

Advanced Technologies for Clean Energy Manufacturing

Isaac Chan, U.S. Department of Energy

The U.S. manufacturing sector remains a powerful driver of the U.S. economy, even after significant job losses and an upsurge in competition from imported goods over the past two decades. Manufacturing contributed nearly \$1.6 trillion to U.S. GDP in 2009 (based on current dollars), or about 11% of the total, and created more wealth than any other sector. Clean energy manufacturing—now on its way to becoming a trillion-dollar global enterprise—presents a rare opportunity for productively focusing investments and revitalizing U.S. manufacturing. Potential benefits of investing in clean energy technology include increasing domestic manufacturing capabilities in clean energy manufacturing, providing access to environmentally sound, clean energy options; improving our position in an emerging, high-value global market; creating enduring, high-paying domestic jobs; and stimulating economic growth.

Examples of Clean Energy Technology

- ✓ Resource recovery and reuse
- ✓ Renewable feedstocks
- ✓ Electricity storage
- ✓ Fuel cells
- ✓ Renewable energy (solar, wind, geothermal, bioenergy, hydro)
- ✓ Nuclear fission and fusion
- ✓ Advanced vehicles

Advances in technology are needed to reduce the time and cost required to translate clean energy innovations into commercial processes, products, and companies in the U.S. Some of the most pressing challenges in manufacturing arise from the need to cost-effectively produce low-cost, high-performance, reliable, and long-life energy technologies at high throughput rates. Advanced, innovative, and ultra-efficient materials, processes, and products are required to lower costs and sustainably deliver the first choice in equipment and components for generating clean, affordable energy.

Some potential technology areas important to manufacturing, particularly for clean energy technology, include:

- **Manufacturing and modification of large engineered surfaces** - Processes are needed to improve or enable cost-effective production of engineered surfaces at large scale for clean energy devices, such as textured silicon for light trapping, textured tubes and pipes for heat transfer, or large blades with enhanced aerodynamics or other specialized properties. The challenge is to reliably manufacture structures with dimensions in the tens or hundreds of meters while consistently providing functional features in the range of 10 to 100 nanometers.
- **Manufacturing and assembling methods for ultra-thin components** - Cost-effective, high-throughput manufacture of clean energy technologies will require methods for handling very thin crystalline or flexible polymeric materials. Critical challenges include consistently meeting exacting product quality parameters without defects, increasing process control, reducing expenses, and adaptation to high-volume manufacturing.
- **Micro-manufacturing for clean energy systems** - Innovative micro-manufacturing techniques are sought for high-volume production of micro-devices or engineered micro-surfaces that can be applied to a variety of clean energy technologies. Such innovative techniques might, for example, lead to continuous roll-forming with embedded micro-features. Some of the key challenges are to

achieve effective use of micro-techniques in high-throughput production; successful fabrication of thin-walled micro-devices on a large scale; and uniform micro features over large surface areas.

- **Bio-inspired or biological manufacturing** - Applied concepts are needed to explore use of biological systems to provide entirely new approaches to manufacturing at the macro-, micro- and nano-scales. Complex and sophisticated biological structures hold untapped potential to out-perform current micro-fabrication or nano-fabrication techniques. Challenges include high-throughput biological growth and engineering the biological structure for optimal performance.
- **Flexible manufacturing methods for clean energy technology** - Manufacturing platforms need to be more flexible and modular to cost-effectively provide greater responsiveness to rapidly shifting customer requirements. Approaches such as single-setup, tool-less manufacturing may be possible, decoupling production from the economies of scale required in traditional machining. Distributed systems (e.g., modular, autonomous) are needed to reduce unit manufacturing costs, improve the energy efficiency of clean energy technologies, and enable wider use in smaller applications. The challenges include developing plug-and-play architectures; machining complex features in metals, ceramics, and composites with a high level of accuracy; and creating simplified tooling and operations.
- **Smart manufacturing (SM)** - Advanced and adaptive smart manufacturing (SM) technologies are needed for clean energy technology to attain high throughput rates, improved product quality, high flexibility, and expanded market share. SM encompasses the development, comprehensive integration, and assimilation of multiple, knowledge-intensive technologies and operating strategies—not only at plant sites, but at enterprise (multi-plant) and regional (multi-company) levels. The SM concept seeks to make full use of IT hardware and software advances embodied in the ‘cyber’ infrastructure. SM creates robust “manufacturing intelligence” to reduce energy consumption; improve the sustainability of operations; drive environmental, health, and safety incidents toward zero; and dramatically increase the competitiveness of U.S. industrial sectors.
- **Low-cost, real-time process control** - New control schemes are needed to optimize energy and material efficiency while maintaining the high quality of clean energy products. Process control is a significant challenge for some newer clean energy technologies that have dramatically ramped up production over the last few years. For some technologically sophisticated products, real-time inspection and monitoring of product quality will become an increasingly critical challenge as the rates of throughput increase.
- **Molecular scale manufacturing** - Manufacturing new products at the molecular scale, as required for some current and emerging clean energy technologies, will benefit from tools that can analyze complex processes with unprecedented scales of granularity. Sophisticated information processing capabilities will be essential for integrating product design and production processes at very small scales. New molecular-scale processes and control systems will require sensing and measurement technology well beyond today’s state of the art.
- **Computational technologies** - Sophisticated hardware and software will be required to enable the efficient application of advanced manufacturing systems, such as digital engineering and manufacturing, advanced robotics, and other intelligent production systems. Advanced computational tools will reduce development time and time to market, resource requirements, and energy inefficiencies.