Benchmarks of Global Clean Energy Manufacturing

Summary of Findings

Increased knowledge of product supply chains can inform decisions related to manufacturing facilities for extracting and processing raw materials, making the array of required subcomponents, and assembling final products. The *Benchmarks of Global Clean Energy Manufacturing* can help policymakers and industry gain deeper understanding of global manufacturing supply chains of clean energy technologies. Prepared by the Clean Energy Manufacturing Analysis Center (CEMAC) analysts at the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL), the report is a first-of-its-kind effort to isolate and quantify the economic impacts of the clean energy manufacturing sectors.

Scope of the Benchmark Study

- **Technologies:** wind turbine components (nacelle, blades, and tower), crystalline silicon (c-Si) photovoltaic (PV) modules, light duty vehicle (LDV) lithium ion battery cells, and light emitting diodes (LED) packages for lighting and other consumer products. Demand for these technologies is growing rapidly as costs decrease and performance improves.
- **Economies:** Brazil, Canada, China (including Taiwan), Germany, India, Japan, Malaysia, Mexico, South Korea, United Kingdom, and United States. These economies represent the largest global manufacturing centers for the four technologies.

Approach

CEMAC developed and uses a common framework and standardized methodologies for assessing and comparing clean energy technology manufacturing supply chains.[1] A product value chain typically includes development, manufacturing, installation/construction, system integration, and operation and maintenance. We focus exclusively on manufacturing, and break that step into four supply chain links (Figure 1).

We established four common points of reference—benchmarks—to provide a standardized basis for comparing key economic aspects of clean energy technology manufacturing on a national and global basis, and for tracking changes as markets and manufacturing processes evolve.

Value Chain for Clean Energy Technologies

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**

Figure 1. Clean energy manufacturing supply chain links. Items in bold are included in the benchmark analysis.

1. See CEMAC's *Standardized Manufacturing Cost and Analysis Methodology*, 2017

The clean energy manufacturing benchmarks include:

- Value Added – Estimate of clean energy manufacturing contribution to national economies
- Trade Flow – Snapshot of trade activity among economies across the supply chain
- Market Size – Relative concentration of consumption of clean energy technologies
- Manufacturing Capacity and Production – Distribution of manufacturing activity and where growth may occur.

Our baseline year is 2014, the most recent year for which reliable, comprehensive data is available.

Results and Findings

1. Larger economies, with more extensive manufacturing supply chains and higher prevailing wages, tend to retain more value added from clean energy manufacturing than smaller economies.

Manufacturing value added generally tracks production revenues from manufacturing clean energy technologies, reflecting the size of an economy's clean energy manufacturing sector. Normalizing the direct clean energy manufacturing value added for each technology by production revenue (yielding an estimate of value added retained) provides insight on the extent that the manufacturing supply chain associated with these clean technologies is domestically sourced and shows how much workers, investors, and governments gain from each unit of production (gray bars in Figure 2).

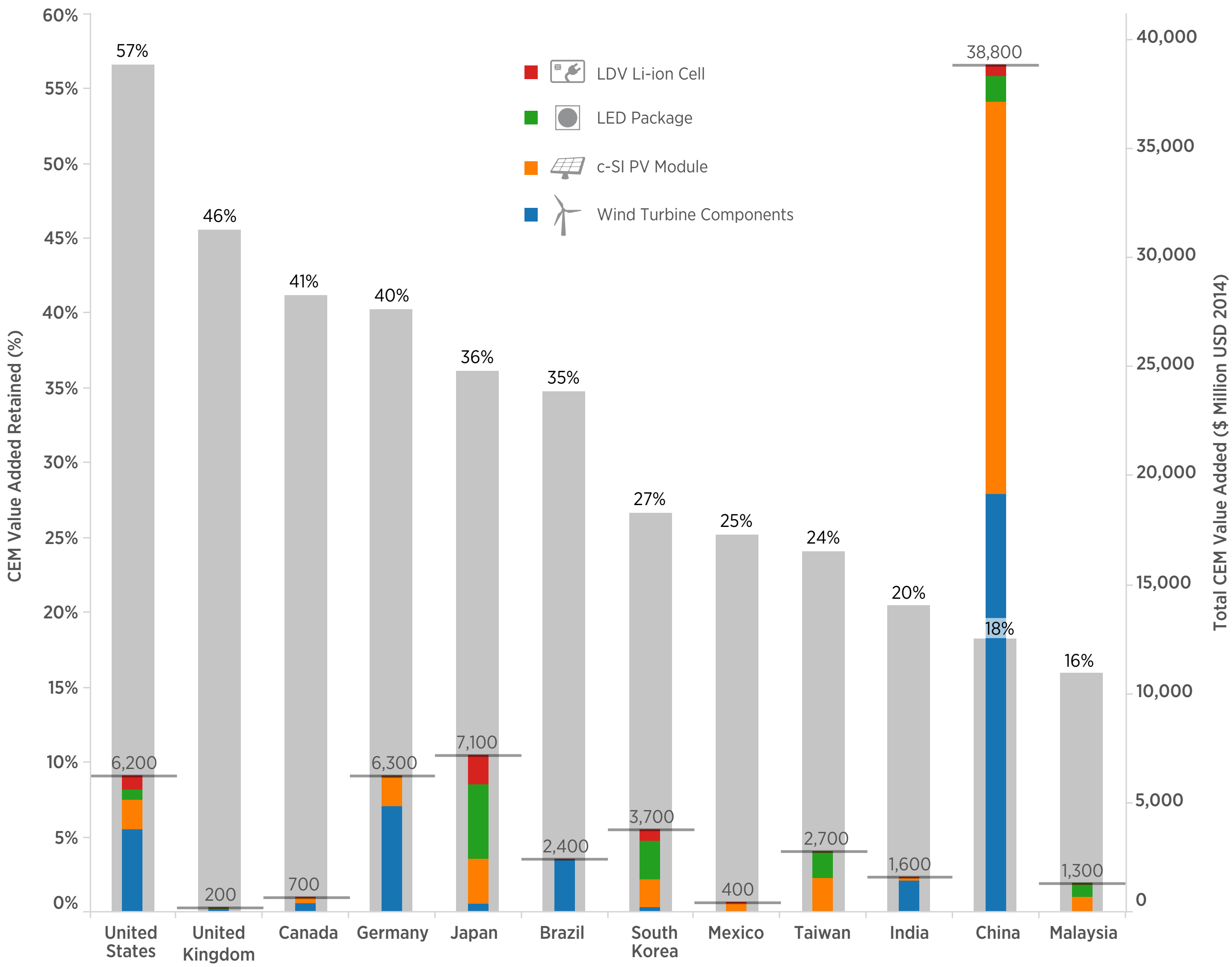

Figure 2. Direct manufacturing value added retention for four clean energy technology supply chains, 2014

The colored bars (right axis) indicate the total clean energy manufacturing value added for each economy; the clean energy manufacturing value added retained within each economy (direct value added as a share of production revenue) is indicated by the gray bars (left axis). See methodology report for data quality discussion.

Larger more productive economies such as the United States tend to retain higher percentages of clean energy manufacturing direct value added as a portion of production revenue over the entire supply chain than other economies. The larger economies tend to have more extensive domestic supply chains, and many of the economies that have higher values for this benchmark also have higher prevailing wages.

2. **Manufacturing of clean energy technologies is a complex global enterprise, with extensive trade among economies to support the geographical distribution of production and demand across the links in the supply chain. Economies that are net importers of end products may be major exporters of upstream processed materials and subcomponents of those same technologies.**

Trade is a significant component of GDP in many economies; balance of trade (exports less imports) is one element of GDP and is influenced by production capacity, capacity utilization, and domestic demand for manufactured products. Figure 3 shows the balance of trade for the four clean energy technologies. C-Si PV modules and LED packages are most

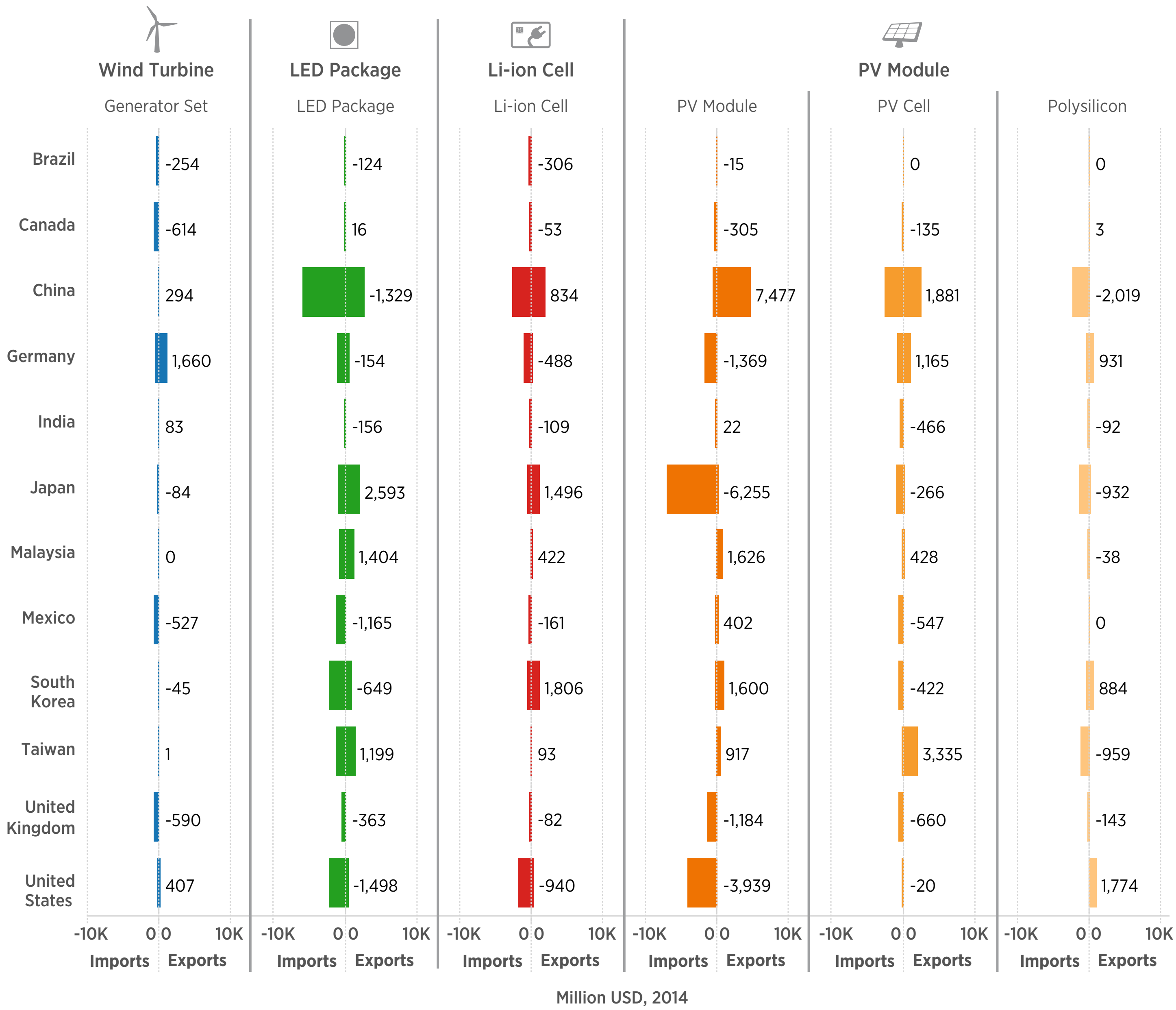

Figure 3. Balance of trade in select clean energy technology end products and across c-Si PV module supply chain, 2014 (Millions USD 2014)

The bars show the clean energy technology end product imports as negative values and the exports as positive values. The balance of trade is noted to the right of the bar. Interactive trade flow charts can be accessed at ManufacturingCleanEnergy.org/Benchmark. Trade data are not dissaggregated for the specific clean energy technologies studied. For wind components, only data for wind generator sets (which consist of a nacelle packaged with blades) were available. Trade data for Li-ion battery cells were not dissaggregated by end use. See methodology report for data quality discussion.

heavily traded, likely as they are more easily shipped than the other end products. Yet, trade of the end product is not the full story; for example, while major PV deployment markets such as the United States and Germany are net importers for PV modules, they are also the largest exporters of polysilicon to make those modules, purchased largely by Japan and China.

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

Manufacturing activity and investment in new manufacturing facilities varies across economies based on demand in domestic markets, demand in export markets, and investment incentives. Figure 4 compares production and demand for the four clean energy technology end products. Wind turbine component production and demand are relatively balanced in each of the 12 economies considered. While China plays a dominant role in PV module manufacturing, production outside of China is generally dispersed across the economies included here (only Brazil and UK have no PV module production). Production of LED packages and LDV Li-ion battery cells is more globally distributed than PV module production, although still concentrated in Asia.

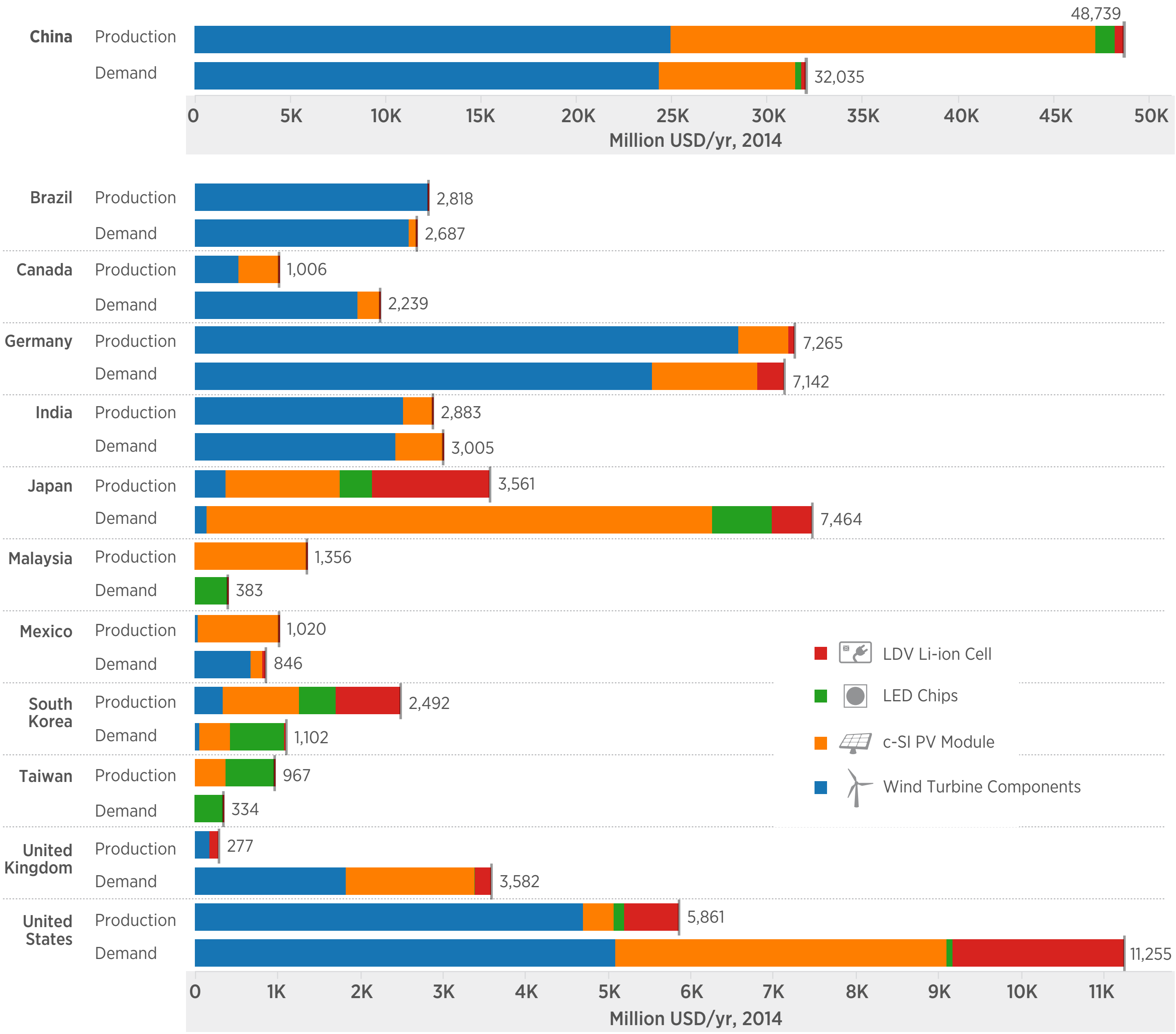

Figure 4. Production and demand for four clean energy technology end products, 2014. Note: LED chip (subcomponent), rather than LED package (end product) data reported, due to lack of economy-specific LED package production data. 2014.

The bars indicate the production and market demand (consumption). See methodology report for data quality discussion.

4. Across the four clean energy technologies evaluated in 2014, there was generally an excess of manufacturing capacity, relative to global demand.

Manufacturing production and capacity data suggest excess capacity existed across the 12 economies assessed in 2014 (Figure 5). The average manufacturing capacity utilizations were estimated at 62% for wind turbine components, 55% for c-Si PV modules, 37% for LED chips, and 41% for LDV Li-ion cells. Excess capacity can be used to meet potential demand growth from increased technology adoption. However, without increased demand, persistent excess capacity can place downward pressure on pricing.

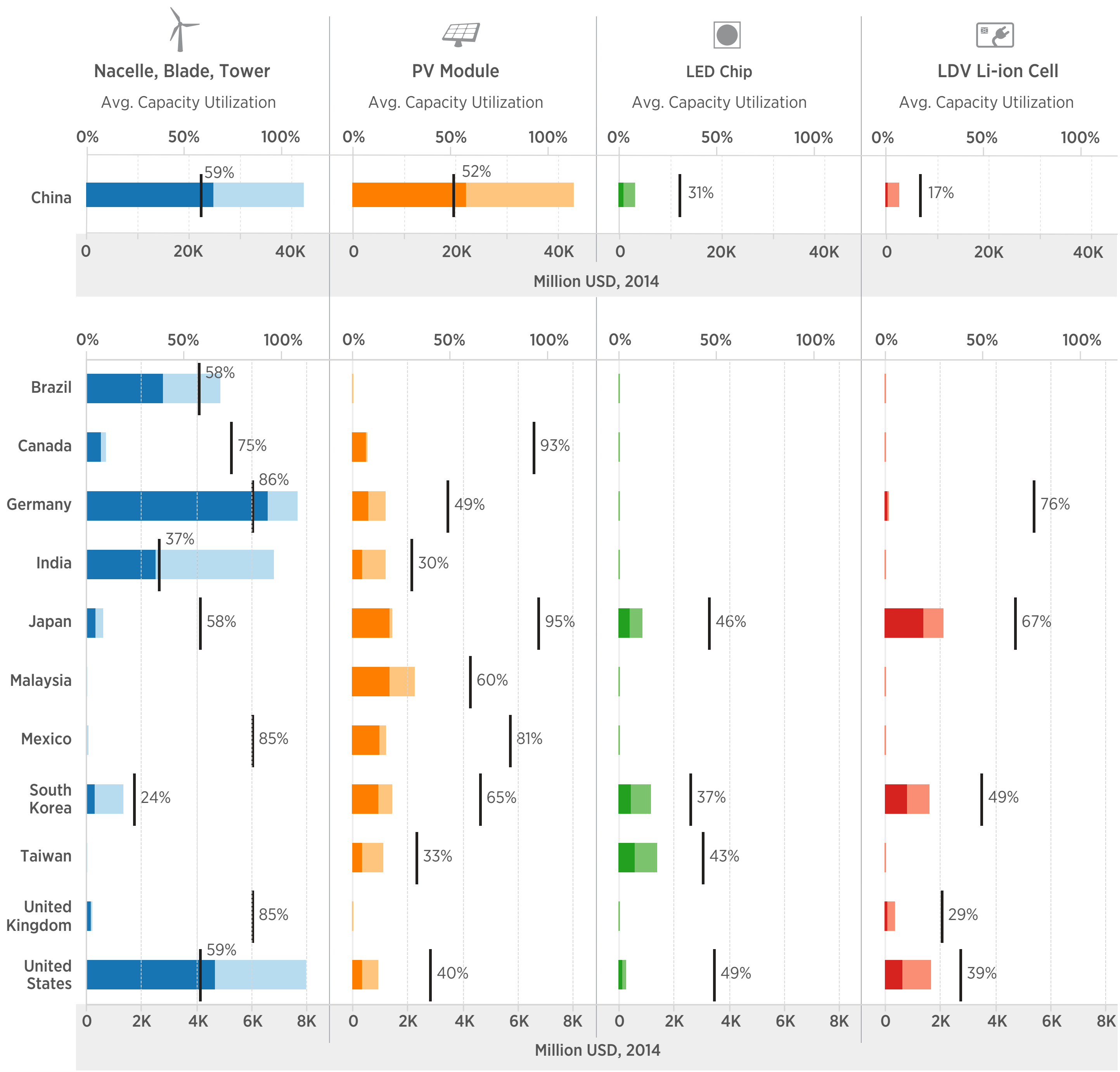

Figure 5. Production and production capacity utilization for four clean energy technology end products by economy. Note: LED chip (subcomponent), rather than LED package (end product) data reported, due to lack of economy-specific LED package production data. 2014.

Each bar shows the production revenue for the end product (darker shade) and the production value of unused manufacturing capacity (lighter shade) based on the lower horizontal scale. The line and numerical value show the capacity utilization rate based on the upper horizontal scale. See methodology report for data quality discussion.

Conclusions

The four clean energy technologies examined in this report are a major part of the burgeoning multi-billion dollar global clean energy industry. Manufacturing of these and other clean energy technologies is a global enterprise that is constantly changing based on market forces and technology advances across the manufacturing supply chain. With this report, CEMAC provides a benchmark of clean energy technology manufacturing around the world, as a reference point against which we can compare over time as the clean energy revolution unfolds.

Front and back page photos from iStock 170522599

CEMAC
Clean Energy Manufacturing Analysis Center

Established in 2015 by the U.S. Department of Energy's Clean Energy Manufacturing Initiative, 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 is operated by the Joint Institute for Strategic Energy Analysis at the DOE's National Renewable Energy Laboratory.

ManufacturingCleanEnergy.org/Benchmark

NREL/BR-6A50-67601 • January 2017