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Distributed Manufacturing for the Process Industries

At the RAPID Manufacturing Institute, we spend a great deal of time thinking about how we can shape the future of the U.S. chemical process industries (CPI). This means working with RAPID members to define both the technical concepts that underpin process intensification (PI) and modular processing, as well as the educational content that will change how current and future chemical engineers think about process development. Decentralized infrastructure is one concept that is poised to greatly impact the CPI.

It's not just the CPI that are being disrupted by decentralized infrastructure. Transportation has undergone major changes with the introduction of ridesharing services, including Uber and Lyft, as well as bike- and scooter-sharing programs, such as JUMP, Zyp, and CitiBike. The desire to move has been decoupled from the need to own a vehicle.

Similarly, low-cost and ubiquitous computing and data storage, arguably drivers for the decentralization revolution, are being upended. Companies such as Amazon, Microsoft, Google, and IBM allow users to outsource data centers to cloud storage options. Users no longer need to own and manage private data centers.

Discrete product manufacturing is being comparably disrupted. Additive manufacturing, whether applied alone or in combination with subtractive machining or other techniques, can be used to digitally print polymers and metals. These 3D-printed shapes can take the form of complex structures that traditional techniques could not achieve. Whereas the design, tooling, and prototyping process used to take days or months, the combination of advanced modeling tools and additive manufacturing now allows users to go from an *in silico* concept to a manufactured part in minutes or hours. For certain industry segments, this promises to dramatically reduce new product development times and spare parts inventories.

While advanced computing has changed the way chemical engineers design and test materials and model and control process systems, the industry has yet to feel the broader impact of decentralization. This is partially rooted in process development history. As chemical engineers, we are trained to think in terms of power law scaling, which produces large, centralized "stick-built" production facilities that take advantage of massive economies of scale. This model will surely continue to serve segments of the CPI, but increasingly sources of dispersed raw materials and energy are changing that paradigm. Consider a few key examples:

The U.S. fossil fuel industry has undergone a revolution in the past decade as shale gas production expanded. Current shale gas infrastructure and the associated economics have reinvigorated the U.S. chemicals industry. Significant investment has been made in new production along the Gulf Coast and in shale gas regions. However, there are countless underutilized shale gas wells. In some cases, the gas is too sour or transportation costs from wellhead to pipeline or production facility are prohibitive. In others, shale gas is flared, generating more greenhouse gas emissions and wasting resources.

Among the many technologies that RAPID members are developing are modular processes for upgrading natural gas at the wellhead. These modular systems range from efficient gas separation and gas sweetening processes to conversion systems that produce high-value liquid chemicals. When deployed thoughtfully, these modular systems could afford wellhead operators options that turn uneconomic wells into distributed manufacturing sites for higher-value products.

The bioproducts sector is going through similar changes. Virgin and waste biomass are routinely cited as new chemical or energy feedstocks, but with the exception of inroads made by ethanol and biodiesel, the promise of an integrated biorefinery has not yet been realized. This is partially because the concept was often envisioned as a large, centralized facility that capitalizes on economies of scale. Experience has shown that collection and transportation of low-density biomass makes these biorefineries logistically challenging and uneconomical. Biorefineries could be reimagined as an array of distributed modular systems. The first converts the biomass to more useful, densified intermediates, including free C5 and C6 sugars or bio-oils. These intermediates are then converted to para-xylene, acrylonitrile, or other products.

Whether we apply the modular process technologies in these examples or other critical applications, such as CO_2 capture and utilization and smaller-scale ammonia production, we see a future for the U.S. CPI that includes significant distributed manufacturing infrastructure. Selective use of nontraditional heating sources (*e.g.,* microwave or induction heating) to drive chemical reactions and application of lower-energy separations technologies (*e.g.,* membranes) might allow some processes to be electrified. At the right scale, such modular processes could be deployed adjacent to distributed solar or wind generating facilities to harness variable, low-cost renewable energy and decarbonize chemical production. Critical to this evolution is technology being developed by our current RAPID-funded projects.

Equally important is the application of decentralized, modular process technology. This is not a one-size-fits-all solution, but a tool that ChEs can use to solve manufacturing problems and an option that developers might use to create new decentralized innovation-based jobs. CEP