CEMAC
Clean Energy Manufacturing Analysis Center

Welcome to the CEMAC Annual Meeting!

13 March 2019

National Renewable Energy Laboratory

Golden, Colorado

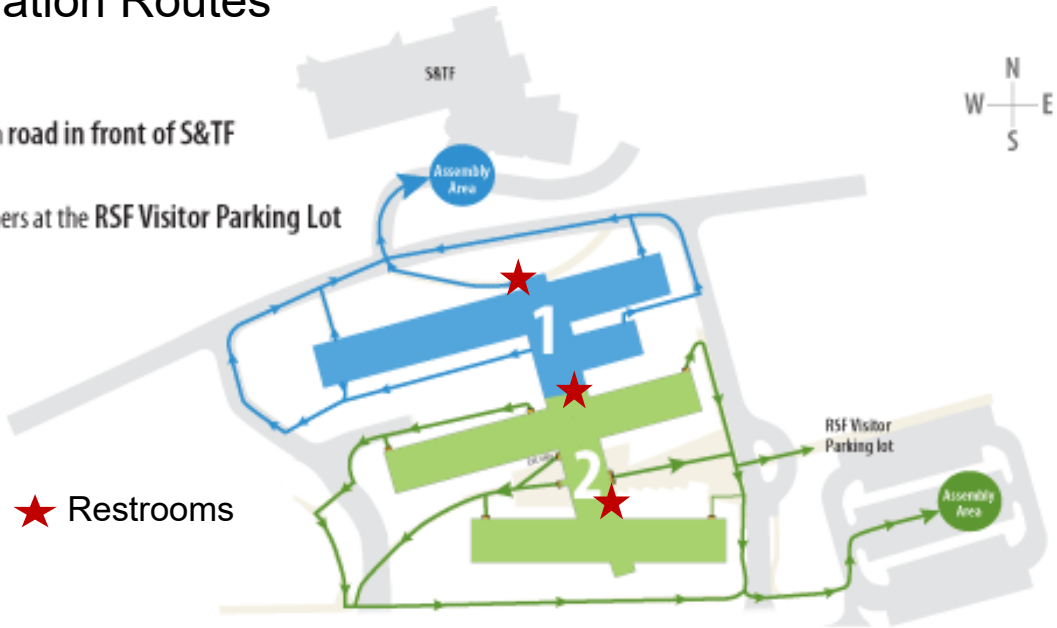
JISEA Joint Institute for Strategic Energy Analysis

Safety and Logistics

RSF Building Evacuation Routes

1 WING A evacuates north and gathers on **road in front of S&TF**

2 WING B AND C evacuates east and gathers at the **RSF Visitor Parking Lot**



Recycling/Compost/Trash

Blue Bin – Recycling	Green Bin – Compost	Gray/Tan Bin - Trash
• Plastics 1-7 • Glass • Cans • Paper	• Any food product • Paper Plates • Napkins, Paper towels, Kleenex • Compostable cups, plates, utensils • Tea bags	• Foil • Cellophane wrappers • Plastic bags • Styrofoam

Welcome

Debbie Sandor, CEMAC Lead

CEMAC Annual Meeting

March 13, 2019

Agenda

1. CEMAC Highlights
2. Advanced Manufacturing and the Circular Economy of Materials
   - Session 1: Global manufacturing: Measuring the value of international trade and supply chains
   - Session 2: Circular economy: Moving toward a circular economy of materials for clean manufacturing

CEMAC

Clean Energy Manufacturing Analysis Center

CEMAC Highlights

- Established in 2015 by the U.S. Department of Energy's Clean Energy Manufacturing Initiative (CEMI)
  - Operated by the Joint Institute for Strategic Analysis (JISEA)

- Provides objective, high- impact analysis, benchmarking, and insights of supply chains and manufacturing for clean energy technologies to promote economic growth and competitiveness in the transition to a clean energy economy

- Helps government and industry by:
  - Delivering credible & independent analysis on supply chains for clean energy technologies
  - Leveraging multidisciplinary teams from multiple institutions (national lab complex, DOE offices, U.S. federal agencies, universities and industry)
  - Utilizing innovative models, tools, and data
  - Increasing capacity for clean energy manufacturing analysis.

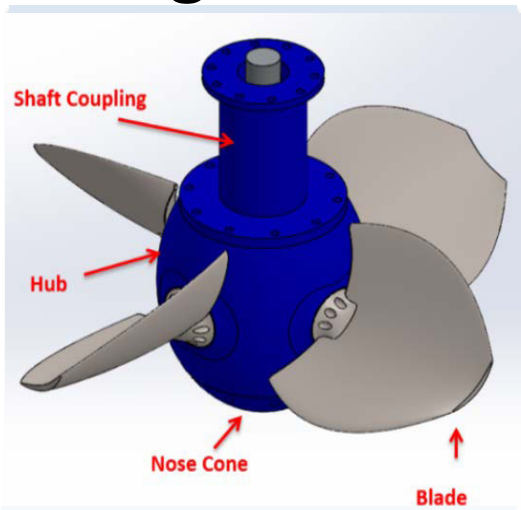
Established CEMAC Methodology & Key Results

Type of Analysis	Method & Approach	Key Result
Global supply chain analysis	-Define supply chain -Identify mfrs -Evaluate market	Raw materials, Production & capacity by mfr and location
Bottom-up comparative cost analysis	Assess cost and value of: -Mfg'd components along supply chain -Technology/mfg process improvements	Cost of mfg in different locations, by cost category (e.g., labor, capital)
Location & scenario analysis	Impact of non-cost factors on location decisions; dynamic site-selection	Examples: labor availability, reliability of grid, currency, quality
Benchmark analysis	Global and national value added impact & trade flow analysis	Economic impacts of clean energy manufacturing

Inform research and investment decisions

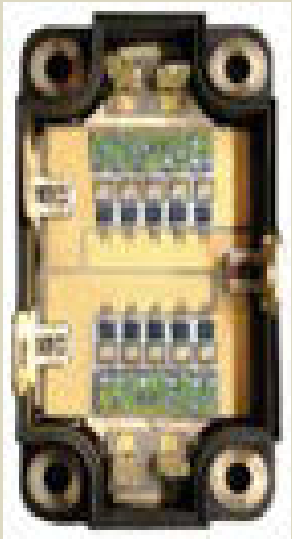
CEMAC Analysis Diverse Portfolio of Clean Energy Technologies

US Manufacturing of Agricultural Equipment for a Bio-based Economy



Supply Chains and Advanced Manufacturing of Small Hydropower Systems

Supply chain for automotive li-ion batteries



Global Manufacturing Cost and Supply Chain Analysis of SiC Power Electronics for Medium-Voltage Motor Drives

Global Supply Chain for Room Air Conditioning Compressors

Current State of Additive Manufacturing in Wind Energy Systems

U.S. manufacturers and suppliers have the potential to play leading roles in the global small hydropower (SHP) supply chain.

CEMAC Lead: Parthiv Kurup

- U.S. is a leading manufacturer of hydropower components and a leading exporter of small hydropower turbines: $35M in exports (2005 – 2015)
- U.S. experience and labor availability across the supply chain could meet domestic (4.8 GW) and global potential (71.7 GW) in re-powering non-powered dams, by 2050
- Significant opportunities for composites and additive manufacturing (AM) in SHP

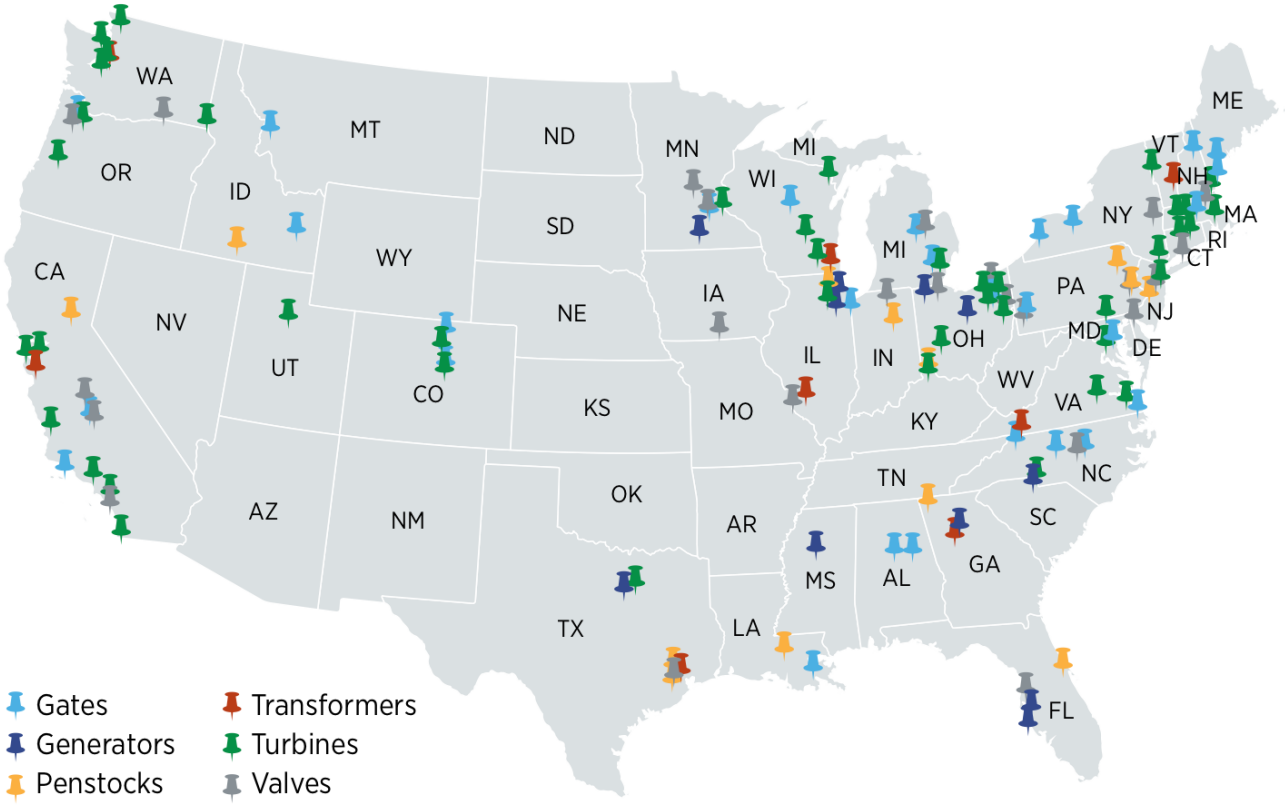


Figure 1. Map of U.S. hydropower manufacturing locations by state and components manufactured (Uría-Martinez, O'Connor, and Johnson 2015)

Standardized geothermal turbines could reduce plant capital costs.

CEMAC Lead: Sertaç Akar

- Today's geothermal turbines are custom designed specifically for varying conditions at different geothermal fields.
- The minimum sustainable price (MSP) varies between $893/kW and $30/kW based on turbine size, standardization, and volume of manufacturing.
- If manufacturers can successfully operate their facilities with standard design turbines, unit MSP per kW for the standard design turbines could be 60-70% cheaper than custom design turbines at larger volumes of manufacturing.

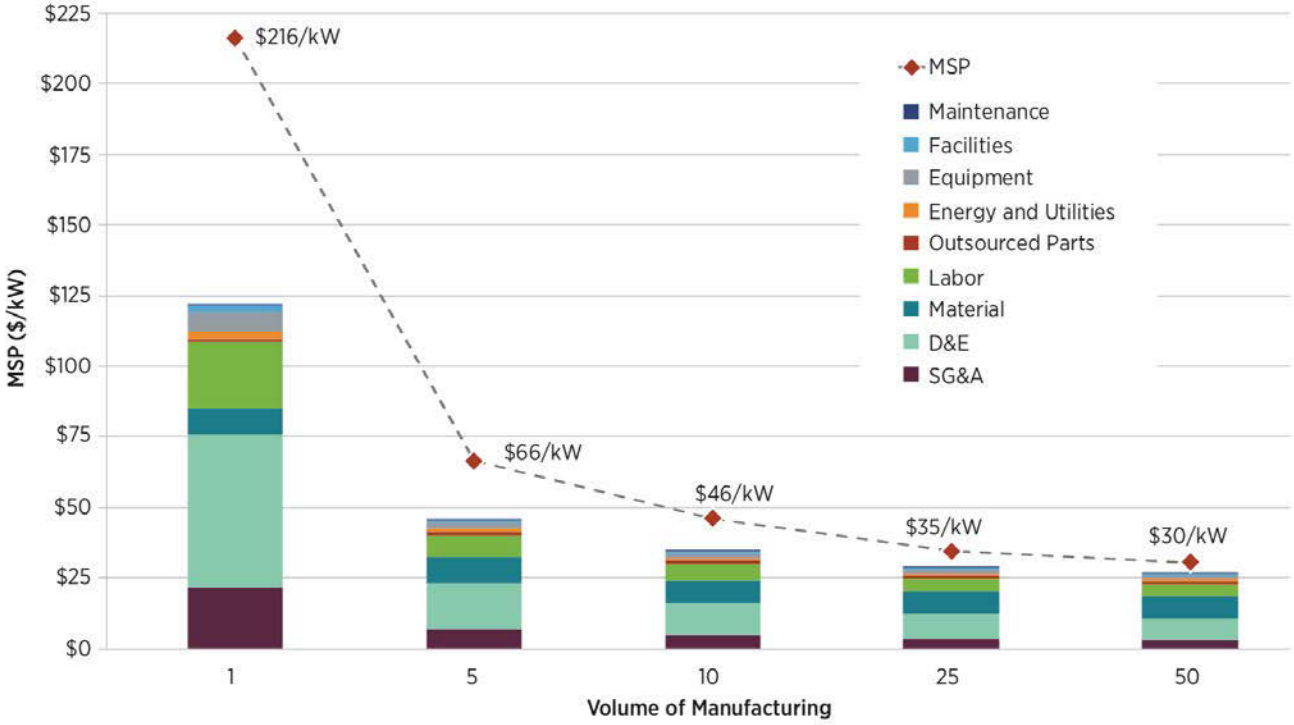
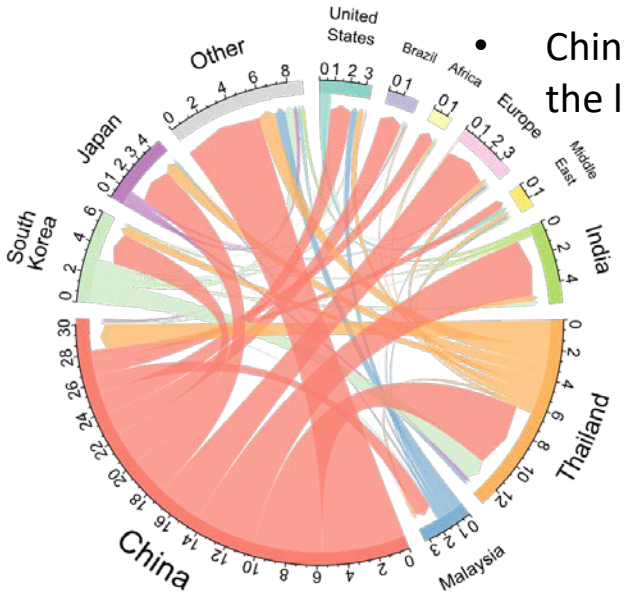


Figure 3. Manufacturing cost drop by cost factor for a standard design (10 units) 5-MWe ORC turboexpander

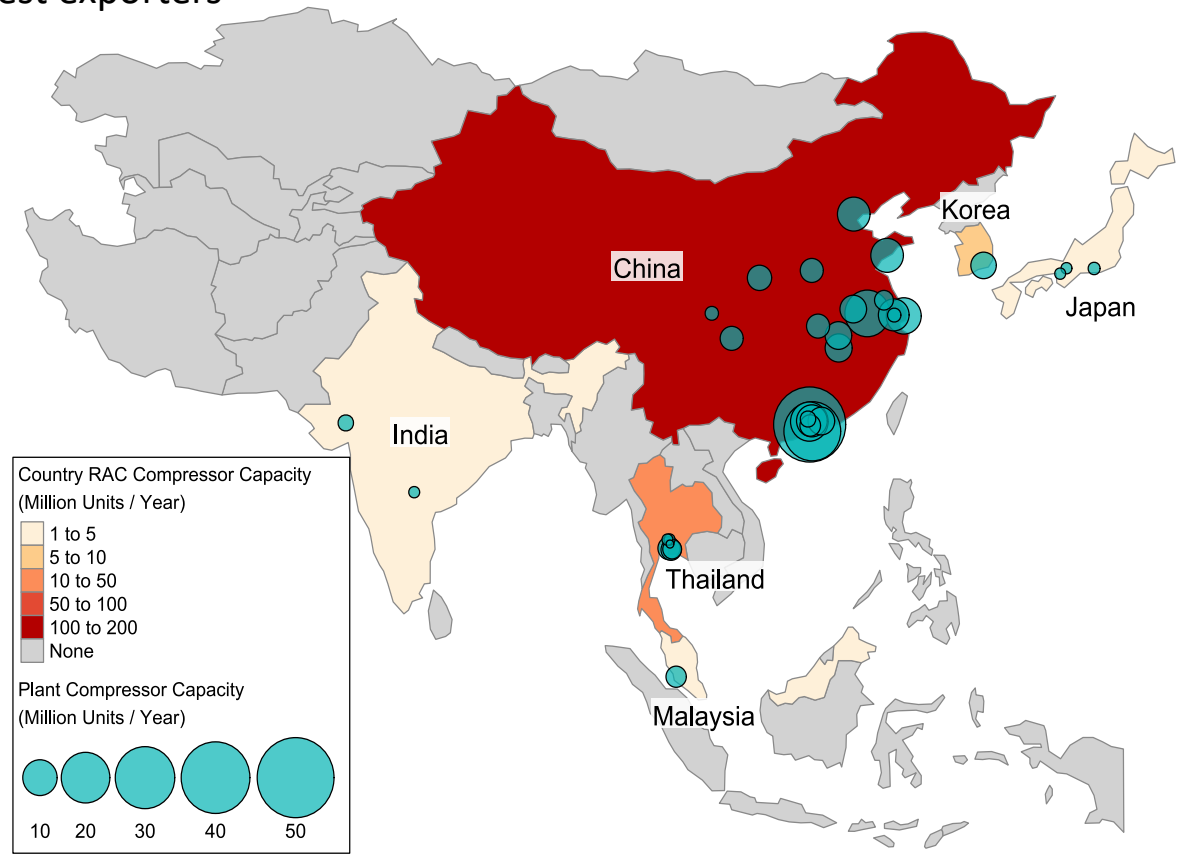
Asia is positioned to lead transition to more efficient, low-GWP residential air-conditioning (RAC) compressors.

CEMAC Lead: Scott Nicholson



2017 Global RAC compressor trade flow, in millions of units.

- China and Thailand are the largest exporters



RAC rotary compressor production capacity in Asia, September 2018

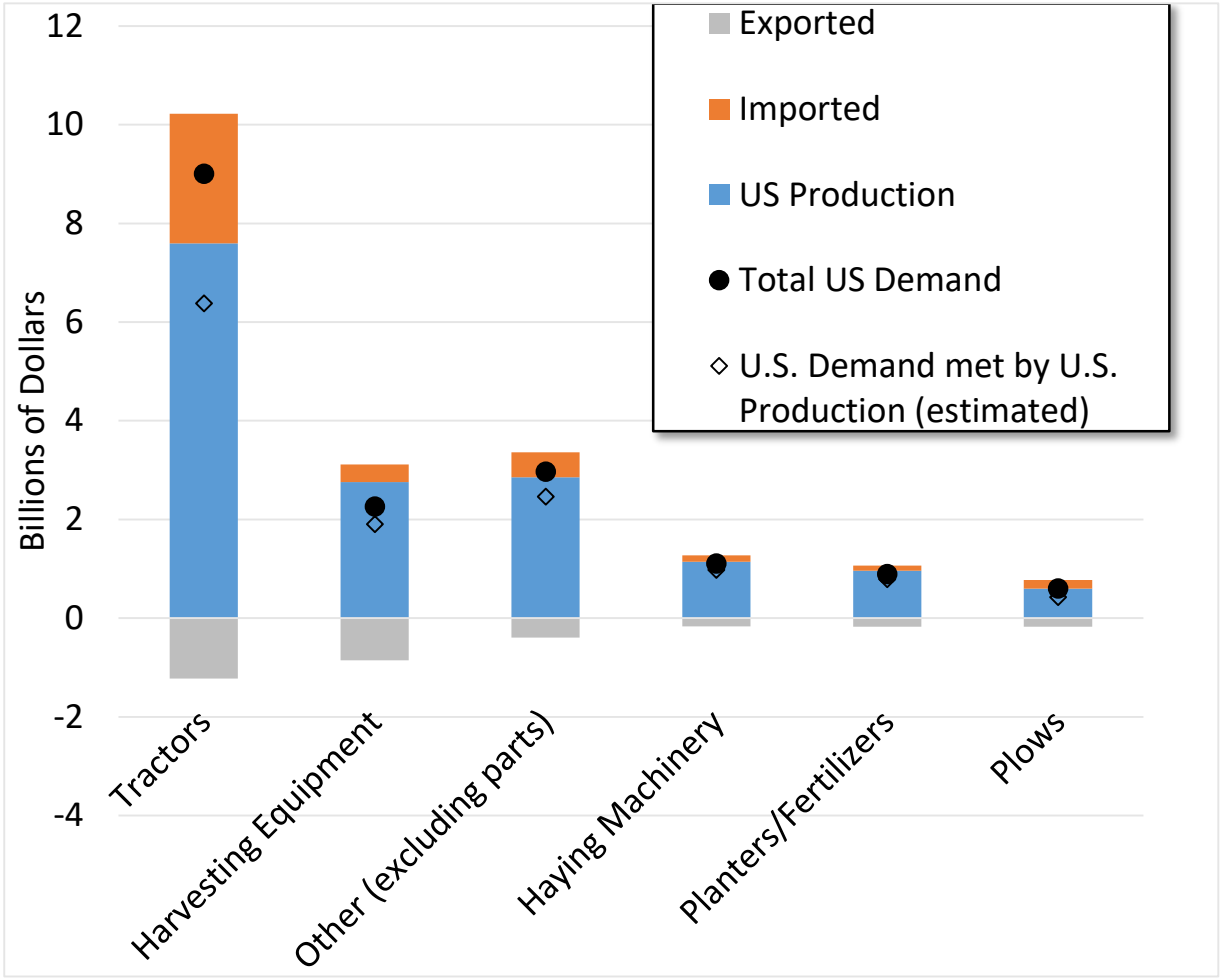
- Residential A/C compressor production is highly concentrated in Asia, led by China, with an estimated annual capacity of nearly 200 million units per year.
- Low market demand and regulations regarding use of some flammable low-GWP refrigerants are limiting adoption

U.S. agricultural equipment manufacturers are positioned to play a leading role in the transition to a bio-economy.

CEMAC Lead: Chad Augustine

- Historically, ~75% of farm machinery and equipment demand in the United States has been supplied by U.S. manufacturers
- Economic impacts of agricultural equipment manufacturing to support transition to billion-ton bio-economy in the US:
  - Value added to the US economy ranges from $6 - $16 billion
  - US employment impacts range from 150K – 200K FTE job years

Note: Estimates assume all required agricultural equipment is newly manufactured (93K-120K total pieces of new equipment) and 75% of equipment is manufactured domestically



2016 U.S. Agricultural Equipment Production and Trade Data

U.S. Demand = Production + Imports - Exports

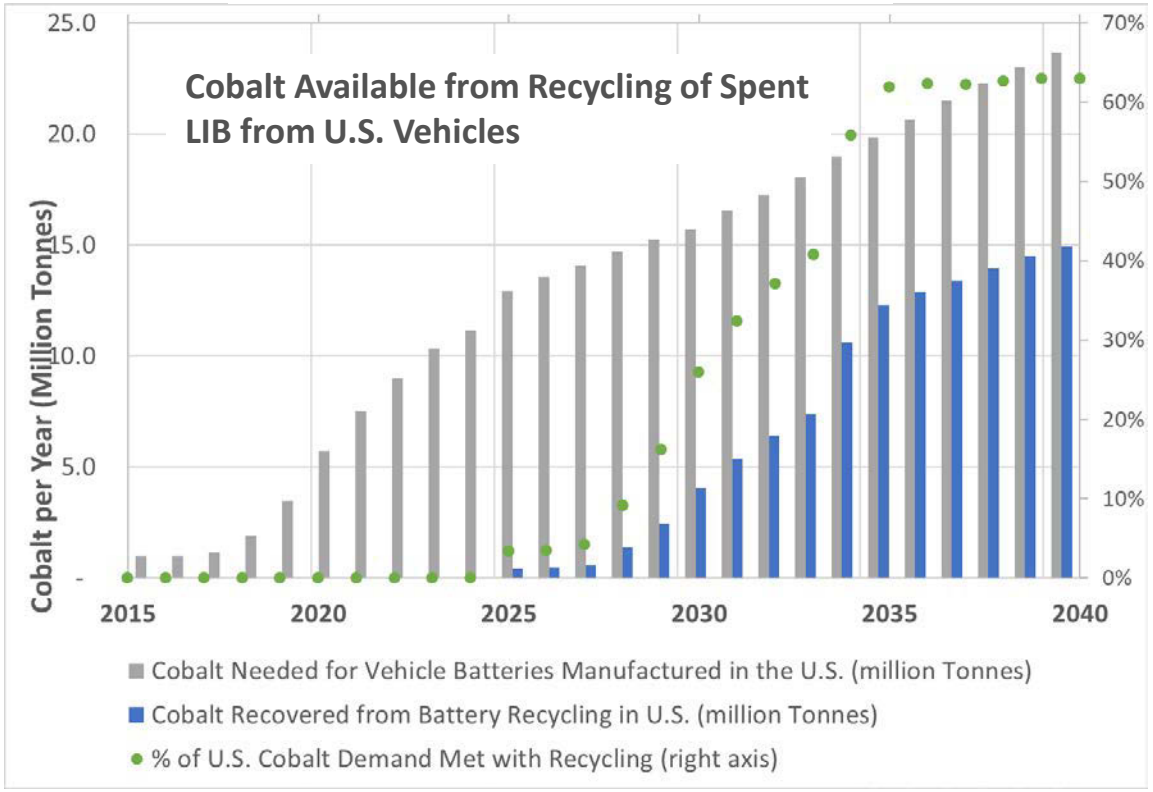
U.S. Demand met by U.S. Production = U.S. Production - Exports

Recycling of Li-ion batteries could supply 65% of U.S. cobalt demand by 2040.

CEMAC Lead: Maggie Mann

- Total global automotive Li-ion battery capacity is expected to exceed 90 GWh and require more than 500 thousand tons of battery materials (Li, Co, Mn, Ni, and Gr) by 2020
- Today, LIB recycling capacity is concentrated in EU and China
- U.S. is poised for expansion of LIB recycling capacity; by 2040, spent batteries from vehicles sold in the U.S. could supply 65% of US cobalt for US vehicle manufacturing
- Recovered cathode materials could save ~ 20% of the total LIB pack cost, with more savings achieved by recovering other materials and parts from spent batteries.

LIB Pack Value Chain in 2016 ($US/kWh)



CEMAC Published Analysis – Technology Specific

Biomass

- Evaluation of Agricultural Equipment Manufacturing for a Bio-based Economy – Forthcoming, in review
- Biochemical Supply Chain for Bioproducts - Forthcoming
- Supply and Value Chain Analysis of Mixed Biomass Feedstock Supply System for Lignocellulosic Sugar Production - *Biofuels, Bioproducts and Biorefining* (*Biofpr) Feb 2019*

Geothermal

- Global Value Chain and Manufacturing Analysis on Geothermal Power Plant Turbines - Sep 2018
- 2018 Research Highlight in Manufacturing: Global Value Chain and Manufacturing Analysis on Geothermal Power Plant Turbines - Oct 2018

Hydrogen

- Insights from Hydrogen Refueling Station Manufacturing Competitiveness Analysis – Dec 2015

Hydropower

- Analysis of Supply Chains and Advanced Manufacturing of Small Hydropower Systems - Jul 2018
- 2018 Research Highlight in Manufacturing: Analysis of Supply Chains and Advanced Manufacturing of Small Hydropower Systems – Oct 2018

CEMAC Published Analysis – Technology Specific

Li-ion Batteries

- Supply Chain of Raw Materials Used in the Manufacturing of Light Duty Vehicle Li-ion Batteries – Forthcoming, in review
- The case for recycling: Overview and challenges in the material supply chain for automotive li-ion batteries – *Sustainable Materials and Technologies Apr 2019*
- Automotive Lithium-ion Cell Manufacturing: Regional Cost Structures and Supply Chain Considerations - Apr 2016
- Automotive Lithium-ion Battery Supply Chain and U.S. Competitiveness Considerations – Jun 2015

Solar PV

- Expanding the Photovoltaic Supply Chain in the U.S.: Opportunities and Challenges – Forthcoming, in review
- System Dynamics of Polysilicon for Solar Photovoltaics: A Framework for Investigating the Energy Security of Renewable Energy Supply Chains"- *Sustainability January 2018*
- The Present and Future Silver Cost Component in Crystalline Silicon PV Module Manufacturing - *PV Tech Mar 2016*
- Economic Measurements of Polysilicon for the Photovoltaic Industry: Market Competition and Manufacturing Competitiveness - *IEEE Journal of Photovoltaics Mar 2015*

Wind

- The Current State of Additive Manufacturing in Wind Energy Systems - Sep 2017

CEMAC Published Analysis –Multiple Applications

Energy-Efficient Building Components/Systems

- Mapping the Supply Chain for Room Air Conditioning Compressors – Forthcoming, in review
- Energy Efficient Insulated Windows – Forthcoming, in review
- Refrigerants (Magnetocaloric and Emerging) – Forthcoming, in review
- 2018 Research Highlight in Manufacturing: End Uses of Low Global Warming Refrigerants – Forthcoming, in review

Carbon Fiber (for Lightweighting)

- Carbon Fiber Manufacturing Facility Siting and Policy Considerations: International Comparison - Jun 2017
- Carbon Fiber from Biomass - Sep 2016
- Global Carbon Fiber Composites Supply Chain Competitiveness Analysis – May 2016

Wide Bandgap Devices (for Improved Power Electronics Efficiency)

- A Techno-Economic Look at SiC WBG from Wafer to Motor Drive – June 2018
- Wide Bandgap Semiconductor Opportunities in Power Electronics – Nov 2017
- A Manufacturing Cost and Supply Chain Analysis of SiC Power Electronics Applicable to Medium-Voltage Motor Drives - Mar 2017
- Manufacturing: SiC Power Electronics for Variable Frequency Motor Drives – Aug 2017

CEMAC Published Analysis – Crosscutting

Annual Highlights

- CEMAC FY15 Research Highlights – Mar 2016

Benchmarking Clean Energy Manufacturing

- Benchmarks of Global Clean Energy Manufacturing 2014 – 2016 – Forthcoming, in review
- Benchmarks of Global Clean Energy Manufacturing – Jan 2017

Innovation Clusters

- Energy Innovation Clusters and their Influence on Manufacturing: A Case Study Perspective – Sep 2017

Recycling and Reuse in Manufacturing – future looking

- Circular Economy – analysis in progress – publications forthcoming

Lead Analysts and CEMAC Topic Leads

- Sertaç Akar (Geothermal)
- Chad Augustine (Bio-energy/Bio-fuels, Ag Equipment)
- Chuck Booten (Refrigerants, Critical Materials, Buildings)
- Scott Carron (Wind)
- Parthiv Kurup (Small Hydro, Concentrating Solar Power)
- Maggie Mann (Lithium ion battery recycling)
- Ahmad Mayyas (H2 and Fuel Cells, Batteries)
- James McCall (Windows, Integrated supply chain)
- Scott Nicholson (A/C Compressors, Biochemicals)
- Samantha Reese (Wide-band Gap/Power Electronics, LED)
- Debbie Sandor (Benchmark)
- Brittany Smith (Solar)

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THANK YOU!

NREL/PR-6A50-73688

This work was authored by the National Renewable Energy Laboratory, managed and operated by Alliance for Sustainable Energy, LLC for the U.S. Department of Energy (DOE) under contract No. DE-AC36-08G029308. Funding provided by the Joint Institute for Strategic Energy Analysis (JISEA). The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, Irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.