CEMAC
Clean Energy Manufacturing Analysis Center

Webinar

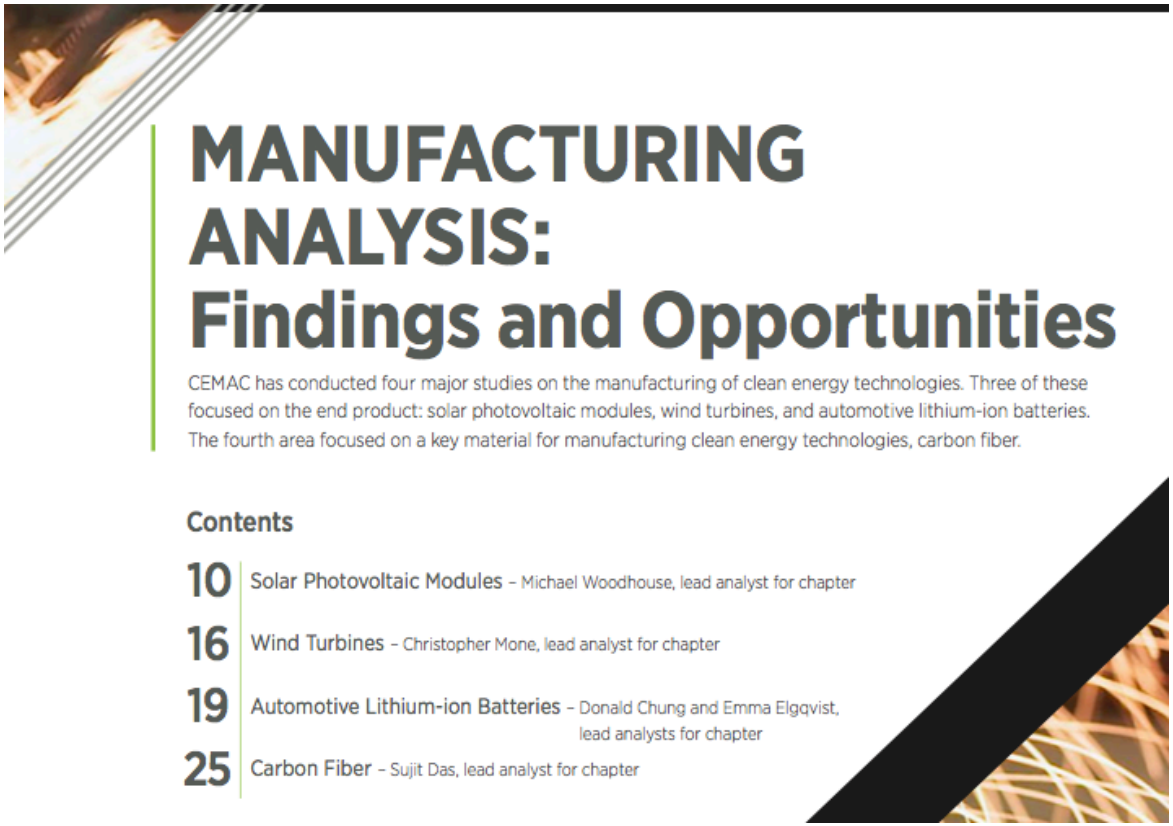
Clean Energy Manufacturing Analysis Center (CEMAC) Research Highlights

5 April 2016

www.manufacturingcleanenergy.org

Agenda

1. **Intro to CEMAC** – Jill Engel-Cox
2. **Carbon Fiber Analysis** – Sujit Das
3. **Automotive Lithium Ion Batteries** – Emma Elgqvist
4. **Q&A**



MANUFACTURING ANALYSIS:
Findings and Opportunities

CEMAC has conducted four major studies on the manufacturing of clean energy technologies. Three of these focused on the end product: solar photovoltaic modules, wind turbines, and automotive lithium-ion batteries. The fourth area focused on a key material for manufacturing clean energy technologies, carbon fiber.

Contents

Clean Energy Manufacturing Analysis Center increases understanding of global manufacturing

CEMAC provides credible, objective, and recurring global clean energy manufacturing analysis to promote the transition to a clean energy economy.

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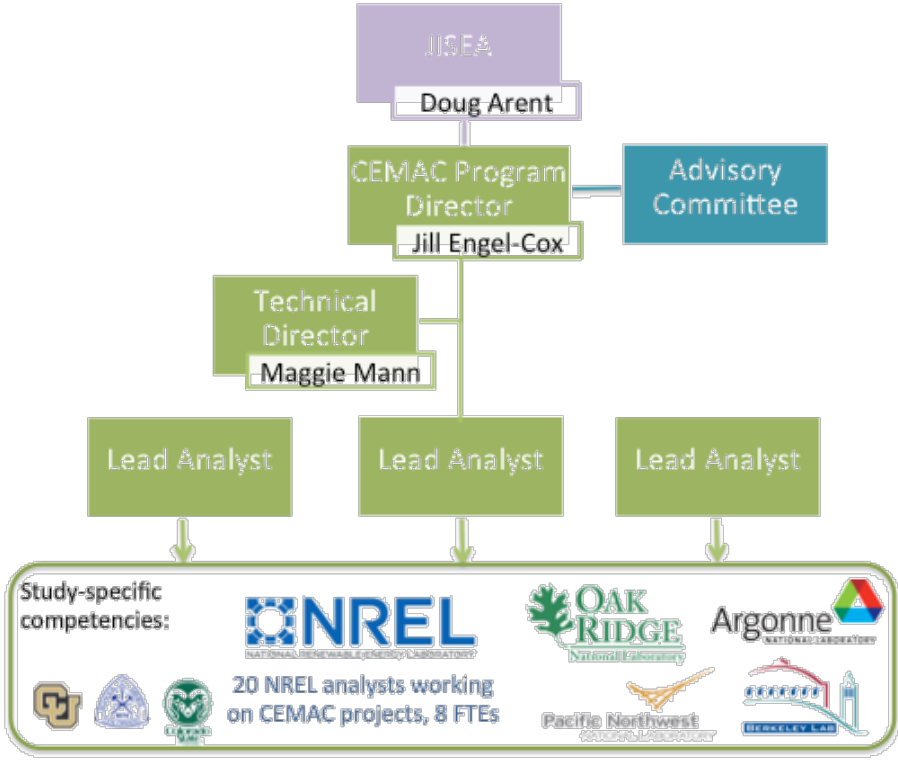
CEMAC will:

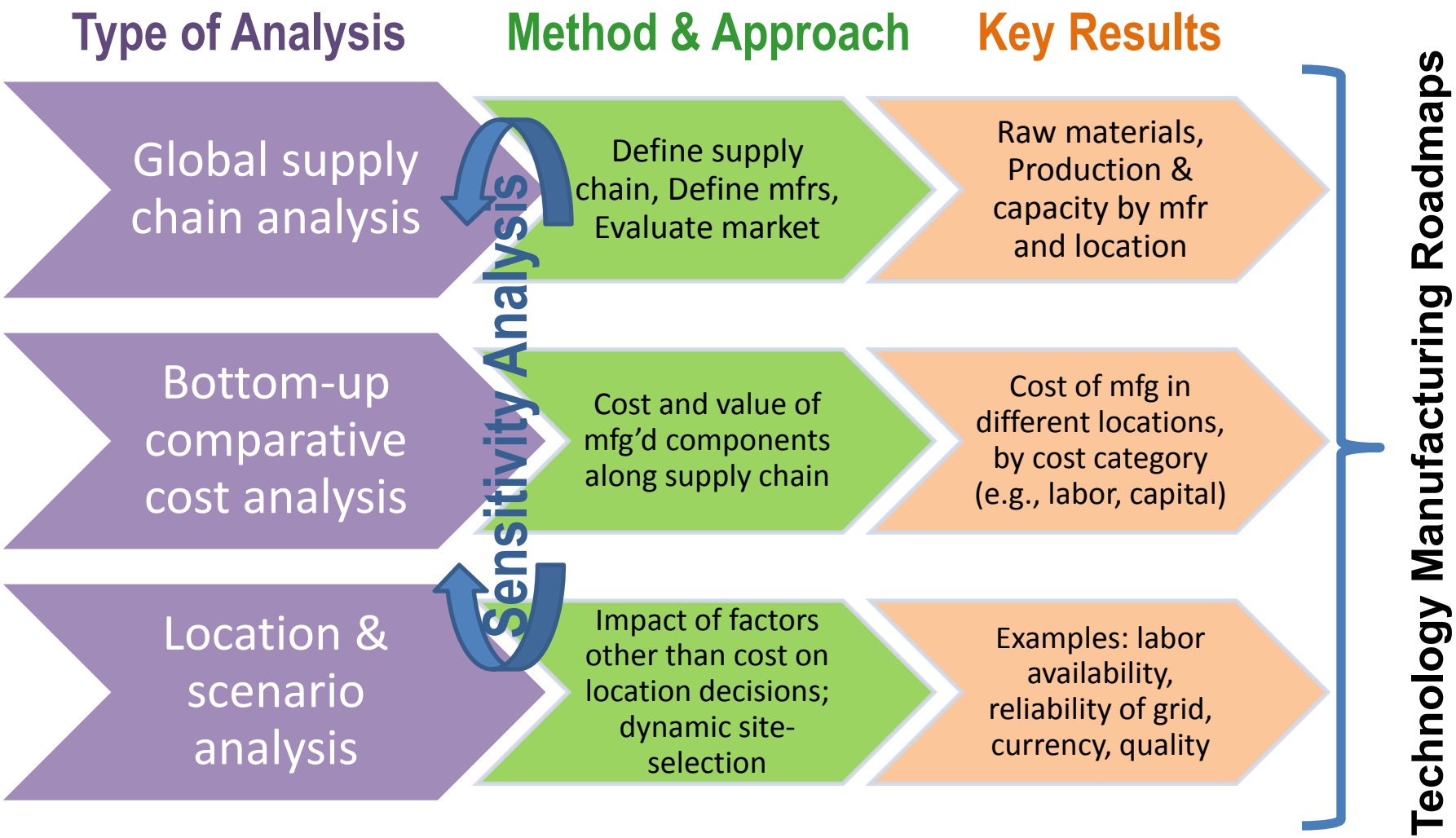
- **Deliver world class analysis** of clean energy manufacturing
- **Engage decisionmakers** from government and industry
- **Develop innovative models and tools** and unique, high-impact publications
- **Increase analytical capacity** for clean energy manufacturing analysis



Elements of CEMAC Manufacturing Analysis

- Innovation potential
- Manufacturing experience: *Learn by Doing*
- Intellectual property
- Cost of energy
- Cost of manufacturing
- Availability of investment capital
- Low-cost labor requirements & availability
- Product quality
- Skilled labor requirements & availability
- Tax policy
- Currency fluctuations
- Import and export policies
- Availability of a reliable grid
- Automation/advanced manufacturing
- Raw material availability
- Ease of transportation
- Existing supply chains
- Synergistic industries and clustering
- Existing or growing market
- Ease of doing business
- Safety
- Regulations
- Inventory costs and supply chain delays

CEMAC Analysis, Methodology & Key Results



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Carbon Fiber for Lightweighting

Sujit Das

April 5, 2016

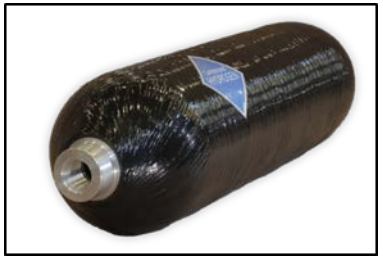
Oak Ridge National Laboratory

OAK RIDGE National Laboratory

Carbon Fiber Clean Energy

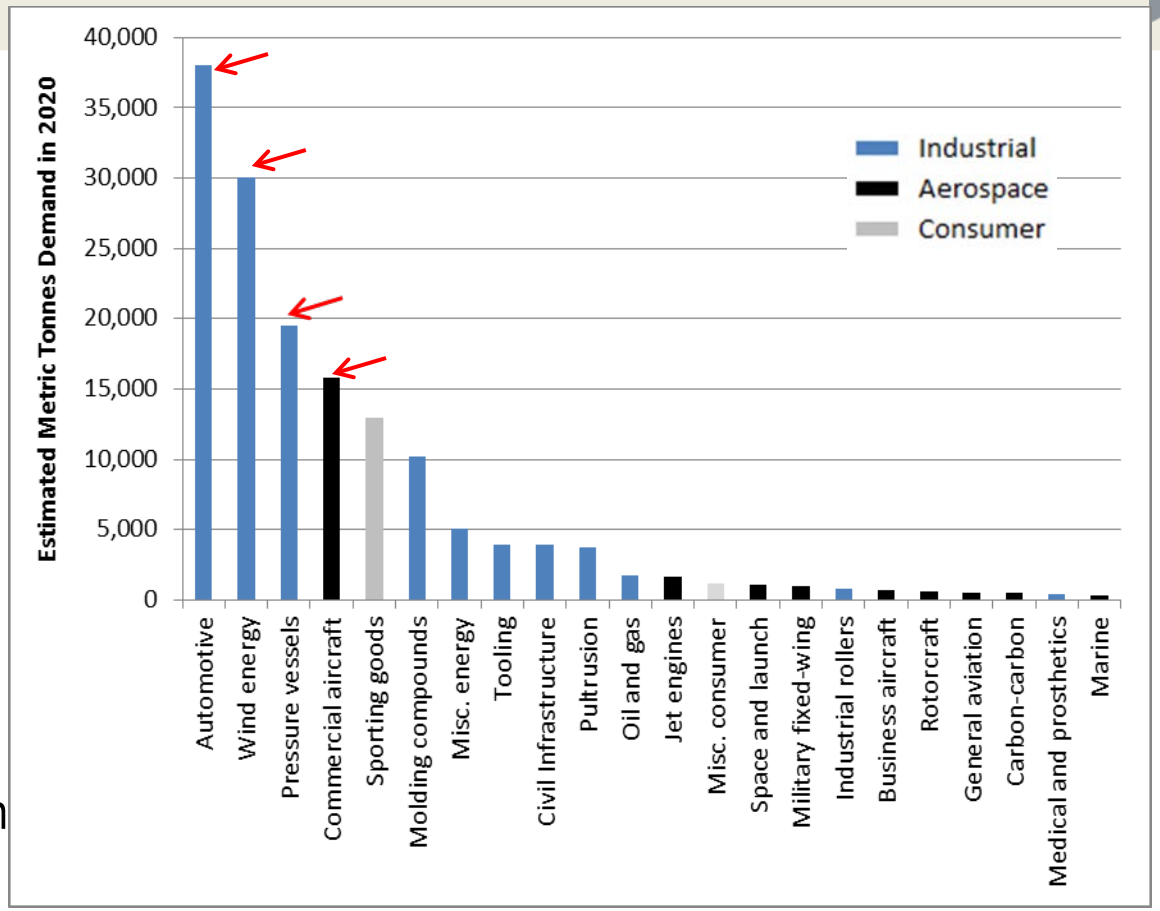
A Key Material for Technologies?

- A petroleum-based lightweight material with >92% carbon (1.6 gm/cc vs. 7.8 gm/cc for steel)
  - Excellent strength, stiffness, and corrosion resistance (Modulus/Density: 5.4x steel)
  - 1.5-5.0x more costly than steel
- Available in the form of '000s (K) of filaments known as tows
  - High-cost, ultra-high modulus smaller tow <24K fibers mainly limited to niche aerospace and defense applications today
- 20-65% mass reduction potential in clean energy manufacturing (lower energy use from lightweighting transportation and longer and lighter blades harness more clean energy)
- A reinforcing agent in high performance polymer composites
  - A wide range of applications in aerospace, industrial, and consumer sectors
  - A huge market potential for a low-cost, large tow fibers with less demanding property
- A key material necessary for clean energy manufacturing technologies



Carbon Fiber Demand by Applications

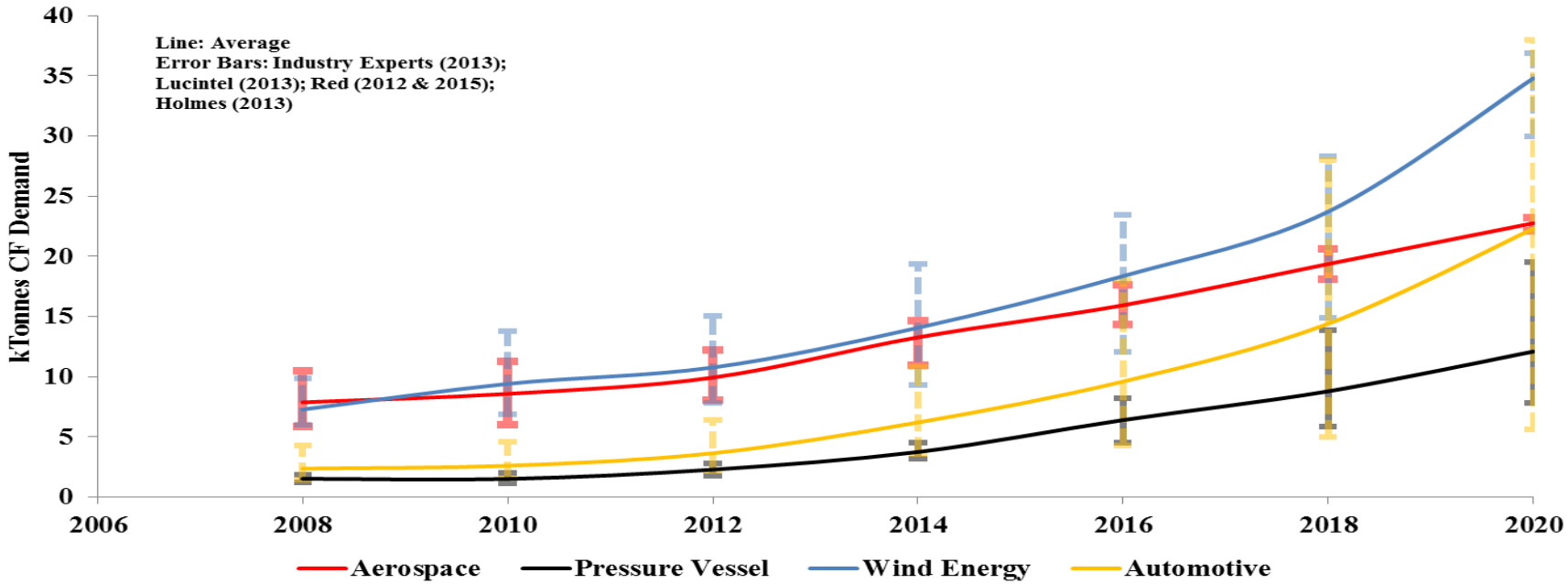
- Industry analysts usually disaggregate demand into 3 major subsectors:
  - Industrial (blue)
  - Aerospace (black)
  - Consumer/sporting goods (gray)
- Each subsector further disaggregated into specific applications (e.g. aerospace subsector has commercial aircraft, general aviation, military fixed-wing, etc.)
- Latest 2020 CF demand projection indicates a major growth in the Industrial sector (Red 2015)
- Markets selected for supply chain competitiveness (wind, aerospace, pressure vessels, and automotive applications) clearly among highest forecasted demand



Data Source: Red, C. (2015). 2015 Global Markets for Carbon Fiber Composites: Adaptations to High Growth and Market Maturity. CW 2015, Knoxville, TN, Dec 8-10

** Note: There can be considerable variance in forecasts among various industry analysts (especially for distant years), but conclusions about which applications are the market leaders generally agree*

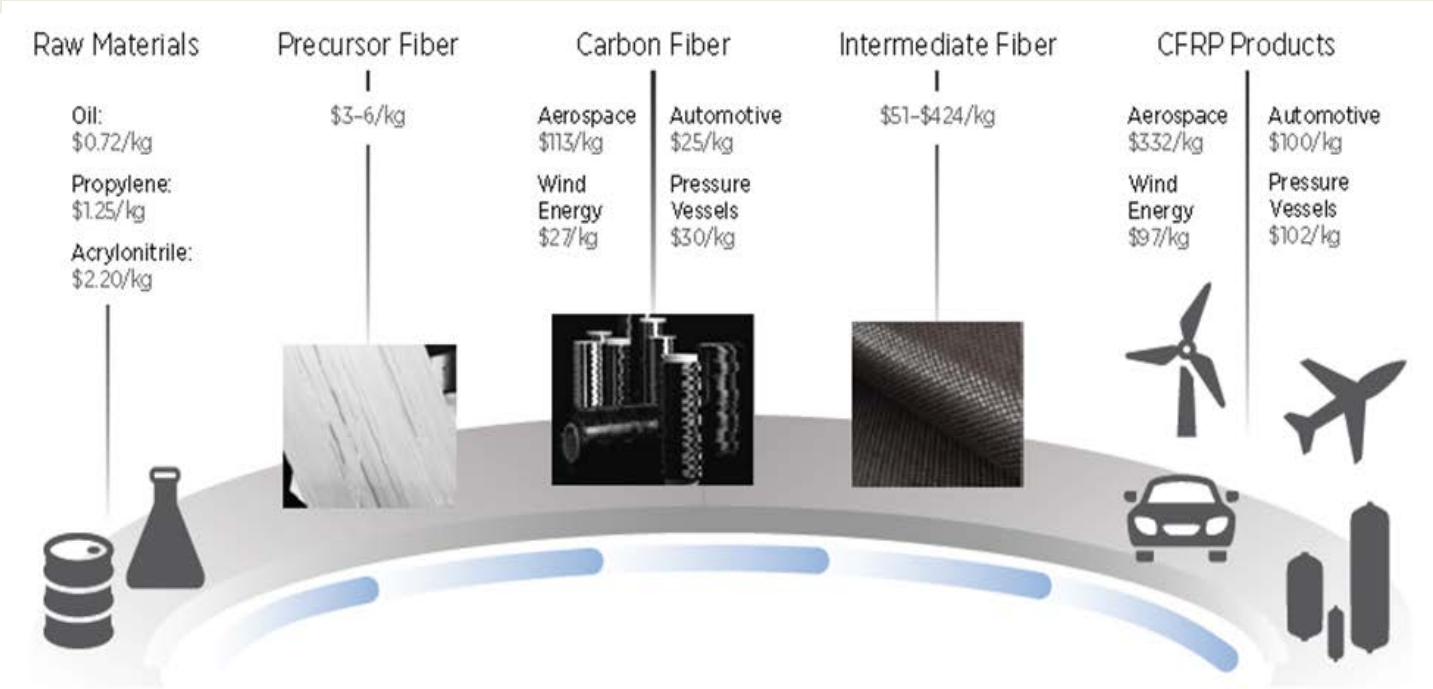
Projected Worldwide CF Demand in Major Sectors



- Latest 2020 projection shows Automotive will have the major share of total 150 Ktonne (vs. ~70 ktonne in 2015) demand, reaching > 35 Ktonne
- Aerospace share will increase to 20-25% of the market by weight, but ~50% of the monetary value due to expensive low tow fibers requirements, i.e., 4x large tow fiber cost
- A significantly higher growth rate for Wind Energy –total optimistic demand reaching similar to automotive by 2020

Industry Experts (2013). Carbon Fiber & Carbon Fiber Reinforced Plastics (CFRP) – A Global Market Overview.
Lucintel (2013). Growth Opportunities in the Global Carbon Fiber Market 2013 – 2018.
Red, C. (2012). 2012 Global Market for Carbon Fiber Composites: Maintaining Competitiveness in the Evolving Materials Market. CW 2012, La Jolla, CA, Dec 4-6
Red, C. (2015). 2015 Global Markets for Carbon Fiber Composites: Adaptations to High Growth and Market Maturity. CW 2015, Knoxville, TN, Dec 8-10
Holmes, M. (2013). Carbon Fibre Reinforced Plastics Market Continues Growth Path. *Reinforced Plastics*. Nov./Dec. 2013

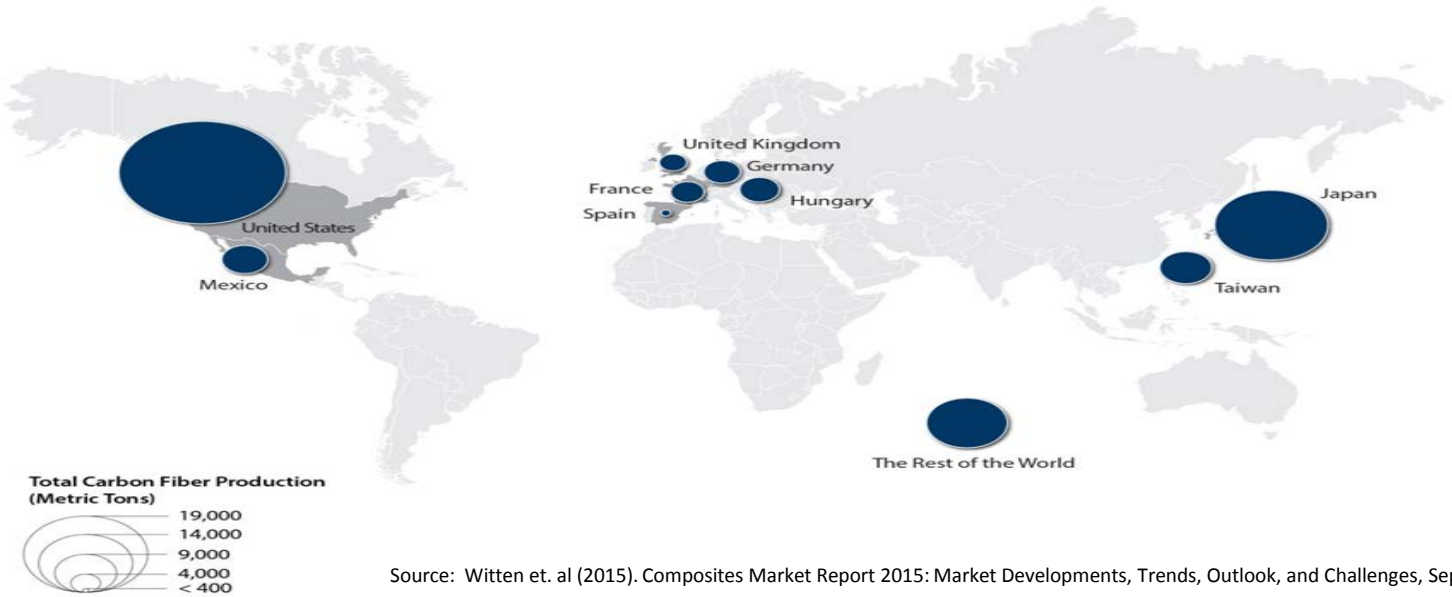
Carbon Fiber Industry Value Chain



Note: World Oil Price = $100/barrel; Carbon fiber and composite values are based on the average of several estimates

- High strength and stiffness carbon fiber value in lightweight clean energy product applications increases towards final product
- Both precursor and carbon fiber manufacturing are integrated as a single supplier more due to proprietary technology than value
- High product value has caused vertical supply chain integration among many manufacturers to the penultimate step of final product manufacturing

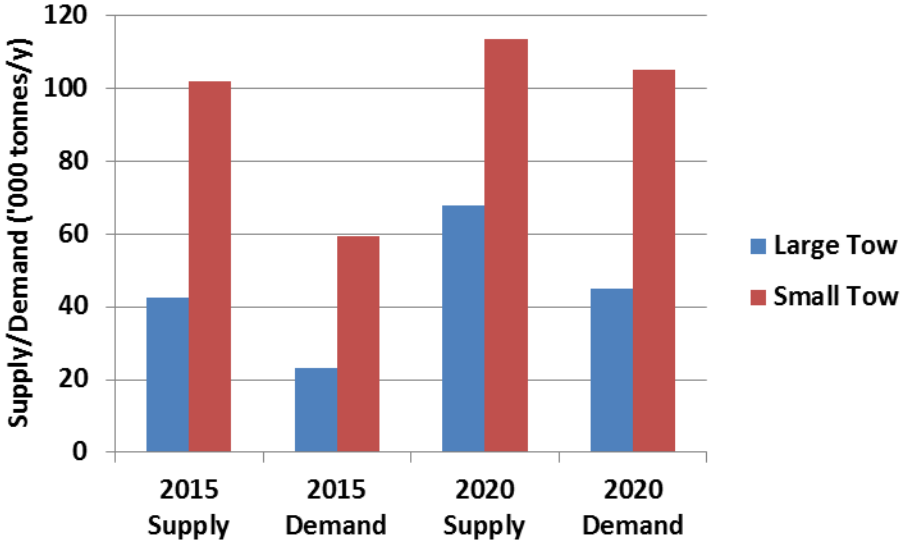
Distribution of Worldwide CF Manufacturing Capacity



Source: Witten et. al (2015). Composites Market Report 2015: Market Developments, Trends, Outlook, and Challenges, Sept.

- CF manufacturing sites concentrated in three main regions of total 125 ktonnes capacity vs 53 ktonnes demand in 2014:
  - North America (31% of global capacity – *Hexcel* is the only U.S. Ownership with ~6% of global capacity)
  - Highly concentrated industry with ~88% of global fiber capacity held by ten leading manufacturers (*Toray* the leading producer with 36% of total global capacity with *Zoltek* acquisition)
  - Japan and Europe with about 20%, but *Japan* with the largest worldwide ownership
- China, Russia, and S. Korea are the new market entrants -- ~7 ktonnes/y in China but faced with technology needs and final product quality challenges

Carbon Fiber Supply/Demand



- A significant level of excess capacity exists, particularly for small tow fibers today (higher nameplate capacity due to non-optimized operation today)
- A substantial increase in large tow carbon fiber capacity will increase in 2020 to meet the anticipated non-aerospace demand growth
- Major large tow fiber capacity is projected to be in Asia, Europe & Russia – North America capacity increase may not be sufficient to meet its anticipated 2020 demand

Red, C. (2015). 2015 Global Markets for Carbon Fiber Composites: Adaptations to High Growth and Market Maturity. CW 2015, Knoxville, TN, Dec 8-10

Carbon Fiber In Wind Turbine Blades

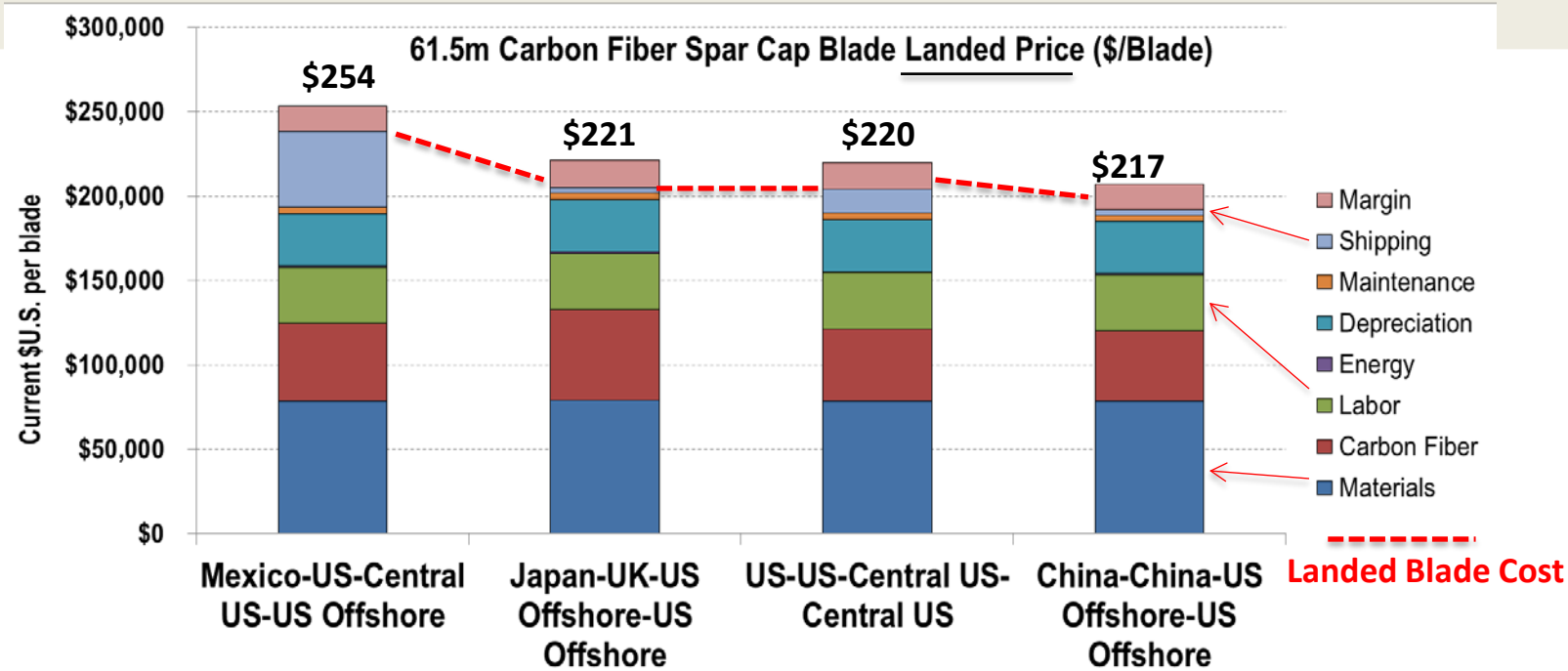
- Turbines are getting larger and blade longer
  - ✓ Energy and revenue increase by R^2
  - ✓ Weight, cost, and blade deflection by R^3
- Large blade design is based on stiffness and deflection than strength
  - ✓ High stiffness of carbon reduces blade deflection, allowing a larger tower diameter for a given blade-to-tower clearance
  - ✓ 20% spar cap mass savings compared to glass
- Lighter, stiffer blades can substantially reduce total system
- Used primarily in the spar, or structural elements (skin, trailing edge etc.) for blades longer than 45m
  - ✓ Vestas Wind Systems: 54.6m
  - ✓ GE Energy: 48.7m
  - ✓ LM Wind Power: 73.5m

Source: http://www.mfgwind.com/sites/default/files/images/pdfs/Carbon%20Blades_WES_0.pdf

50K Tow Textile Acrylics Carbon Fiber – Regional Competitiveness

- Lower energy cost facilitates US being one of the least cost producers compared to Japan – the most expensive producer
- China is the second least cost producer, but competitive with Mexico in terms of price
- Higher energy price and corporate tax rate cause the most expensive fiber in Japan
- Shipping cost impact on the cost competitiveness is relatively insignificant
- Recent production capacity announcements dictated by acquisition of acrylic fiber plant (Zoltek, Mexico) and to satisfy local demand (Hexcel, France)

61.5m Carbon Fiber Spar Cap Blade – Regional Competitiveness



- Materials has the largest share (~ 60%) of blade cost, of which carbon fiber has ~40% share of total
- Lower cost Chinese raw material allows to be the most competitive domestic blade manufacturing facility
- Shipping has a significant cost share – longer and lighter blade manufacturing and energy generation must be co-located
- Longer and lighter blade improves domestic competitiveness of carbon fiber blade manufacturing – particularly for offshore wind energy

Major Observations – Carbon Fiber Industry Competitiveness

- Major demand growth is projected in the industrial sector of clean energy product manufacturing, particularly wind energy, automotive, and pressure vessels
- High level of vertical integration in the supply chain due to proprietary manufacturing technology and increased value added towards final part manufacturing
- Low-cost large tow carbon fiber production capacity needs to increase (small tow, high quality, premium grade small tow carbon fibers for aerospace today)
- Lower shipping cost of carbon fiber allows the final product manufacturing to be located near the final demand point
- An appropriate material for lightweighting the longer turbine blade growth -- A large offshore competitive domestic wind energy manufacturing potential (shipping cost avoidance of longer blades)
- Stable supply, low costs, and consistent quality will be important factors in maintaining the domestic manufacturing competitiveness

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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

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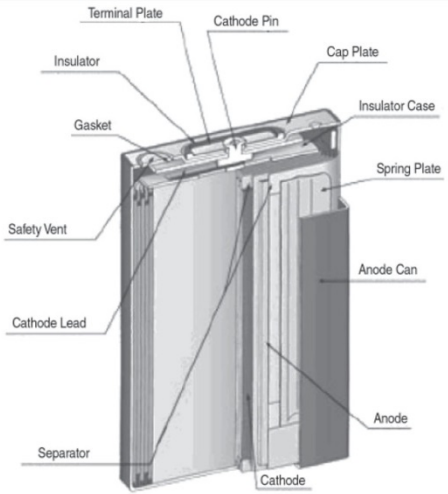
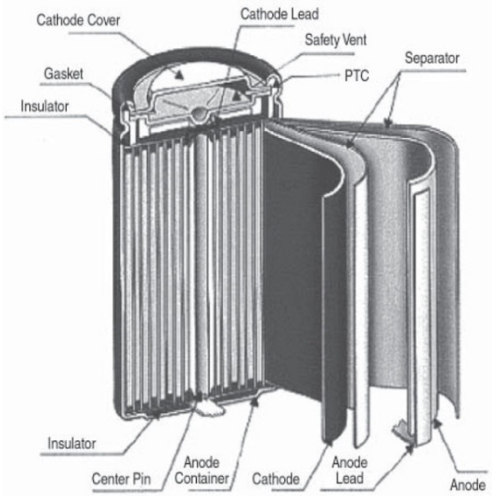
Lithium-Ion Battery Introduction

- 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



Schematic Images: Daniels (2008). Copyright 2008 by The Minerals, Metals & Materials Society. Reprinted with permission.

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)

LIB Cell Manufacturing Locations: Today, LIB Cell Manufacturing Is Heavily Concentrated in Asia…

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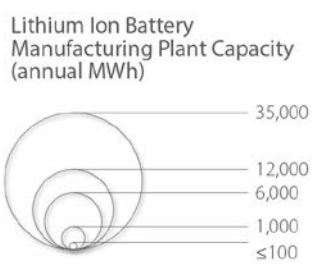

	Fully Commissioned	Partially commissioned	Under construction	Announced
China	11,152	3,038	16,244	19,246
Japan	13,623	0	0	0
Korea	6,570	0	0	0
U.S.	4,125	0	0	35,150
EU	1,293	0	5,000	0
Rest of World	3,390	0	0	120
TOTAL	**40,153**	**3,038**	**21,244**	**54,516**

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 (2016).

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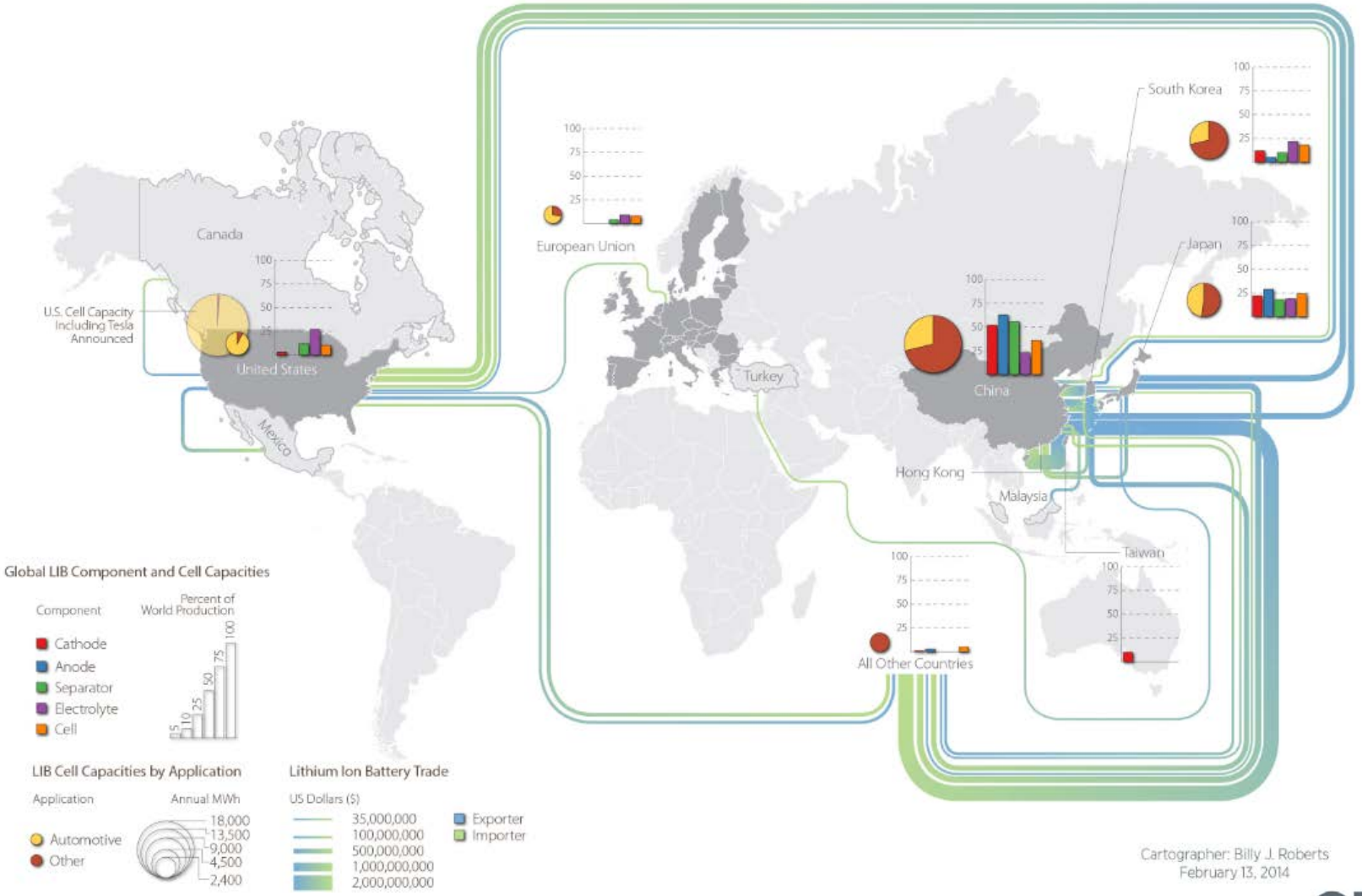
…As Is Upstream Materials Manufacturing

Regional LIB Supply Chains and Trade Flows



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

xEV Sales: BEV, PHEV Sales Steady - HEV Sales Slow

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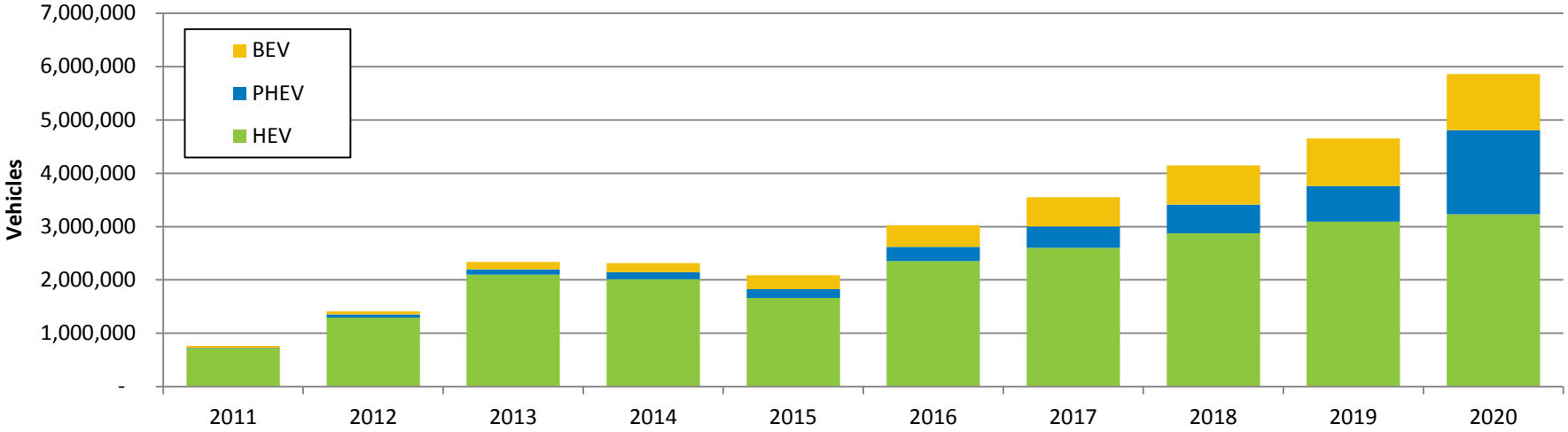
xEV Sales and Forecasts :Total xEV sales grew rapidly 2011-2014 @ 47% CAGR



BEVs	PHEVs	HEVs
35% CAGR 2011-2014	19% CAGR 2011-2014	50% CAGR 2011-2014
32% CAGR forecast 2015-2020	57% CAGR forecast 2015-2020	14% CAGR forecast 2015-2020
BEV and PHEV penetration of addressable markets is still growing (e.g. A- and B-segments)		But, sales flat to declining 2013-2015

xEV Projected Growth vs. Manufacturing Capacity: Robust xEV LIB Demand Growth Expected

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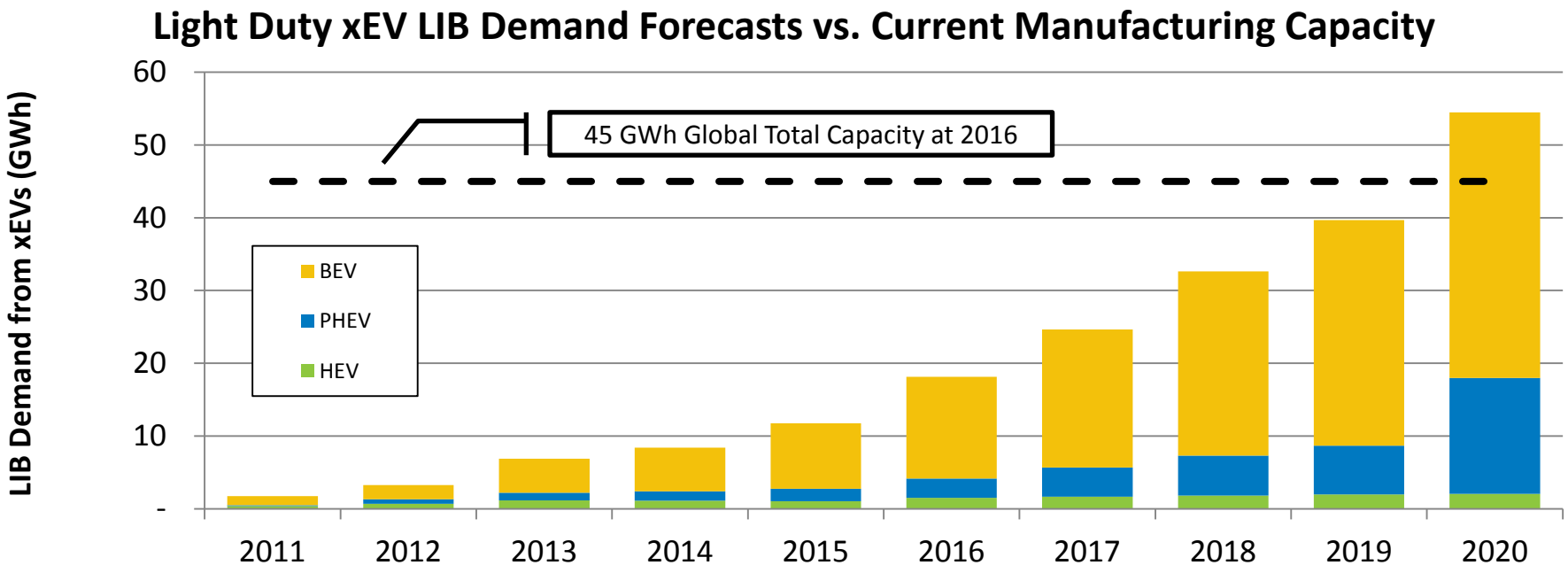
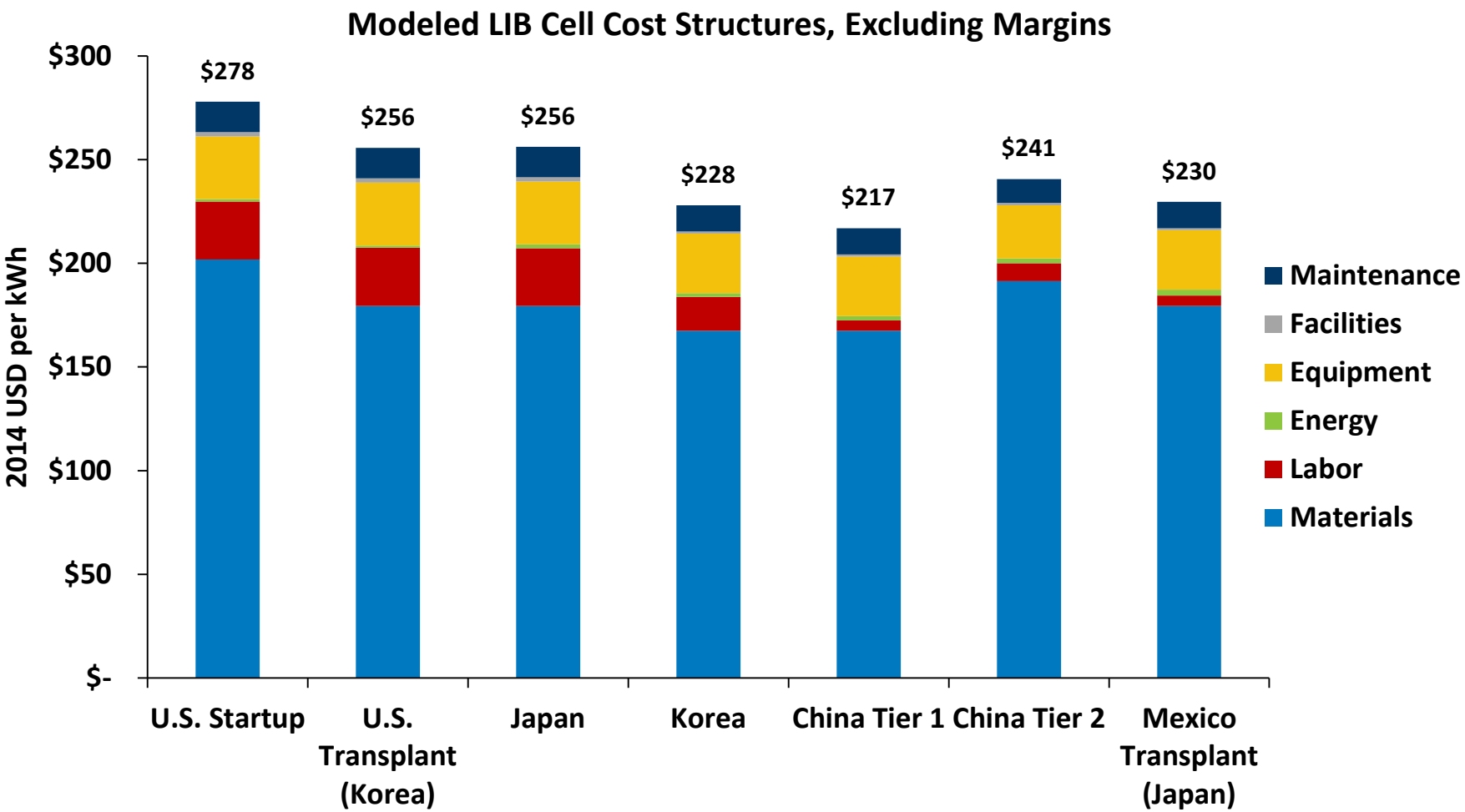


- **2016 global capacity utilized by 2020**
- **36% CAGR in LIB forecast from 2015-2020**
- **LIB demand estimates are driven by BEVs and PHEVs**
- **However, Consumer Electronics Represent the Majority of Demand for LIBs**

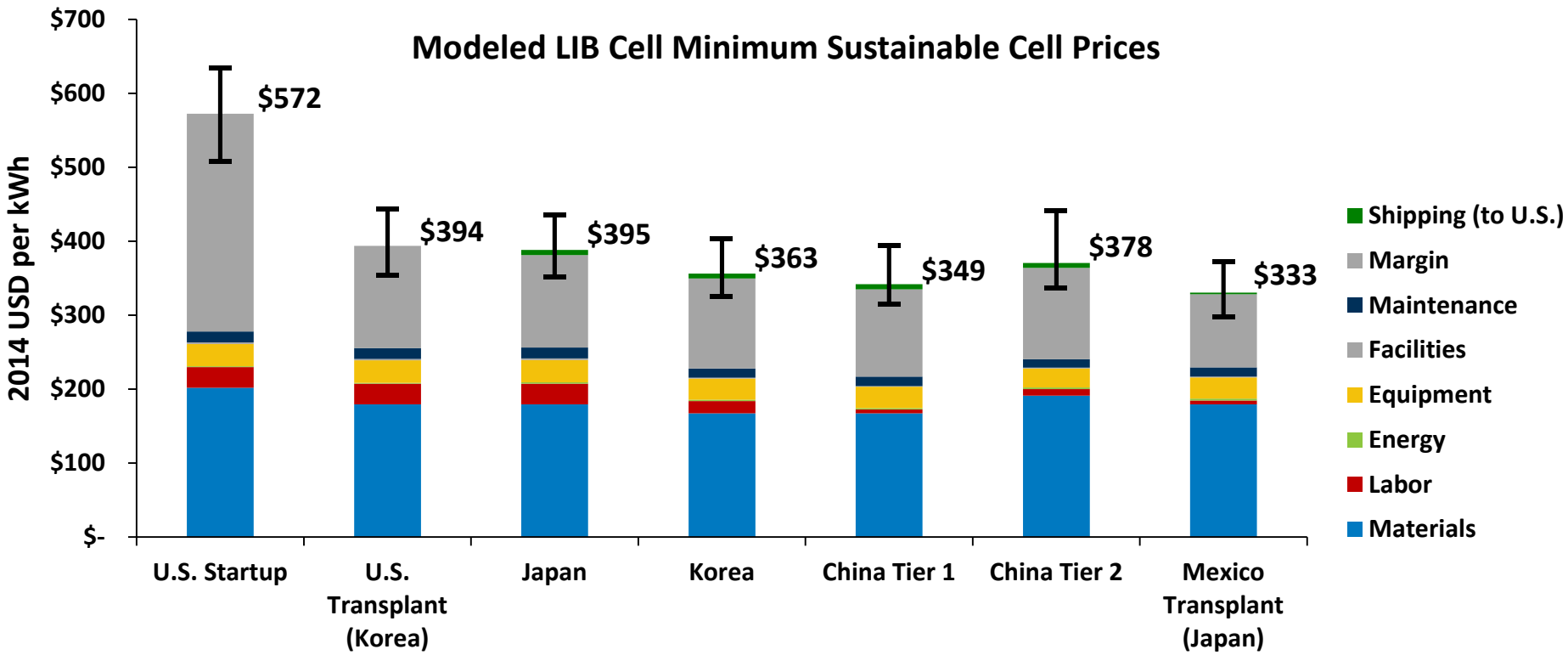
Sources: BNEF 2016; Navigant 2015; Technavio 2015; Roland Berger 2015; International Energy Agency (IEA) 2015; Oak Ridge National Laboratory (ORNL) 2015; NREL
Note: Assumed energy storage requirements: 1 kWh for HEVs; 10 kWh for PHEVs; 35 kWh for BEVs; Some estimates put stationary storage demand at ~6 GWh in 2016.
estimates

Modeled Cost: Material Cost Primary Driver



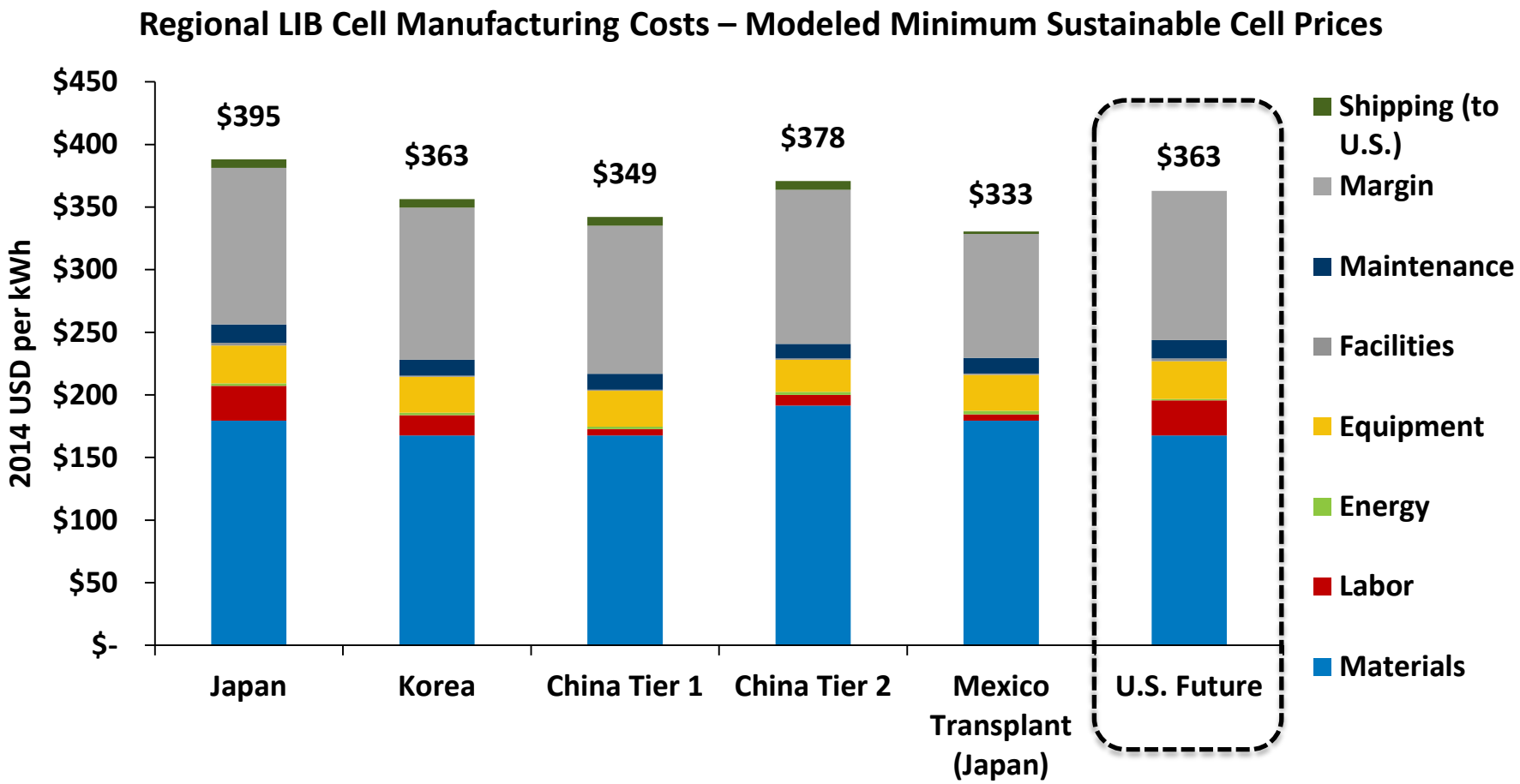
- Materials and labor constitute the key cost differences across countries.
- Labor costs are driven by location, whereas materials costs are driven by country and company characteristics.

Modeled Price: 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.

Modeled Price: The US Could Be Competitive Under the Right Conditions

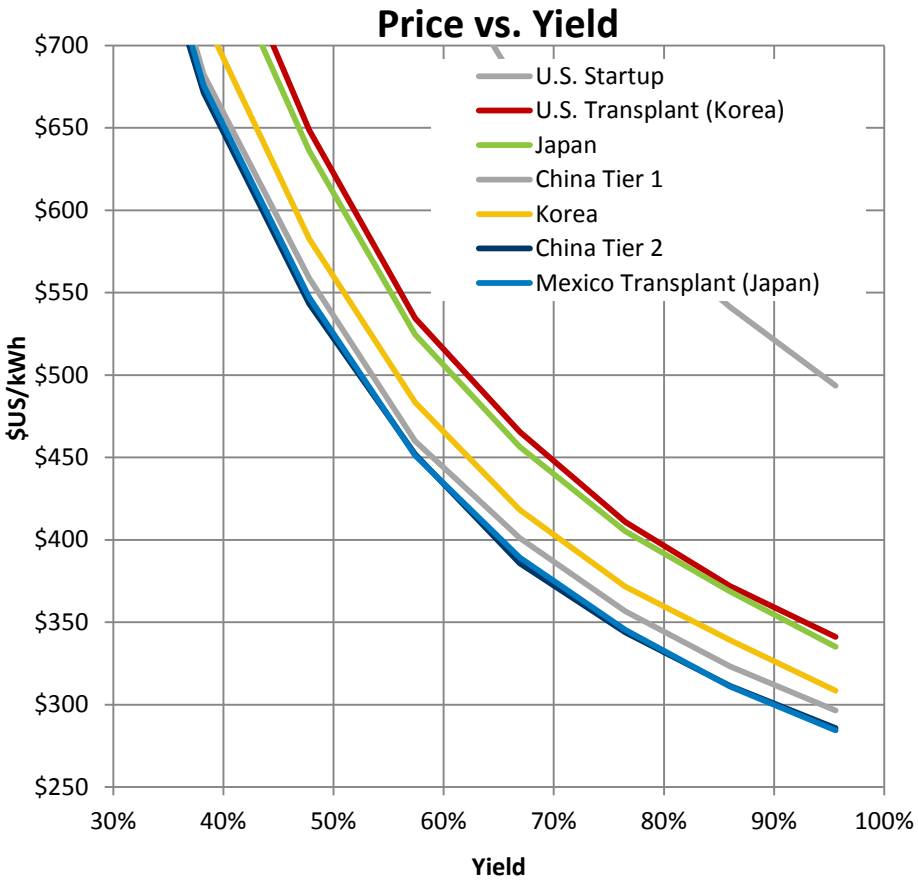


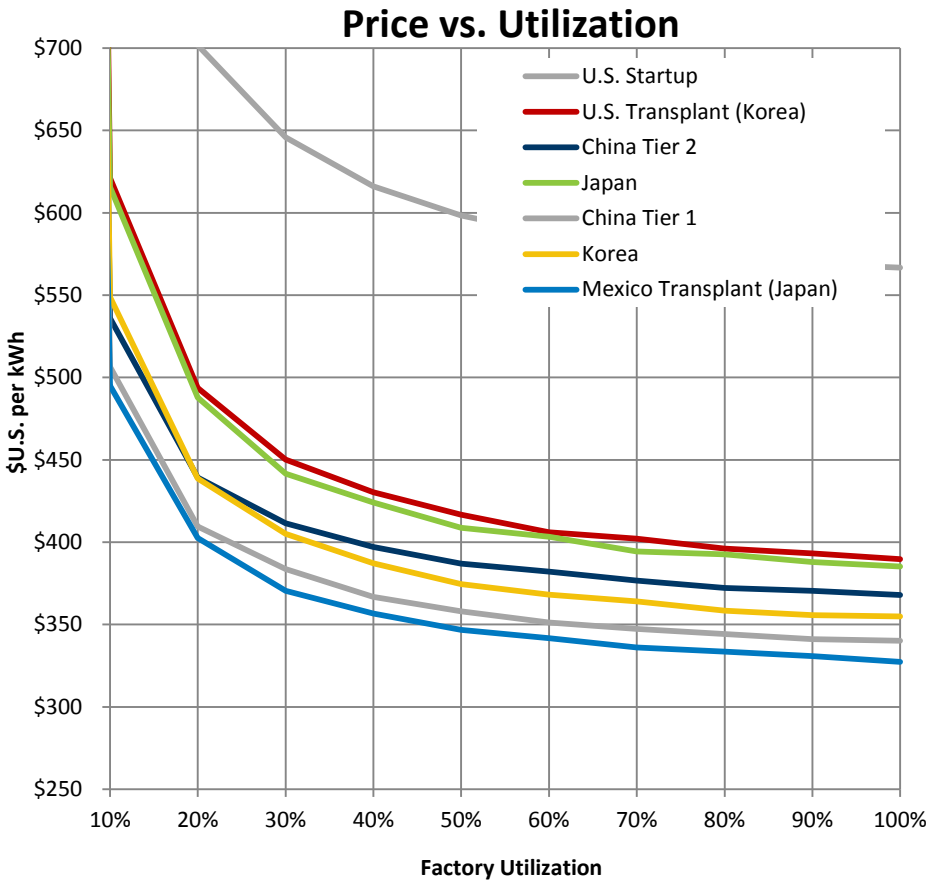
The United States could potentially host competitive LIB cell manufacturing given two assumptions:

- Materials costs are eventually equalized with those enjoyed by materials cost leaders Korea and China Tier 1
- An 8% after tax cost of capital is achieved for U.S.-based facilities.

Source: CEMAC cost analysis (January 2015).

Sensitivity to Manufacturing Conditions: 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).

Summary of 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.

- Asian competitors currently dominate the market, but **lower sustainable prices may be possible from Mexican and U.S. production locations under certain circumstances**.

- 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.

Questions and Answers

Please send your questions in writing in the chat box

Thank you!

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