Global Manufacturing and Trade of Renewable Energy Technologies

Presented by Jill Engel-Cox

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Payne Institute for Earth Resources, Colorado School of Mines

20 March 2018

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National Renewable Energy Laboratory

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National Renewable Energy Laboratory

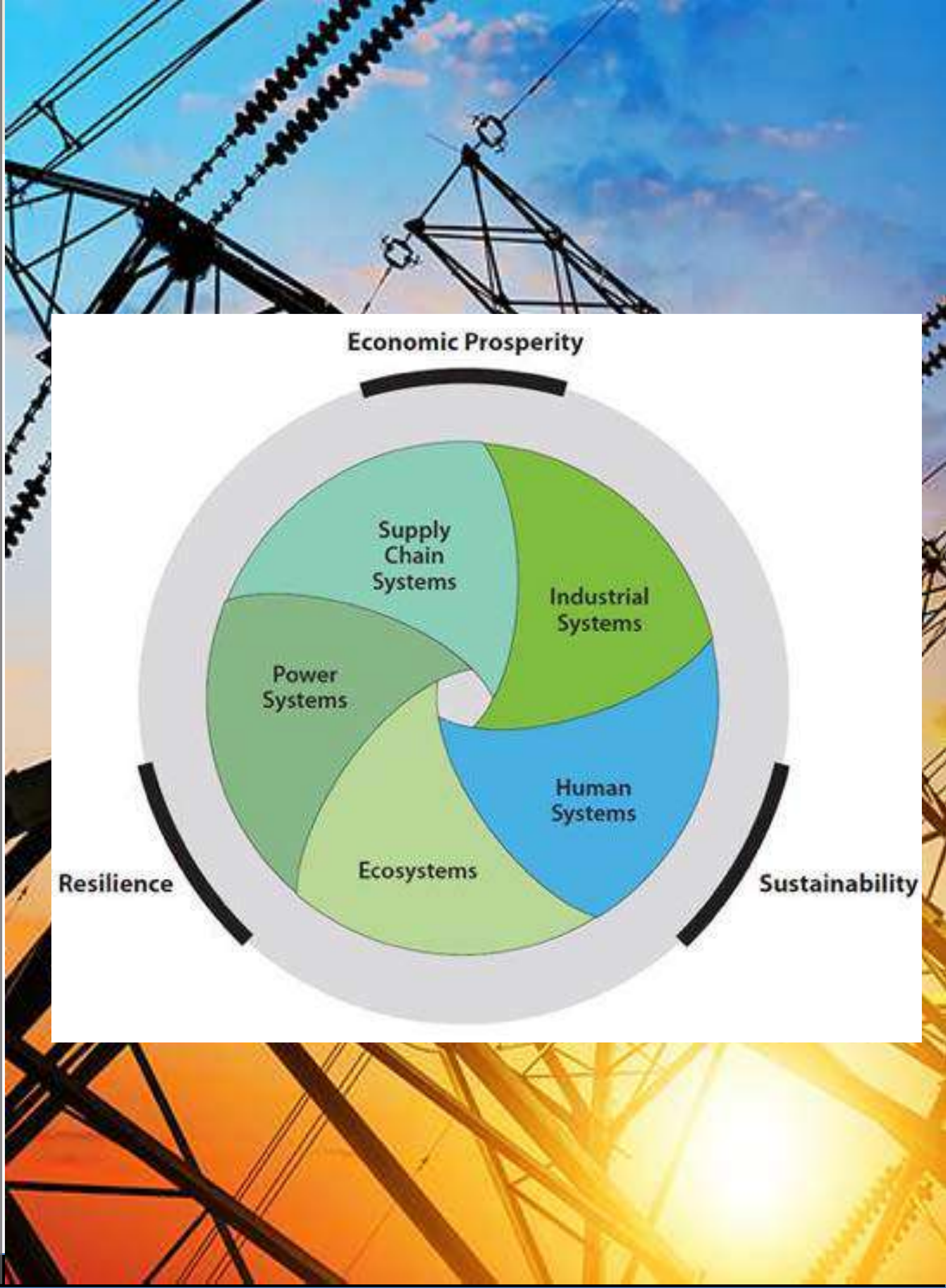
Mission: NREL advances the science and engineering of energy efficiency, sustainable transportation, and renewable power technologies and provides the knowledge to integrate and optimize energy systems.

- 1700 employees + 700 visiting researchers + 80 post-doctoral students + 234 student interns
- 327-acre campus in Golden & 305-acre National Wind Technology Center 13 miles north
- 58 R&D 100 awards and more than 1000 published materials

http://www.nrel.gov/about/

Joint Institute for Strategic Energy Analysis (JISEA)

JISEA's research and analysis connects technologies, economic sectors, and continents to catalyze the transition to the 21st century energy economy.



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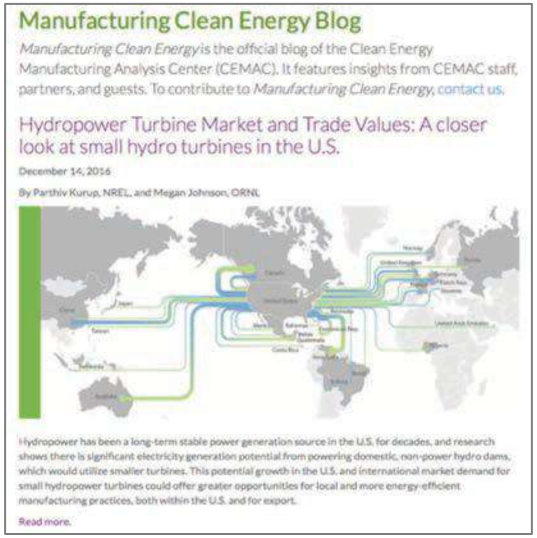
Systems analysis of global manufacturing supply chains for innovation, policy, and market applications

Communication of Results


Manufacturing Clean Energy Blog

Manufacturing Clean Energy is the official blog of the Clean Energy Manufacturing Analysis Center (CEMAC). It features insights from CEMAC staff, partners, and guests. To contribute to *Manufacturing Clean Energy*, contact us.

Hydropower Turbine Market and Trade Values: A closer look at small hydro turbines in the U.S.

December 14, 2016

By Parthiv Kurup, NREL, and Megan Johnson, ORNL

Hydropower has been a long-term stable power generation source in the U.S. for decades, and research shows there is significant electricity generation potential from powering domestic, non-power hydro dams, which would utilize smaller turbines. This potential growth in the U.S. and international market demand for small hydropower turbines could offer greater opportunities for local and more energy-efficient manufacturing practices, both within the U.S. and for export.

Read more.

Advanced Scientific Analysis


The present and future silver cost component in crystalline silicon PV module manufacturing

Michael Redlinger[1], Michael Woodhouse[2] & Roderick G. Eggert[1]

[1]Division of Economics and Business, Colorado School of Mines (CSM), Golden, Colorado; [2]Strategic Energy Analysis Center, National Renewable Energy Laboratory (NREL), Golden, Colorado, USA

ABSTRACT

The purpose of this paper is to determine how increased c-Si PV module production might affect future silver demand and prices, as well as the impacts on total c-Si module manufacturing costs. A bottom-up estimation of the current and potential material intensity (tonnes of silver per GW) for silver in c-Si PV cell fabrication is presented. Partly because of concerns about material intensity, and also because of the changing economics of manufacturing, there is some interest in shifting away from the traditionally higher material intensity approach of screen printing with silver paste to alternative metallization techniques, such as electroplating, which uses substantially less silver. To evaluate how PV's changing demand for silver might affect future silver prices, and the impact in terms of manufacturing costs, some scenarios of silver's contribution to c-Si PV cell manufacturing costs are compiled on the basis of projected changes in demand and price as a result of changes in material intensity. The analysis indicates that an expansion of c-Si production from 55GW/year to 250GW/year results in a 0.05–0.7¢/W increase in manufacturing costs because of higher silver prices. As an illustration of this, the current estimates of the manufacturing costs for the two contrasting methods – silver screen printing and nickel–copper–silver electroplating – are presented.

Reports for Policy and R&D Decision Makers

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Tesla Flips the Switch on the Gigafactory

Batteries are the limiting factor for electric cars, but few automakers have made a similar commitment to produce them, choosing instead to let suppliers like LG Chem and Samsung shoulder the risk. In 2015, 88 percent of the global lithium ion cell manufacturing took place in China, Japan, and South Korea, according to a report by the Clean Energy Manufacturing Analysis Center.

Value Chain for Clean Energy Technologies

Development → Manufacturing → Installation/ Construction → System Integration → Operation & Maintenance

Manufacturing Supply Chain Links

Raw Materials	Processed Materials	Sub-Components	Clean Energy Technology End Product
Silica, Silver	**Polysilicon,** Silver Paste, Glass	**C-Si PV Wafer, C-Si PV Cell,** Frame, Encapsulant	**C-Si Solar PV Module**
Iron, Neodymium, or Dysprosium Ores	**Steel,** Fiberglass, Carbon Fiber, Neodymium and Dysprosium Alloys	Permanent Magnets, **Generators,** Gear Assemblies, Steel Components	**Wind Turbine Components: Blades, Tower, Nacelle**
Lithium, Cobalt, Nickel, Graphite Ores	**Cathode Materials, Anode Materials, Electrolytes**	**Separators,** Housings, Metal Foils, Tabs	**Light Duty Vehicle Li-ion Battery Cell**
Gallium, Indium, Yttrium Ores	**Sapphire Substrates,** Trimethyl Gallium (TMG), Trimethylindium (TMI), YAG Phosphors	**LED Chips**	**LED Package**

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Outline

- Energy Markets
- Clean Energy Technologies and Their Manufacturing
  - Wind Turbines
  - Solar Photovoltaics
  - Lithium ion Batteries
- Discussion and Questions

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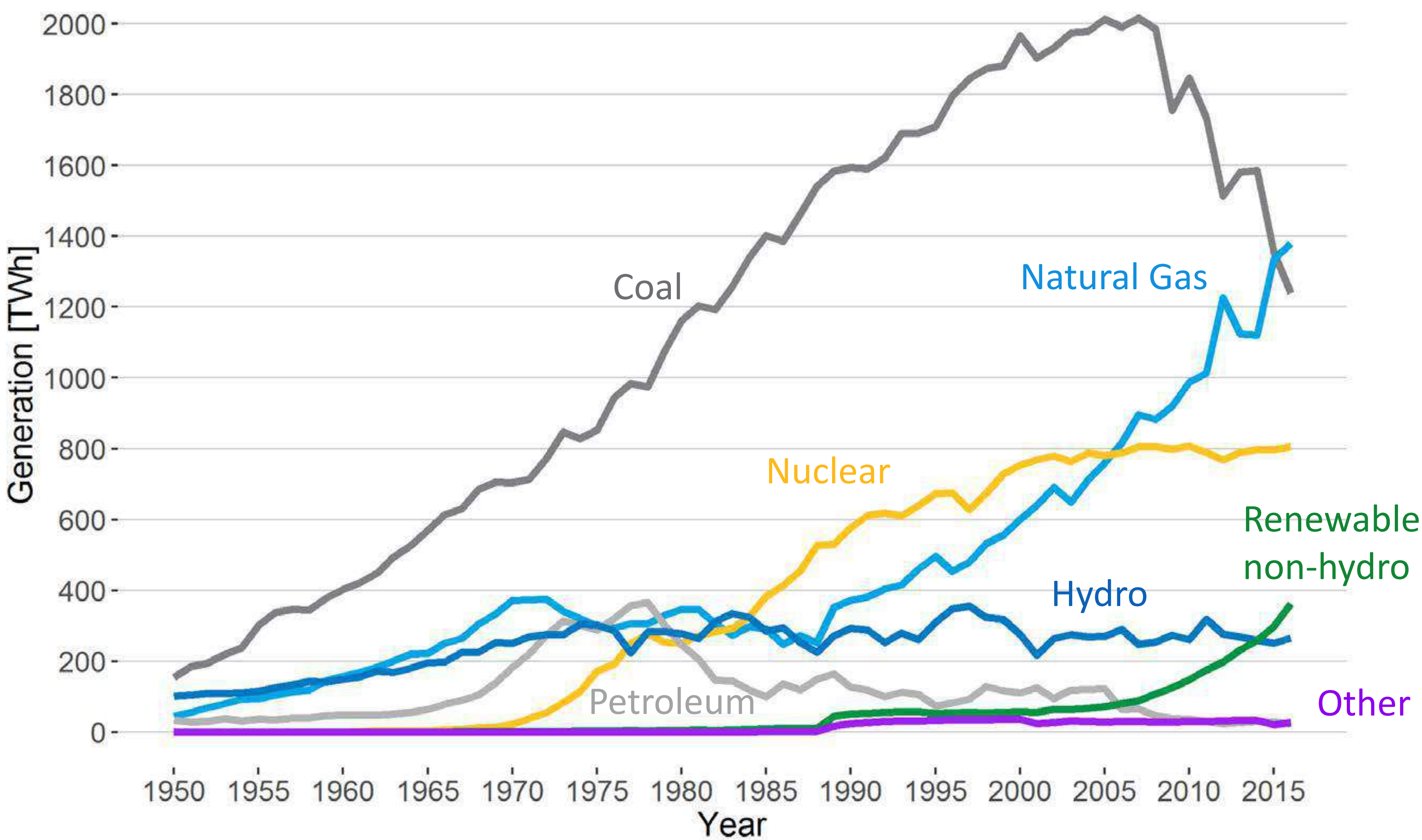
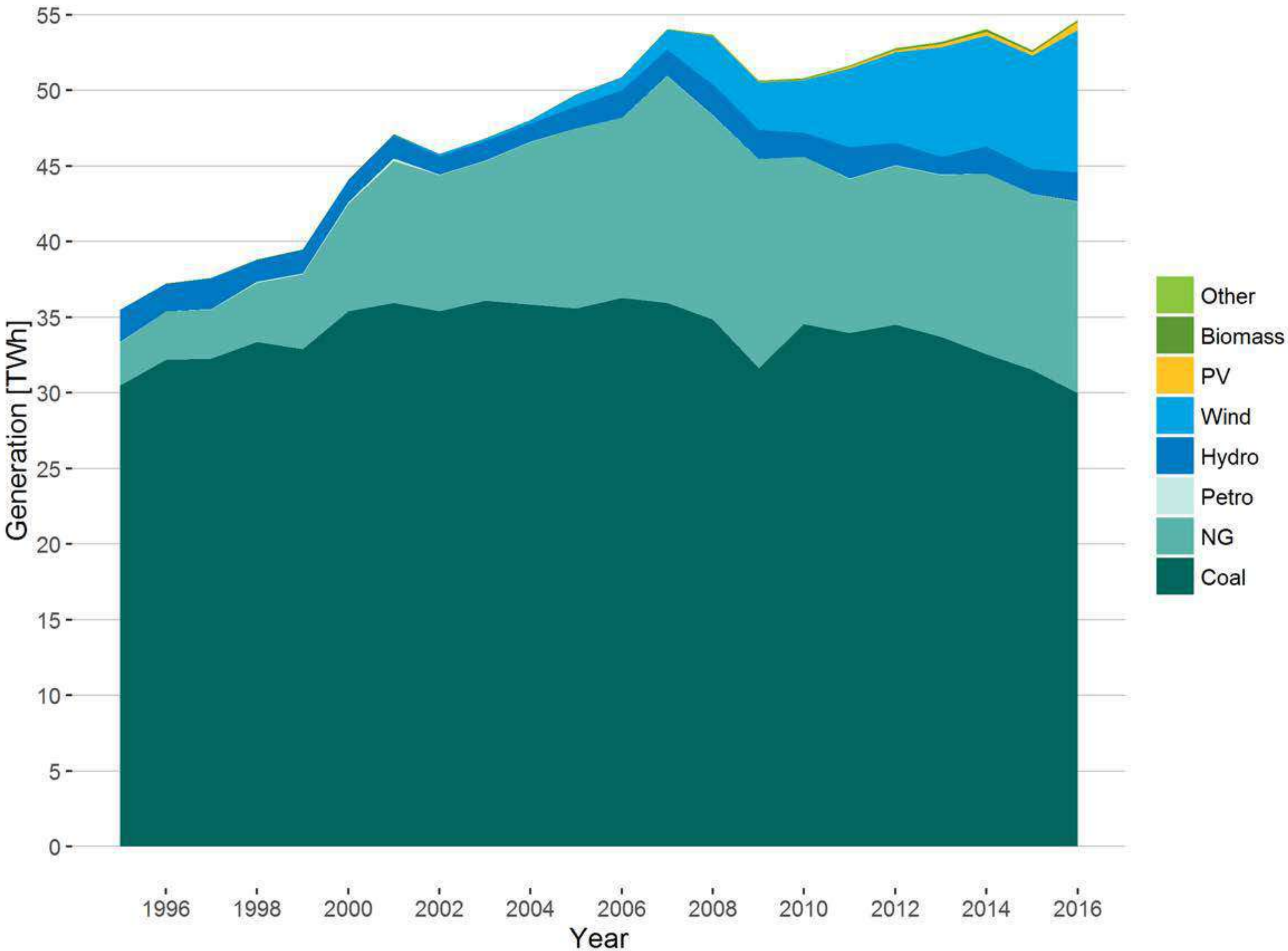
U.S. Electricity Generation Shares & Trend (1950-2016)



The U.S. Power Sector Is Undergoing Profound Transformation
Significant shift from coal to natural gas power generation

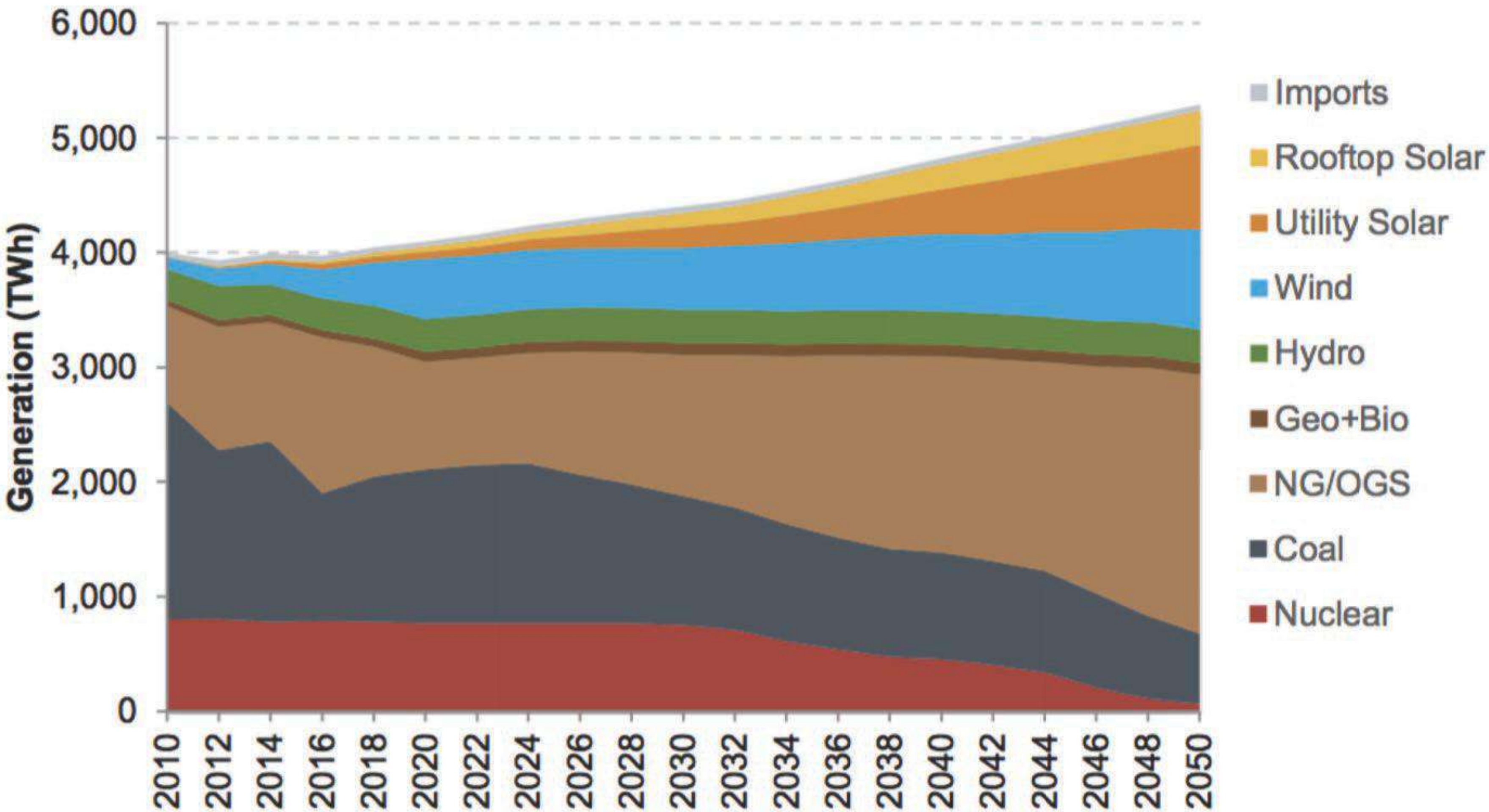
Source: EIA Electric Power Monthly and EIA Form 860. Note: 2016 data is a 12-monthly rolling average with data through June 2016.

Trends in the Colorado Power System



Source: EIA-923; Steinberg 2016 – Colorado and the Clean Power Plan, Presentation to the CDPHE

NREL Electricity Scenario Mid-case Generation Mix

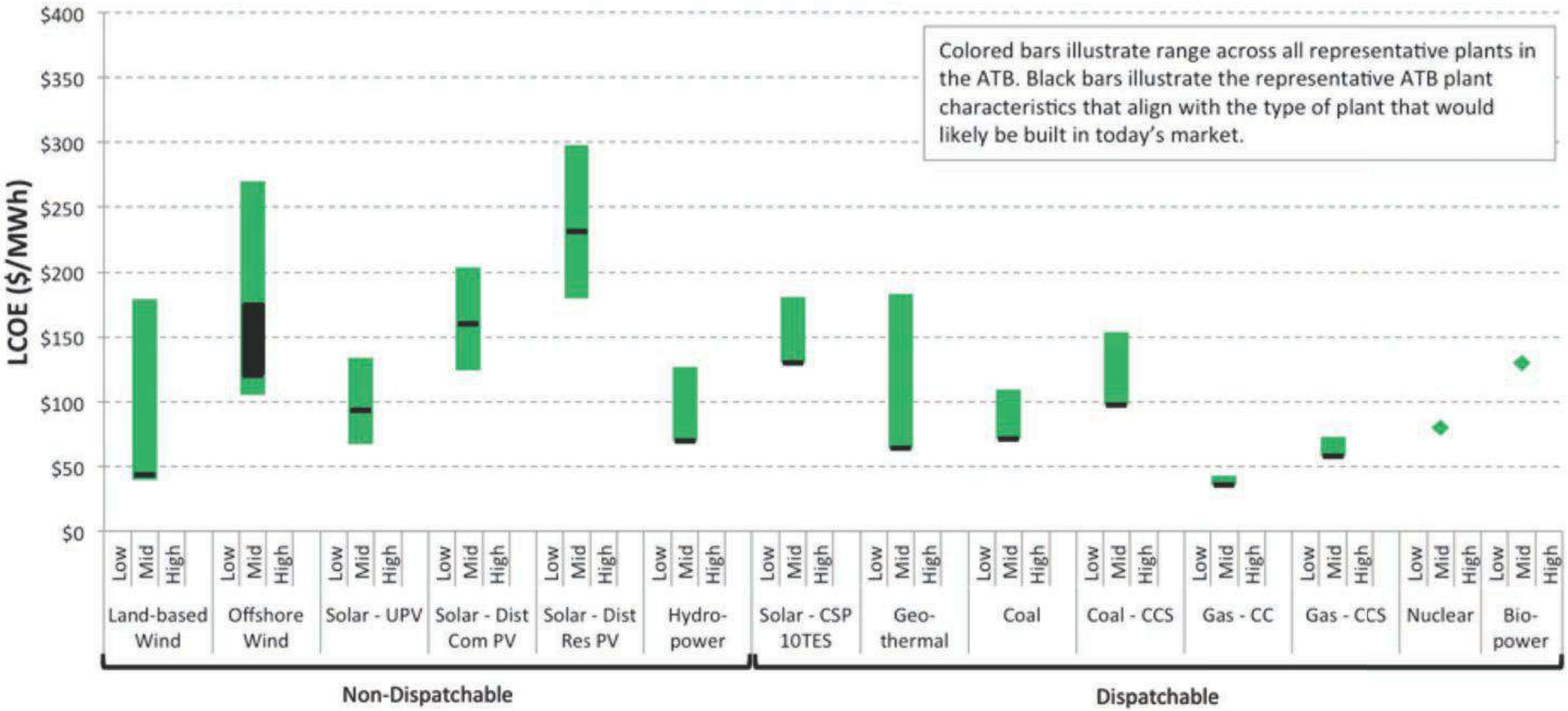


Projected generation is dominated by natural gas, wind and solar
http://www.nrel.gov/analysis/data_tech_baseline.html

Generation by technology type in the Central Scenario, from: NREL 2016 Standard Scenarios Report: A U.S. Electricity Sector Outlook

Current Cost of Renewable & Traditional Electricity

Levelized Cost of Electricity ranges by technology. Values are in 2015$.

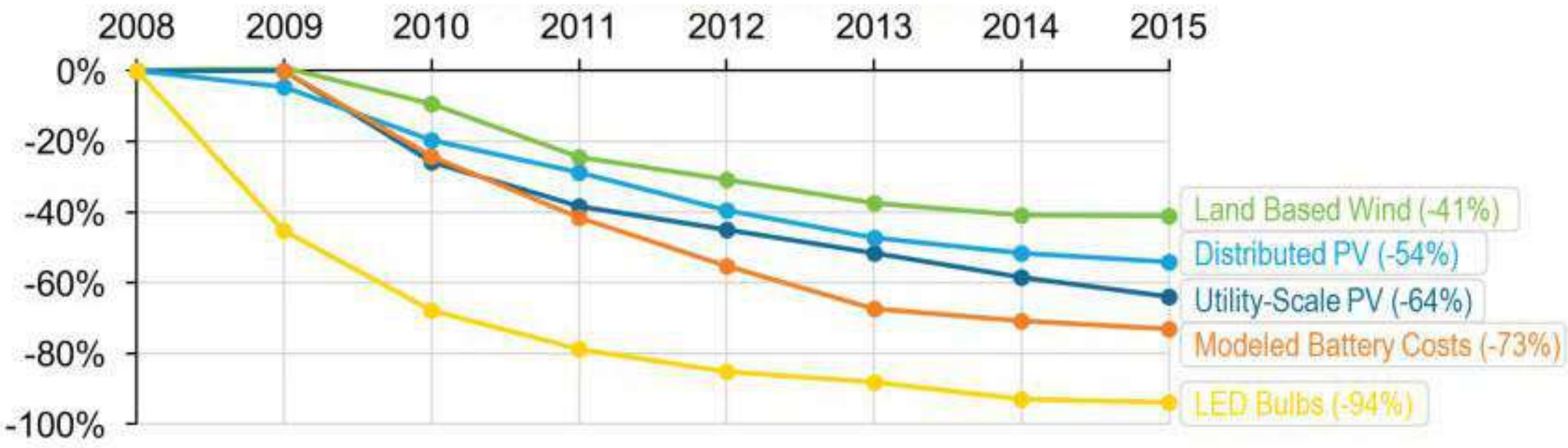


2017 ATB LCOE range by technology for 2015 based on current market conditions
Source: National Renewable Energy Laboratory Annual Technology Baseline (2017), http://atb.nrel.gov

Variability due to: Technology; Location; Time (Present v. Future)

Costs for Renewable Technologies are Falling

Renewable Energy Technology % Cost Reductions since 2008



Source: DOE, Revolution Now, 2016

Advanced energy technologies are providing real-world solutions

- They drive a domestic energy economy and are increasingly cost-competitive
- Energy manufacturing and installations provide major opportunities for economic development

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Wind Turbines - Onshore

Peetz Table Wind Energy Center
- Peetz, Colorado
- 575 MW

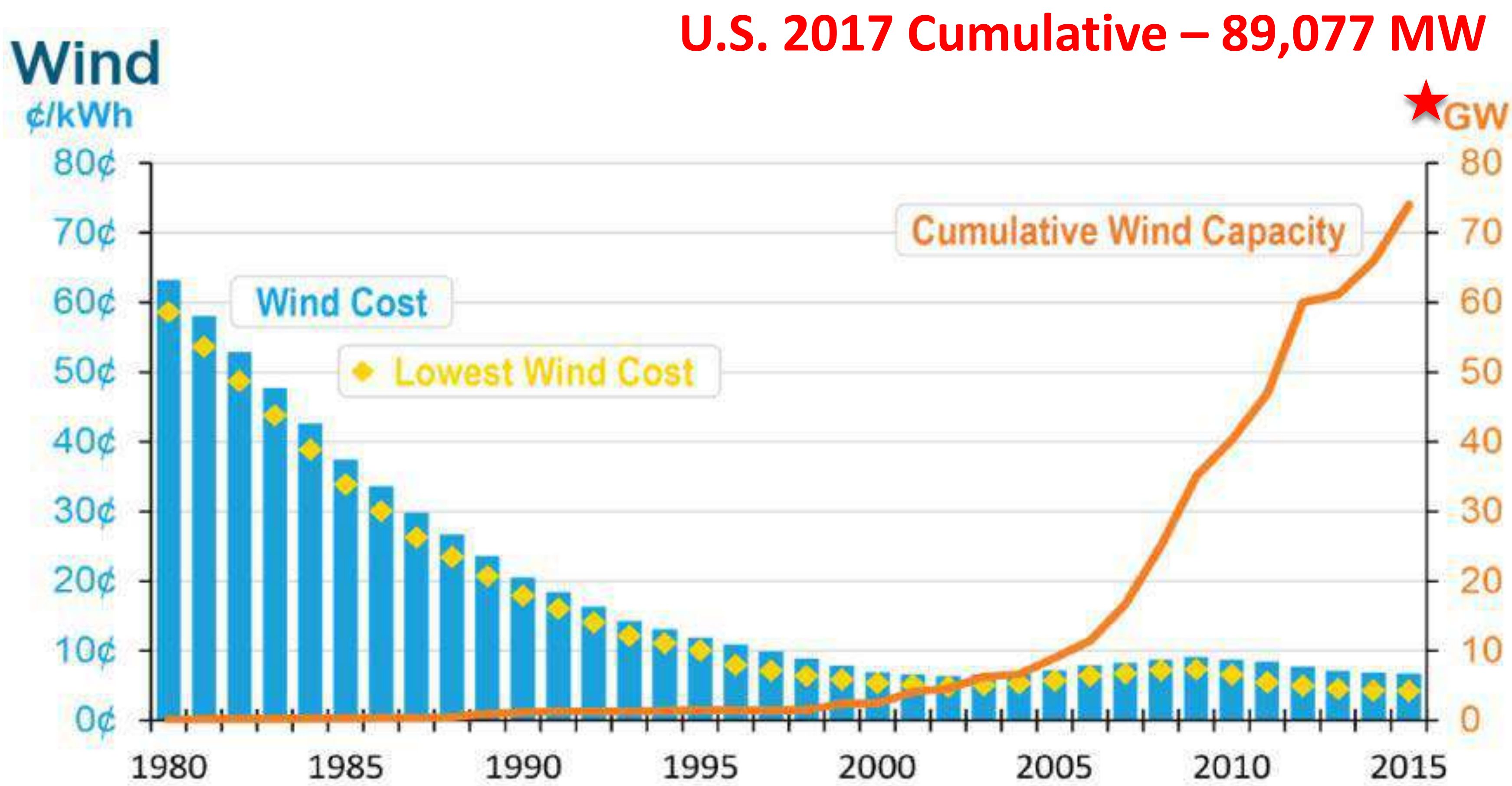
Cedar Creek Wind Farm
- Grover, Colorado
- 550 MW

Wind Turbines – Offshore

Westermeerwind Wind Farm
- Noordoostpolder, Netherlands
- 144 MW

Horn Rev Wind Farm
- West coast of Denmark
- 160 MW

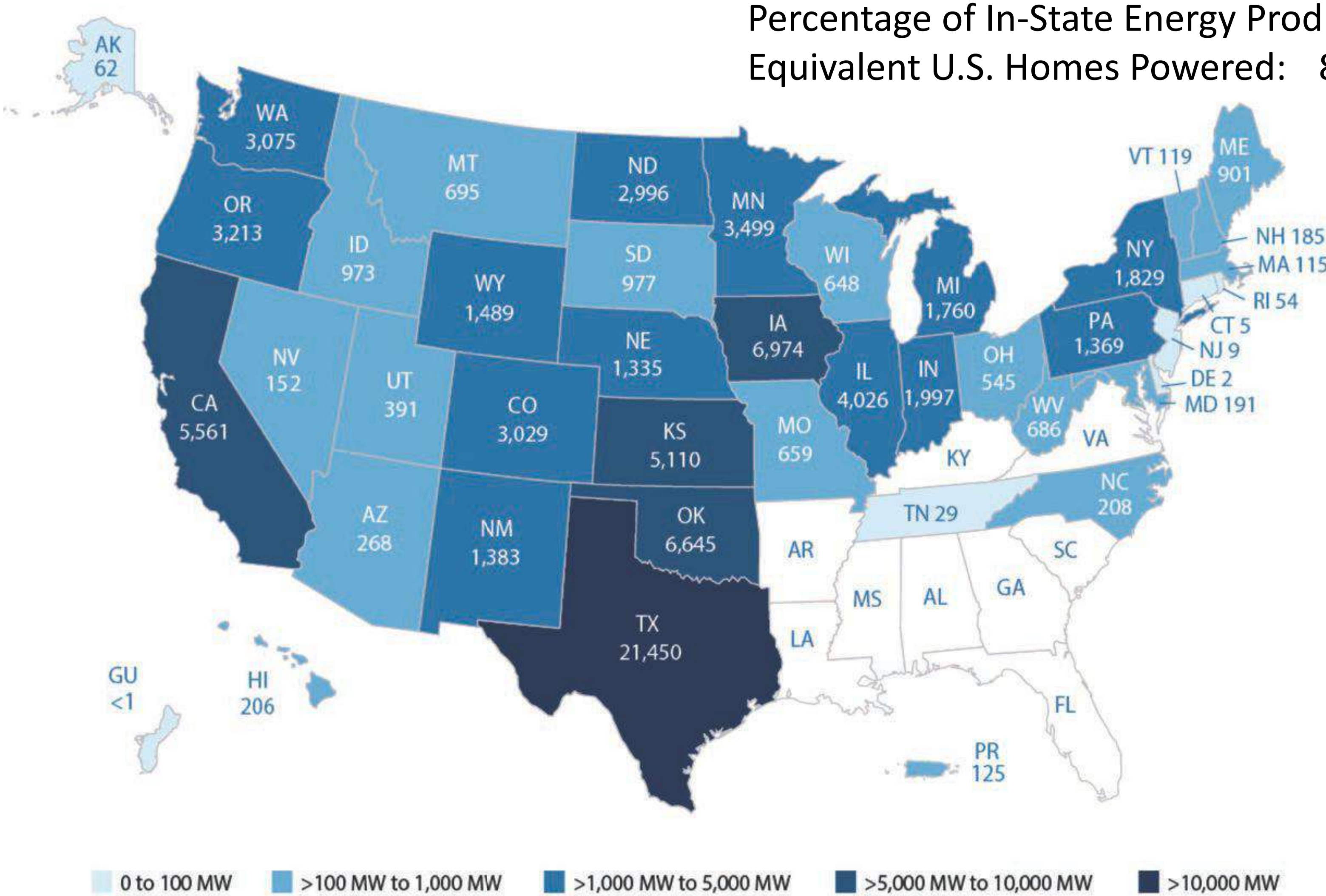
Wind Market Growth Driven by Price Declines



Source: DOE 2016: Revolution…now, the future arrives for five clean energy technologies; AWEA, https://www.awea.org.

U.S. & Colorado Wind Market (installed capacity, MW)

Colorado (2017): Rank – 9
Installed: 3104 MW (1,949 turbines)
Percentage of In-State Energy Production: 17.3%
Equivalent U.S. Homes Powered: 871,000



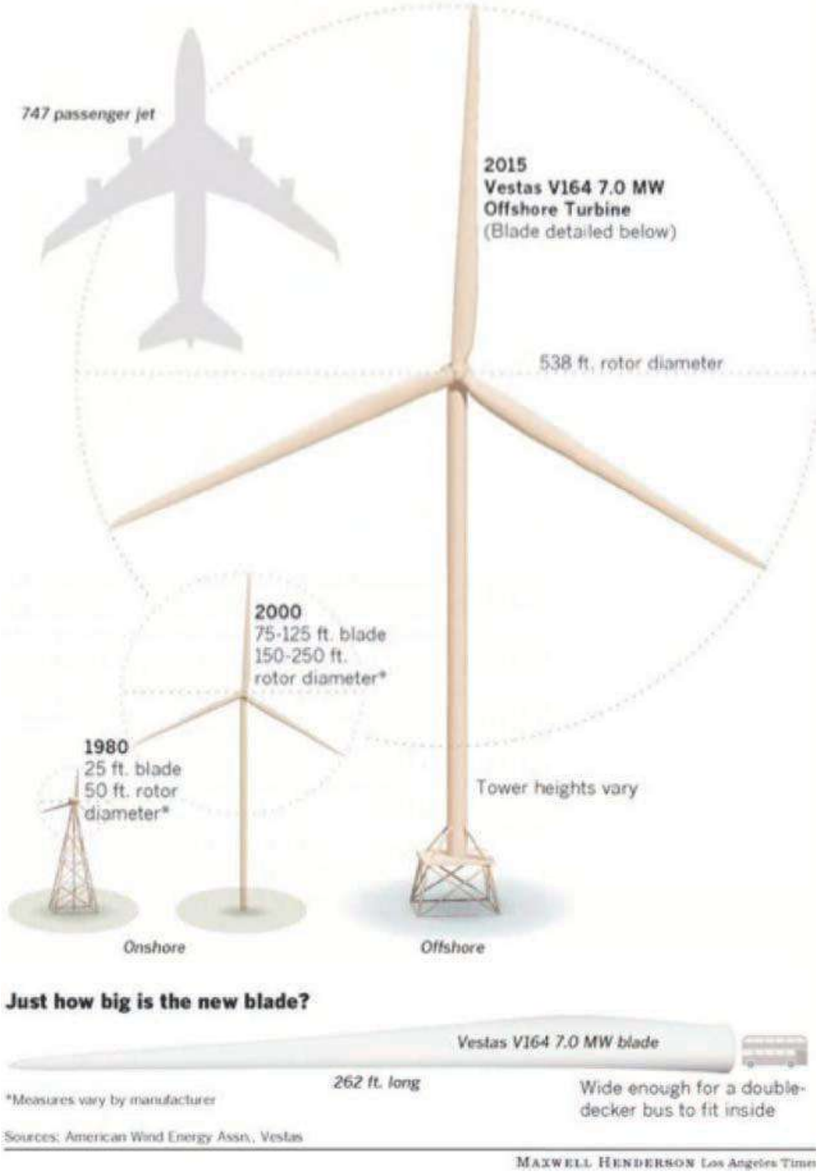
Source: American Wind Energy Association, https://www.awea.org/wind-energy-facts-at-a-glance/

Wind Machines – Scale, Capacity Factor Increasing, Manufacturing Costs Declining

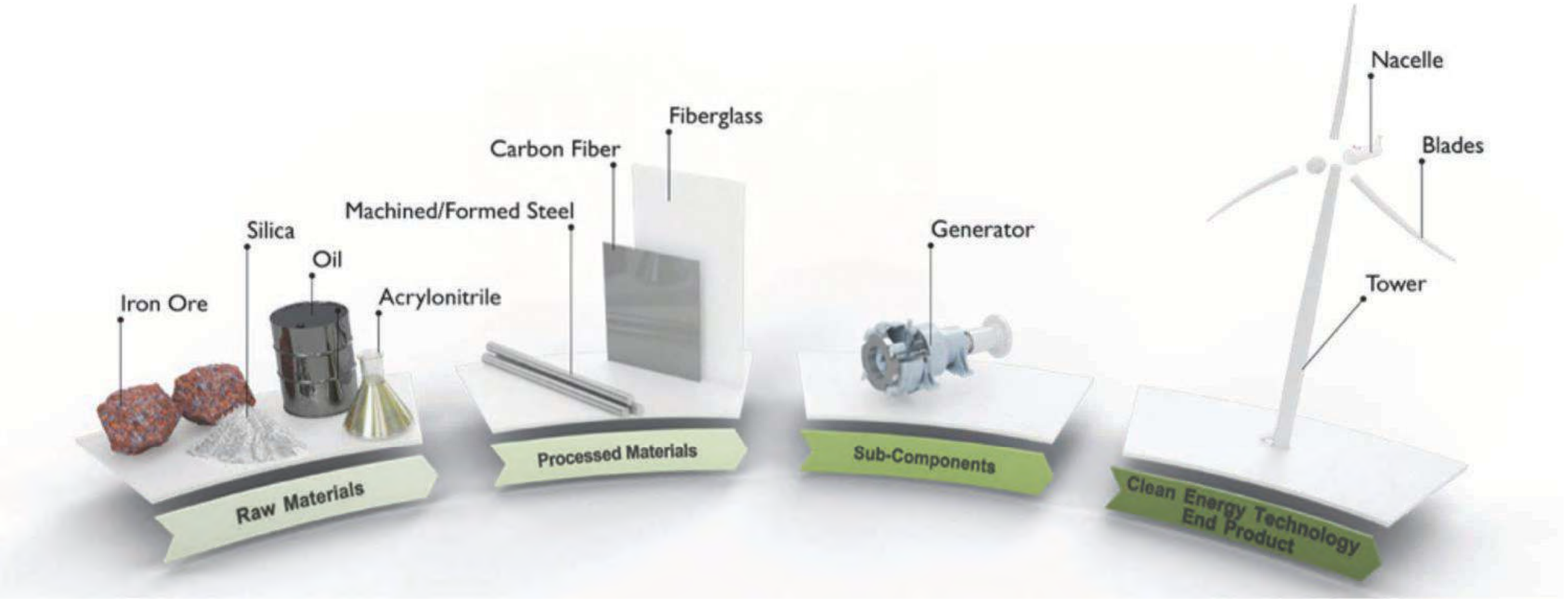
Avg. Wind Turbine Capacity Factors by Build Year

1998-2001: 24.5%
2004-2011: 32.1%
2014-2015: 42.6%

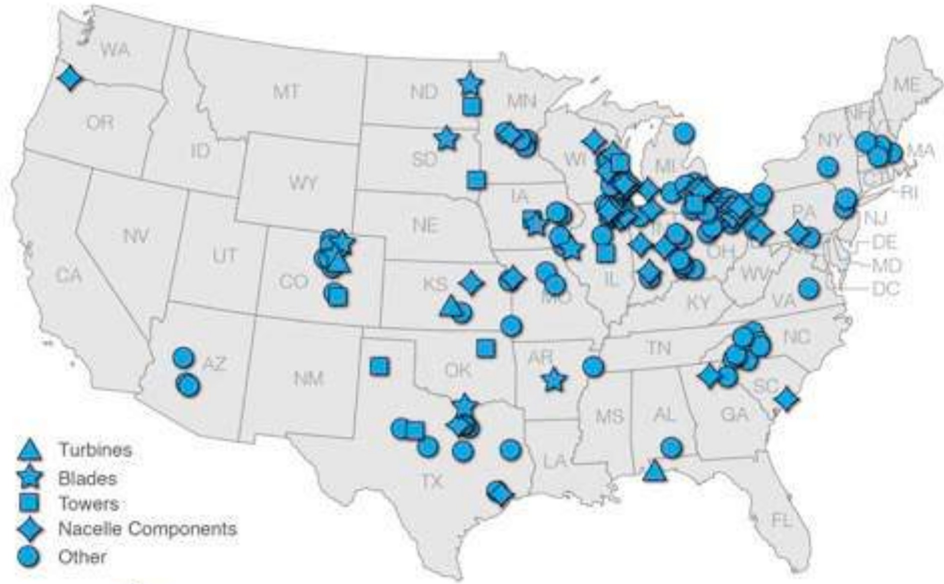
Compare: Natural Gas Plant: 56%; Coal Fired Plant: 53%; Nuclear: 92%; Solar Photovoltaic: 27%



Supply chain of wind turbines



Wind Power: A Manufacturing Success Story



More than 145 major wind turbine manufacturing and assembly facilities operate in the U.S. with more than 500 manufacturing facilities total contributing.

Over 15 facilities in Colorado.

U.S. leading wind turbine manufacturing

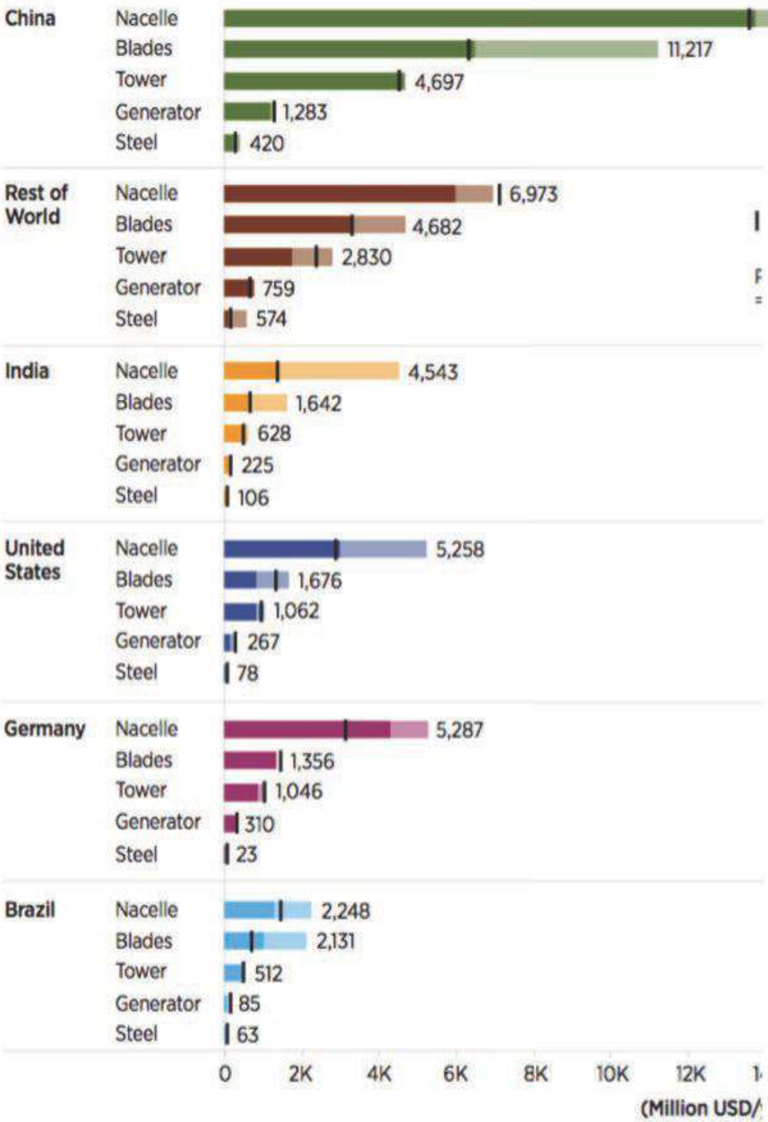
- One of the top three countries for wind turbine manufacturing
- U.S.-made turbines installed domestically & exported to Canada, Brazil, and Mexico
- $3.76 billion value added to U.S. economy in 2014
- Domestic content is 80%–85% for towers, 50%–70% for blades/hubs, & >85% for nacelles

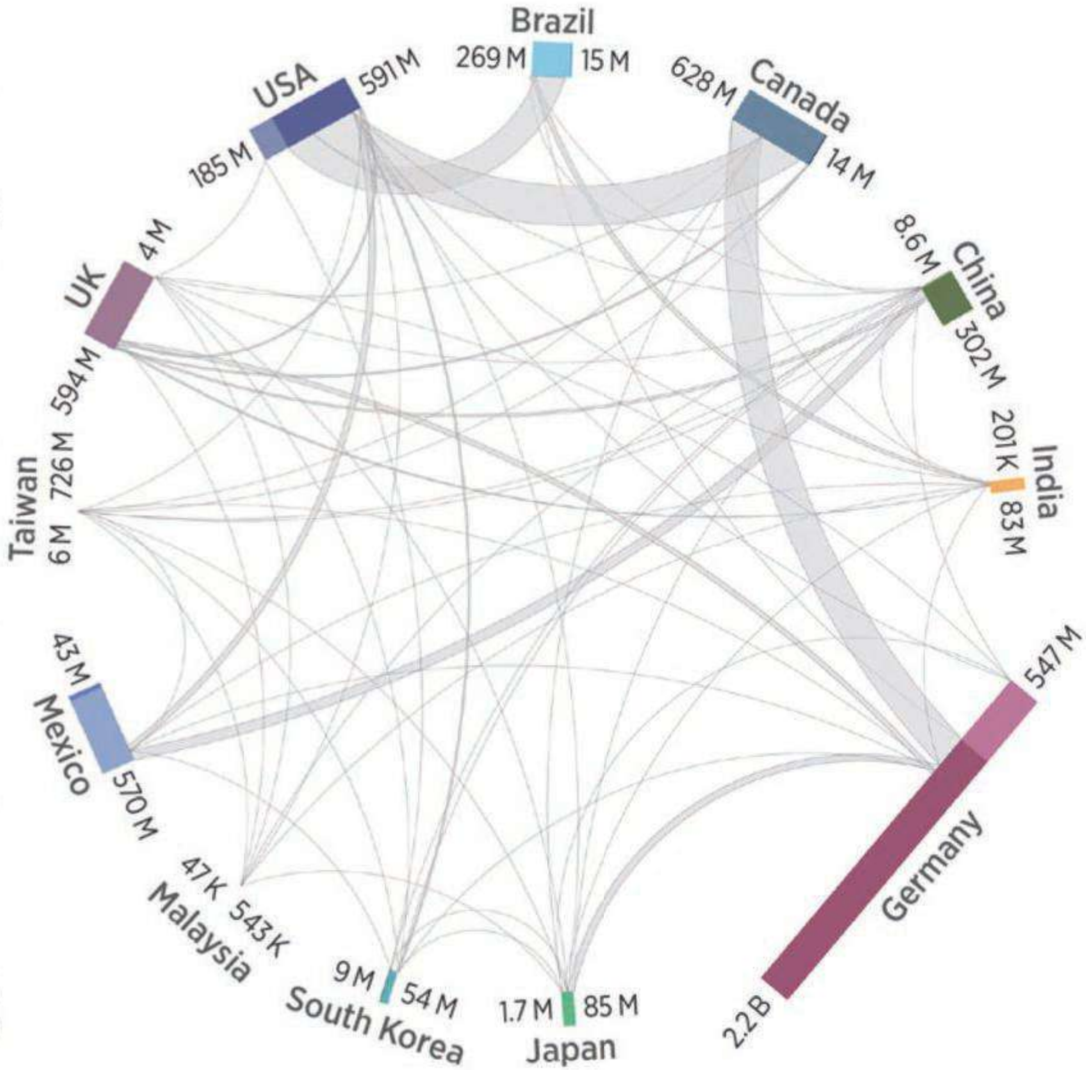
Leadership came from public & private support

- Technology validated and improved through NREL research and industry partnerships
- Early government policies encouraged deployment
- Market growth enabled establishment of supply chains and manufacturing at scale
- Resulting price declines enabled more growth
- Trade agreements enabled $560 million in exports in 2014
- New innovations still being developed at NREL

Sources: Benchmarks of Global Clean Energy Manufacturing, CEMAC, 2017; Wind Turbines Made in the USA, CEMAC Blog, 2017.

Manufacturing, domestic demand, and balance of trade in wind generator sets (2014 data)





Source: Benchmarks of Global Clean Energy Manufacturing, CEMAC, 2017.

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Solar PV Markets – Residential

1-10 kW scale
Grid connected or off-grid

Solar PV Markets – Commercial

IKEA
1 MW
Atlanta GA
(also Centennial CO)

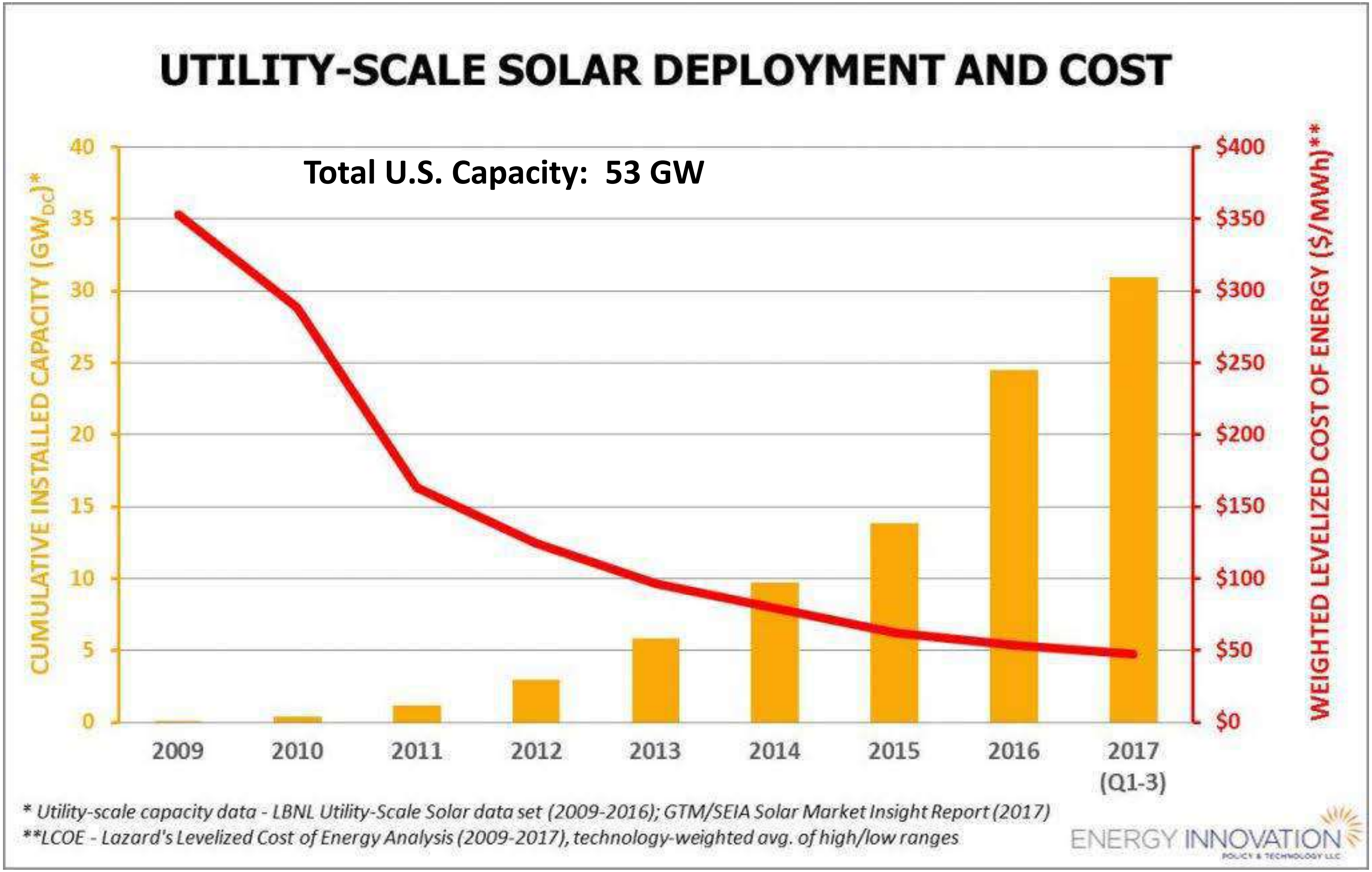
Apple Park
17 MW
Cupertino CA

Solar PV Markets – Utility

Solar Star (California)
- BHE Renewables
- 1.7 million SunPower c-Si panels
- 579 MW
- Power for 255,000 homes
- 5.0 square miles

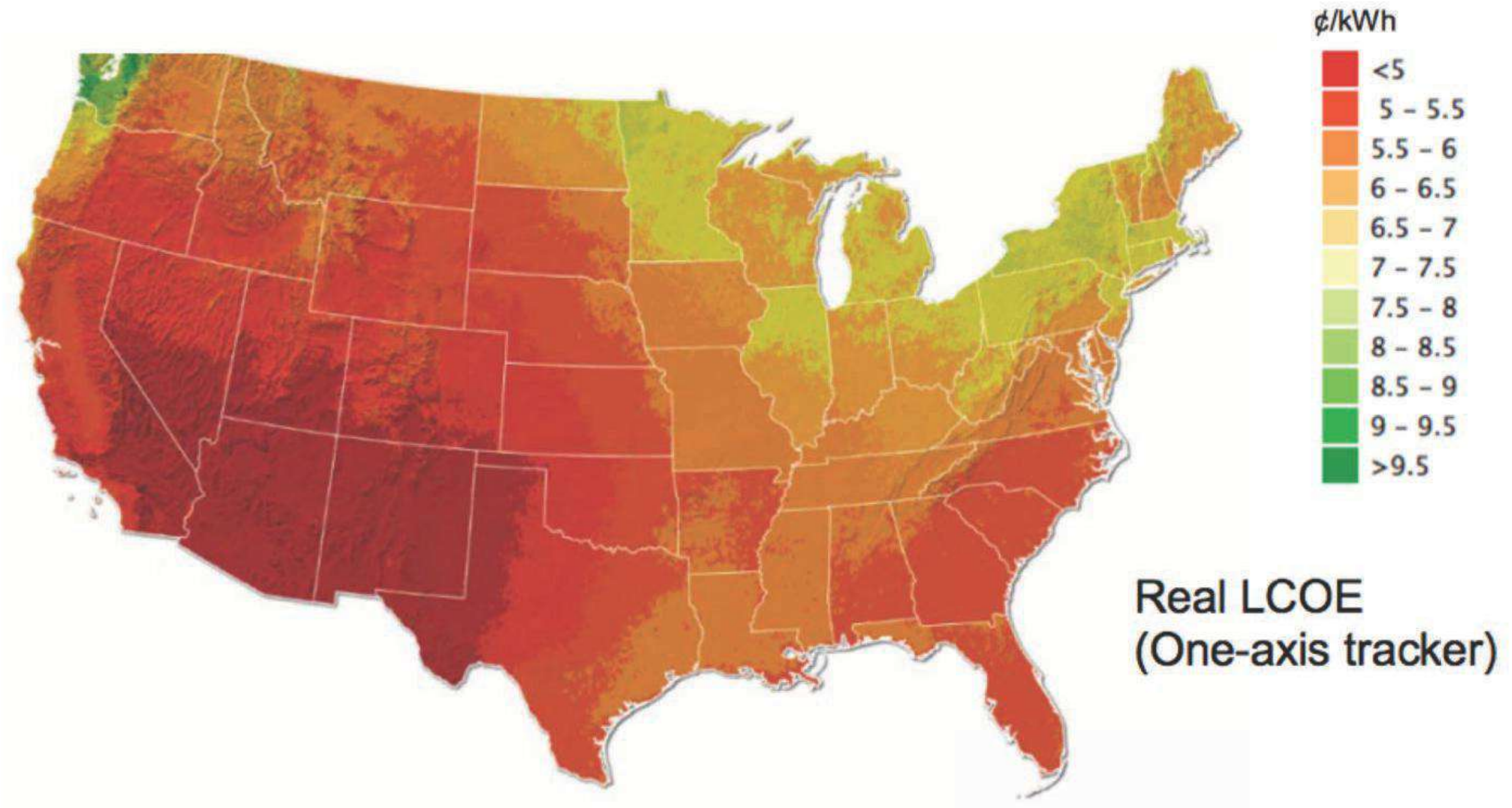
Comanche Solar (Colorado)
- Novatus (PPA with Xcel)
- Trina c-Si panels
- 120 MW
- Power for 31,000 homes

Trends in PV Power



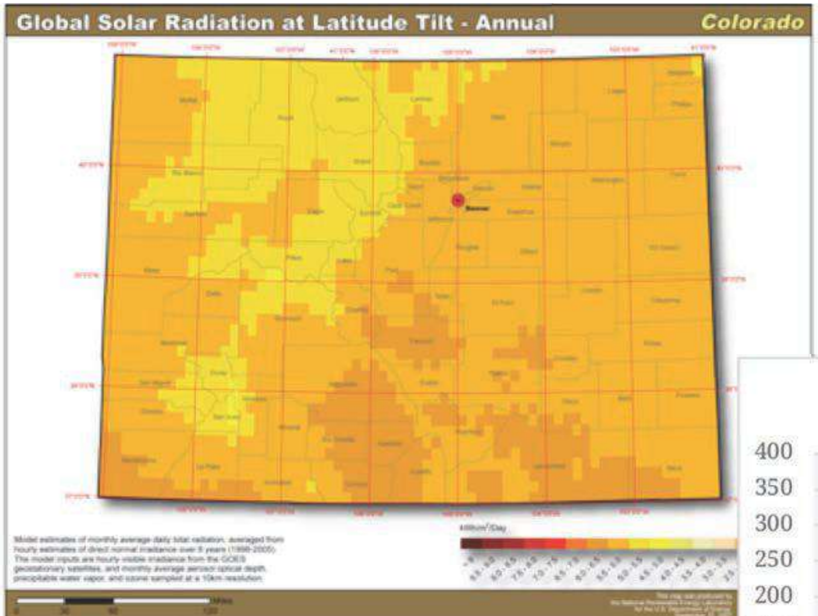
Source: Energy Innovation, http://energyinnovation.org/

Cost of Solar Energy Depends on Location

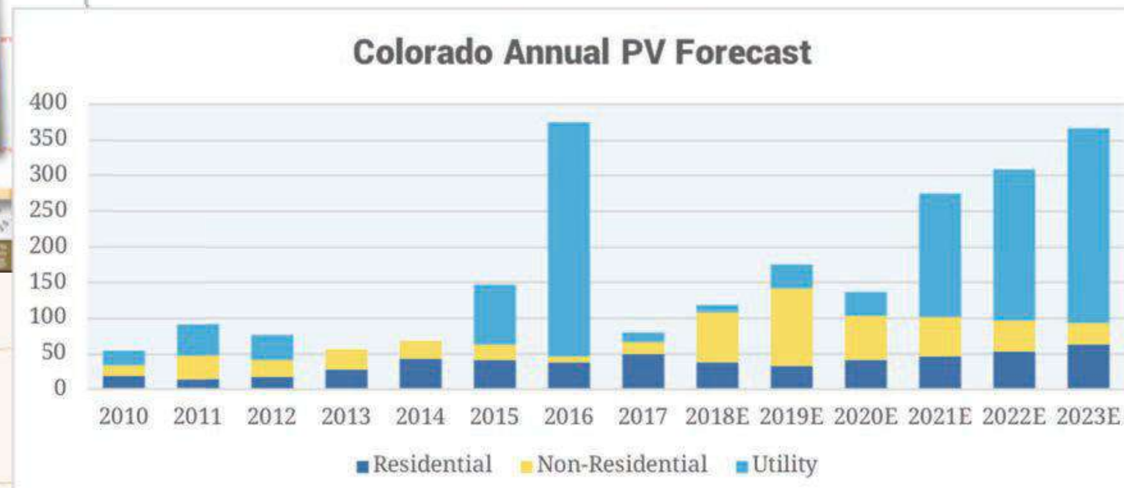


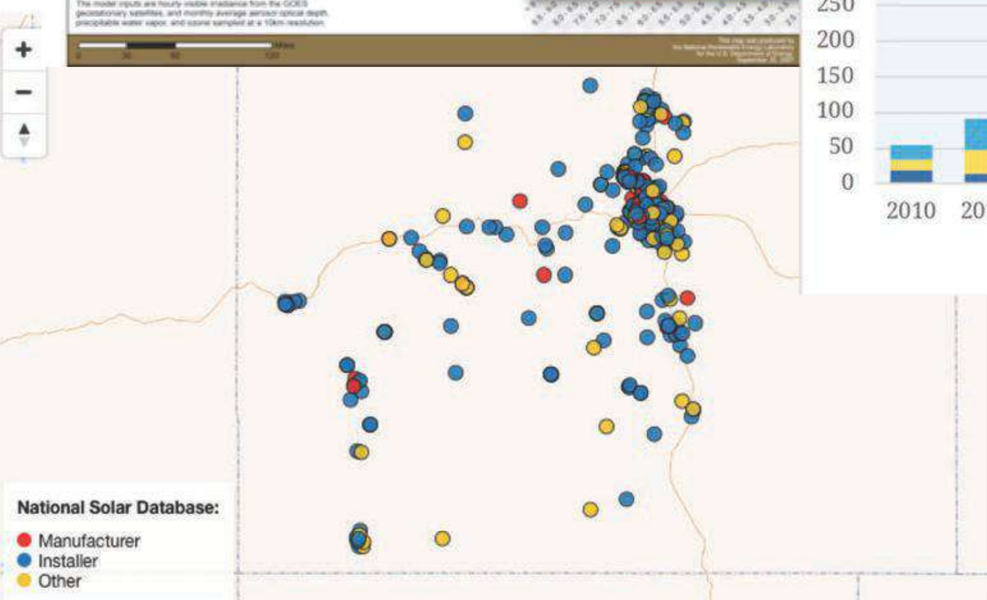
Source: U.S. Solar Photovoltaic System Cost Benchmark: Q1 2016

Colorado Solar Development



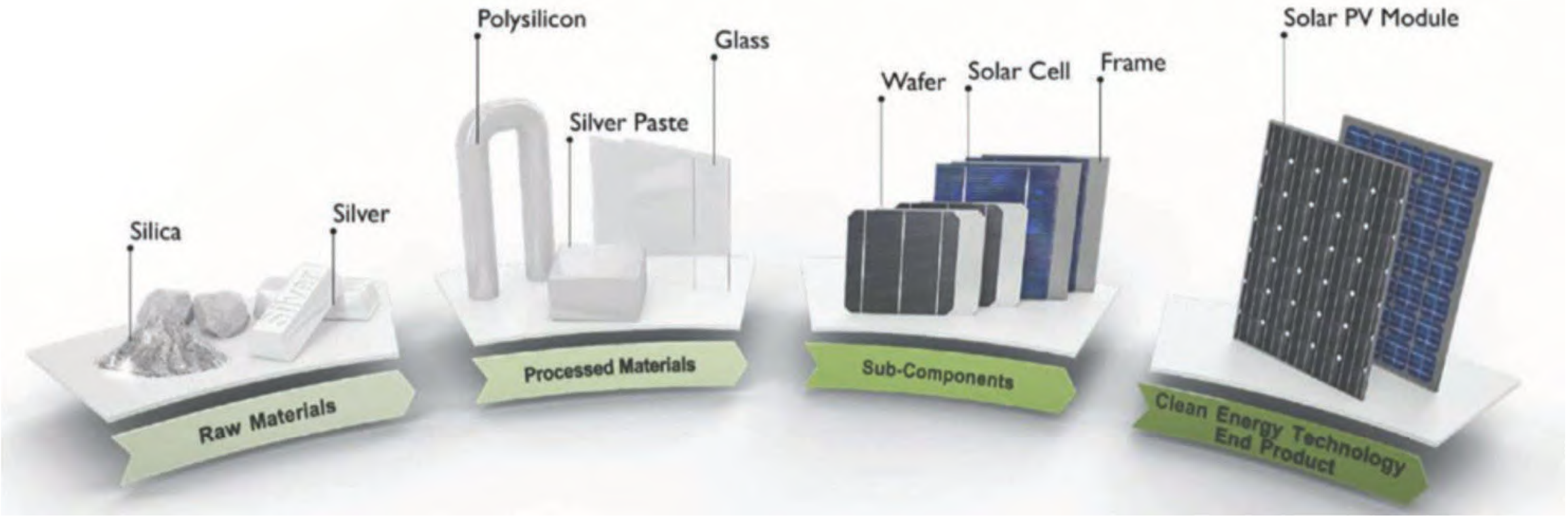
Colorado Rank – 12
Installed: 997 MW
Percentage of In-State Energy Production: 2.67%
Equivalent U.S. Homes Powered: 200,180



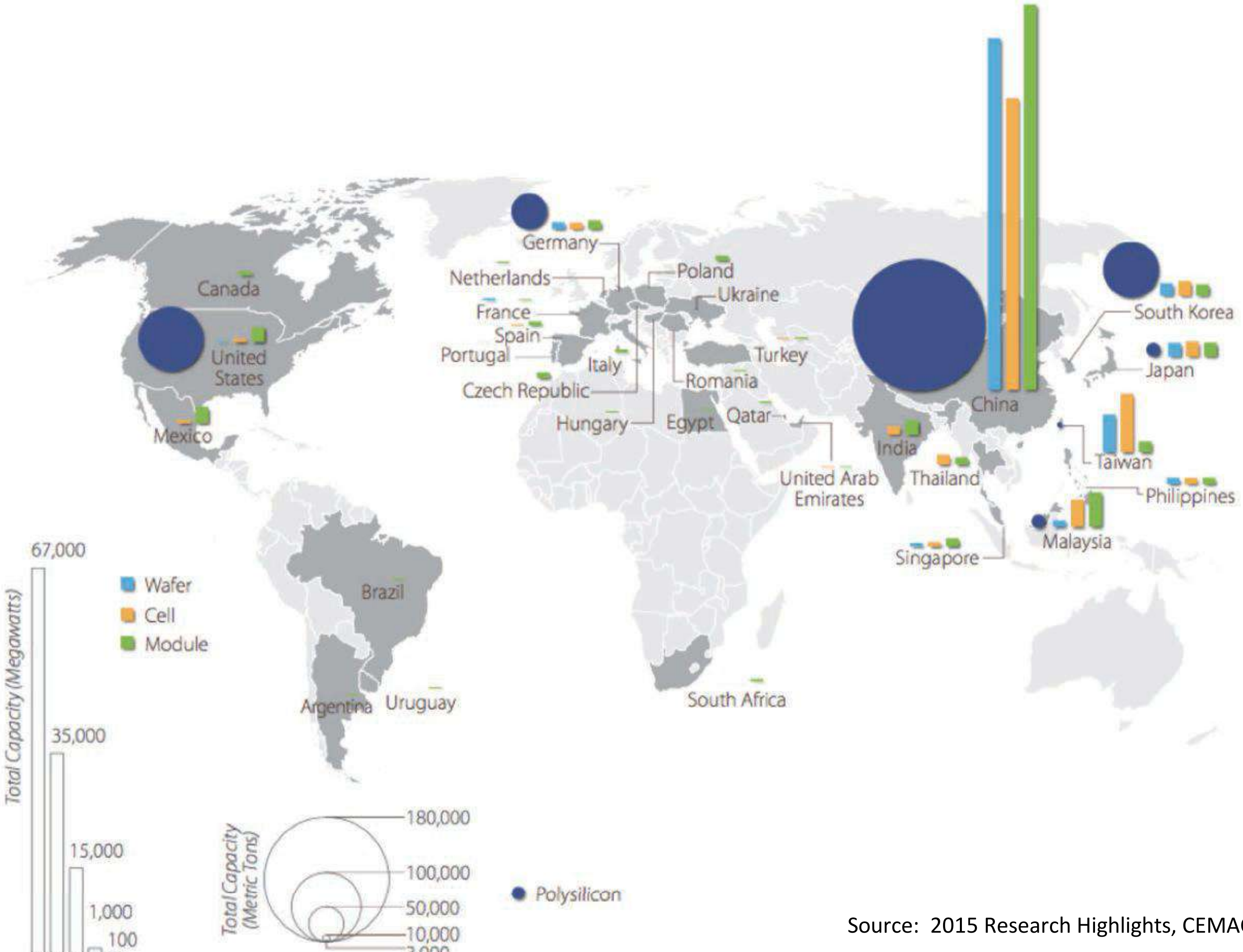


Sources: NREL and SEIA

Supply chain of PV panels

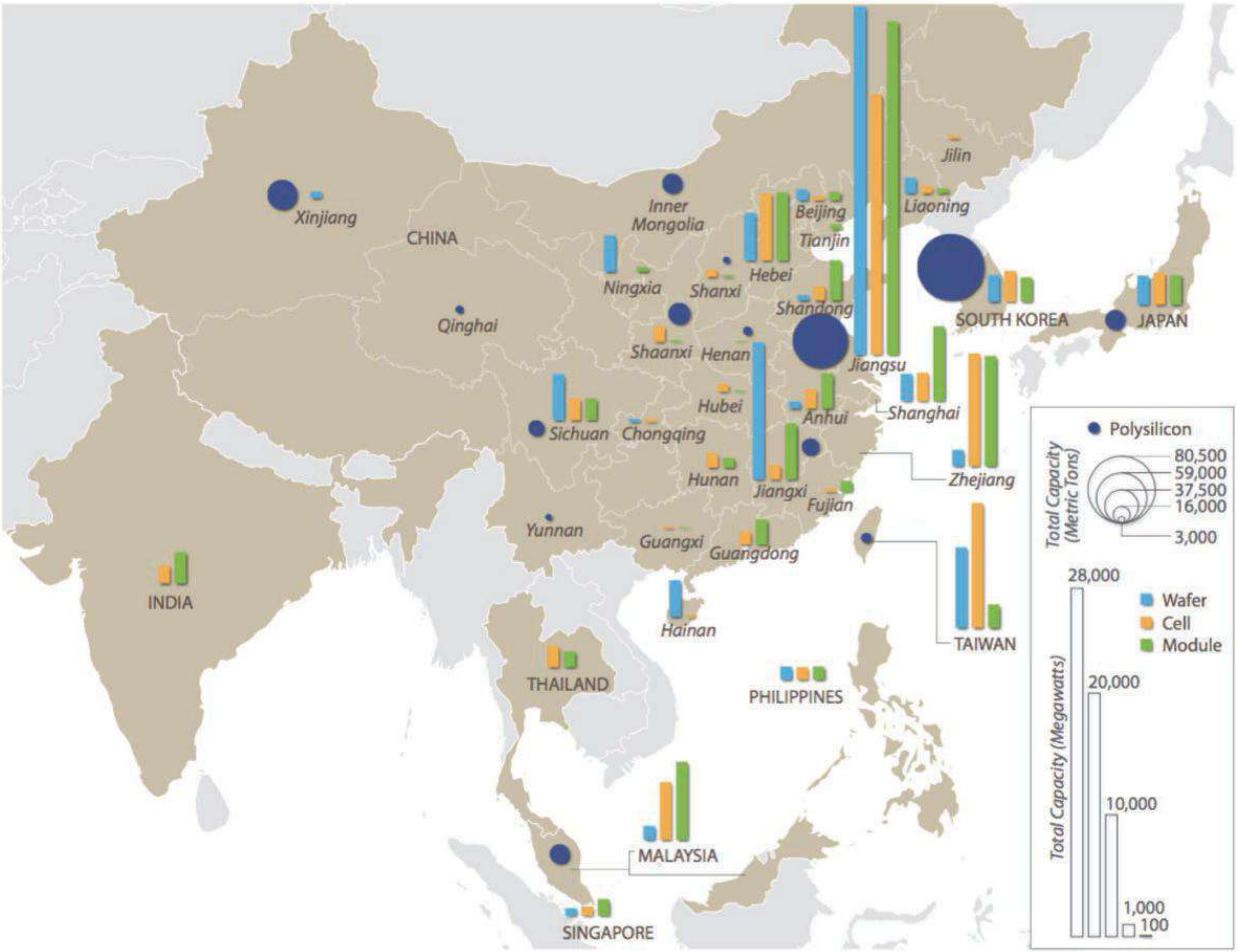


Global Solar PV Component Manufacturing (2015)



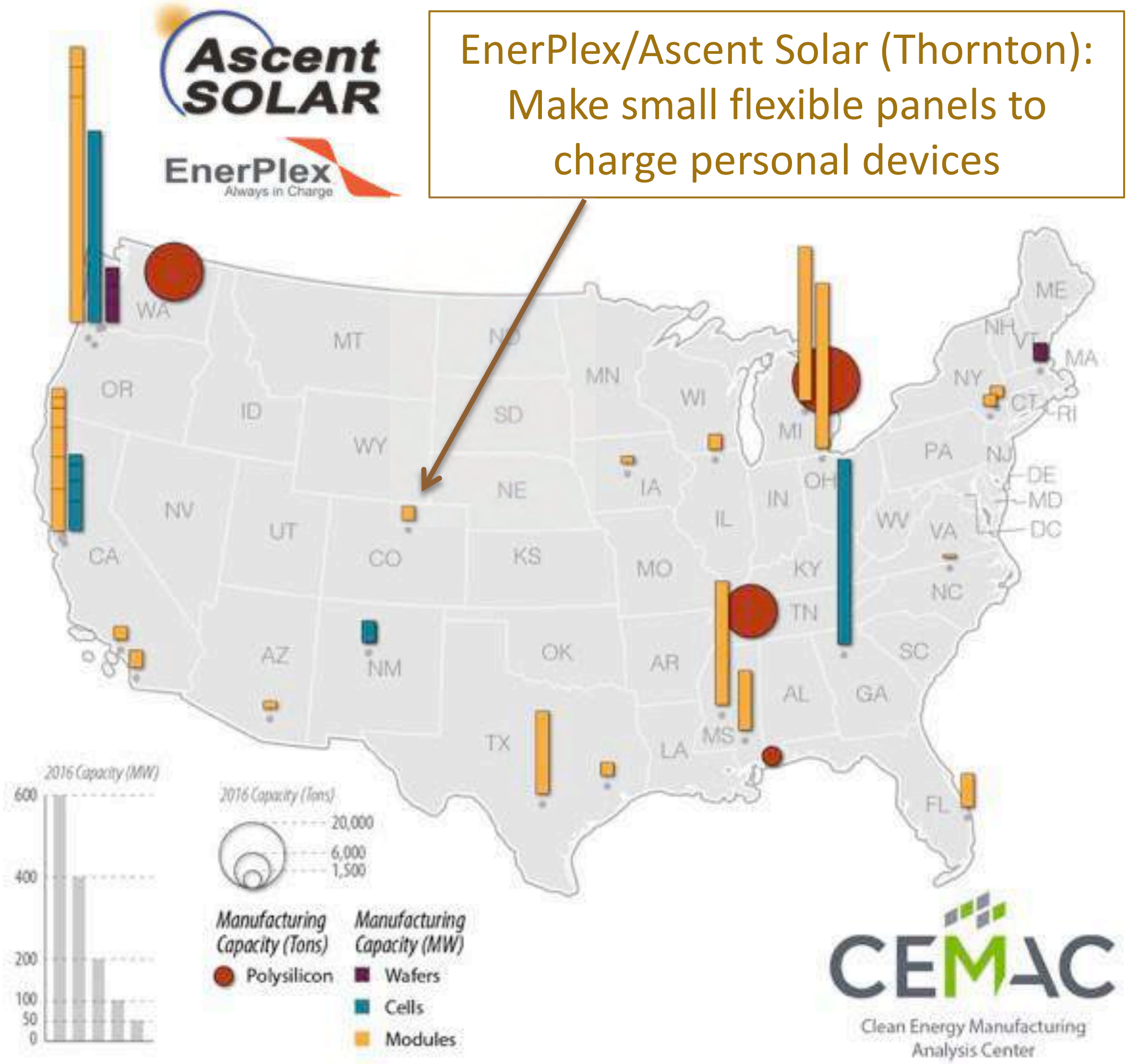
Source: 2015 Research Highlights, CEMAC, 2016.

Asia Solar PV Component Manufacturing (2015)



Source: 2015 Research Highlights, CEMAC, 2016.

Solar PV Manufacturing in the U.S.



Solar energy growing in U.S.

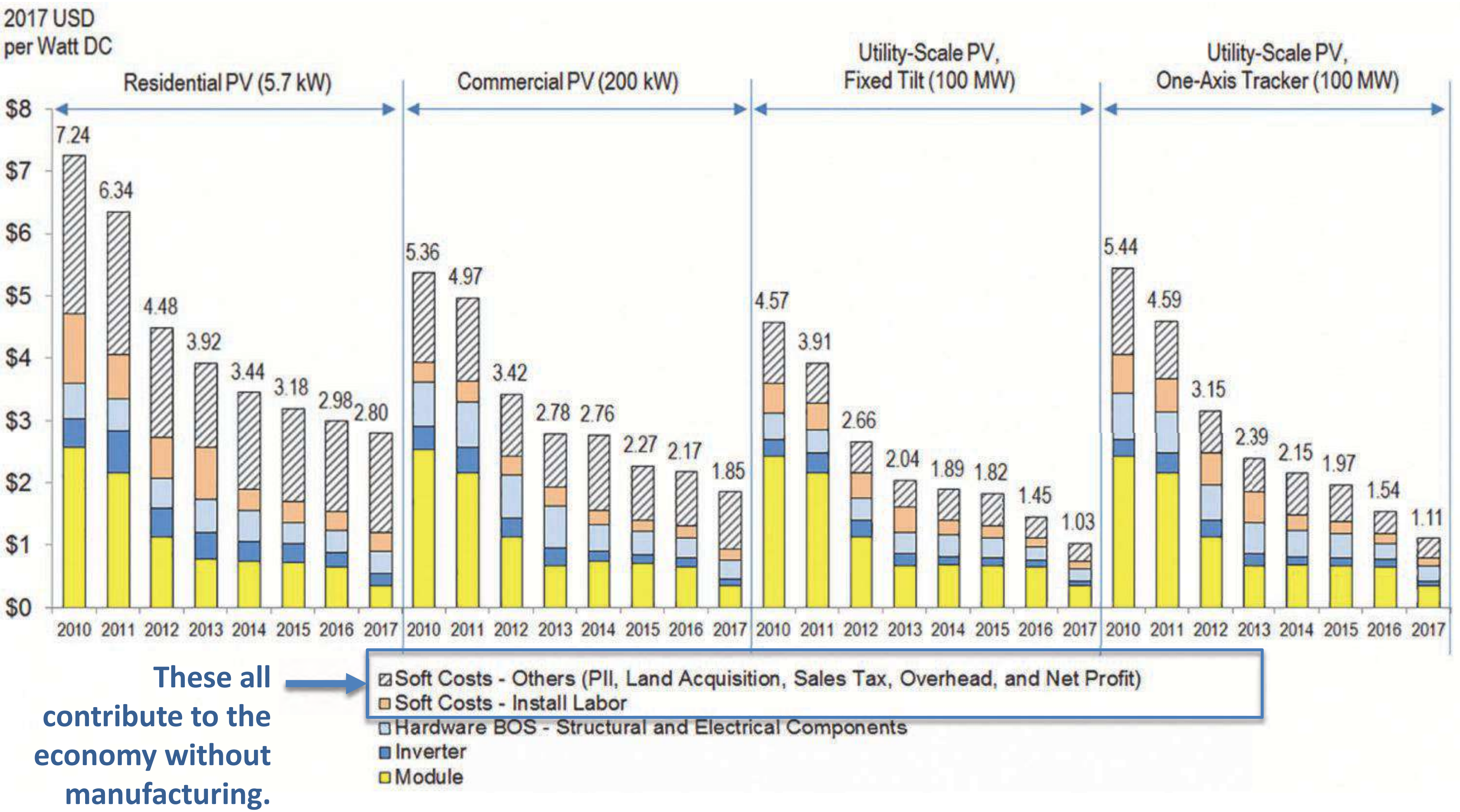
- In 2016, 14.8 gigawatts (GW) of solar installed in U.S., a 97% increase over installations in 2015.
- $23 billion U.S. solar market installed more than 42 GW
- U.S. is one of top manufacturers of polysilicon

Manufacturing and market is exciting but challenging

- From 2013 to 2016, average PV module prices fell by 51%
- Solar power purchase agreements reaching sub-retail rates in some locations

Sources: Benchmarks of Global Clean Energy Manufacturing, CEMAC, 2017; Solar PV in the USA, CEMAC Blog, 2017.

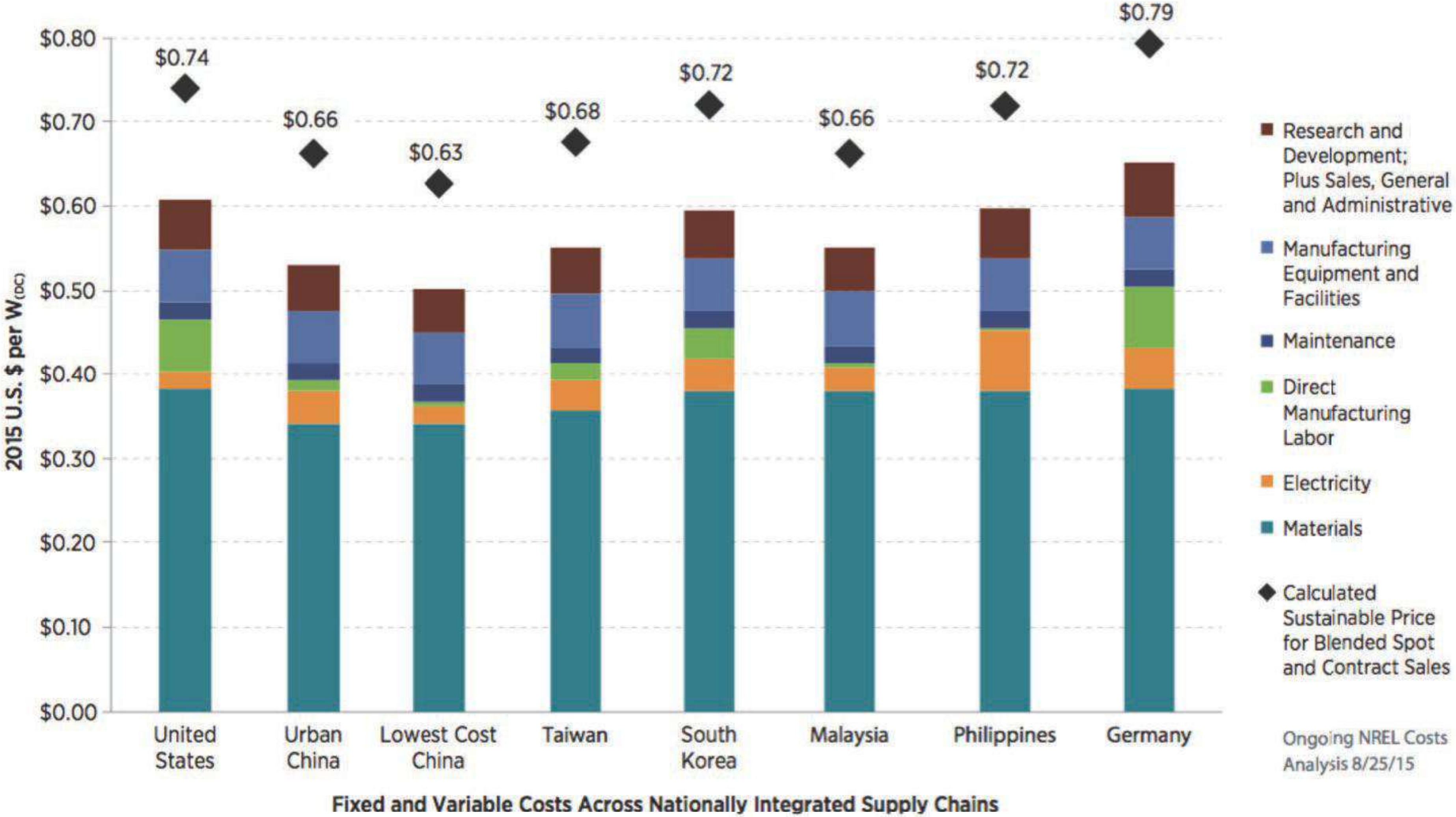
PV System Installation Prices



Source: NREL. The U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017, https://www.nrel.gov/news/press/2017/nrel-report-utility-scale-solar-pv-system-cost-fell-last-year.html

Modeled PV Manufacturing Costs by Component & Country

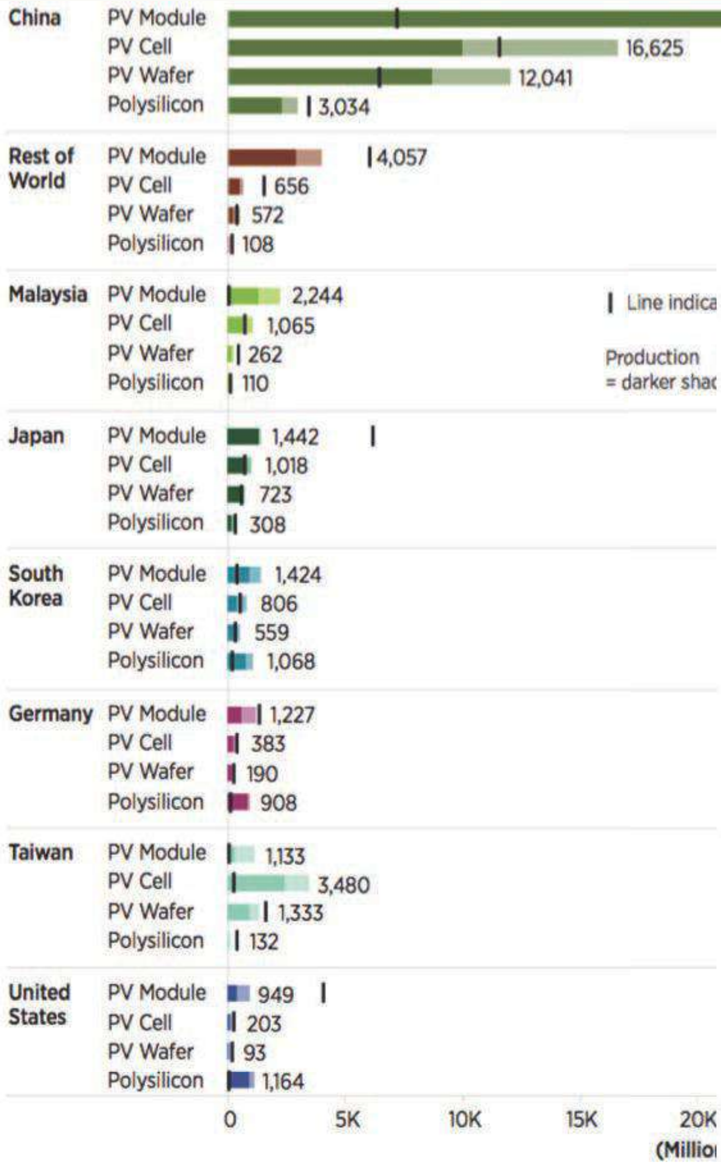
Note: Cost numbers from 2015 and they are much lower now due to rapid cost declines.

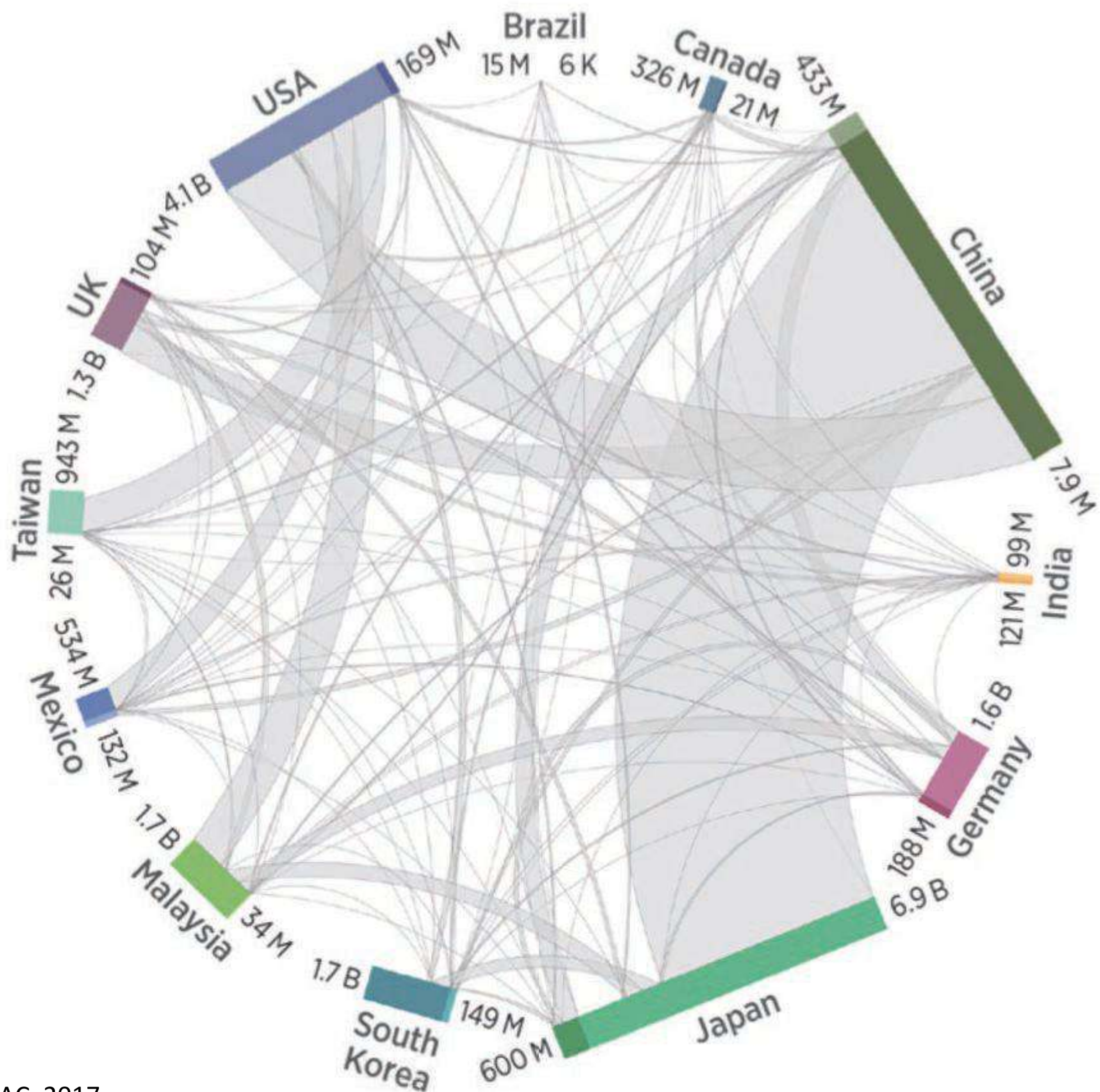


Note: Input Data Assumes No Tax Exemptions or Tariffs, Module Power= 255 W(DC)

Source: 2015 Research Highlights, CEMAC, 2016.

Manufacturing, domestic demand, and balance of trade in PV (2014 data)





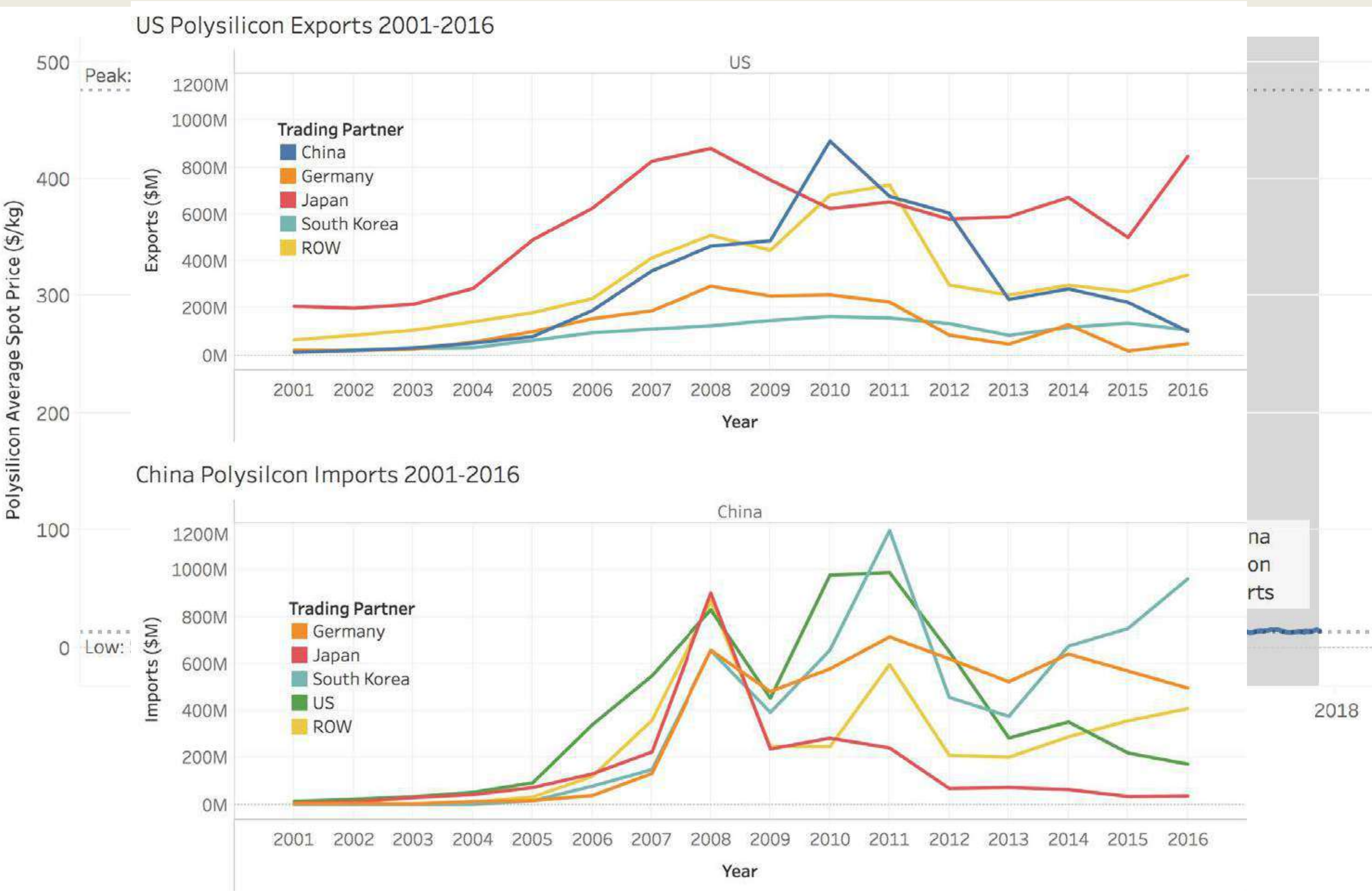
Source: Benchmarks of Global Clean Energy Manufacturing, CEMAC, 2017.

Balance of trade varies across supply chain (2016 data)

Economies that are net importers of end products may be major exporters of upstream processed materials and subcomponents of those same technologies.

Source: Benchmarks of Global Clean Energy Manufacturing, CEMAC, 2017.

Dynamic Trade in Polysilicon due to trade policy



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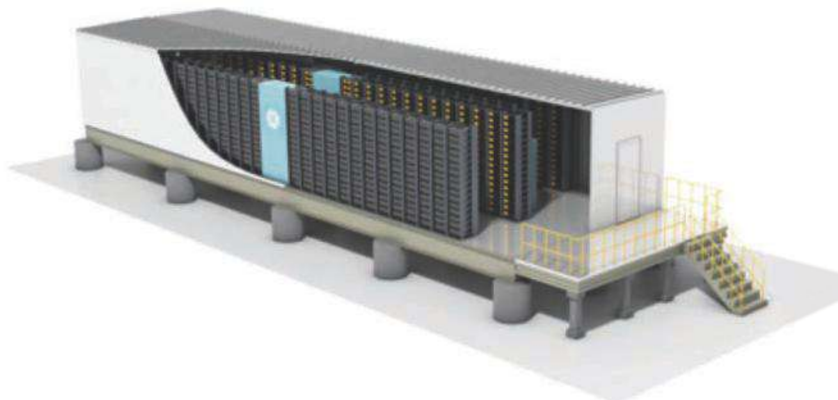
Lithium ion battery markets

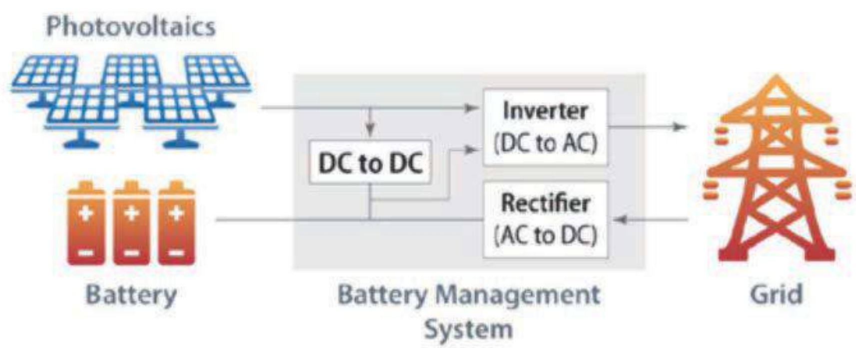
Consumer Products

Stationary

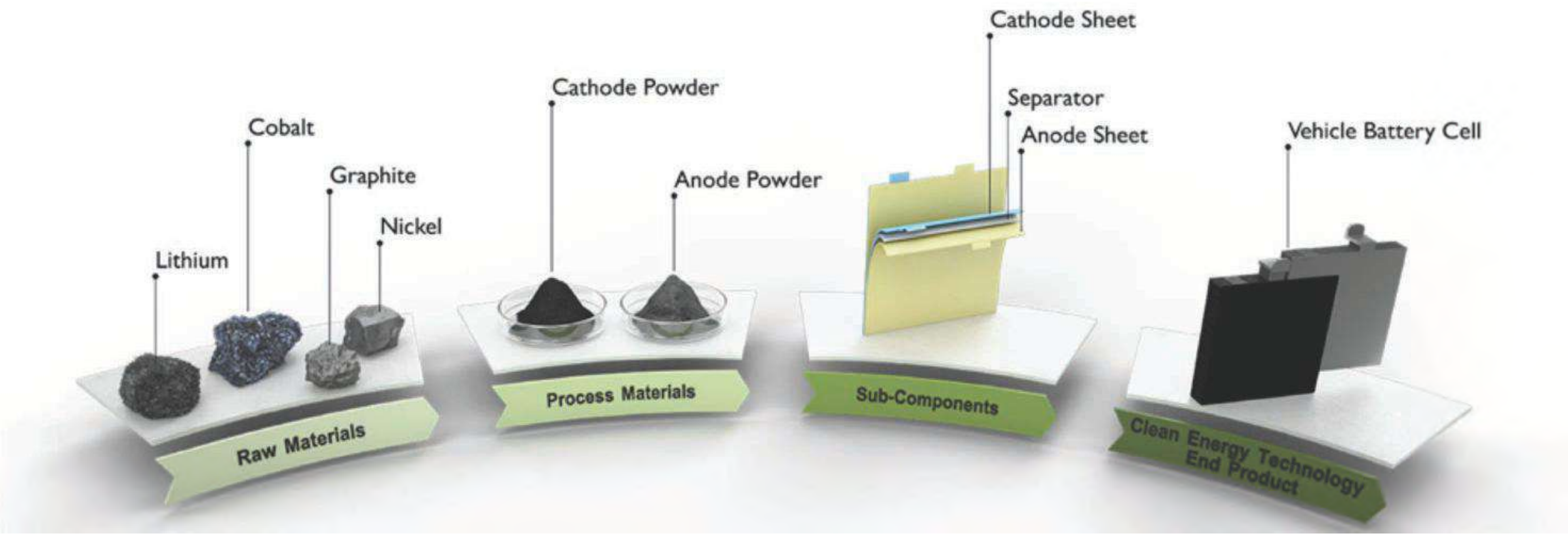


Transportation

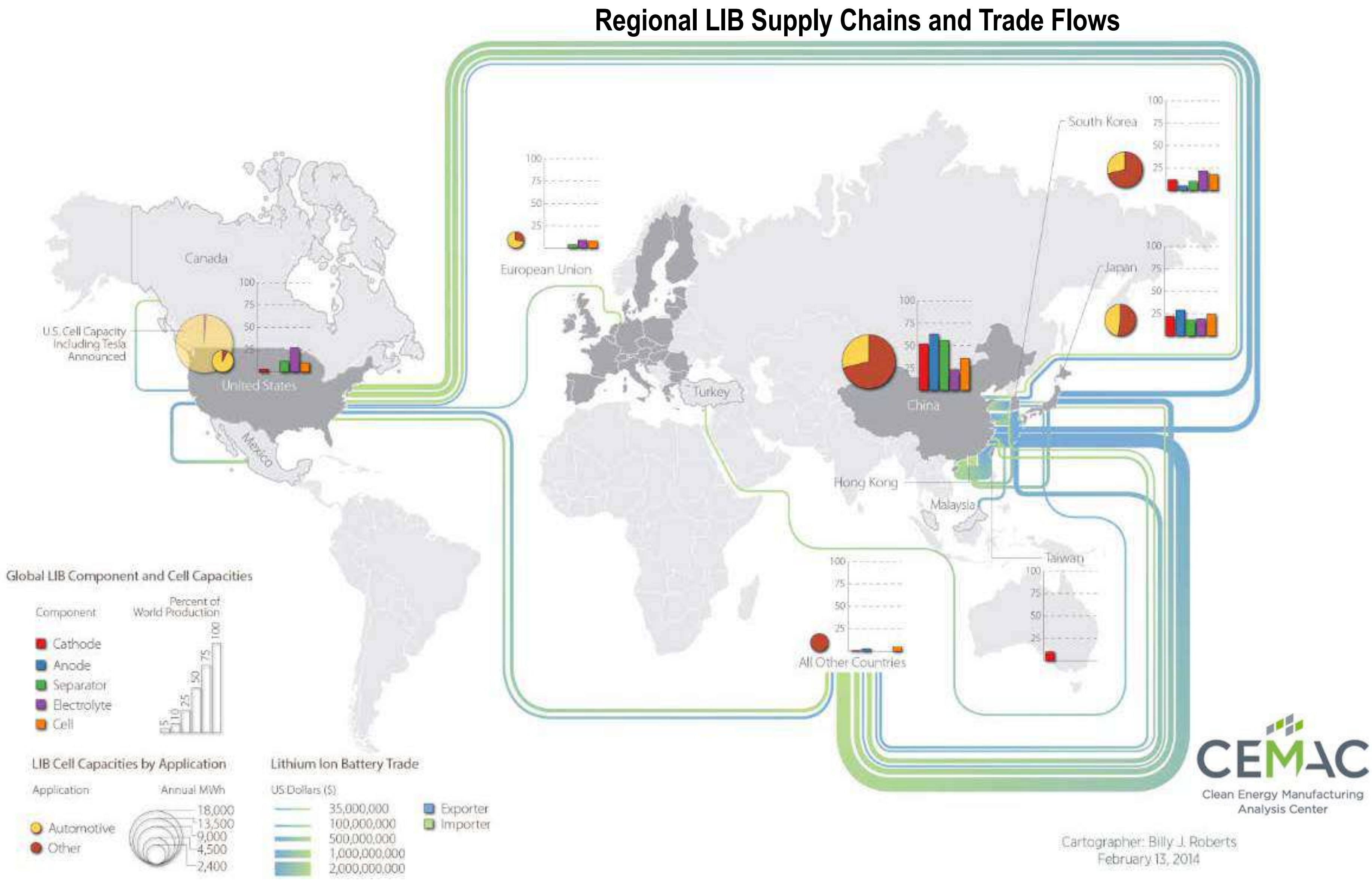
Hybrid Stationary



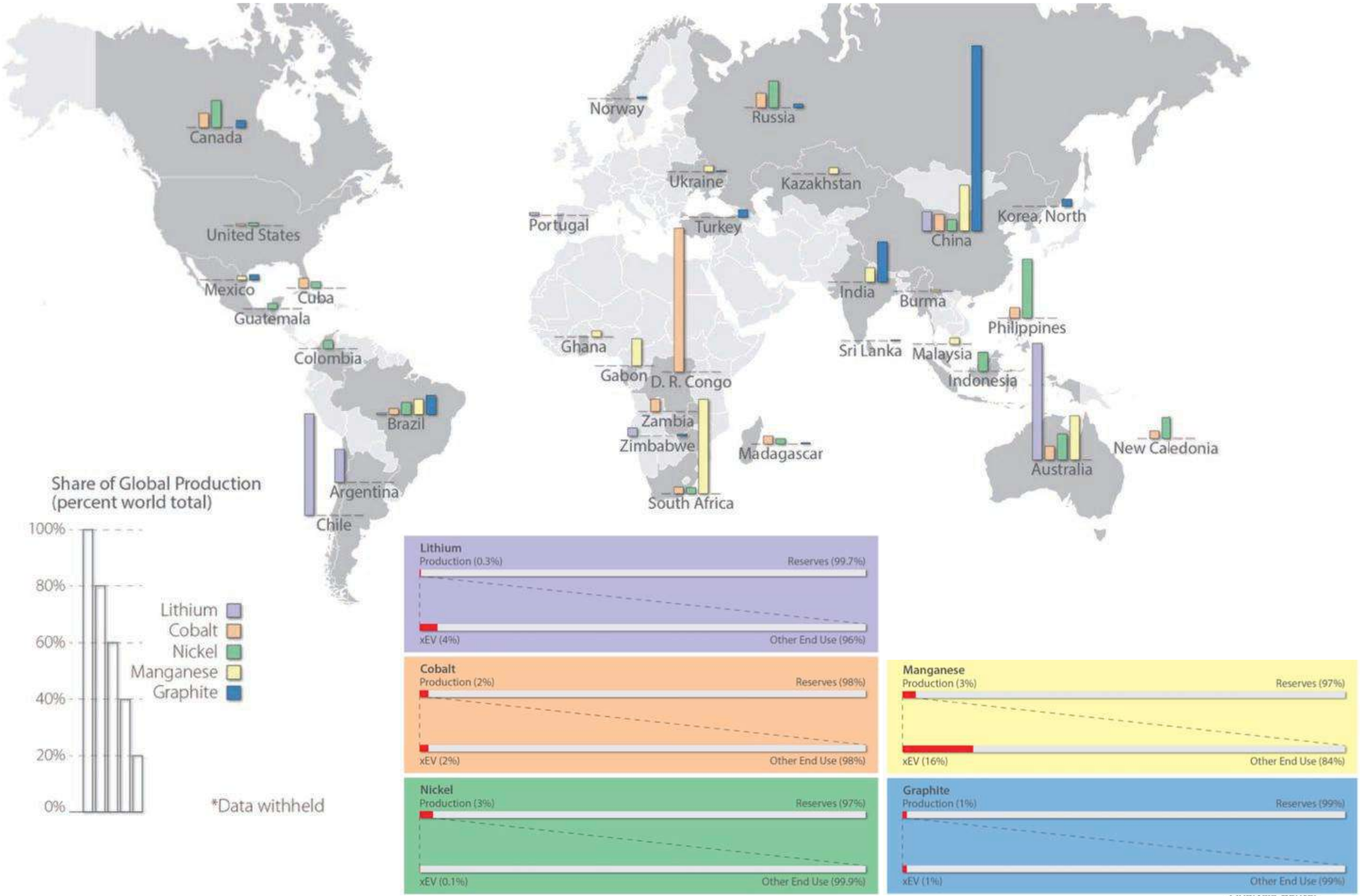
Supply chain of lithium ion batteries



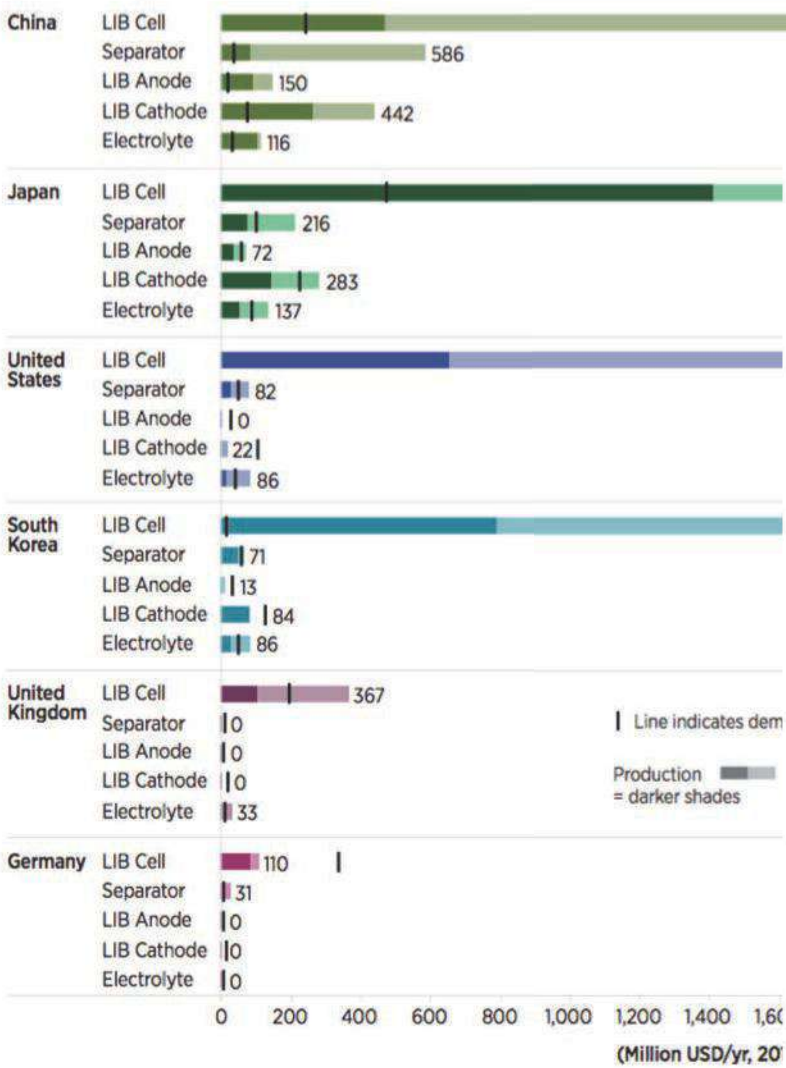
Global distribution of Li-ion battery manufacturing capacity and drivers of capacity development

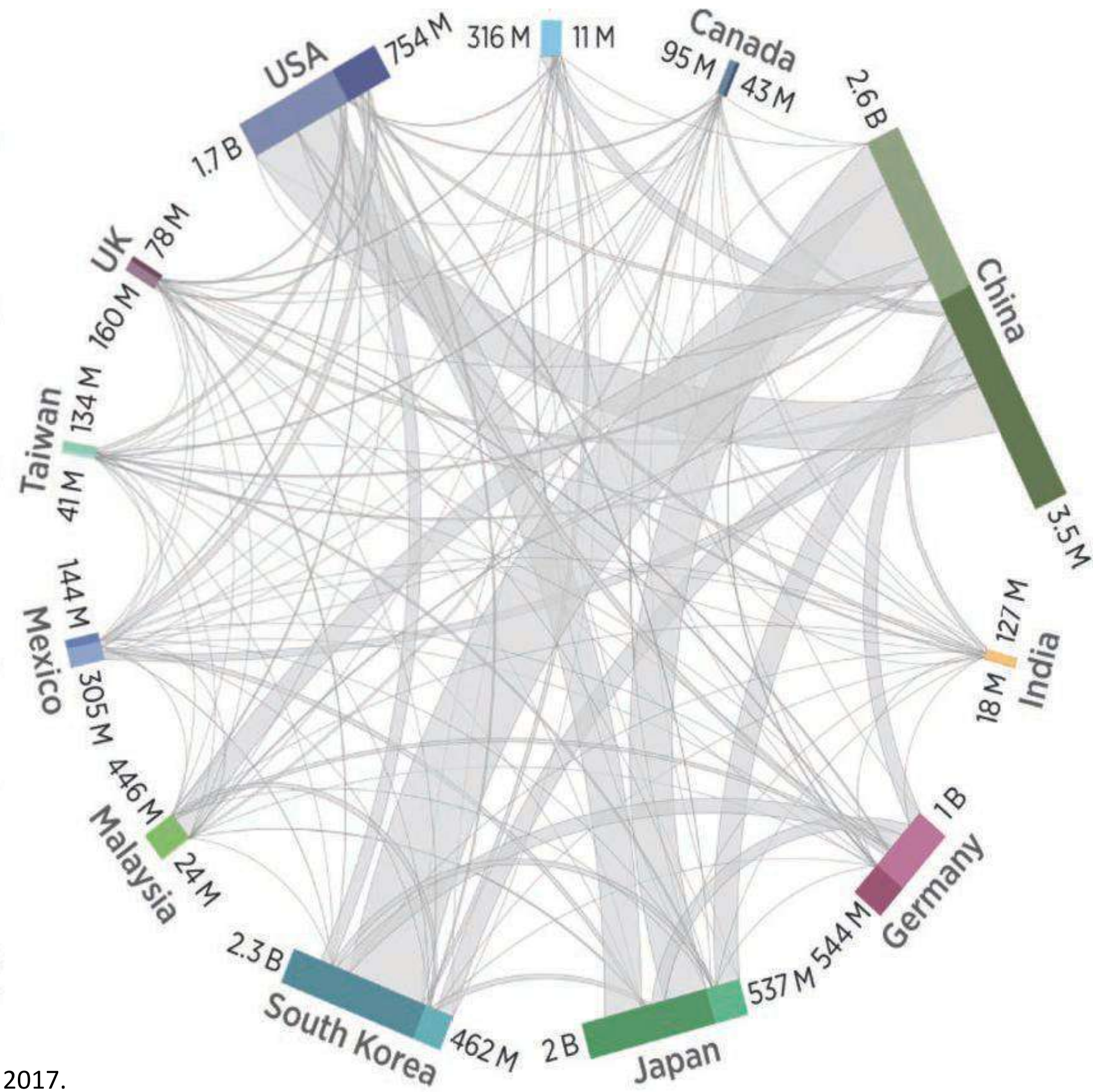


Distribution of critical materials for lithium ion battery manufacturing and possible risks



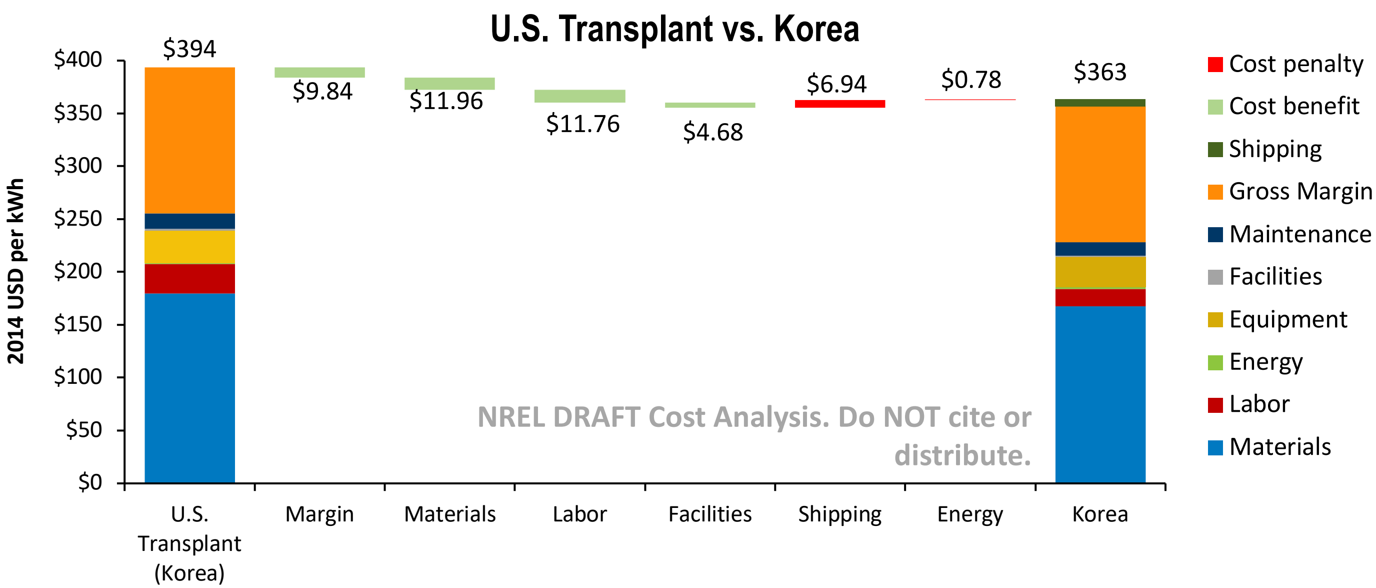
Manufacturing, domestic demand, and balance of trade in Li-ion battery cells for vehicles (2014 data)





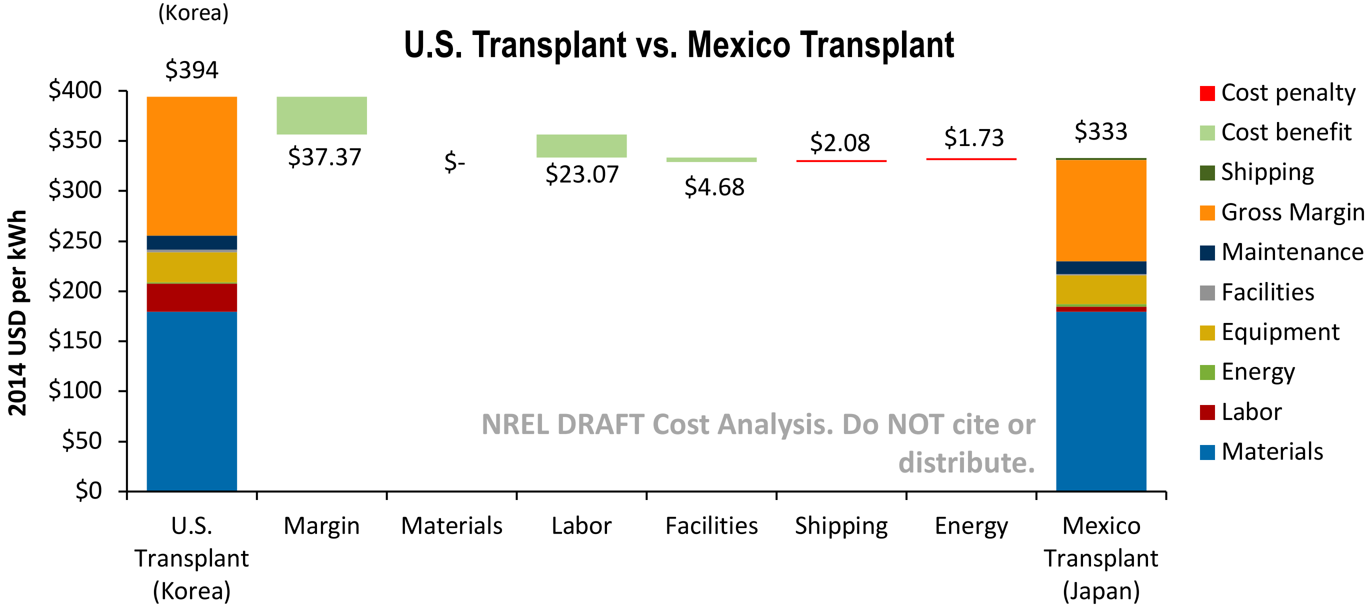
Source: Benchmarks of Global Clean Energy Manufacturing, CEMAC, 2017.

Example: U.S.-based LIB manufacturers may be challenged by incumbents and/or some low-cost production locations



Value: Quantifies the factors related to competiveness

- Korea's advantage relative to the United States is driven by lower required margins, labor, materials, and facilities costs.



- Mexico's advantage relative to the United States is driven by lower required margins, labor, and facilities costs.

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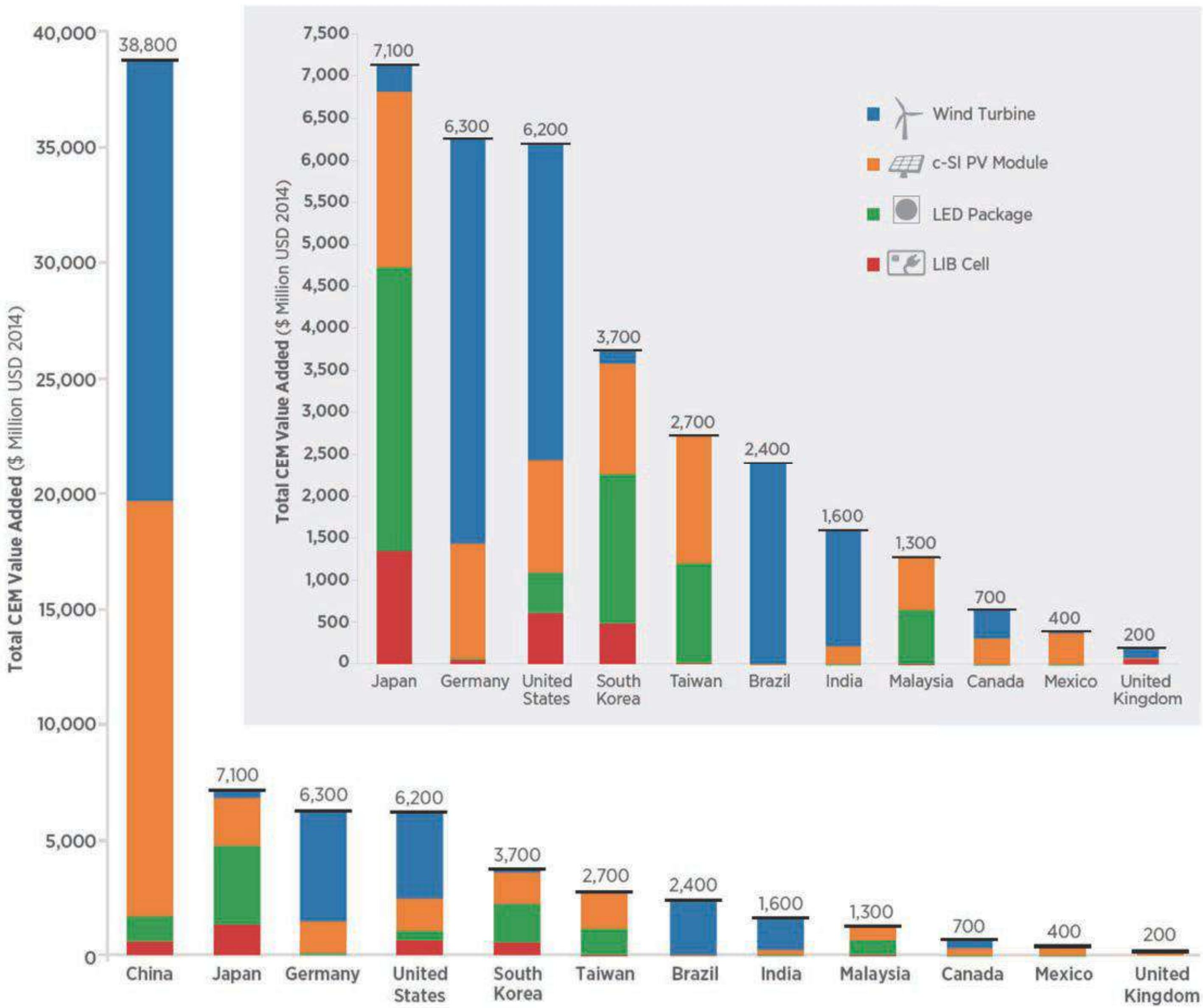
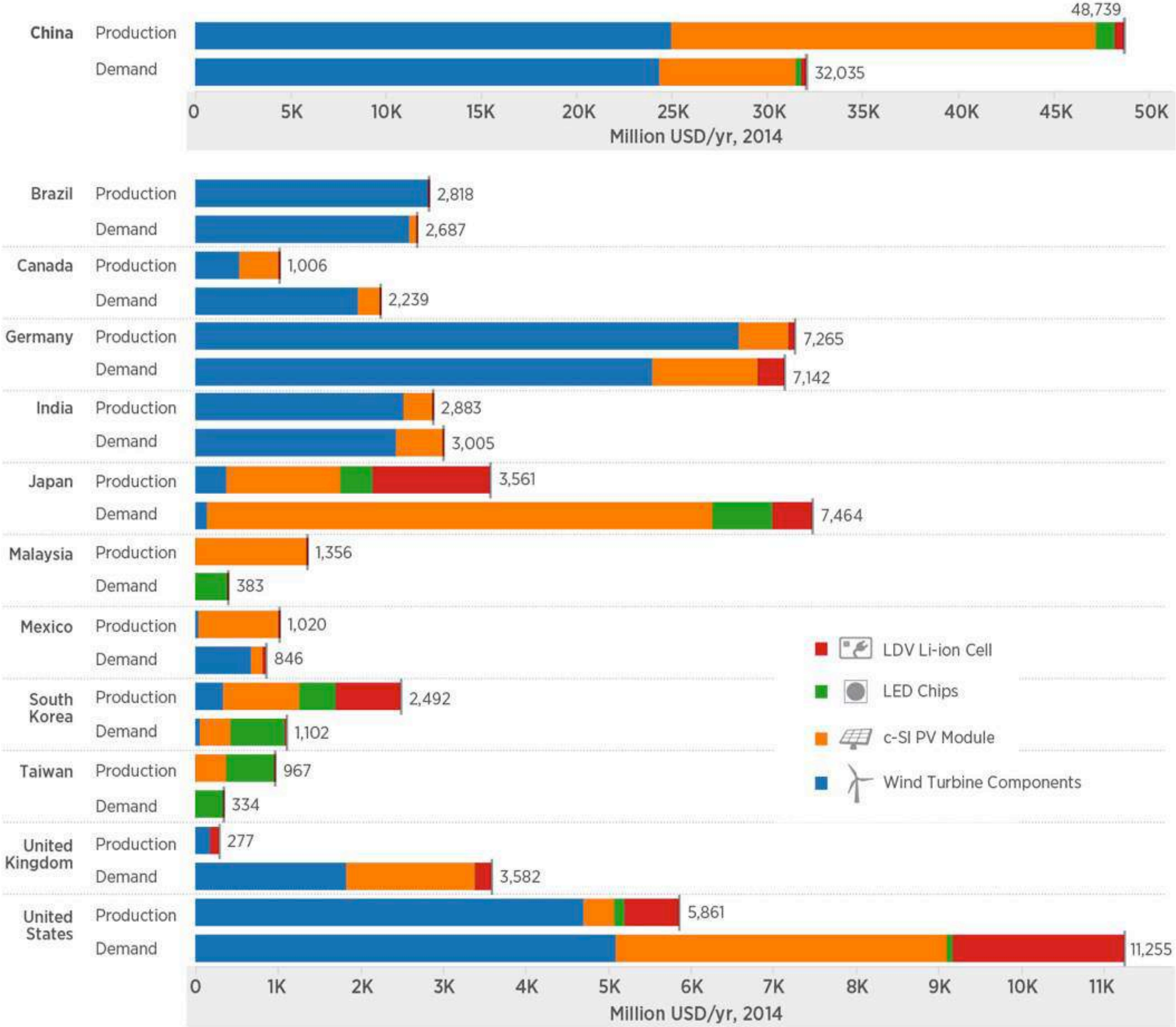
Benchmark Finding: Total & technology mix of value added from clean energy manufacturing varies significantly by country



Manufacturing value added for c-Si PV modules, wind turbine components, LED packages, and LDV Li-ion battery cells is highest for China, Japan, Germany and the United States and lowest for the United Kingdom, Mexico, and Canada.

Benchmark Finding: Production not always co-located with demand



Wind components are typically made in the same economies that have high demand, but manufacturing and demand for c-Si PV modules, LED chips, and LDV Li-ion battery cells are less coincident.

Production of wind turbine components and c-Si PV modules is more concentrated than production of LED chips and LDV Li-ion battery cells.

Conclusions and Overall Findings

Value Chain for Clean Energy Technologies

- **Dynamic**: Clean energy technology manufacturing and trade reflect the dynamics of a high-growth decade within an increasingly complex set of policy environments.
- **Investment**: Manufacturing activity and investment in new manufacturing facilities respond to both domestic demand and export markets, but both are not required.
- **Location**: Location of manufacturing facilities varies by technology, depending on need for economies of scale, transportation requirements, investment incentives, access to supply chains, etc.
- **Demand**: Increasing deployment of technologies provides manufacturers with more stable demand, enables investment, and drives down prices through economies of scale.
- **Full Value Chain**: Other parts of the value chain—research, installation, operations—generate significant value in their own right.
- **Knowledge**: Deeper knowledge of the product supply chains and market volumes are needed to inform industry and government decisions.

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Questions, Answers, and Discussion

Thank you!

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Website: www.manufacturingcleanenergy.org