Bioprocessing



Beyond Process Development: AI Reshaping Use of Digital Twins

Artificial intelligence is changing how biopharma creates and uses digital models of manufacturing processes

By Gareth Macdonald

In industrial engineering, digital twins—computer models of systems or processes—let scientists try out ideas before finalizing designs. In addition, on the factory floor, twins can model processes in real-time, enabling automated control.

Initially, the most common use of digital twins in biopharma was for process development. Engineers would use a combination of historical and experimental data as well as sound scientific principles to model, test, and then fine-tune unit operations.

Process development is still a major focus, but in recent years digital twins have started to be employed more widely, according to Zachary Sample, an enterprise consultant at industrial engineering firm, **Emerson**.

"Digital twin technologies can bring value across the entire biopharmaceutical development chain, leading to faster time to market. As a result, we are seeing digital twins implemented at every stage of the pipeline.

"In process development," Sample continued, "digital twins can help teams improve their understanding of the process and drive predictability across the entire development stage. Teams can use digital twins to unlock rapid prototyping, reduce the overall number of experiments necessary to define the process, and define the specific parameters to provide an optimized process."

Digital twins have multiple uses in commercial manufacturing as well, Sample says. "Digital twins provide an ideal platform for training and testing, to drive operational excellence. A robust simulation platform facilitates the movement toward more autonomous operations, improves performance predictions, drives predictive reliability, and ensures product quality."

Sample cited a recent customer project Emerson worked on as an example, explaining, "Simulation software was able to help the team improve processes and product purity.

"Through rigorous testing via process models, the team was able to reduce impurity levels from hundreds of parts per million (ppm) to 20 ppm. They also reduced crystallization time from eight hours to 20 minutes."

Another customer used Emerson's digital twin technology to optimize a spray drying process. "Experimentation was costly, so they needed a more efficient and cost-effective way to assess process variations.

"Using simulation software, the team was able to employ experimental data to test, dramatically reducing the cost of experimentation to reach the target," Sample said.

Digital future

Digital twins are already well-established in biopharma, and companies continue to test new uses, according to Alexander Seyf, CEO of U.K.-based industrial "smart technology" developer, **Autolomous**.

"We see some truly fascinating appli-

Above. Digital twins are helping engineers to develop and optimize biopharmaceutical manufacturing processes before they are moved into the production facility. The efficiency gains and increased yields more than offset the initial costs researchers say. [SweetBunFactory/iStock/Getty Images Plus]

cations beyond simple process optimization. Some companies are using digital twins to create "soft sensors," which are virtual models that estimate hard-to-measure attributes like nutrient levels or viral vector titer in real-time. This enables more flexible process control.

"Another significant use is in tech transfer and scale-up, where a twin can simulate the shift from a small lab-scale process to a full-scale manufacturing run, significantly lowering risk and time to market," he said.

This is in keeping with the approach taken by **GSK**, which is using 54 digital twin models across 12 drug products to simulate processes, anticipate issues, and accelerate manufacturing.

GSK has also used digital twins during technology transfer to third-party contractors, manufacturing scale-up, and product launches. Twins have also informed the firm's manufacturing equipment selection for various infectious disease and HIV-related projects.

In addition, for one vaccine, a digital twin helped GSK optimize the processes and unlock capacity to produce an extra million doses.



Already well-established in the process development lab, digital twins are increasingly being used on the factory floor to monitor and automate the control of biopharmaceutical manufacturing operations. The ability to use process data to build models that provide feedback in real-time also helps improve quality control processes. [primeimages/Getty Images]

AI revolution

The biopharmaceutical industry's use of digital twins is only likely to become more diverse, according to Sample, who says advances in AI will be a major catalyst.

"Historically, digital twins have required significant effort for implementation. That is changing dramatically as automation suppliers have begun building AI capabilities into the software," he said. "Today, instead of needing many process engineers to spend months of time to perform the modeling, AI tools reduce the barrier for configuration."

And, Sample says, soon AI will be able to make models—digital twins—automatically.

"If we feed an AI tool with chromatography skid data with the source information, the AI tool can understand what that means from a first principles standpoint. It knows what a chromatography skid is and can build a model from that data."

"We can use AI to build deterministic models and then also use that same AI to perform hybrid modeling—which is especially helpful where the modeling strategy is unclear and we do not have the mechanistic models to bridge the gap with empirical models.

"Ultimately," Sample continued, "AI advances are leading to a future where digital twins are both more robust and simultaneously easier to develop and deploy."

This view is shared by Daniel Espinoza from the faculty of engineering at Lund University in Sweden, who points to the additional computational power provided by AI systems as the key dynamic.

"The mechanistic digital model has been well studied and documented over the past 20 years, and the techniques and groundwork for real-time digital shadows and digital twins already exist.

"The way to drive progress forward in their application in industry lies in solving the fundamental issues of computational cost and data availability. The latter requires innovation in online sensor technologies, while the former can be solved in two ways: by improving the simulation speed by means of parallelization or more efficient solver algorithms, or by replacing the mechanistic digital model with a fully data-driven or hybrid approach," he said.

But the impact AI has on digital twins—and process modeling in general—may be even more profound according to Espinoza, who suggests that, with enough data, such systems could even replace traditional approaches.

"Artificial neural networks (ANNs) have been showcased as candidates for so-called surrogate models, replacing the mechanistic model entirely and achieving similar performance with much faster computation speeds.

"A downside to these is that the amount of data required to train them is much greater than for mechanistic models, requiring either much more experimentation time and resources, or an already-trained mechanistic model to

generate training data," he said. "Hybrid approaches, such as physics-informed neural networks (PINNs), bypass the data requirement by including a mechanistic constraint to the neural network."

Seyf also expects that AI will come to redefine how biopharma uses digital twins.

"The evolution of digital twins in biopharma will be characterized by more integration and autonomy. We expect twins to become even more advanced, transitioning from focusing on a single process or asset to a "digital thread" that covers the entire product lifecycle—from R&D to manufacturing and supply chain logistics.

"AI and automation will drive this change. AI could eventually make twins self-optimizing, allowing them to adjust and predict in real-time to maintain optimal conditions and prevent failures without human oversight," he said. "This move towards autonomous manufacturing will greatly enhance efficiency, quality, and compliance, ultimately speeding up the delivery of life-saving therapies to patients." GEN

Point of View

Continued from page 21

industrial biotechnology. These various readiness frameworks can transform partnership negotiations from subjective assessments to data-driven milestone structures.

Additionally, the National Biotechnology and Biomanufacturing Initiative has committed $2 billion to ensure "we can make in the United States all that we invent in the United States." Yet without robust private sector engagement through partnership models like BIBs, this vision remains unrealized. To maximize BIB partnerships' potential, federal policymakers should consider three proven incentive frameworks—the CHIPS Act, tax deferrals and capital gains exclusions in designated Opportunity Zones, and permanent R&D tax credits—to create a new model of public-private partnerships (PPPs). These incentive frameworks leverage proven bipartisan models, and mirroring them can create comprehensive benefits for investment in biomanufacturing facilities and equipment, workforce development, innovation, and R&D that make corporate participation in BIB partnerships highly profitable.

Lastly, the emerging policy landscape supports expanded corporate-startup partnerships. The National Biotechnology and Biomanufacturing Initiative's call for a National Biotechnology Coordination Office would provide centralized coordination across multiple agencies, while proposed Independence Investment Funds could provide non-dilutive risk capital for early-stage ventures. Organizations like BioMADE have already shown how this vision can be operationalized through milestone-based grants and infrastructure co-development. Through cost-sharing and milestone-oriented funding, BioMADE has fostered the development of nine new bioindustrial projects, including waste-to-bioproducts, natural rubber from dandelions, and scalable purification processes, demonstrating that government grants can mirror BIBs' logic without prescribing the science. These initiatives create the regulatory clarity and financial foundation necessary for large-scale corporate engagement in BIB structures.

Despite current budget challenges, American leadership in artificial intelligence, biotechnology, and augmenting our workforce is a bipartisan issue, because they are national security issues. Senators Todd Young (R-IN) and Alex Padilla (D-CA) are leading the legislative groundwork with six key bills. The proposed Foundation for Enabling Biotechnology Innovation Act aims to "foster public-private partnerships" and "accelerate U.S. biotechnology commercialization," while the NSCEB-endorsed report explicitly calls for making "biomanufacturing scale-up predictable, rapid, and cost-competitive" through federal investment. These efforts, though nascent, show that political will is aligning around incentive structures to support a model such as BIBs.

Making BIBs a reality

The timing couldn't be better. America's entrepreneurial advantage lies in our boldness and willingness to innovate with new ways of doing business. While other countries may have government-directed industrial policies, the U.S. excels at creating novel partnership structures that align private sector incentives. BIBs represent exactly this kind of American innovation: a market-driven solution that leverages our unique combination of entrepreneurial startups and industrial expertise.

Corporate leaders, biotech startups, investors, industry participants, and federal policymakers all have a role to play in seizing the opportunity to own America's bio-industrial leadership. BIBs offer a roadmap, but what remains is the will to act. The companies and policymakers that recognize this moment and commit to systematic BIB development will shape the next chapter of American manufacturing. The bioeconomy revolution is not inevitable—it requires deliberate choices and sustained commitment through new models of public-private collaboration. ■

Henry Lee, PhD, is the CEO of Cultivarium.