

# **The Cognitive Revolution of Process Systems Engineering: From Automation to Autonomy and Human Empowerment**

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## **Abstract**

PSE has long been defined by mathematical modeling, simulation, control, and optimization. Linear models formed the foundation, followed by complex, non-linear, dynamic, and multi-scale systems. Advanced MPC systems control processes based on physics and chemistry, and a "mechanistic" understanding of the world continuously advances the design of products and processes.

However, the world is becoming too complex for purely mechanistic approaches. Data generation is exponential. The need for adaptability, sustainability, flexibility, and efficiency has surpassed traditional automation capabilities.

This is where a revolutionary paradigm shift is presently taking place; from automation to *cognition*. Process systems can now "understand" their environment, not just "execute" commands on them. Data is being interpreted with context, not just analyzed. Systems are transitioning from predictive maintenance to autonomous, self-optimizing, and self-healing. Human cognition and creativity is amplified by factors we have not seen before by any other means. Human capital is not becoming redundant. On the contrary, human capital is becoming far more important than ever before.

Integrating Machine Learning, Deep Learning, and Knowledge Graphs with physical models (hybrid modeling) bridges the gap between "what" happens and "why" it happens.

This cognitive evolution presents challenges. Ensuring AI-driven decisions are trustworthy and explainable is key. Physical laws, such as the conservation of mass and energy, must be embedded into neural networks. Scalable AI must function in the reality of a chemical plant.

My presentation aims to address these fundamental questions, and to present a new control-theoretic framework of machine intelligence that can frame all of these questions for practical solutions.

The future of PSE involves a partnership between human intuition and such machine intelligence. The goal is to empower process engineers with a cognitive partner to handle the complexity of the modern world, not replace them.

In view of all these developments, my presentation will explore, debate, and redefine the boundaries of what is possible in process system engineering as we move forward.