JISEA Joint Institute for Strategic Energy Analysis

Supply Chain for Energy Technologies

Fall 2021 GTMI Lunch and Learn

4 October 2021 (Virtual)

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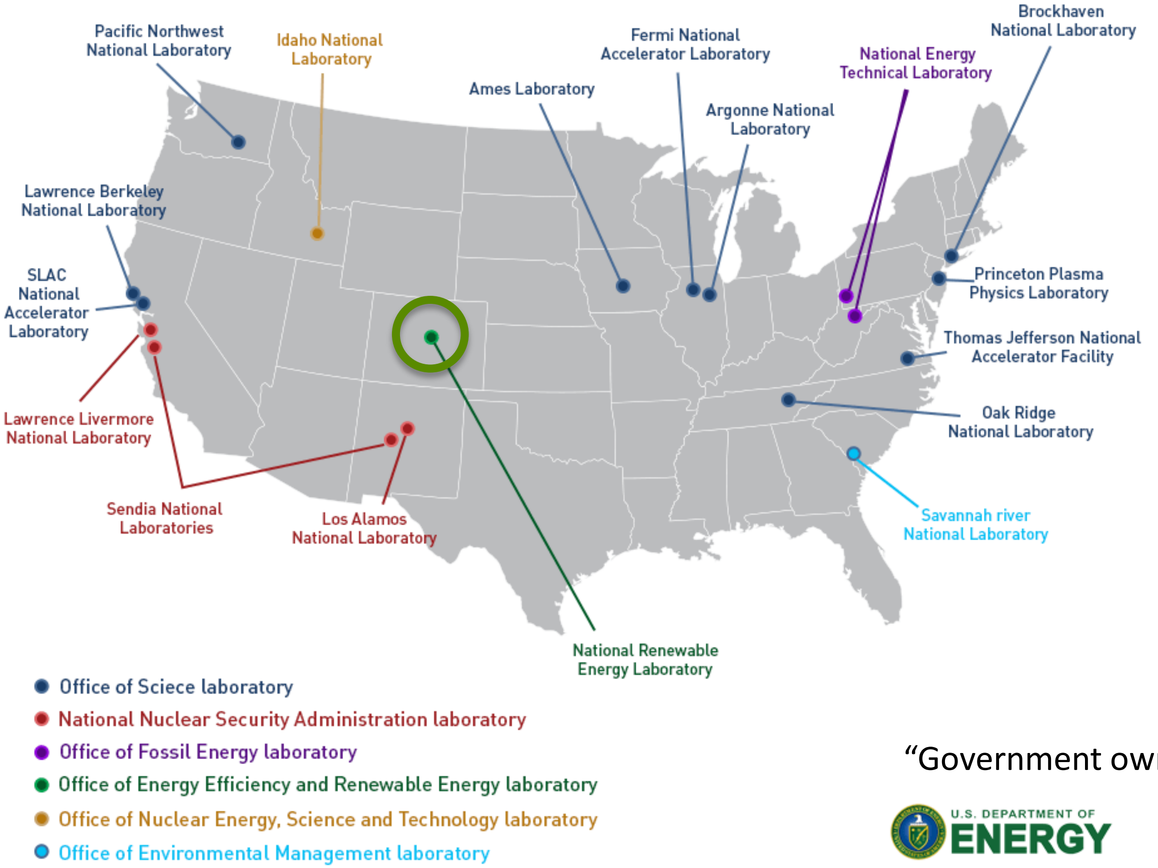
NREL Transforming ENERGY | COLORADO SCHOOL OF MINES EARTH • ENERGY • ENVIRONMENT | COLORADO STATE UNIVERSITY | MIT Massachusetts Institute of Technology | Stanford University | University of Colorado Boulder

Outline

1. Overview of NREL/JISEA and MOU with Georgia Tech
2. Techno-economic Value and Tools
3. Benchmarking Clean Energy Technology
4. TEA Storytelling
5. Understanding Geopolitical Landscape and Technology Impact
6. Other TEA Tools

17 U.S. Department of Energy National Laboratories



"Government owned, contractor operated"

National Renewable Energy Laboratory

NREL Transforming ENERGY

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.

Example Technology Areas:

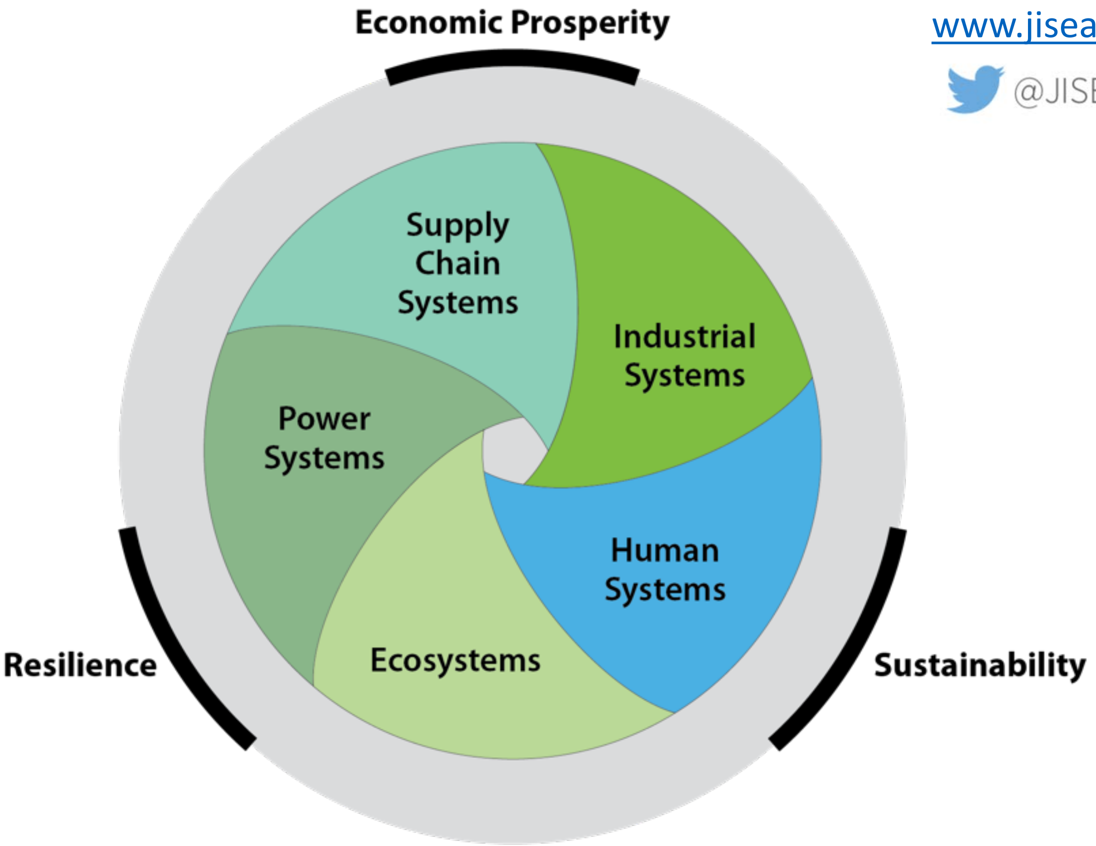
www.nrel.gov/about

- 2,900 employees and postdoctoral researchers, interns, and visiting professionals
- 327-acre main campus in Golden & 305-acre Flatirons Campus with National Wind Technology Center 13 miles north
- 69 R&D 100 awards. More than 1,000 scientific and technical materials published annually

JISEA

Joint Institute for Strategic Energy Analysis

Connecting technologies, economic sectors, and continents to catalyze the transition to the 21st century energy economy.



www.jisea.org

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Founding Partners:

NREL Transforming ENERGY · Colorado School of Mines · Colorado State University · Massachusetts Institute of Technology · Stanford University · University of Colorado Boulder

Memorandum of Understanding: NREL & Georgia Tech

- Signed March 2021 to build on research collaborations that have resulted in over 60 peer-reviewed articles on topics such as sustainable buildings, energy materials, and biomass processing
- Overall Goal of MOU: Enhancing collaboration between individual staff, faculty, and students at NREL and Georgia Tech
- Three principal goals
    1. Solve Big Problems
    2. Sustain and Engage Human Capital
    3. Accelerate Technology Adoption
- Further increase jointly held intellectual property, leading to a greater scale of technology dissemination for the public good.

Technical Focus Areas of Mutual Interest

- Integrated Energy Pathways
  - Research on the future energy system that integrates renewables, building and industrial loads, energy storage, and transportation
- Advanced Research on Integrated Energy Systems (ARIES) Initiative*
- Electric grid resilience
- Renewable energy technologies
- Cyber security of renewable energy systems
- Integrated techno-social systems analysis
- Electrons to Molecules advanced carbon capture concepts and materials
- Advanced materials for energy applications
- Advanced manufacturing for energy applications

*https://www.nrel.gov/aries/

Opportunities for Researchers, Students, Staff at Both Institutions

- Potential for making available resources to ensure a successful collaboration
  - Offices
  - Shared staff
  - Sabbaticals
  - Programmatic integration of researchers, faculty, and students
- Faculty and students may have the opportunity to work for designated periods on projects in the NREL facilities.
- NREL-funded research collaborations may afford graduate students' opportunities to develop new skills and research paths.

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What does Techno-Economic Analysis (TEA) do?

- Provide data to put the research problems in context and help analytically show technology potential.
  - Quantify the impact of research breakthroughs

- Help show domestic manufacturing impact

- Using supply chain and trade flow analysis
  - Understand geopolitical landscape
  - Understand the potential for material scarcity
  - Highlight areas that could be bottlenecks

Techno-economic Analysis

Tools:

- Bottom-up cost analysis
- Trade flow
- Value add at different stages

Metrics:

- Component cost
- System Cost
- Value Add
- Time

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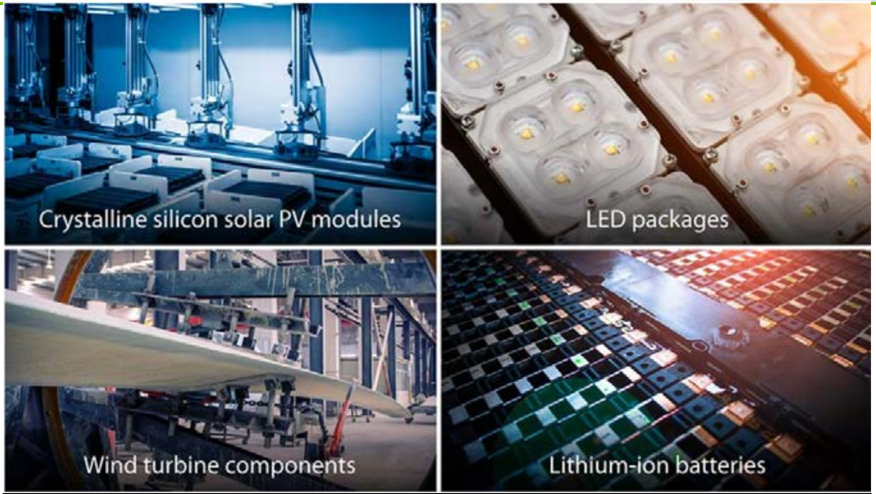
Updated Benchmark Report Informs Manufacturing & Policy Decisions

Clean Energy Manufacturing Analysis Center (CEMAC), a program under the Joint Institute for Strategic Energy Analysis (JISEA), released an updated version of its *Benchmarks of Global Clean Energy Manufacturing* report.

An Advanced Manufacturing Program research team, including contributors from the National Wind Technology Center (NWTC), in addition to the Strategic Energy Analysis Center and Integrated Applications Center, helped lead this effort.

Findings include:

- China played the largest role in supporting global demand for these technologies
- Gaps between production and demand across the economies and supply chain were met through an extensive global trade network
- Total value added from production of the four benchmark technologies across the 13 economies decreased from $89.6 billion in 2014 to $87.3 billion in 2016, in part due to declining unit costs of clean energy technologies



Benchmarks of Global Clean Energy Manufacturing assesses manufacturing supply chains for four leading clean energy technologies: crystalline silicon solar PV modules, LED packages, wind turbine components, and lithium-ion batteries. Photos courtesy of iStock

https://www.jisea.org/benchmark.html
https://www.nrel.gov/docs/fy21osti/78037.pdf

Significance & Impact

- These benchmark findings help to inform manufacturing and policy decisions, including those around R&D and international trade

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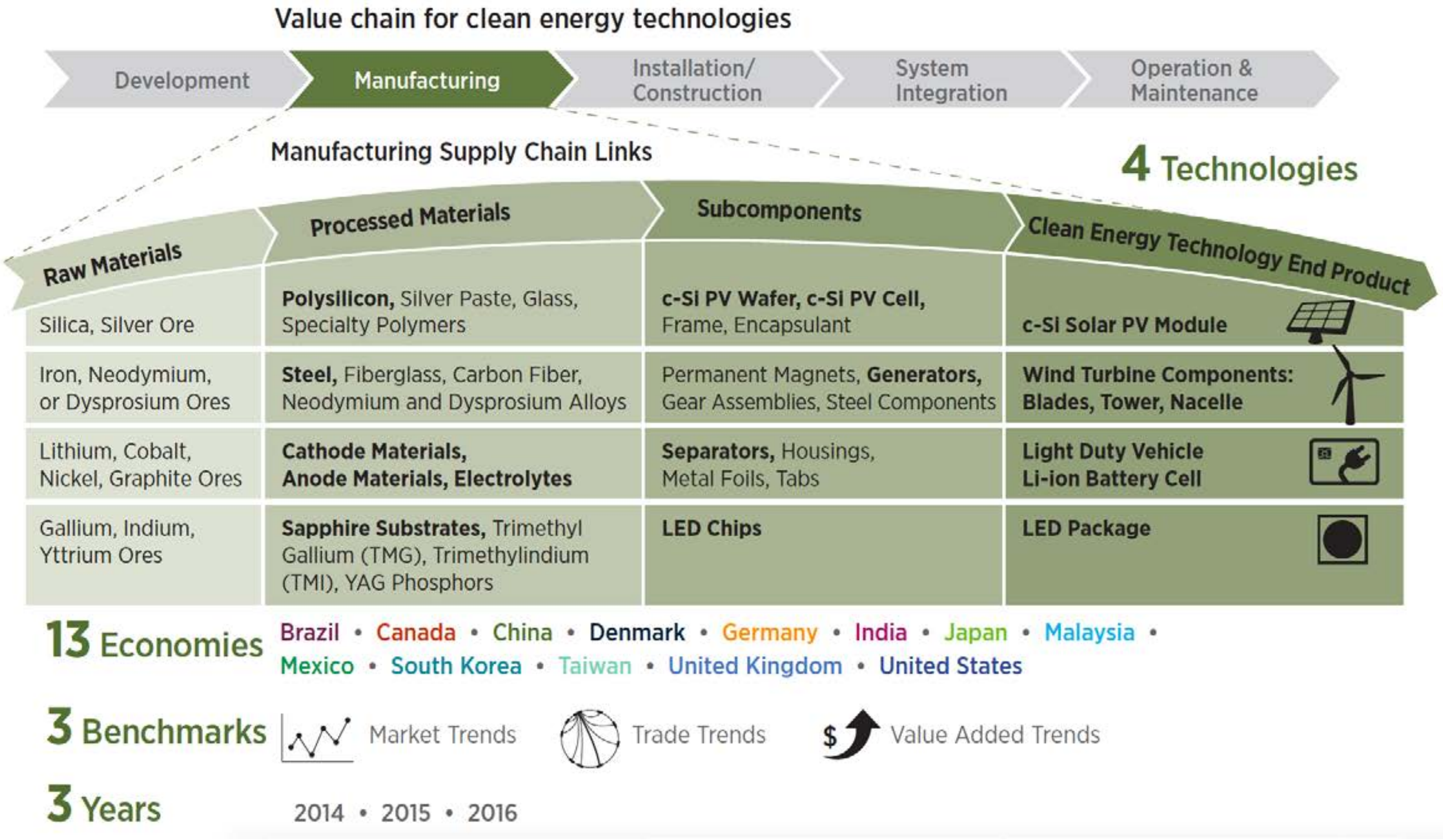
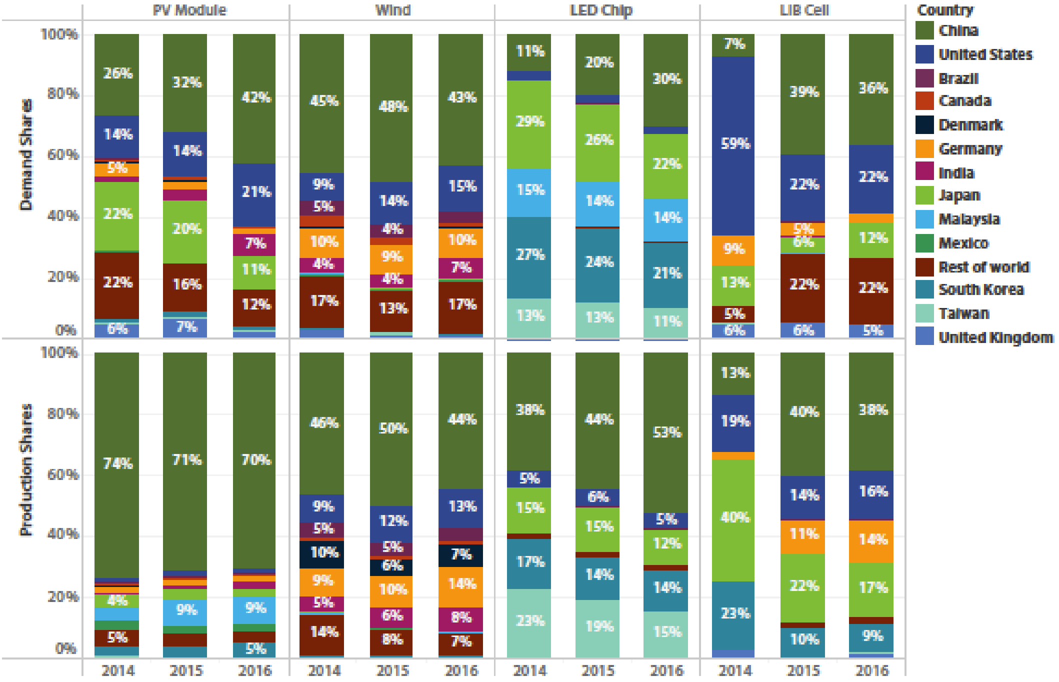
Benchmark Report



https://www.nrel.gov/docs/fy21osti/79692.pdf

Demand and Production

Clean energy technology end product global demand and production shares by economy, 2014–2016

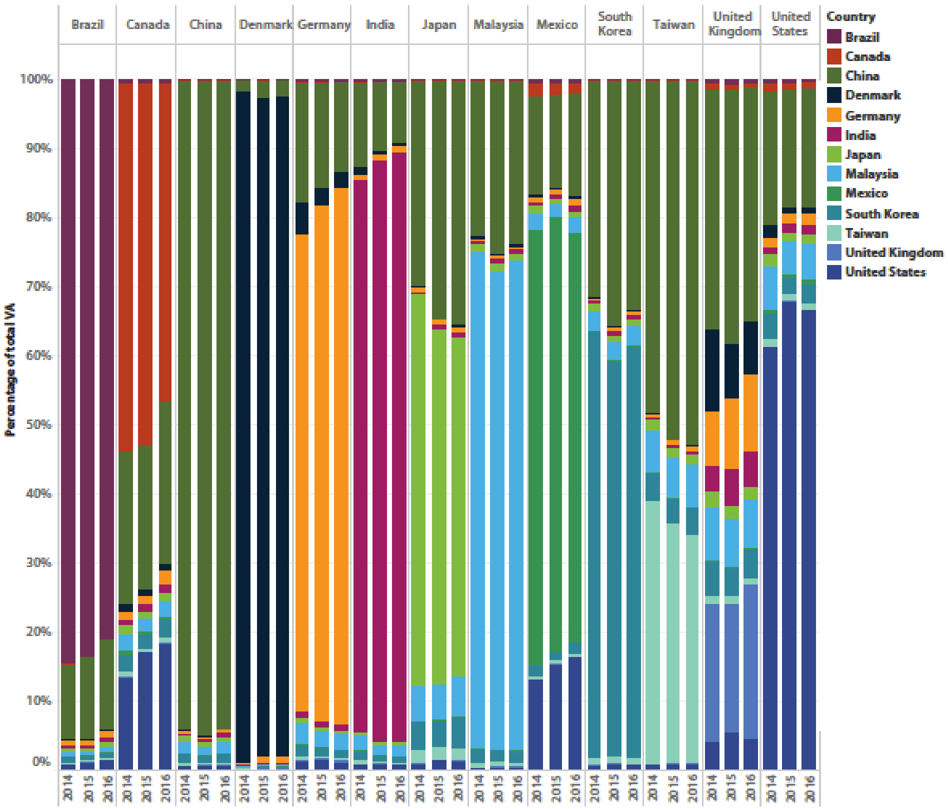


Breakdown (in %) of global demand (top) and production (bottom) by economy for benchmarked clean energy technology end products.
Note that LED chip data are presented in place of LED package data. (Due to a lack of availability of economy-specific demand data for LED packages, the benchmark analysis assumes that demand for LED packages is equal to production throughout the study).

https://www.nrel.gov/docs/fy21osti/79692.pdf

Economic Value

Clean energy manufacturing total value added (tVA) domestic and non domestic contribution, 2014–2016



For each economy (listed across the top), color-coded bars show the share of tVA accrued from domestic and non domestic production of clean energy technologies for 2014 through 2016. Domestic bars (generally the largest in each column) represent the share of tVA (iVA plus dVA) from domestic production. Non domestic bars represent the share of tVA (iVA only) from production in other economies (dVA only occurs in the economy where production occurs).

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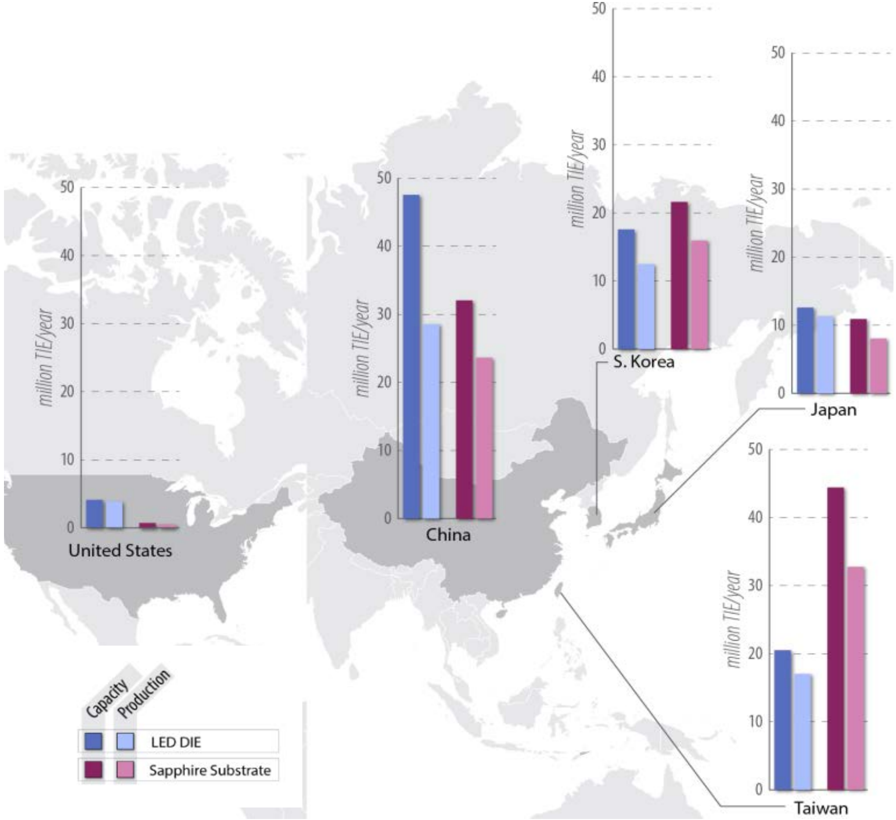
Tell a Story…

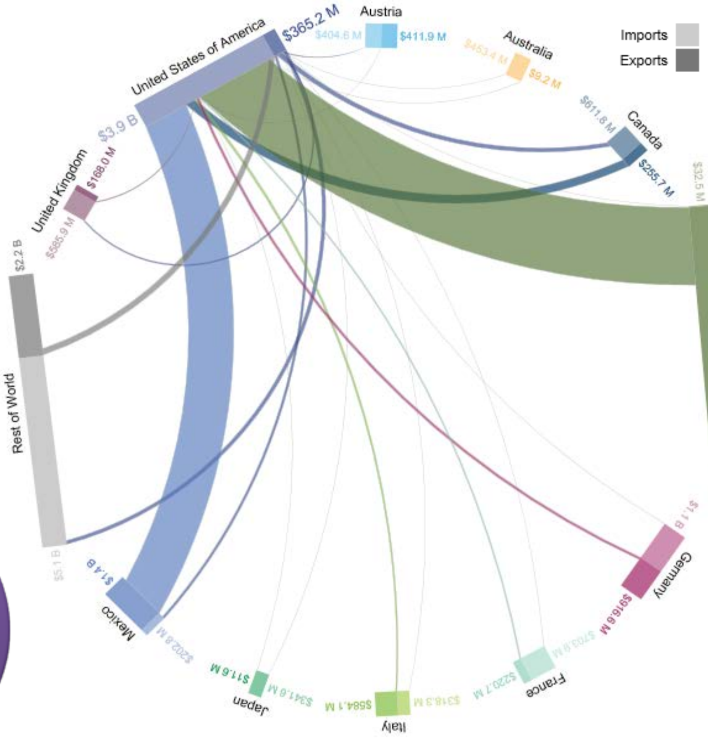
Die and Substrate: Capacity & Production (2015)



Source: Mukish, Pars, and Eric Virey. 2014. *LED Packaging Technology and Market Trends 2014*. Lyon, France: Yole Développement. , NREL Analysis

U.S. Luminaires (2015)

- US light market- $17.3 billion
- US imported $3.9 billion in luminaires
- The US therefore manufactured domestically ~$13 billion in lighting products
  - 77% of total revenue sold

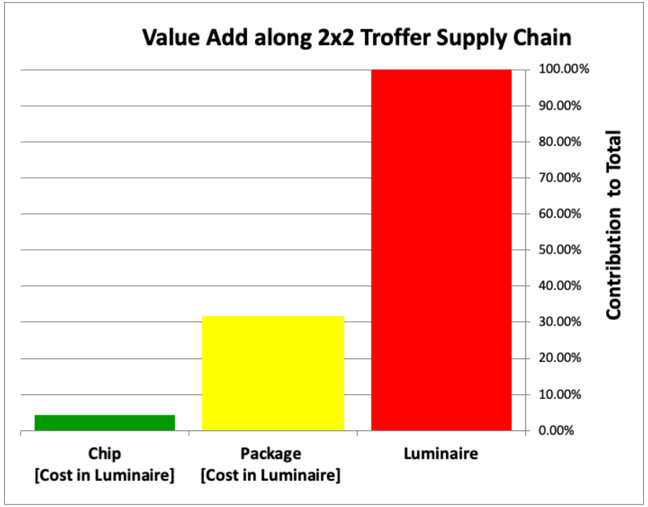


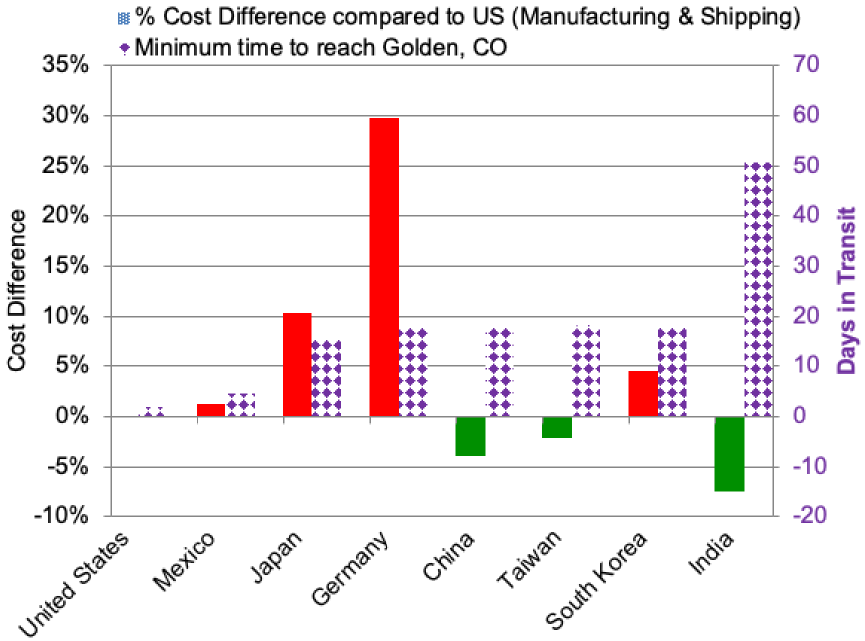
Reese, S. B., K. Horowitz, M. Mann, and T. Remo. "Research note: LED lighting–A global enterprise." *Lighting Research & Technology* (2020): 1477153520901757.

Cost/Time Tradeoff

- With shipping only:
  - China
  - India
  - Taiwan

  still **cheaper**





- Still significant time to reach Golden, CO

Reese, S. B., K. Horowitz, M. Mann, and T. Remo. "Research note: LED lighting–A global enterprise." *Lighting Research & Technology* (2020): 1477153520901757.

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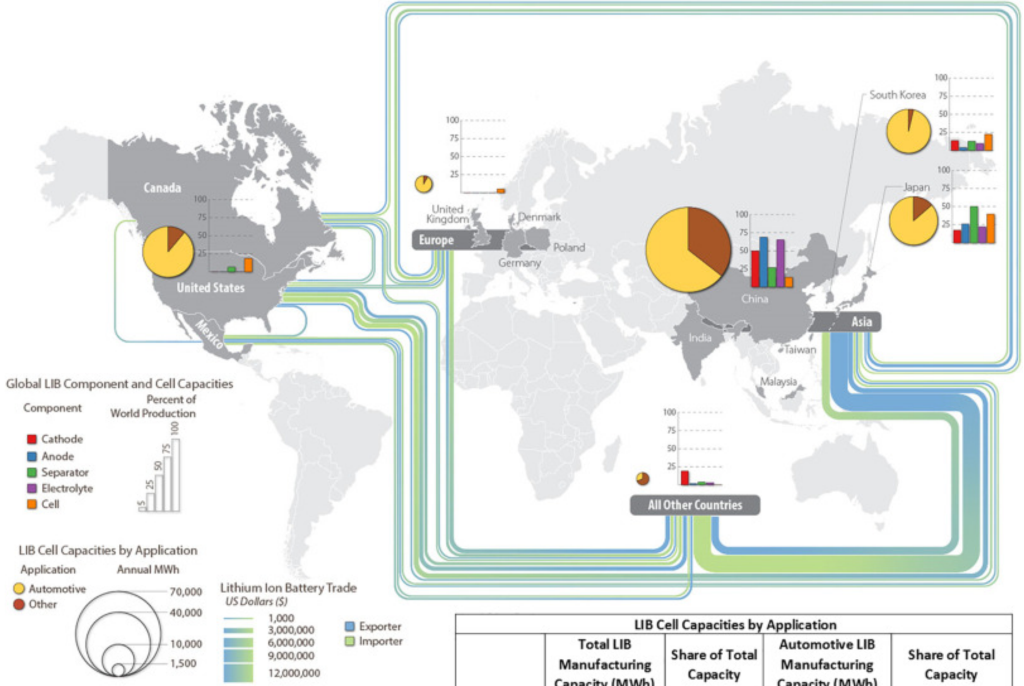
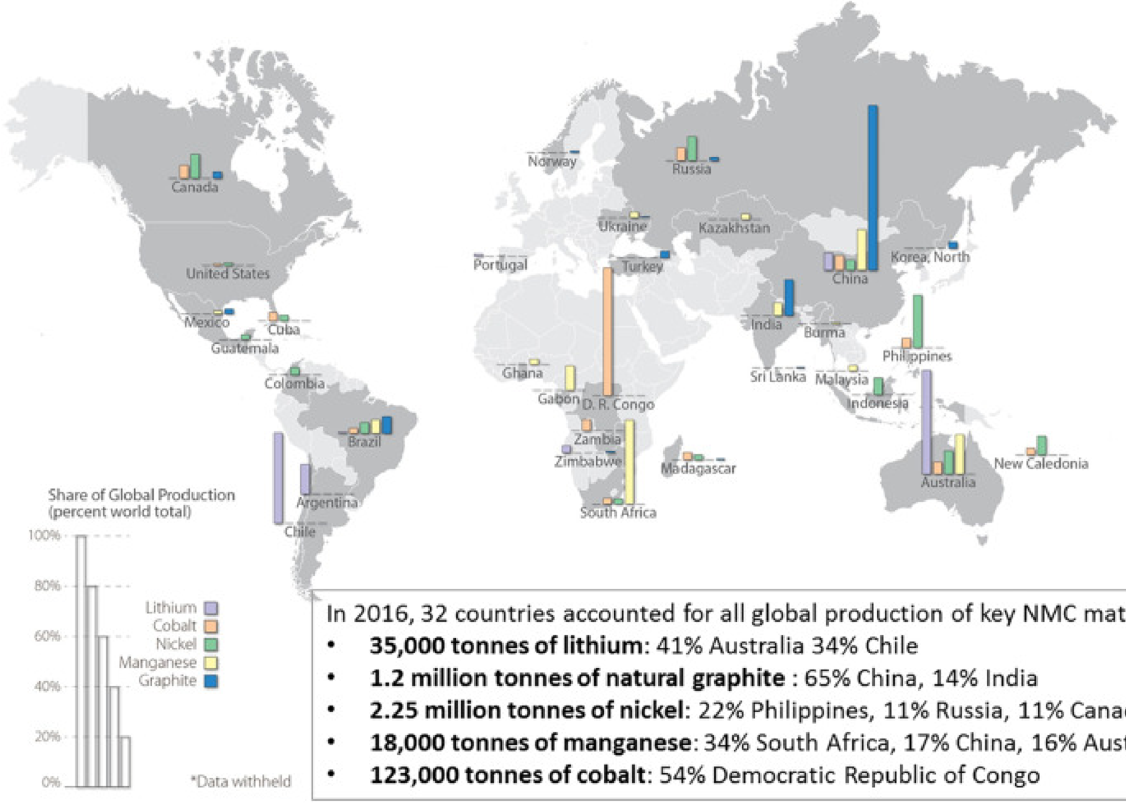
Understanding Manufacturing and Trade Flow



LIB Cell Capacities by Application				
	Total LIB Manufacturing Capacity (MWh)	Share of Total Capacity	Automotive LIB Manufacturing Capacity (MWh)	Share of Total Capacity
China	118,234	62.3%	50,670	44.3%
Japan	22,479	11.8%	19,414	17.0%
S. Korea	18,547	9.8%	17,874	15.6%
U.S.	24,766	13.1%	22,016	19.2%
E.U.	2,626	1.4%	2,400	2.1%
Rest of World	3,110	1.6%	2,110	1.8%
Total	**189,762**	**100%**	**114,484**	**100%**

Mayyas, Ahmad, Darlene Steward, and Margaret Mann. "The case for recycling: Overview and challenges in the material supply chain for automotive li-ion batteries." *Sustainable materials and technologies* 19 (2019): e00087.

Battery Raw Materials



In 2016, 32 countries accounted for all global production of key NMC materials

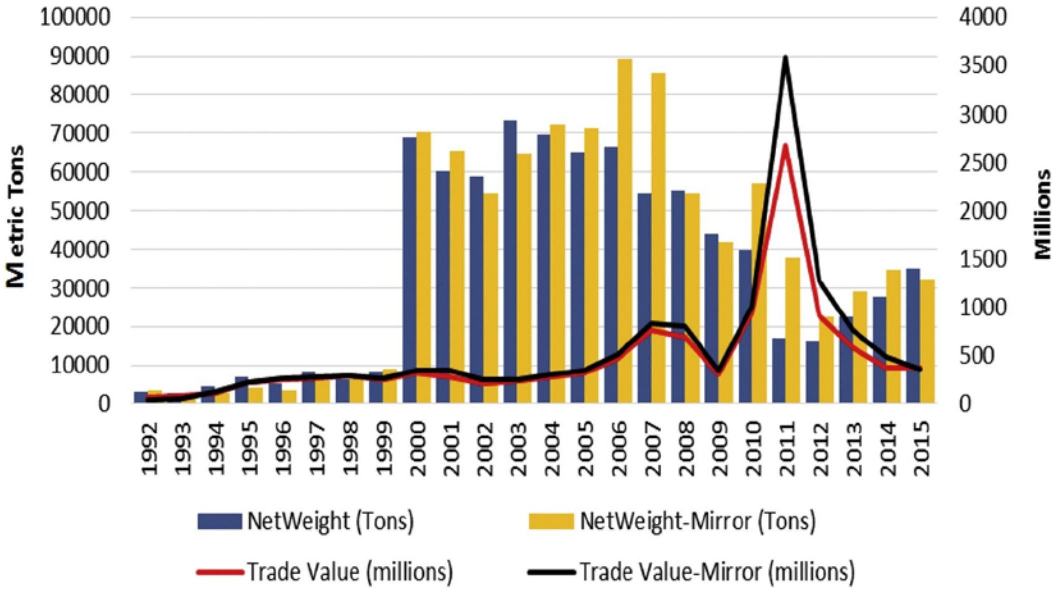
- **35,000 tonnes of lithium**: 41% Australia 34% Chile
- **1.2 million tonnes of natural graphite** : 65% China, 14% India
- **2.25 million tonnes of nickel**: 22% Philippines, 11% Russia, 11% Canada, 9% Australia
- **18,000 tonnes of manganese**: 34% South Africa, 17% China, 16% Australia
- **123,000 tonnes of cobalt**: 54% Democratic Republic of Congo

Mayyas, Ahmad, Darlene Steward, and Margaret Mann. "The case for recycling: Overview and challenges in the material supply chain for automotive li-ion batteries." *Sustainable materials and technologies* 19 (2019): e00087.

Physical Supply Chain- Geopolitical

Trade dispute resulted in a 2010 China export limits on rare earth elements

- Result was 7X price increase and scarcity of getting material

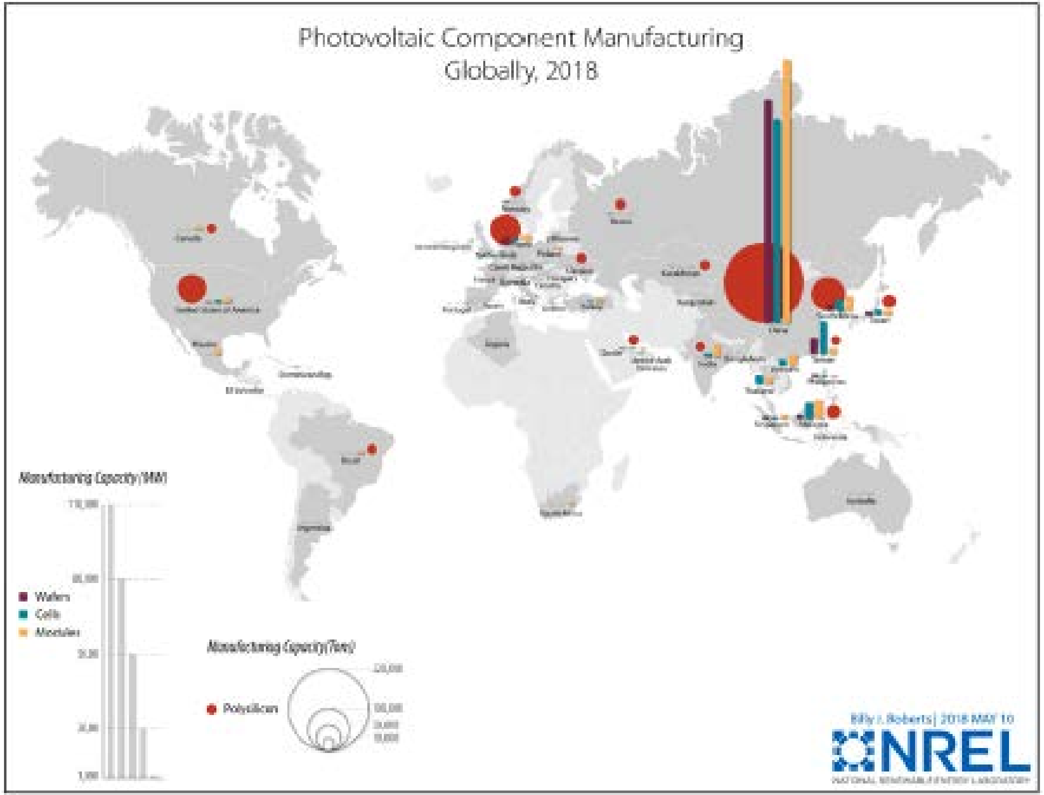


Mancheri, Nabeel A., Benjamin Sprecher, Gwendolyn Bailey, Jianping Ge, and Arnold Tukker. "Effect of Chinese policies on rare earth supply chain resilience." *Resources, Conservation and Recycling* 142 (2019): 101-112.

Silicon PV Manufacturing

Current Administration banned solar from Xinjian province in June

Trade analysis shows the potential impact that ban could have



Woodhouse, Michael A., David J. Feldman, Ran Fu, Brittany Smith, Kelsey A. Horowitz, Ashwin Ramdas, and Robert M. Margolis. *The international supply chain and manufacturing costs for photovoltaic modules, and project economics of systems including storage*. No. NREL/PR-6A20-73948. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2019.

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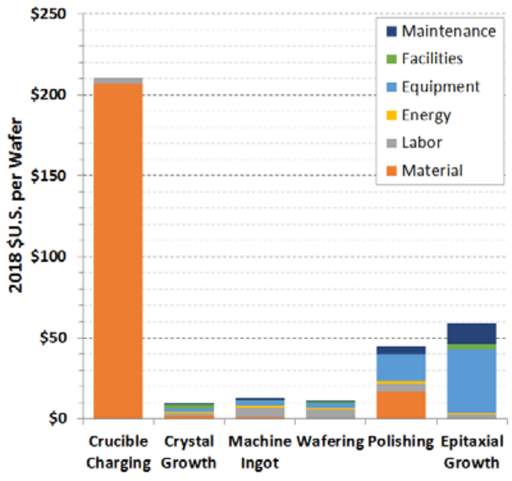
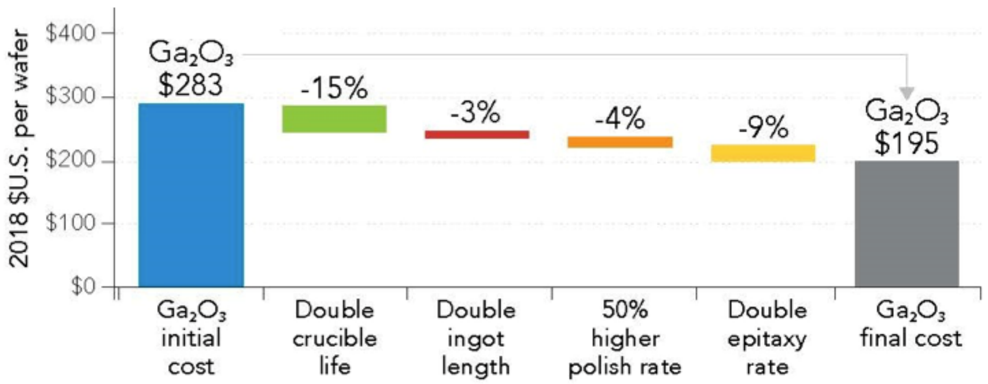
Highlight Cost Reduction Opportunities

- Bottom-up manufacturing cost analysis has capability to:
  - Identify manufacturing processes that are primary cost drives
    - Provide quantitative insights into areas were advances would be most impactful
- Bottom-up models enable technology advancement roadmaps to cost reduction



Ga_2O_3 Wafer Manufacturing Cost

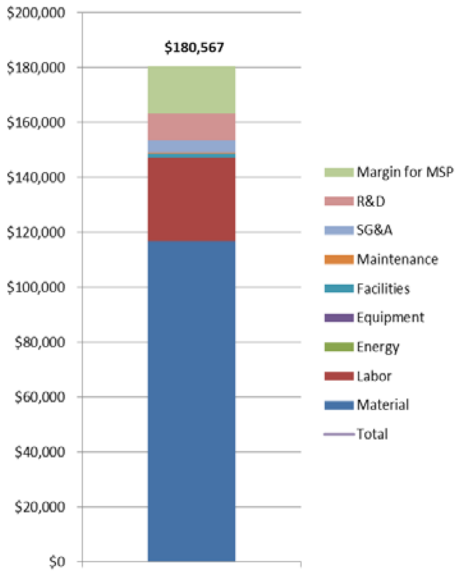


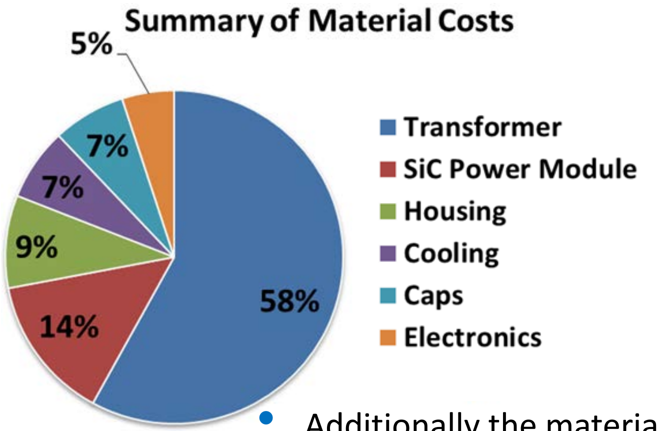
Ga_2O_3 Wafer Cost Reduction Path

Reese, Samantha B., Timothy Remo, Johney Green, and Andriy Zakutayev. "How much will gallium oxide power electronics cost?." *Joule* 3, no. 4 (2019): 903-907.

System Manufacturing Cost Comparison

- The minimum sustainable price (MSP) of new technology can be calculated and compared to incumbent technology
- In this example a medium voltage variable frequency motor drive using SiC power electronics is comparable in price to incumbent technology based on Si



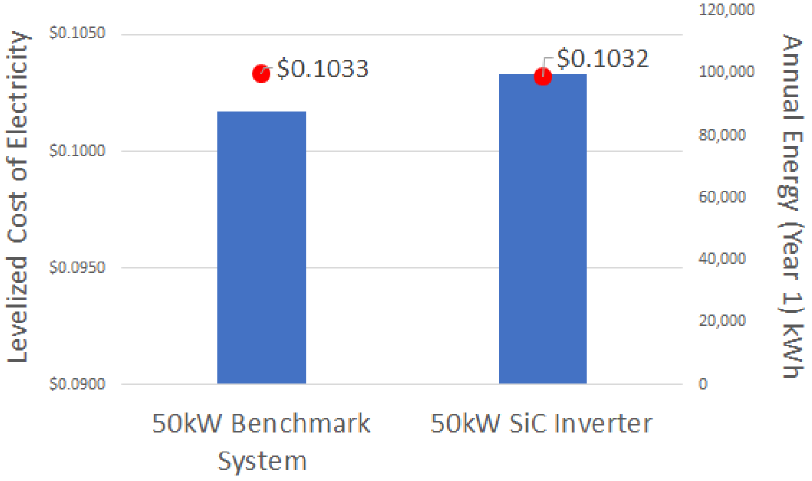


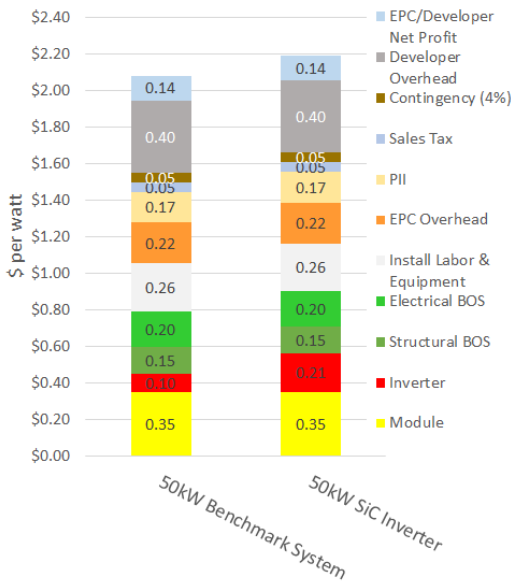
- Additionally the material cost analysis shows that further gains could be realized if SiC based electronics replace the transformer in the motor drive

Horowitz, Kelsey, Timothy Remo, and Samantha Reese. *A manufacturing cost and supply chain analysis of SiC power electronics applicable to medium-voltage motor drives*. No. NREL/TP-6A20-67694. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2017.

System Capabilities Provide Long Term Savings

- When the price exceeds current state of art it is still feasible to demonstrate economic viability.
  - For instance-> a case study comparing a 50kW SiC inverter to the SETO benchmarked 50kW Si based inverter.
    - SiC inverter system cost is 5.3% higher than benchmarked cost using a Si based inverter
    - SiC inverter system energy generation is 14% higher
    - Levelized Cost of Electricity (LCOE) is lower with SiC inverter based system
    - Does not take into account smaller size
    - Does not account for likely higher lifetime due to reduced cooling needs





Singh, Akanksha, Samantha Reese, and Sertac Akar. "Performance and Techno-Economic Evaluation of a Three-Phase, 50-kW SiC-Based PV Inverter." In *2019 IEEE 46th Photovoltaic Specialists Conference (PVSC)*, pp. 0695-0701. IEEE, 2019.

Thank you!

NREL/PR-6A50-81151

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