Summary

1. Clean Energy Manufacturing Analysis Center
2. Example of Clean Energy Manufacturing Analysis
3. Questions, Answers, and Discussion
Origin: Manufacturing Analysis Bridges Strategic Gaps

What is the global & regional supply chain?

What are competitiveness drivers?

How is competitiveness changing?

How does competitiveness align with roadmaps?

Multi-channel outreach

Transparent, consistent, validated methods

Widely available reports and insights

Regular updates to analysis

Protection of proprietary data

DOE Offices

F500 Firms

State & local gov’t

National Labs

Startups

Federal officials

Academics

Protection of proprietary data

Regular updates to analysis

Multi-channel outreach

Transparency, consistent, validated methods

Widely available reports and insights

What is the global & regional supply chain?

What are competitiveness drivers?

How is competitiveness changing?

How does competitiveness align with roadmaps?
Clean energy technologies are those that:

1. produce energy with fewer environmental impacts than conventional technologies, or
2. enable existing technologies to operate more efficiently, consuming fewer natural resources
3. includes renewable energy, cleaner non-renewable energy, and energy efficiency technologies
4. applications in electricity generation, fuel production, and sustainable transportation
CEMAC Vision & Mission

The Clean Energy Manufacturing Analysis Center (CEMAC) will be a definitive world leader of credible, objective, and recurring global clean energy manufacturing analysis to promote the transition to a clean energy economy.

The Clean Energy Manufacturing Analysis Program will:

• **Deliver world class analysis**, benchmarking, and insights of supply chains and manufacturing for clean energy technologies

• **Engage decisionmakers** to inform their decisions on investment strategies and policy to promote economic growth and competitiveness in the transition to a clean energy economy

• **Develop innovative models and tools**, distinctive talent, and unique and high-impact publications

• **Increase capacity** of other analysts to conduct clean energy manufacturing analysis through collaboration and training
Multi-organizational staff & partnerships

Lead Analyst
Lead Analyst
Lead Analyst

JISEA
Doug Arent
CEMAC Program Director
Jill Engel-Cox

Technical Director
Maggie Mann

Advisory Committee
Steering Committee

Study-specific competencies drawn from partner Labs:

Coordinated through Partner Working Group

Experts and students from university partners:

University of Colorado
TU
CO
BS
CEMAC Advisory Committee provides input

**Paul Camuti**
Senior Vice President Innovation & Chief Technology Officer
Ingersoll-Rand, Davidson, NC

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Executive in Residence, ERB Institute
University of Michigan, Ann Arbor, MI

**Dylan Cooper**
Lead Energy Marketing Specialist
The Dow Chemical Company
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Director, Clean Energy Initiative
The Pew Charitable Trusts, Washington, DC

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First Solar, Inc., Tempe, AZ

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Iberdrola Renewables
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Atlanta, GA

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Barclays, New York, NY

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Vice President –
Senior Credit Officer, Global Project & Infrastructure Finance
Moody’s Investors Service
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Georgetown University, Washington, DC

**Matt Zaluzec**
Manager of the Materials and Manufacturing Research
Ford Motor Company
Canton, MI
# Summary of manufacturing analysis types

<table>
<thead>
<tr>
<th>Analysis Type</th>
<th>Sample Outputs</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Supply Chain Analysis</strong></td>
<td>• Identification of key supply chain links, and their geographic distribution</td>
<td>• Improved understanding of potentially risky elements within the supply chain</td>
</tr>
<tr>
<td></td>
<td>• Supply curves for critical or scarce elements</td>
<td>• Combined with cost modeling, enables quantitative analysis of impacts to production costs</td>
</tr>
<tr>
<td><strong>2. Bottom-up Cost Analysis</strong></td>
<td>• Detailed engineering analysis of production processes</td>
<td>• Development, analysis, and validation of manufacturing technology value propositions</td>
</tr>
<tr>
<td></td>
<td>• Cost structure and drivers at each process stage and link in value chain</td>
<td>• Analytical basis for setting technology cost, price, and performance targets</td>
</tr>
<tr>
<td></td>
<td>• Benchmarking of current costs</td>
<td></td>
</tr>
<tr>
<td><strong>3. Technology Manufacturing Roadmaps</strong></td>
<td>• Cost-benefit analysis of proposed technology performance and manufacturing</td>
<td>• Rigorous method to compare technology development pathways</td>
</tr>
<tr>
<td></td>
<td>process improvements</td>
<td>• Identification and prioritization of R&amp;D areas based on cost and technology impacts</td>
</tr>
<tr>
<td><strong>4. Site Selection Support and Dynamic Modeling</strong></td>
<td>• Analysis of regional differences in production costs</td>
<td>• Better informed decision making for siting facilities and sourcing materials and components</td>
</tr>
<tr>
<td></td>
<td>• Analysis of location and other contextual information impacting manufacturing</td>
<td>• Informed feasibility assessment of manufacturing locations, both domestic and internationally</td>
</tr>
<tr>
<td></td>
<td>• Models of change scenarios and effect on manufacturing costs and supply</td>
<td>• Identification of risks with most impact and of mitigation approaches</td>
</tr>
<tr>
<td></td>
<td>chains</td>
<td></td>
</tr>
</tbody>
</table>
Elements of 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
## Current Portfolio of Technical Projects

<table>
<thead>
<tr>
<th>Technology</th>
<th>Tech Office</th>
<th>Lead Analysts</th>
<th>Partner Labs</th>
</tr>
</thead>
<tbody>
<tr>
<td>WBG Devices for Industrial Motors</td>
<td>AMO</td>
<td>Sam Reese, Kelsey Horowitz</td>
<td>NREL, ORNL</td>
</tr>
<tr>
<td>Carbon Fiber for Lightweighting</td>
<td>AMO</td>
<td>Sujit Das, Sam Booth</td>
<td>ORNL, NREL</td>
</tr>
<tr>
<td>Biomass-Derived Chemicals &amp; Products</td>
<td>BETO</td>
<td>Mary Biddy, Chris Scarlata, Jennifer Dunn, Felix Adom</td>
<td>NREL, PNNL, ANL</td>
</tr>
<tr>
<td>Conventional Heat Pumps</td>
<td>BTO</td>
<td>Anna Wall, Sam Reese, Rob Tenent</td>
<td>NREL</td>
</tr>
<tr>
<td>Magnetocaloric Cooling</td>
<td>BTO</td>
<td>Chuck Booten, Rob Tenent</td>
<td>NREL, ORNL</td>
</tr>
<tr>
<td>Energy-Efficient Insulated Windows</td>
<td>BTO</td>
<td>Jørn Aabakken, James McCall, Pieter Gagnon, Charlie Curcija</td>
<td>NREL, LBNL</td>
</tr>
<tr>
<td>LED Commercial Lighting</td>
<td>BTO</td>
<td>Sam Reese, Kelsey Horowitz</td>
<td>NREL</td>
</tr>
<tr>
<td>Hydrogen Refueling Stations</td>
<td>FCTO</td>
<td>Ahmad Mayyas</td>
<td>NREL, PNNL, ANL, Sandia</td>
</tr>
<tr>
<td>Geothermal Binary Power Plants</td>
<td>GTO</td>
<td>Sertaç Akar, Anna Wall</td>
<td>NREL</td>
</tr>
<tr>
<td>Solar PV</td>
<td>SETO</td>
<td>Donald Chung, Mike Woodhouse, Ran Fu, Kelsey Horowitz, Tim Remo</td>
<td>NREL</td>
</tr>
<tr>
<td><strong>Vehicle Li-ion Batteries</strong></td>
<td>VTO</td>
<td>Donald Chung, Emma Elgqvist</td>
<td>NREL, ANL</td>
</tr>
<tr>
<td>Wind Components via Additive Mfg</td>
<td>WWPTO</td>
<td>Christopher Mone, Tim Remo</td>
<td>NREL, ORNL</td>
</tr>
<tr>
<td>Hydropower Modular Systems</td>
<td>WWPTO</td>
<td>Jason Cottrell, Parthiv Kurup</td>
<td>ORNL, NREL</td>
</tr>
</tbody>
</table>
Automotive Lithium-ion Battery (LIB) Supply Chain

Donald Chung, Emma Elgqvist, CEMAC

With contributions from experts at Argonne National Laboratory, National Renewable Energy Laboratory, U.S. Department of Energy, and Industry Partners
Key xEV LIB Value Chain Characteristics

2014 Best-in-Class PHEV LiB Value Chain ($U.S./kWh)

<table>
<thead>
<tr>
<th>Raw Materials</th>
<th>Processed Materials</th>
<th>Electrodes</th>
<th>Cells</th>
<th>Battery Pack</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>$168</td>
<td>$28</td>
<td>$146*</td>
<td>$229</td>
<td>$571</td>
</tr>
<tr>
<td>Share</td>
<td>29%</td>
<td>5%</td>
<td>26%</td>
<td>40%</td>
<td>100%</td>
</tr>
<tr>
<td>Currently Shipped</td>
<td>Globally</td>
<td>Globally</td>
<td>Regionally</td>
<td>Globally</td>
<td>Locally</td>
</tr>
<tr>
<td>Success Factors</td>
<td>• Indigenous resources</td>
<td>• Critical to quality</td>
<td>• Critical to quality</td>
<td>• Critical to quality</td>
<td>• End-product knowledge and integration know-how</td>
</tr>
<tr>
<td></td>
<td>• Low export restrictions or limitations</td>
<td>• Demand assurance</td>
<td>• Processing know-how: e.g. coating thickness uniformity, solvent &amp; moisture content.</td>
<td>• Processing know-how: e.g. stack uniformity, drying, formation, electrolyte additive</td>
<td>• Proximity to customers: shipping costs, exchange of technical specifications</td>
</tr>
</tbody>
</table>

* Ex factory gate – shipping from Asia to the west coast of the United States adds approximately $7/kWh
Sources: NREL estimates; BNEF (2014); Pike (2013)

These costs are changing rapidly and dramatically. Frequent updates in dynamic markets are required!
LIB Cell Manufacturing Locations and Capacity: Today, LIB Cell Manufacturing Is Heavily Concentrated in Asia...

<table>
<thead>
<tr>
<th>Country</th>
<th>Fully Commissioned</th>
<th>Partially commissioned</th>
<th>Under construction</th>
<th>Announced</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>11,152</td>
<td>3,038</td>
<td>16,244</td>
<td>19,246</td>
</tr>
<tr>
<td>Japan</td>
<td>13,623</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Korea</td>
<td>6,570</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>U.S.</td>
<td>4,125</td>
<td>0</td>
<td>0</td>
<td>35,150</td>
</tr>
<tr>
<td>EU</td>
<td>1,293</td>
<td>0</td>
<td>5,000</td>
<td>0</td>
</tr>
<tr>
<td>Rest of World</td>
<td>3,390</td>
<td>0</td>
<td>0</td>
<td>120</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>40,153</strong></td>
<td><strong>3,038</strong></td>
<td><strong>21,244</strong></td>
<td><strong>54,516</strong></td>
</tr>
</tbody>
</table>

Note: This map includes factories that are fully and partially commissioned, under construction, and announced. Capacity is not disclosed for all factories.
...As Is Upstream Processed Materials Manufacturing

Regional LIB Supply Chains and Trade Flows

Sources of raw materials for Lithium Ion Batteries
• 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.
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 diversified sales channels; process and technology innovations; and other learning effects.
  • Incumbent experience can manifest as higher production yields, which significantly influence competitive manufacturing opportunities.

• 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.
More information can be found in detailed reports on our website and our Annual Research Highlights Report.

Available on our website
www.manufacturingcleanenergy.org
More information...

Website:  www.manufacturingcleanenergy.org (check out our blog!)
LinkedIn:  www.linkedin.com/company/clean-energy-manufacturing-analysis-center (please follow!)

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.

From Classroom to Factory Floor
January 29, 2016
By Jill Engel-Cox, Ph.D., Clean Energy Manufacturing Analysis Center

The U.S. Energy Department’s Industrial Assessment Centers (IACs) program celebrates 40 years of service to industry this year.
Purpose: Provide annual assessment of global state of clean energy manufacturing to inform energy policy and investment strategies and promote economic growth

Target release: Fall 2016

Future: Defined & started annual Benchmark Report

Market Benchmark: Manufacturing Capacity

China

U.S.

Market Benchmark: Global Market Size

Trade Benchmark: Global Trade Flows

Trade Benchmark: Value Added

Table 12. Value Added Supported by Solar Photovoltaic Manufacturing in the United States ($ 2014 Millions)

<table>
<thead>
<tr>
<th></th>
<th>Polysilicon</th>
<th>Wafers*</th>
<th>Cells</th>
<th>Modules</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>$284</td>
<td>$0</td>
<td>$81</td>
<td>$488</td>
<td>$852</td>
</tr>
<tr>
<td>Indirect</td>
<td>$278</td>
<td>$0</td>
<td>$59</td>
<td>$359</td>
<td>$696</td>
</tr>
<tr>
<td>Total</td>
<td>$561</td>
<td>$0</td>
<td>$140</td>
<td>$847</td>
<td>$1,548</td>
</tr>
</tbody>
</table>
Proposed: Scenario Analysis with Dynamic Modeling

Example question that can be explored: What conditions would lead to competitive LIB cell manufacturing in the U.S.?

- How resilient would a U.S. LIB industry be to disruptions or long term trends?
- What are influences and feedbacks around locating new LIB manufacturing?
- What impact would shifts in competition for manufacturing resources among different industries have on LIB?
- Which components of LIB costs evolve most quickly and most regionally?
- How do varying incentives and a U.S. cost disadvantage interact?
- What are the drivers for long term U.S. manufacturing attractiveness?

Dynamic modeling facilitates learning and
- Highlights potential shifts in the industry.
- Explores scenarios leading to different industry profiles.
- Sheds light on evolutionary paths and viability of change.
- Identifies points of leverage for influencing industry evolution.
- Assesses industry’s response to disruption and its resilience.

Related questions
Questions, Answers, and Discussion

Thank you!
CEMAC seeking collaboration with industry and universities

Clean Energy Manufacturing Analysis Center assists industry by providing objective value chain and cost analysis on the manufacturing of clean energy technologies.

Types of analysis include:
1. Supply chain overview and analysis
2. Bottom-up manufacturing cost analysis
3. Technology manufacturing roadmaps
4. Site selection support and dynamic modeling

How to work with CEMAC:
• Sponsor proprietary analysis
• Jointly sponsor open sector studies with similar industries
• Participate in U.S. DOE small business voucher program
• Share information to contribute to government-sponsored studies

Website: www.manufacturingcleanenergy.org