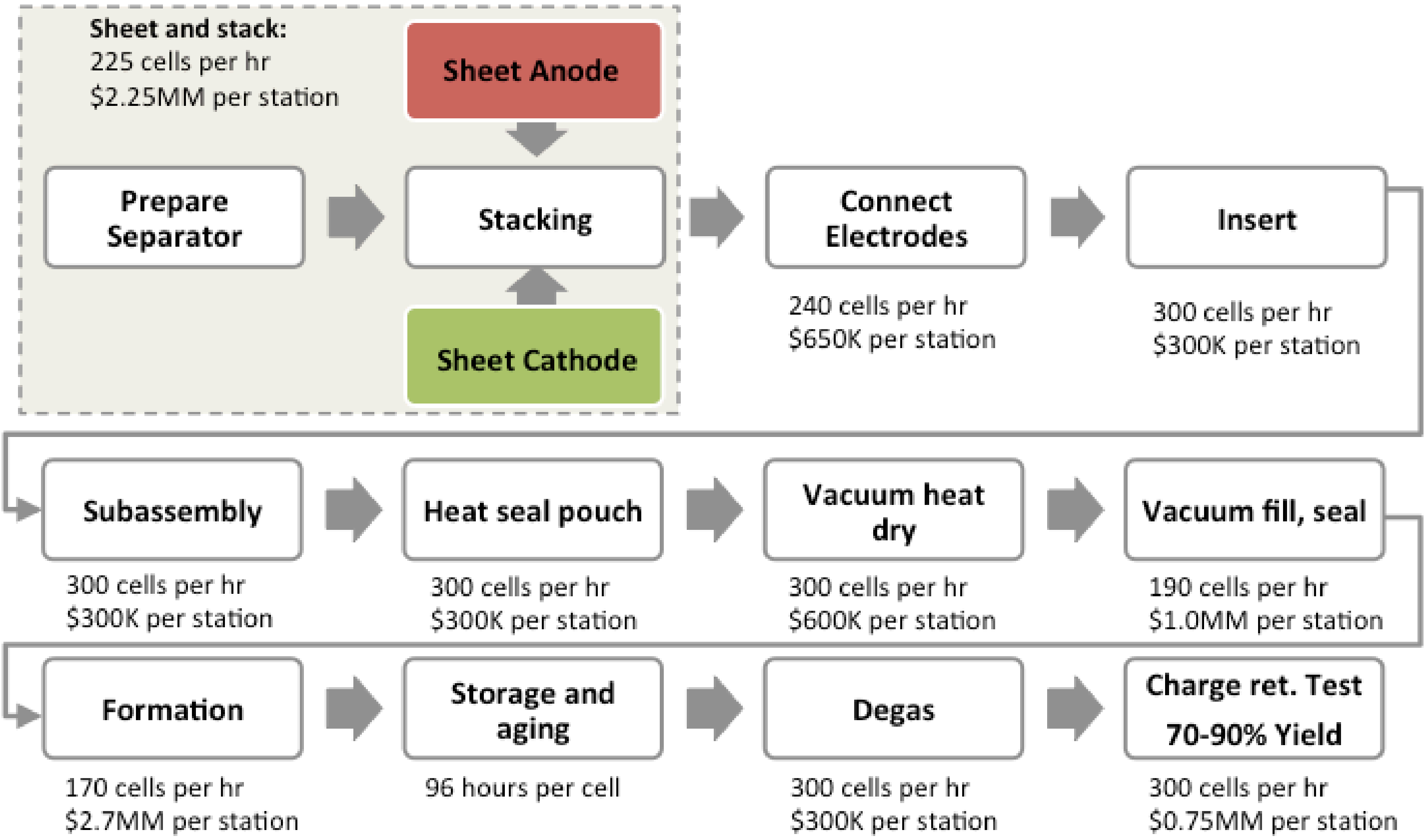
- Estimates Minimum Sustainable Prices (MSPs)
  - Creates P&L and cash flow based upon total cost structures
  - Computes the MSP price given assumptions for volume development over time and the required returns.



The general LIB cell production process flow, throughput, and equipment costs are presented to familiarize the reader with the LIB cell production process that is captured in the CEMAC cost model. The costs and throughputs for capital equipment are representative of automated, high-speed equipment typically utilized in best-in-class facilities. Equipment costs shown are for major equipment only, and are costs per station. Some process steps may require multiple stations depending upon the overall factory production (cells per year) being modeled. Further, the costs shown do not include installation or auxiliary equipment costs. These costs are omitted in the figure for simplicity and graphic clarity, but the model does incorporate all costs associated with each production step.

Equipment costs, throughput, installation costs, and auxiliary equipment costs vary by scenario as noted.

LIB Cell Production Process: Stacked Pouch Cell Assembly



See previously noted facility factors for differences across scenarios.

Regional Comparison of Cell Manufacturing Costs

Modeled Country Scenarios

Scenario	Description	Company Domicile / Manufacturing Location
U.S. Startup[1]	Relatively new market entrant with focus on technology R&D through commercialization.	U.S. / U.S.
U.S. Transplant (Korea) [1]	U.S. manufacturing facility owned by a Korean corporate parent with experience in automotive and consumer electronics LIB.	Korea / U.S.
Japan[1]	Japanese firm with experience in automotive and consumer electronics LIB.	Japan / Japan
Korea[1]	Korean firm with experience in automotive and consumer electronics LIB.	Korea / Korea
China Tier 1[1]	Chinese firm with experience in automotive and consumer electronics LIB.	China / China
China Tier 2[1]	Chinese firm with experience in automotive and consumer electronics LIB. Firm employs less automated processes and slightly lower quality materials.	China / China
Mexico Transplant (Japan)[2]	Mexican manufacturing facility owned by a Japanese corporate parent with experience in automotive and consumer electronics LIB. Combines Mexico region advantages with incumbent firm advantages.	Japan / Mexico
U.S. Future[2]	U.S. firm partnering with more experienced firms to produce LIBs in the U.S. Combines U.S. region advantages with incumbent firm advantages.	U.S. / U.S.

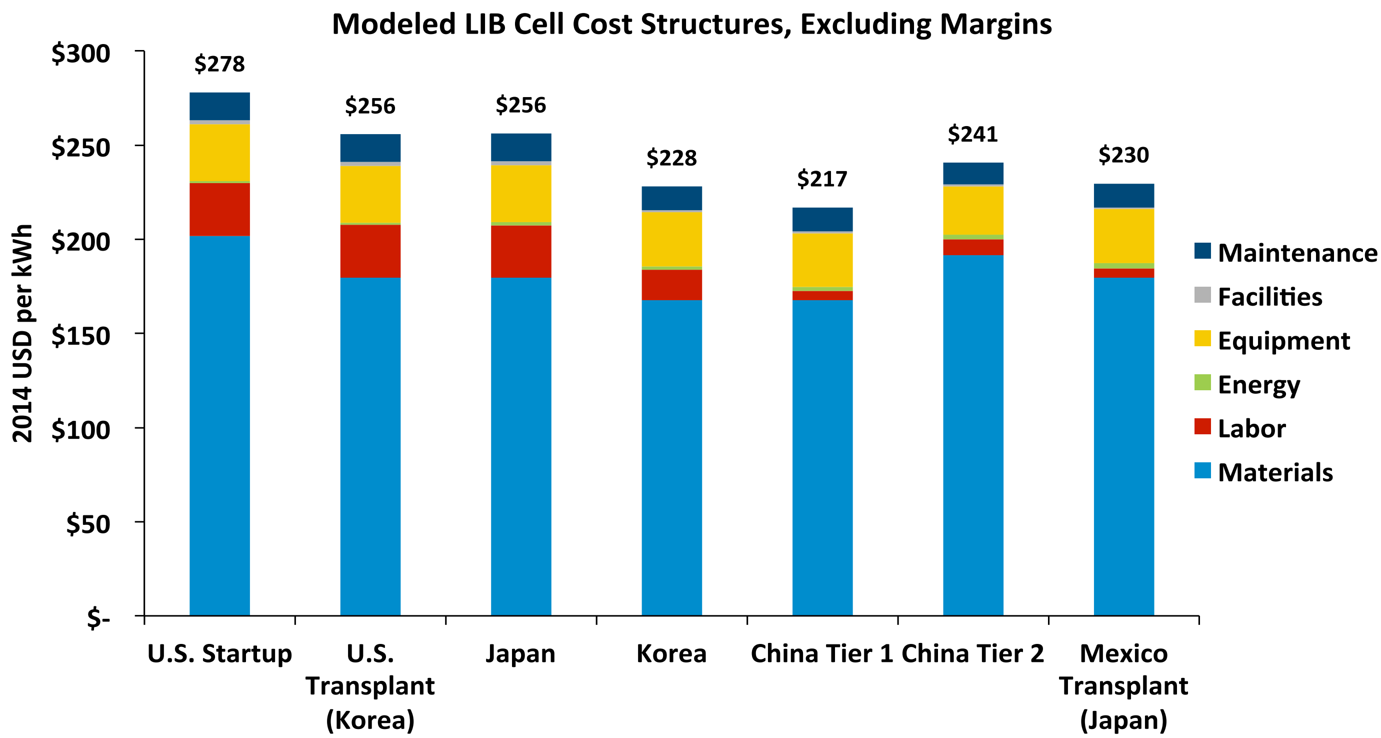
[1] Representative scenario
[2] Future scenario

Representative scenarios are developed with the intent of benchmarking the performance of actual firms operating in the countries noted, and aligning with the overall scenario descriptions. Future scenarios are developed to understand the effects of various drivers upon the potential competitiveness of country/firm scenarios, and the risks and opportunities these may present. Future scenarios are not intended to benchmark any currently existing scenarios or country conditions.

Modeled costs are for large format, 20 Ah stacked pouch cells with NMC cathodes and graphite anodes. Production volume is assumed to be 8.3 million cells (600 MWh) per year. Unless otherwise noted, the cost model also assumes 85% utilization and 80% total yield across all country scenarios except in the China Tier 2 scenario. A 70% total yield and 90% utilization are assumed for the China Tier 2 scenario due to lower automation levels modeled in that scenario. This also drives the lower equipment pricing and higher labor cost (due to lower labor productivity) observed in the China Tier 2 scenario when compared to China Tier 1. Actual utilizations and especially yields likely vary significantly among firms, even among those within the same country. Yields are assumed to depend in part on a firm's cumulative production experience in small and large format LIB cell production.

Regional Comparison of Cell Manufacturing Costs

Lowest Modeled Costs: China, Korea, and Mexico



- Materials and labor constitute the key cost differences across countries.
- Labor costs are driven by location, whereas materials costs are driven by country and company characteristics.

The materials cost category is comprised of four main material categories:

- Cathode active materials, here modeled as NMC – 30% of the total materials cost
- Separator – 18%
- Electrolyte – 16%
- Anode active materials, here modeled as graphite – 11%.
- Other materials each comprise 10% or less of the total materials cost (CEMAC 2014).

Materials costs tend to be a function of cell manufacturing company characteristics. Pricing is determined in part by purchasing volume, but also by the nature of the relationships between LIB manufacturers and their suppliers. Asian manufacturers tend to have well-established relationships with regionally co-located materials suppliers. These close relationships, and the co-located nature suppliers, appears to confer pricing advantage beyond volume-based discounts. Further, some degree of vertical integration across Asian market participants drives lower effective material costs for certain cell producers. While these advantages manifest in Asia, they could be reproduced in other geographies as there do not appear to be endemic, region-specific characteristics that contribute to this advantage.

By comparing the highest and lowest total cost regions, it appears that the differences in materials and labor costs drive the majority of cost variation between the regions (not including margins). The difference in materials and labor costs constitute 12% and 9%, respectively, of the total average cost structure.

Materials pricing assumptions are nuanced. The model applies a two-part breakdown of materials discounts. First, general material prices are assumed to be lower for incumbent manufacturers based on purchasing volumes, and an equivalent "base" cost discount is applied to all cases except the United States Startup case. Second, additional local production discounts are applied in the Korea and China scenarios, as it appears that close supplier relationships and industry clusters, which are encouraged by national industry development incentives, confer additional material cost advantage to LIB cell manufacturers located in these countries. This local discount is also applied separately to NMC materials only, as again Korea and China appear to enjoy processed NMC materials pricing that is lower than pricing available to cell producers located elsewhere.

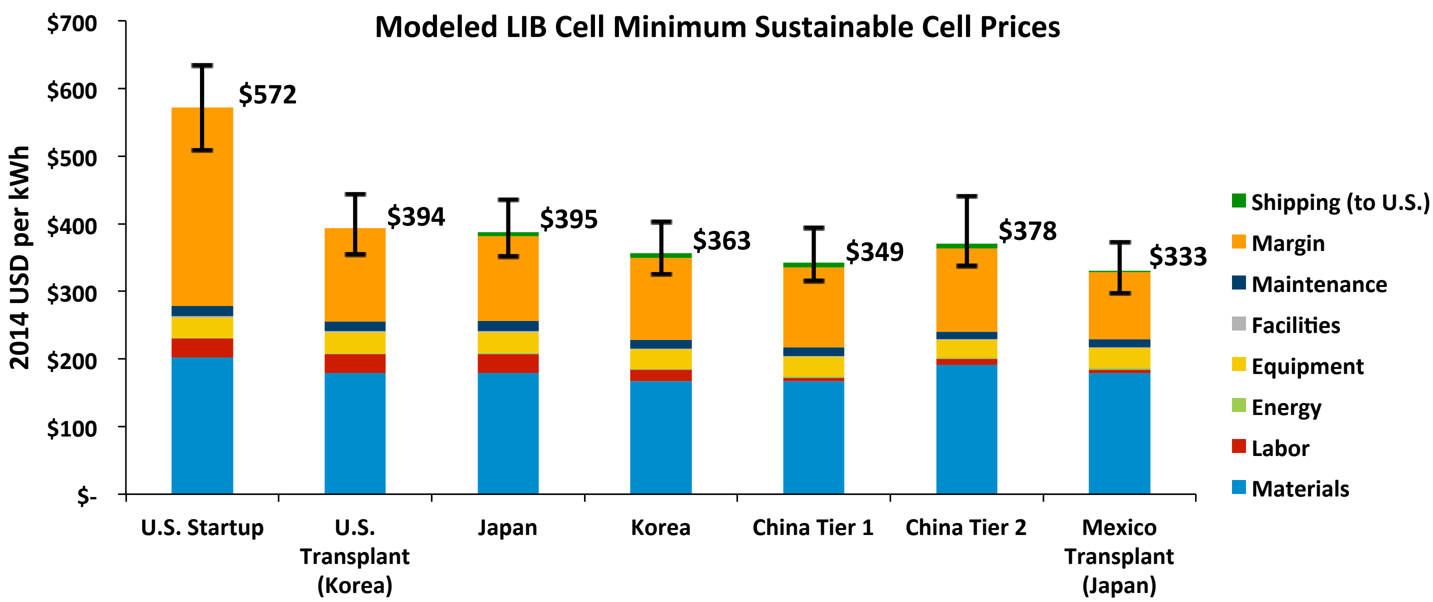
For example, volume pricing discounts are applied to the Mexico scenario because the scenario assumes an experienced Japanese corporate parent. However, the second stage material discount is not applied to this scenario, as the additional discount is assumed to be applicable only to manufacturers co-located with the materials suppliers in either Korea or China.

In contrast, labor costs are modeled entirely as a function of the region alone, and thus the relative labor rates for the scenarios are more straightforward to estimate. Labor rates in China have been rising steeply in recent years, while labor rates in Mexico have remained stagnant, and as a result Chinese rates may actually be in excess of Mexican labor rates today ((Han 2014, Coy 2013, Reuters 2013). Because of these recent trends, the model assumes equivalent labor rates for China and Mexico. We make this assumption because labor rates in China are neither completely transparent nor consistently reported.

Though we are not aware of any significant LIB manufacturing in Mexico, we include a Mexico scenario for purposes of comparison because it is geographically close to U.S. markets, and Mexico's labor rates are lower than the United States and equivalent to or lower than labor rates in China. This scenario is intended to represent not only the potential competitiveness of Mexican production, but also what might be possible if any country were able to reproduce the combination of advantages (low labor and capital costs) modeled in that scenario.

Regional Comparison of Cell Manufacturing Costs

In the Long-run, Mexico May Support the Lowest Sustainable Price



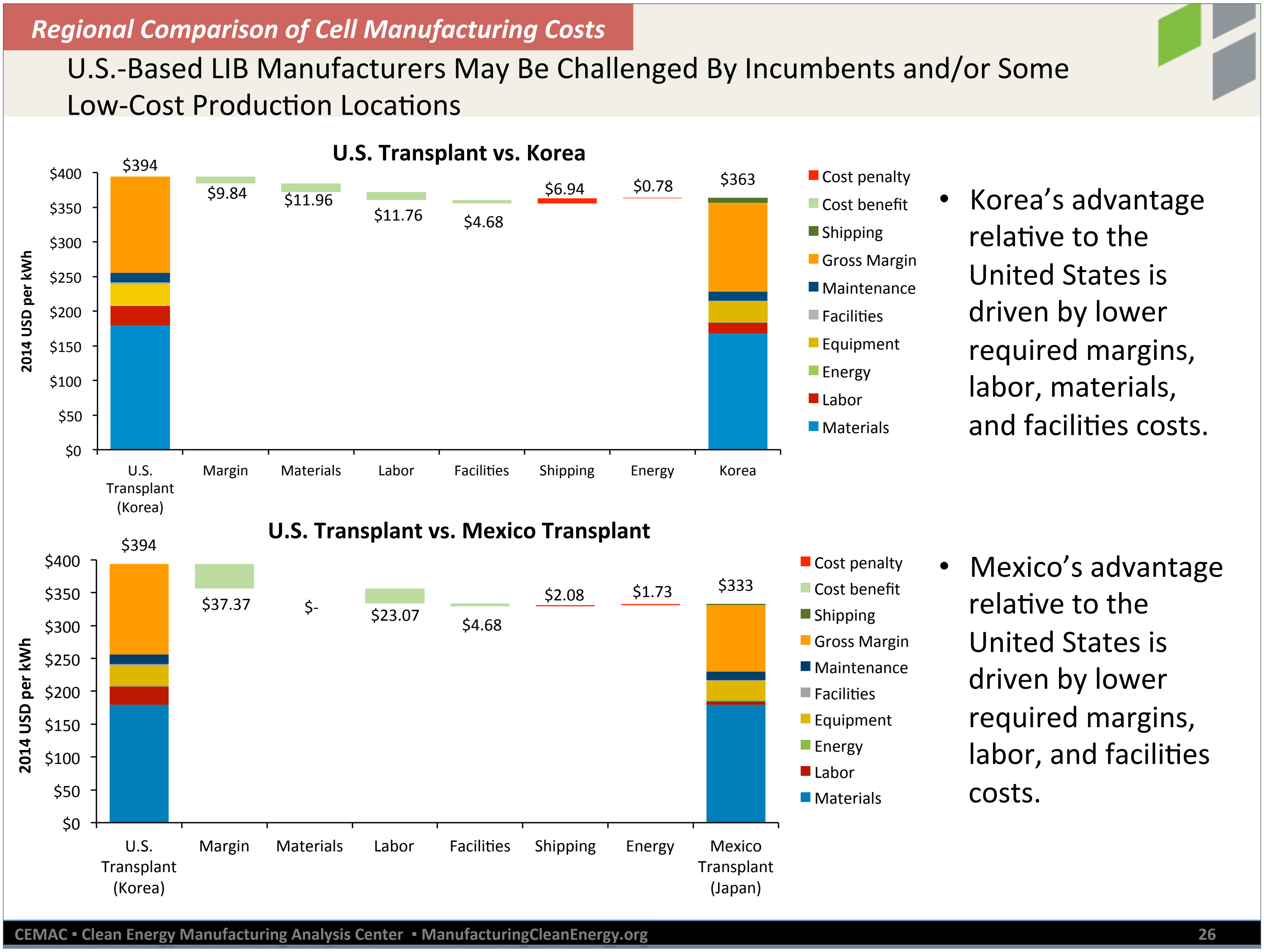
- Mexico's low cost of labor, combined with a low cost of capital could sustain the most competitive prices on the global market.
- Prices shown are modeled MSPs – actual market pricing is also influenced by firm-specific strategies and overall industry conditions.
- Error bars represent the 5th and 95th percentile MSPs resulting from uncertainty analysis – significant overlap across region scenarios indicate potential cost competitiveness of nearly all scenarios.

Minimum sustainable pricing is derived by incorporating the modeled capital and operating costs into a discounted cash flow analysis, where cell sales at the MSP must generate sufficient return to cover the assumed cost of capital. Regional average costs of capital were estimated using a set of comparable firms domiciled and publicly traded on exchanges within each of the countries of interest. For the transplant cases (Korean transplant in the United States, Japanese transplant in Mexico), the cost of capital assumed was based upon the parent company's country of origin. The model appends an additional country risk premium (or discount) based upon the credit default swap spreads against sovereign bonds between the parent company's country of domicile and the manufacturing facility location.

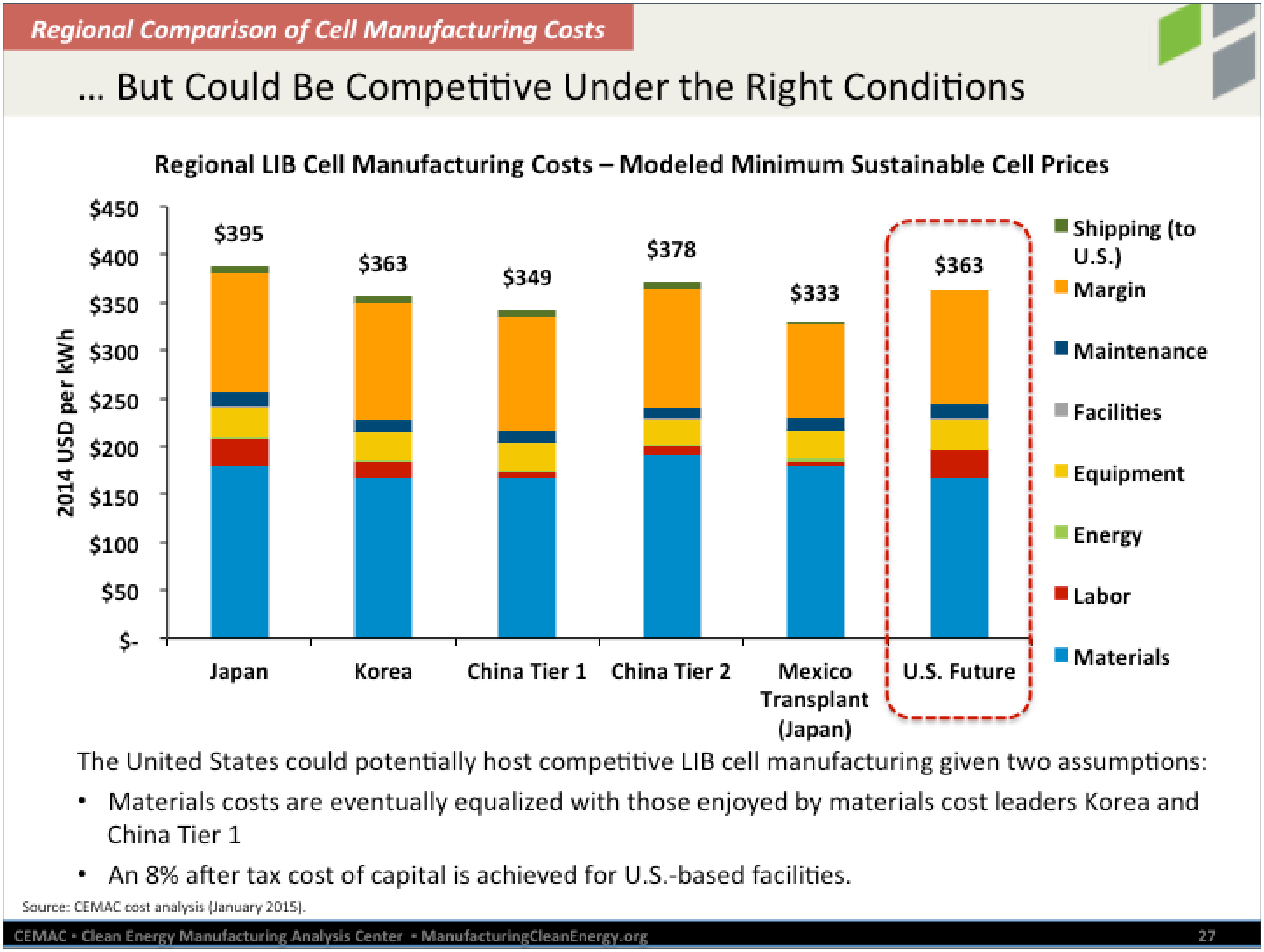
While the overall modeled cost structure for a possible Mexican LIB plant is slightly higher than that of Chinese and Korean plants, the sustainable pricing achievable is the lowest of all scenarios. Mexico's lowest sustainable price is driven by a combination of a competitive total cost structure and a low cost of capital. China tier I and Korea constitute the next lowest tier of sustainable prices, with modeled prices being within ~4% of each other. This is an unsurprising result, given that companies from these regions currently dominate LIB cell markets, along with Japanese firms.

The U.S. scenarios trail the other scenarios due to slightly higher costs for materials, labor, and facilities, while also requiring relatively high returns. The U.S. Startup case in particular is hampered by a ~14% cost of capital and the resulting high margin requirements. The cost of capital for this scenario was developed using actual financial data from U.S. startup A123 when it was an independent, publicly traded firm.

However, a significant amount of overlap in uncertainty ranges suggests that nearly all regions could potentially host competitive manufacturing under the right conditions.



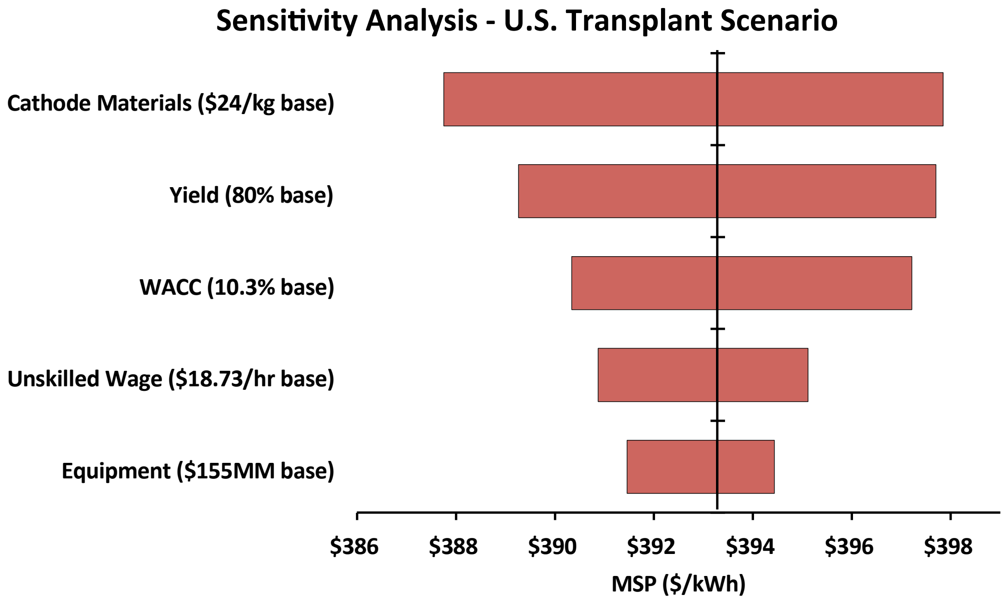
While U.S. materials prices could conceivably be equalized with materials cost leaders like Korea and China (China not pictured), it is not likely that the United States could reduce labor or facilities costs to match those found in lower cost regions. However, these advantages could possibly be offset by improvements in other cost categories.



Even though prices under the Mexico scenario remain difficult to match, future U.S. pricing could possibly be competitive with current minimum sustainable pricing from low-cost producer nations such as Korea and China. While the assumptions required to create the competitive U.S. Future case (with MSPs at or below Japan and China Tier 2 scenarios) are aggressive, it is possible that these conditions could be met at some point in the future. Regarding cost of capital assumptions, for example, using two established U.S.-based battery manufacturers (JCI and Energizer) as comparables suggests an average WACC of 8.3% appears possible for U.S. companies engaged in the battery sector.

Nonetheless, U.S.-based manufacturing faces difficult challenges given its disadvantages in various cost categories and the current relative immaturity of the U.S. supply chain and market participants.

Cathode Materials, WACC, and Yield Are Key Price Drivers

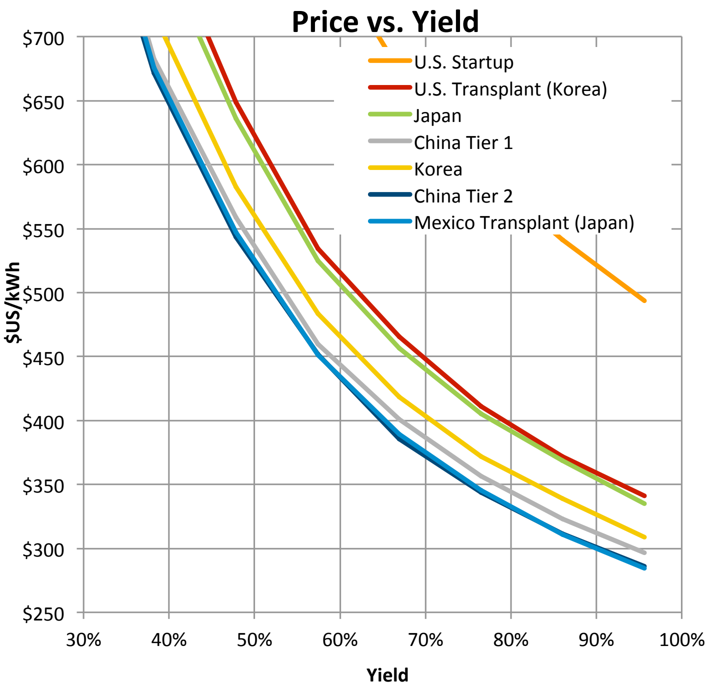


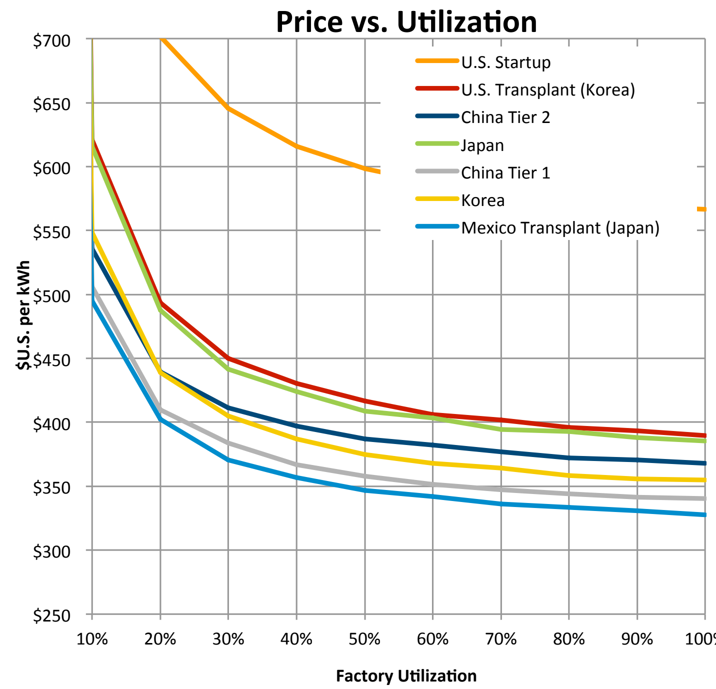
- Input parameters were varied by +/- 10% (relative) from base values to identify the modeled price sensitivities to various input assumptions
- The U.S. Transplant scenario is shown, but all scenarios were most sensitive to cathode materials cost, yield, and WACC
- Utilization was analyzed separately due to the localized response of the model relative to the most likely utilization levels assumed

Source: CEMAC cost analysis (January 2015).

Regional Comparison of Cell Manufacturing Costs

MSPs Fall as Yield and Utilization Increase





- CEMAC estimates that actual large format cell yields range from 70%-90%. Yield is defined here as yield of the cell production process only, to include input material scrap rates, but does not include total precursor material processing yields.
- Firm-level utilization is very uncertain, with global average utilization at 22% at the beginning of 2014, but firm-level utilizations are likely higher for leading firms with established sales channels.

Sources: CEMAC cost analysis (January 2015), AAB (2014).

Utilization and yield have a material effect upon unit costs and sustainable prices. We present detailed yield and utilization sensitivities here because there is a wide disparity in estimates of both metrics for automotive LIB cell production globally, and because the effects of these parameters are not explicitly shown in the stacked bar charts.

CEMAC analysis suggests that large format LIB cell yields range between 70%–90%. This range can be attributed to the difficulty associated with precisely and consistently controlling the electrochemical reactions utilized in the battery manufacturing process. The range is also in part due to the relative immaturity of the industry itself (specifically in producing large format cells), and the diversity of experience levels various competitors possess. Incumbent firms likely achieve the higher end of this range due to their experience gained from LIB production for consumer electronics applications, although large format cells can present some unique challenges. Higher yields are one way in which Japanese firms with relatively high cost structures may be able to compete effectively against rivals from Korea and China, who generally enjoy lower cost structures but potentially lower yields. In manufacturing, yield advantages are typically fleeting and diminish as competitors improve their yields as their cumulative production volumes increase.

Utilization today is particularly uncertain at the firm level due to overall overcapacity. While price is less sensitive to utilization than yield, utilization still has a material effect, especially at particularly low values. Given that global average utilization is at 22% today, it is certain that some firms are operating below this point, where the effect upon MSP is most severe.

Summary: Modeled Regional Cost Scenarios

- Among the modeled scenarios, the Korea and China cases achieve the lowest pricing across the locations with existing automotive LIB manufacturing.
- The Mexican Transplant future case achieves the most competitive sustainable cell pricing overall, but cost input assumptions are less certain because the supply chain and LIB manufacturing experience in Mexico is limited.
- Materials, margin, labor, and facilities costs constitute the major differences when comparing the U.S. scenarios to lower-price regions.
- Modeling indicates that the United States could be competitive with the Korea and China scenarios given equivalent materials costs and an 8% (or lower) cost of capital.
- Yield and levels of plant utilization are critically important to achieving cost competitiveness.
    - We assumed equivalent levels across the scenarios (except in the China Tier 2 scenario) to enable a comparison of many other cost input factors.
    - Regional and/or firm-specific variances of yield and utilization could alter the results.

III Factors Influencing Manufacturing Location Decisions

Non-cost Factors Drive Some LIB Factory Location Decisions

Qualitative factors influencing factory location decisions
• Policy and regulatory contexts
• Access to raw materials (graphite, lithium, cobalt, nickel, manganese)
• Ease-of-doing-business considerations
• Logistical risks and proximity to end-markets
• Protection of intellectual property, including process innovations
• Supply chain optimization (may include vertical integration)
• Brand and reputation
• Access to talented workforce, especially to advance RD&D

Sources: CEMAC interviews; Porter, M. E. and Rivkin, J. W. (2012); International Bank for Reconstruction and Development / The World Bank (2013).

IV Strategic Insights

Key xEV LIB Value Chain Characteristics

2014 Best-in-Class PHEV LIB Value Chain ($US/kWh)

	Raw Materials	Processed Materials	Electrodes	Cells	Battery Pack	TOTAL
VALUE		**$168**	**$28**	**$146*** **(cum. $342*)**	**$229**	**$571**
SHARE		**29%**	**5%**	**26%**	**40%**	**100%**
CURRENTLY SHIPPED	**Globally**	**Globally**	**Regionally**	**Globally**	**Locally**	
SUCCESS FACTORS	• **Indigenous resources** • Low export restrictions or limitations	• **Critical to quality** • **Demand assurance** • **Cost of capital** • **Production cost inputs:** e.g. regulatory, energy.	• **Critical to quality** • **Processing know-how**: e.g. coating thickness uniformity, solvent & moisture content.	• **Critical to quality** • **Processing know-how**: e.g. stack uniformity, drying, formation, electrolyte additive	• **End-product knowledge and integration know-how** • **Proximity to customers**: shipping costs, exchange of technical specifications	

* Ex factory gate – shipping from Asia to the west coast of the United States adds approximately $7/kWh
Sources: CEMAC estimates; BNEF (2014); Pike (2013)

There is no standardized automotive LIB value chain today, but the major components include processed materials for electrodes and other components, cell manufacturing, and pack manufacturing. With respect to vertical integration, various manufacturers are employing different approaches.

Pack production is now and will likely remain concentrated in the regions where their respective xEVs are built. This is because complete packs are not cost-effective to ship, are specific to the xEVs in which they are employed, and are typically designed and built by the automakers themselves (AAB 2014).

In contrast, LIB electrode materials, other processed materials, and complete sealed cells can be shipped without significant cost penalty relative to current market prices. Shipping electrode materials can increase risk of moisture contamination, but most production processes can dry these materials before incorporation into cells. The ability to ship these goods suggests that regions and firms producing competitively-priced cells, components, and processed materials can effectively serve global markets.

U.S. cell producers appear to be disadvantaged in the current market, but the United States could become competitive in parts of the value chain with high potential value. Cells represent 27% of the value-added in complete automotive LIB packs, but 34% of the value-added comes from electrodes and other processed materials, an area where the United States could possibly compete. The United States already assembles cells into battery packs for xEVs manufactured domestically, which comprises 39% of total LIB pack value.

LIB Manufacturing Considerations for Automotive Applications

- Factors driving the cost competitiveness of LIB manufacturing locations are mostly built; though some regional costs are significant and should be considered.
  - Regional-driven costs include: costs of capital, labor, and policy considerations.
  - Built advantages include: supply chain developments and competition, access to materials, and production expertise.
- Incumbent competitors from the consumer electronics LIB market leverage significant advantages when competing in the automotive market.
  - Advantages include: robust supply chains and leverage over suppliers; strategic partnerships and more diversified sales channels; process and technology innovations; and other manufacturing learning effects.
  - Incumbent experience can manifest as higher production yields, which significantly influence competitive manufacturing opportunities.
- Current automotive LIB production capacity is significantly underutilized, affecting the unit cost of production and potentially impacting market prices and capacity investment decisions – however, demand growth may come into balance with capacity as early as 2018.
- Asian competitors currently dominate the market, but lower sustainable prices may be possible from Mexican and U.S. production locations under certain circumstances.
- Firms may be pursuing strategies and location decisions that only partially integrate regional cost considerations.

The market for automotive LIBs is relatively immature, and characterized today by low utilizations, relatively low yields, and a diversity of participants with varying levels of experience. Yet, in terms of market share the industry is moderately concentrated, with 93% of share divided among 11 competitors (AAB 2014). As demand increases through 2020 and beyond, competitors will likely consolidate capacity, improve yields, and incrementally advance currently commercialized technologies to improve costs going forward (Roland Berger 2012, Pike 2013).

Quantifiable drivers of competitiveness can be generalized into two categories: regional cost drivers and firm-specific characteristics. The major region-specific cost factors influencing location decisions include labor, facilities, and materials costs. These costs tend to be lower in China and Korea when compared to the United States, contributing to their leading position with respect to lowest sustainable prices. Cost structures that are potentially achievable in Mexico could also be competitive globally, as Mexico offers low labor rates. If low labor costs are combined with a low cost of capital (for example, from a foreign parent company), Mexico may be able to sustain the lowest prices among the scenarios analyzed.

Firm-level characteristics influencing costs favor incumbent competitors who have gained experience building LIB cells for consumer electronics applications. Much of the knowledge gained and commercial relationships built transfer to automotive LIB cell production, and thus confer significant advantage to incumbent firms. Key incumbent advantages include: greater cumulative production experience, manifested as higher yields; volume purchasing discounts for materials; established supply chain relationships that support discounted materials costs; amortization of some fixed costs across greater volumes/end markets; potential cross-utilization of some capacity; greater ability to withstand large market fluctuations; and greater financial credibility and production track record with respect to stringent automotive OEM requirements.

Material costs are significant (~74% of the total cell cost structure before margin), and appear to have both a firm-specific component and a region-driven component. Firm-level drivers include purchasing volumes and strength of supplier relationships. However, evidence suggests that a regional element to materials discounts also exists. Suppliers appear to extend discounts to regionally co-located LIB cell manufacturing customers, and these discounts are not extended to foreign manufacturers. These types of favorable regional relationships tend to be prevalent in Korea and China especially, and reflect governmental policies targeted toward creating robust, globally competitive LIB supply chain clusters (Patil 2008, Haley 2012, Stewart et. al. 2012).

Overall, many factors contribute to competitiveness and manufacturing location decisions. Automotive LIB manufacturing competitiveness is influenced by multiple considerations beyond regionally-driven costs. These factors can offset regional cost advantages in the current state of the market. Further, the relative immaturity and imbalance in the automotive market suggests that firm-specific strategies may have a disproportionate effect on location decisions currently. However, location decisions will likely incorporate cost of production to a higher degree as the market matures.

We thank a number of partners, especially Libby Wayman (formerly of the DOE Clean Energy Manufacturing Initiative, CEMI), Brian Walker (DOE CEMI), and David Howell (DOE's Vehicle Technologies Office), who supported this work as part of the DOE Clean Energy Manufacturing Initiative.

Several industry partners, collaborators from Argonne National Laboratory, Ahmed Pesaran from CEMAC, and Al Goodrich and Ted James formerly of CEMAC also contributed significantly to the development and review of the analysis.

More information about the U.S. DOE's Clean Energy Manufacturing Initiative is available online:
http://www1.eere.energy.gov/energymanufacturing/index.html

More information about the U.S. DOE's Vehicle Technologies Office is also available online:
http://energy.gov/eere/vehicles/vehicle-technologies-office

V Appendix

Works Cited

Advanced Automotive Batteries (AAB). (2013, February). Will Advances in Battery Technology be Sufficient to Sustain the PHEV/EV Market?

Advanced Automotive Batteries (AAB). (2014). Assessing the Future of Hybrid and Electric Vehicles: The xEV Industry Insider Report.

Avicenne Energy. (2012, October 24-26). The Worldwide Battery Market 2011-2025. Nice, France.

Avicenne Energy. (2014, September 16-18). xEV Market and Its Impact on the Battery Business. Novi, MI.

Bloomberg New Energy Finance. (2014, January 30). Energy Smart Technologies – Energy Storage – Research Note: H1 2014 Electric Vehicle Battery Price Index.

Bloomberg New Energy Finance. (2014, February 28). Energy Smart Technologies – Analyst Reaction: Tesla's 'Gigafactory': Separating Hype from Reality.

Bloomberg New Energy Finance. (2014). Manufacturing Plants Data Tool. Retrieved May 15, 2014, from Bloomberg New Energy Finance: https://www.bnef.com/plants/search

Brodd, R. J. and Carlos Helou. (2012, December 22). Cost Comparison of Producing High-Performance Lithium-ion Batteries in the U.S. and in China. *Journal of Power Sources*.

Coy, P. (2013, June 27). Four Reasons Mexico Is Becoming a Global Manufacturing Power. *Bloomberg Business*. Bloomberg L.P. Web. Retrieved January 2015 from http://www.bloomberg.com/bw/articles/2013-06-27/four-reasons-mexico-is-becoming-a-global-manufacturing-power.

Daniel, C. (2008, September). Materials and Processing for Lithium-ion Batteries. *The Member Journal of The Minerals, Metals & Materials Society*. Vol. 60. No. 9. pp. 43-48.

Deutsche Bank Research. (2014, July 25). Sovereign Default Probabilities Online. Retrieved July 25, 2013, from Deutsche Bank Research website: https://www.dbresearch.com/servlet/reweb2.ReWEB?rwnode=DBR_INTERNET_EN-PROD$EM&rwobj=CDS.calias&rwsite=DBR_INTERNET_EN-PROD.

Han, C. (2014, December 17). As China's Economy Slows, So Too Does Growth In Worker's Wages. *The Wall Street Journal/WSJ China Realtime Report*. Dow Jones & Company. Web. Retrieved January 2015 from http://blogs.wsj.com/chinarealtime/2014/12/17/as-chinas-economy-slows-so-too-does-growth-in-workers-wages/.

Haley, Usha C.V. (2012, January). Putting the Pedal to the Metal: Subsidies to China's Auto-Parts Industry from 2001 to 2011. Economic Policy Institute Briefing Paper #316. Retrieved from Economic Policy Institute website, January 5, 2015. http://www.epi.org/publication/bp316-china-auto-parts-industry/

HybridCars.com. (2014, April 28). Dashboard. Retrieved May 16, 2014, from HybridCars: http://www.hybridcars.com/market-dashboard/

International Bank for Reconstruction and Development / The World Bank (2013). "Doing Business 2013." 10th Edition.

International Energy Agency (IEA). (2011, June). Technology Roadmap: Electric and Plug-in Hybrid Electric Vehicles (EV/PHEV). Retrieved May 15, 2014, from International Energy Agency: http://www.iea.org/publications/freepublications/publication/name,3851,en.html

Oak Ridge National Laboratory (ORNL). (2013). Oak Ridge National Laboratory. Retrieved May 14, 2014, from Vehicle Technologies Market Report: http://cta.ornl.gov/vtmarketreport/index.shtml

Patil, Pandit G. (2008, January). Developments in Lithium-Ion Battery Technology in the Peoples Republic of China.

Pike Research. (2011). Lithium-Ion Battery Materials: Japan Dominates in the EV Era. Blog post. Retrieved June 26, 2014, from Navigant Research website: http://www.navigantresearch.com/blog/articles/lithium-ion-battery-materials-japan-dominates-in-the-ev-era

Pike Research. (2013). Electric Vehicle Batteries.

Pisano , Gary P. and Willy C. Shih. (2009, July-August). Restoring American Competitiveness. *Harvard Business Review*.

Porter, M. E. and Rivkin, J. W. (2012). "Choosing the United States – In Contests To Attract High-Value Business Activities, The U.S. Is Losing Out More Than It Should." Harvard Business Review. March 2012.

Reuters. (2013, April 4). Update 1-Mexicon Hourly Wages Now Lower Than China's-Study. Retrieved January 2015 from http://www.reuters.com/article/2013/04/04/economy-mexico-wages-idUSL2N0CR1TY20130404.

Roland Berger. (2012, October 24-26). Technology & Market Drivers for Stationary and Automotive Battery Systems. Nice, France.

Roland Berger. (2012, October). Lithium-Ion Batteries – The Bubble Bursts.

Stewart, Terence P., Elizabeth J. Drake, Philip A. butler, Jumana Misleh, Ping Gong, Jessica Wang, Ni Y. Meggers, David DePrest. (2012, January). China's Support Programs for Automobiles and Auto Parts Under the 12th Five-Year Plan. Retrieved from Stewart and Stewart website, January 5, 2015. http://www.stewartlaw.com/Content/Documents/S%20and%20S%20China%20Auto%20Parts%20Subsidies%20Report.pdf

U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE). (2014). Maps and Data. Retrieved May 15, 2014, from Alternative Fuels Data Center: http://www.afdc.energy.gov/data/

U.S. Environmental Protection Agency (EPA). (2013). Light-Duty Automotive Technology and Fuel Economy Trends: 1975 through 2012. Appendix D. Retrieved May 20, 2014, from U.S. EPA: http://www.epa.gov/otaq/fetrends.htm

Detailed Regional Price Analysis: Key Assumptions

		U.S. Startup	U.S. Transplant	Japan	Korea	Tier 1 China	Tier 2 China	Mexico
	unit	*U.S.-Based New Entrant*	*Korea Owned, U.S. Factory*	*Japan Owned, Japan Factory*	*Korea Owned, Korea Factory*	*China Owned, China Factory*	*China Owned, China Factory*	*Japan Owned, Mexico Factory*
Unskilled Cost of Wages[1]	*$/hr*	$18.73	$18.73	$18.55	$10.88	$3.34	$3.34	$3.34
Skilled Cost of Wages[2]	*$/hr*	$26.95	$26.95	$26.70	$15.65	$13.41	$13.41	$13.41
Cost of Salary [3]	*$/yr*	$90,365	$90,365	$89,529	$52,491	$16,112	$16,112	$16,112
Indirect:Direct Labor Ratio		0.35	0.35	0.35	0.35	0.35	0.35	0.35
Working Days per Year	*days/yr*	350	350	350	350	350	350	350
Working Hours per Day	*hrs/day*	24	24	24	24	24	24	24
Weighted Average Cost of Capital[4]	*%*	14.3%	10.3%	7.0%	10.6%	11.4%	11.4%	7.2%
Price of Electricity[5]	*/kWh*	$0.040	$0.040	$0.070	$0.070	$0.077	$0.077	$0.107
Price of Natural Gas[6]	*/m³*	$0.00026	$0.00026	$0.00103	$0.00051	$0.00051	$0.00051	$0.00026
Price of Building Space[7]	*/m²*	$1,700	$1,700	$1,700	$805	$805	$805	$805
Equipment Installation Costs[8]	*%-equipment*	12.0%	12.0%	12.0%	6.0%	6.0%	6.0%	6.0%
Equipment Discount[9]	*%-equipment*	0.0%	0.0%	0.0%	0.0%	0.0%	35.0%	0.0%
Corporate Tax Rate[10]	*%*	40.0%	40.0%	35.6%	24.2%	25.0%	25.0%	30.0%
SG&A[11]	*%-revenues*	12.3%	12.3%	12.3%	12.3%	12.3%	12.3%	12.3%
R&D[12]	*%-revenues*	20.0%	3.5%	3.5%	3.5%	3.5%	1.8%	3.5%
Expected inflation[13]	*%*	2.0%	2.0%	1.9%	2.7%	2.9%	2.9%	3.7%
Total Yield[14]	*%*	80%	80%	80%	80%	80%	70%	80%
Automation		Yes	yes	yes	yes	yes	no	yes
Electrode line speed	*m/min*	20	20	20	20	20	10	20

[1] Bureau of Labor Statistics, 51-9198 Helpers-Production Workers, http://www.bls.gov/OES/current/oes519198.htm#ind

[2] Bureau of Labor Statistics, 51-9141 Semiconductor Processors, http://www.bls.gov/oes/current/oes519141.htm

[3] Bureau of Labor Statistics, 51-1011 First-Line Supervisors of Production and Operating Workers, http://www.bls.gov/oes/current/oes511011.htm International Labor rates adjusted by international manufacturing labor rates, http://www.bls.gov/fls/ichcc.pdf

[4] Public financial data accessed from Bloomberg Terminal for the following companies: Wanxiang Qianchao, BYD Co Ltd, Panasonic, Hitachi, NEC Corp, Toshiba, Samsung SDI, LG Chem, SK Innovation, Johnson Controls, Energizer; accessed December 2014

[5] Energy Information Agency, Washington state for industrial customers, http://www.eia.gov/electricity/data.cfm#sales; Korea – Bloomberg, http://www.bloomberg.com/news/2013-01-09/south-korea-increases-power-prices-second-time-to-curb-demand.html; China: Bloomberg, http://www.bloomberg.com/news/2011-05-30/china-raises-industrial-power-prices-in-15-provinces-to-help-ease-shortage.html; Mexico – Secretaria De Energia, http://www.sener.gob.mx/portal/Mobil.aspx?id=1606

[6] Energy Information Agency, http://www.eia.gov/todayinenergy/detail.cfm?id=3310

[7] Brodd, 2012

[8] CEMAC estimate

[9] CEMAC estimate assuming less automated, lower throughput equipment

[10] Tax rates from KPMG: http://www.kpmg.com/global/en/services/tax/tax-tools-and-resources/pages/corporate-tax-rates-table.aspx; 5/26/2014

[11] Public financial data accessed from Bloomberg Terminal for the following companies: Wanxiang Qianchao, BYD Co Ltd, Panasonic, Hitachi, NEC Corp, Toshiba, Samsung SDI, LG Chem, SK Innovation, Johnson Controls, Energizer; accessed December 2014

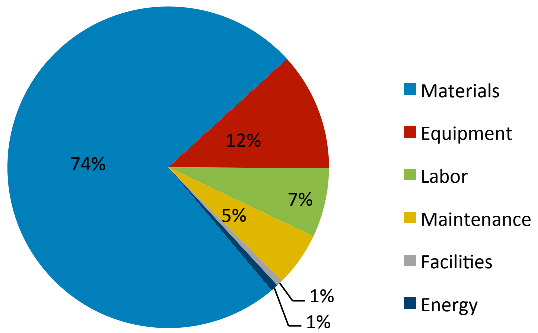
[12] Public financial data accessed from Bloomberg Terminal for the following companies: Wanxiang Qianchao, BYD Co Ltd, Panasonic, Hitachi, NEC Corp, Toshiba, Samsung SDI, LG Chem, SK Innovation, Johnson Controls, Energizer; accessed December 2014

[13] PriceWaterhouseCoopers: http://www.pwc.com/gx/en/issues/economy/global-economy-watch/projections/june-2014.jhtml; accessed June 2014.

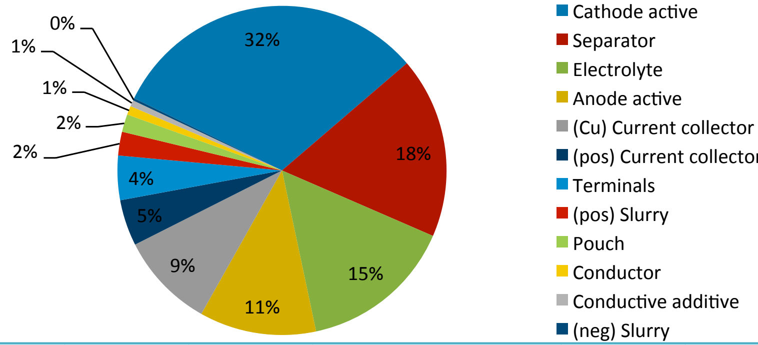
[14] Confidential conversation with industry

Detailed Material Cost Assumptions and Regional Discounts

Average Modeled Total Cost Breakdown



Average Modeled Material Cost Breakdown



			U.S. Startup	U.S. Transplant	Japan	Korea	Tier 1 China	Tier 2 China	Mexico
Part	*Description*	*unit*	*U.S.-Based New Entrant[4]*	*Korea Owned, U.S. Factory*	*Japan Owned, Japan Factory*	*Korea Owned, Korea Factory*	*China Owned, China Factory*	*China Owned, China Factory*	*Japan Owned, Mexico Factory*
Anode active material	Natural graphite (carbon coated)	USD/ kg	$14.87	$14.87	$ 14.87	$13.09[1]	$13.09[1]	$13.09[1]	$ 14.87
	Synthetic graphite	USD/ kg	$18.00	$18.00	$18.00	$15.84[1]	$15.84[1]	$15.84[1]	$18.00
Binder	SBR (5.0 wgt-%)	USD/ kg	$6.00	$5.52[2]	$5.52[2]	$5.52[2]	$5.52[2]	$5.52[2]	$5.52[2]
Solvent	Water (96 wgt-% of slurry mix)	USD/ kg	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Current collector	12 um Rolled Copper	USD/ m^2	$1.80	$1.66[2]	$1.66[2]	$1.66[2]	$1.66[2]	$1.66[2]	$1.66[2]
Cathode active material	NMC333-G (89 wgt-%)	USD/ kg	$30.00	$24.00[3]	$24.00[3]	$20.10[3]	$20.10[3]	$18.00[3]	$24.00[3]
Conductive materials	Carbon black (6 wgt-%)	USD/ kg	$7.50	$6.90[2]	$6.90[2]	$6.90[2]	$6.90[2]	$6.90[2]	$6.90[2]
Binder	PVDF (5 wgt-%)	USD/ kg	$30.00	$27.60[2]	$27.60[2]	$27.60[2]	$27.60[2]	$27.60[2]	$27.60[2]
Solvent	NMP (96 wgt-% of slurry mix)	USD/ kg	$18.00	$16.56[2]	$16.56[2]	$14.40[1,2]	$14.40[1,2]	$14.40[1,2]	$16.56[2]
Current collector	20 um Aluminum	USD/ m^2	$0.80	$0.74[2]	$0.74[2]	$0.74[2]	$0.74[2]	$0.74[2]	$0.74[2]
Separator	20 um PP (uncoated)	USD/ m^2	$2.00	$1.84[2]	$1.84[2]	$1.84[2]	$1.84[2]	$1.84[2]	$1.84[2]
	20 um PVDF based	USD/ m^2	$5.00	$4.60[2]	$4.60[2]	$4.60[2]	$4.60[2]	$4.60[2]	$4.60[2]
Electrolyte	EC/DMC/MEC-LiPF6	USD/ kg	$19.57	$18.00[2]	$18.00[2]	$18.00[2]	$18.00[2]	$18.00[2]	$18.00[2]

[1] Local production cost discount from cluster effects and policy interventions – 12% for all regions where applied

[2] Volume discount – 8% for all regions where applied 3NMC discounts driven by volume purchasing, and from cluster effects and policy interventions – 20% for U.S. Transplant, Japan, and Mexico; 33% for Korea and China Tier 1; 40% for China Tier 2 4Base cost from ANL's BatPak, http://www.cse.anl.gov/batpac/