Editorial
Automation in Green Manufacturing

MANUFACTURING accounts for a significant portion of energy expenditure. The industry's energy demand is one-third of the total energy consumption in the U.S. Limited natural resources may be used to generate these energy. Greenhouse gases, harmful emissions may also be generated during material processing, and waste disposal may create pollution to the environment. All these can lead to harmful consequences to our future. Although substantial improvement has been made, the energy and environment still remain as top concerns for manufacturers and consumers despite the economic downturn. Thus, energy efficient and environmentally friendly (EEEF) manufacturing practices are of significant importance.

Green manufacturing plays a key role to provide cleaner energy source, reduce atmospheric emissions, degrade the impact of greenhouse gasses, save natural resources and energy, maximize yield and minimize waste, etc. It would not only be important to the rapidly growing renewable energy and clean technology sector, but also be substantially beneficial to society and economy. It is estimated that green energy can save EU 3 trillion euros by 2050. The "green" jobs are growing faster than overall job growth in the U.S. Thus, going "green" or "sustainable" is not an option, but a necessity. It is noticeably becoming a major component of the missions for manufacturers to stay globally competitive.

Green manufacturing covers a broad spectrum of manufacturing, from development of green technology products, implementation of advanced manufacturing and production technologies, and introduction of energy efficient and environmentally friendly manufacturing processes and systems, from the plant floor to the enterprise level, and the whole supply chain. Here, we interpret green manufacturing as follows:

- Manufacturing of green technology products, in particular, those used in renewable energy systems and clean technology equipment.
- Manufacturing process and system control to address energy and environmental concerns, such as reducing pollution and waste, reducing emissions, minimizing natural resource and energy usage, recycling and reusing what was considered as waste before, etc.

Automation, as an vital element to the success of green manufacturing, plays a crucial role to achieve the "green" objective in manufacturing. It stands at the forefront of redesigning, restructuring, re-engineering, and retooling operations and processes to be more environmentally and socially sustainable. It has attracted substantial effort from researchers in both academic and industrial communities to provide efficient scientific and engineering solutions for green manufacturing. In recent years, significant advances in technology and the fast growing and rapidly changing markets have generated numerous innovations in automation. At the same time, many new techniques have emerged in applying and implementing these innovations. Such advances have significantly expanded the scope of traditional automation research.

The central theme of this Special Issue is *emerging opportunities and future directions in automation for green manufacturing*, where information technology based modeling, analysis, control and optimization are the focus areas. The purpose is to show the state-of-the-art research and applications in the general area of automation in green manufacturing, by bringing together researchers and practitioners from both academia and industry, to address the significant advancement, expose the unsolved challenges, present the critical needs for integration with new technologies, and provide visions for future research and development. This Special Issue presents original, significant and visionary automation papers describing scientific models, methods and technologies with both solid theoretical development and practical importance that improve process, efficiency, productivity, quality, and reliability in green manufacturing.

The contributions in this Special Issue can be divided into the following categories in green manufacturing: renewable energy products and systems; energy savings in manufacturing processes and systems; remanufacturing system design; and emission reduction in supply chain management. Specifically, the following papers are included in this Special Issue.

The first category addresses renewable energy source, which includes manufacturing and operation of alternative energy products, such as batteries for electric vehicles, and system design to support manufacturing activities using renewable energy sources, such as electricity generated by wind turbines and solar panels.

Ju, Wang, Li, Xiao and Biller, in paper, "Virtual Battery: A Battery Simulation Framework for Electric Vehicles," introduce a battery simulation framework for electric vehicles, within which the impact of quality of welding process on battery performance during usage, such as charge, discharge, cell capacity, etc., can be analyzed. Such information could be used to improve manufacturing process to achieve better quality and reliability in batteries.

Villarreal, Jimenez, Jin, and Cabrea-Rios, in their paper, "Designing a Sustainable and Distributed Generation System for Semiconductor Wafer Fabs," study designing a grid-connected distributed generation (DG) system to provide electricity to the semiconductor wafer fabs using renewable energy sources, i.e., wind and solar power. Simulation-based optimization method is applied to determine the type and capacity of the equipment to minimize DG life cycle cost.

The second category focuses on energy savings in manufacturing, such as operational control and robot scheduling to minimize energy consumptions in production, optimal design of facility and production to reduce energy cost.

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Chen, Zhang, Arinez, and Biller, in paper "Energy-Efficient Production Systems Through Schedule-Based Operations," introduce a transient analysis method to predict the performance of a serial production line. Using such a method, machine startup and shutdown schedules can be determined based on the current status of the line and production requirement to achieve energy consumption reductions.

Sun and Li, in their paper, "Opportunity Estimation for Real-Time Energy Control of Sustainable Manufacturing Systems," investigate the opportunities for energy control in manufacturing systems without sacrificing productivity. A method is presented to estimate such opportunities by considering system behavior and buffer levels to shut down machines or assign them to sleep mode so that energy cost can be reduced.

Mashaei and Lennartson, in paper, "Energy Reduction in a Pallet-Constrained Flow Shop Through On–Off Control of Idle Machines," design a control policy to turn off the idle machines and reduce their energy consumption level for a closed-loop flow shop. A desired set points of control parameters are derived to govern plant operations so that machine operation and pallet movements are coordinated to maintain minimal energy usage and obtain the desired throughput.

Wigstrom, Lennartson, Vergnano, and Breitholtz, in paper, "High-Level Scheduling of Energy Optimal Trajectories," present a new trajectory scheduling algorithm to minimize energy consumption in robotic manufacturing systems. By applying the dynamic programming to design robot trajectories, an energy optimization model is introduced to schedule manipulations of speed and acceleration by the robot controller.

Liu, Zhao, Huang and Zhao, in their paper "A simulation-based tool for energy efficient building design for a class of manufacturing plants," explore an energy efficient design of a manufacturing plant by considering energy consumption due to production, weather, and building configurations, etc. Using EnergyPlus to estimate energy consumption, a stochastic programming problem is formulated to minimize energy cost and solved using Ordinal Optimization.

The third category extends the study to remanufacturing, which plays a significant role to achieve sustainability and multiple life cycles. This includes remanufacturing system analysis, design and optimization, such as strategies for recycling, reassembly, etc.

Wolf, Colledani, Gershwin, and Gutowski, in paper, "A Network Flow Model for the Performance Evaluation and Design of Material Separation Systems for Recycling," develop a network flow model to analyze the performance of a material separation process with recycling, which targets multiple desirable materials and refines them to specified levels of purity and recovery. In addition to performance evaluation, the model is used to solve system design problems to improve the performance of recycling systems.

Jin, Hu, Ni, and Xiao, in paper, "Assembly Strategies for Remanufacturing Systems With Variable Quality Returns," investigate the optimal assembly strategy in a remanufacturing facility which substitutes returned products with good quality modules, and reassembles them to satisfy customer orders. A Markov decision model is introduced to characterize the structure of the optimal control policy.

Li, Tang, Li, and Li, in paper, "A modeling approach to analyze variability of remanufacturing process routing," present an analytical method to study remanufacturing process routings. Four graphical evaluation and review technique-based models are proposed to represent and analyze the variability of remanufacturing task sequences and investigate the relationships between remanufacturing process dynamics and system performance.

Finally, the last category considers supply chain management, within which multiple firms work together to reduce negative environmental impact.

Benjaafar, Li, and Daskin, in their paper, "Carbon Footprint and the Management of Supply Chains: Insights From Simple Models," illustrate how carbon emission concerns can be integrated into decision making with respect to procurement, production and inventory management. They also investigate the impact of collaborations among firms within the same supply chain on their cost and carbon emissions, and study the incentives the firms may have in seeking the collaborations.

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