Modular, Intensified Processes Promote Resilient Manufacturing

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The COVID-19 pandemic has exposed unique vulnerabilities — illustrated most acutely in the healthcare sector. A sudden surge in demand for chemical and material products (*e.g.,* hand sanitizer, N-95 face masks, gloves, test kits) caused shortages due to the lack of manufacturing capacity and supply chain bottlenecks. The processes and systems required to address the surge and reduce the magnitude and/or duration of the disruption were not resilient.

Resilience is the capacity to bounce back or recover from a disruption. In the context of manufacturing, the disruption could be a supply chain failure, extreme weather event, new regulations, cyber-attack, or physical threat such as a pandemic.

Traditional operations risk management focuses on tackling supply chain disruptions while the production or manufacturing process remains static. This paradigm does not consider distributed manufacturing systems, which can be deployed in the wake of a disaster to perform as well as or better than existing systems. Chemical engineers have long considered risk management, but are just beginning to think about resilience. While risk management is proactive — efforts are designed to prevent or defuse threats before they occur — resilience focuses on the aftermath, including recovery and adaptation.

The most resilient options, however, may not always be the most efficient or economical. Real-world traffic networks illustrate this tradeoff best. For example, the transportation network of Jacksonville, FL, is connected by just a few large bridges that span the St. Johns River. The network is efficient during normal operations but suffers during a disruption. The traffic in Los Angeles, CA, on the other hand, is infamous even on a normal day. But, because the roads are highly interconnected, motorists are able to take multiple routes, enabling the system to recover relatively well from disruptions.

The chemical process industries (CPI) are more like Jacksonville than Los Angeles. Current plants were built for baseline efficiency, not to weather a disruption. The concentration of oil, gas, and petrochemical facilities along the Texas Gulf Coast, for example, enables easy access to shipping terminals and abundant, inexpensive oil and gas. But, in the event of a disruption, such as a hurricane, clustering increases the potential for significant loss of functionality in the petrochemical and refining sector.

Across the CPI, the focus has been on inexpensive, high-volume commodity products or high-performance, low-volume specialty products. Distributed modular chemical process intensification (MCPI) is an alternative to the current bigger-is-better plant model. MCPI is an attractive concept because factory-built modular plants can be easily distributed, repositioned, and stacked in parallel to achieve scale, while process intensification (PI) can overcome the inherent loss of economies of scale associated with a smaller process. Some critics of MCPI point to the loss of economies of scale, but recent studies argue that many of those economies can be recouped through economies of module mass production.

The resilience advantages of MCPI are clear. Small modular MCPI plants are flexible and can be deployed and redeployed in response to various disruptions, such as feedstock supply interruptions. Small modular plants are quicker to build (and rebuild), because modules are fabricated in an efficient factory setting and the plant site can be prepared during the fabrication. Also, if a major manufacturer were to suddenly exit the market, the lower upfront capital cost for MCPI could lower the barrier for a new company to fill the void.

MCPI could help democratize the CPI similar to the way personal computers democratized computing, the internet democratized information, and additive manufacturing democratized discrete manufacturing. Resilient manufacturing would give rise to distributed processes capable of converting raw materials to final products at or close to the feedstock or point of use. Distributed inline blending operations for hand sanitizer production from readily available raw materials or flexible, on-demand production of vaccines or other therapeutics could help address our current crisis.

Multiscale process systems studies have streamlined scaleup. These efforts required overcoming challenges that have motivated the design of new process equipment and control strategies and better operational features. This work has promoted PI and created smaller but better facilities that have fewer stages and are often more resilient, eliminating links in the supply chain susceptible to failure. Incorporating the concepts of reliability, flexibility, robustness, agility, and disaster risk management with MCPI techniques can provide unique solutions for the resilience of the manufacturing sector. MCPI will be in demand where resilience is valued over baseline economics. CEP