Process Operations
from Automation to Autonomy

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Siemens Process Industries Software

Advances in the Digitalisation of the Process Industries
Manchester, 16 October 2025

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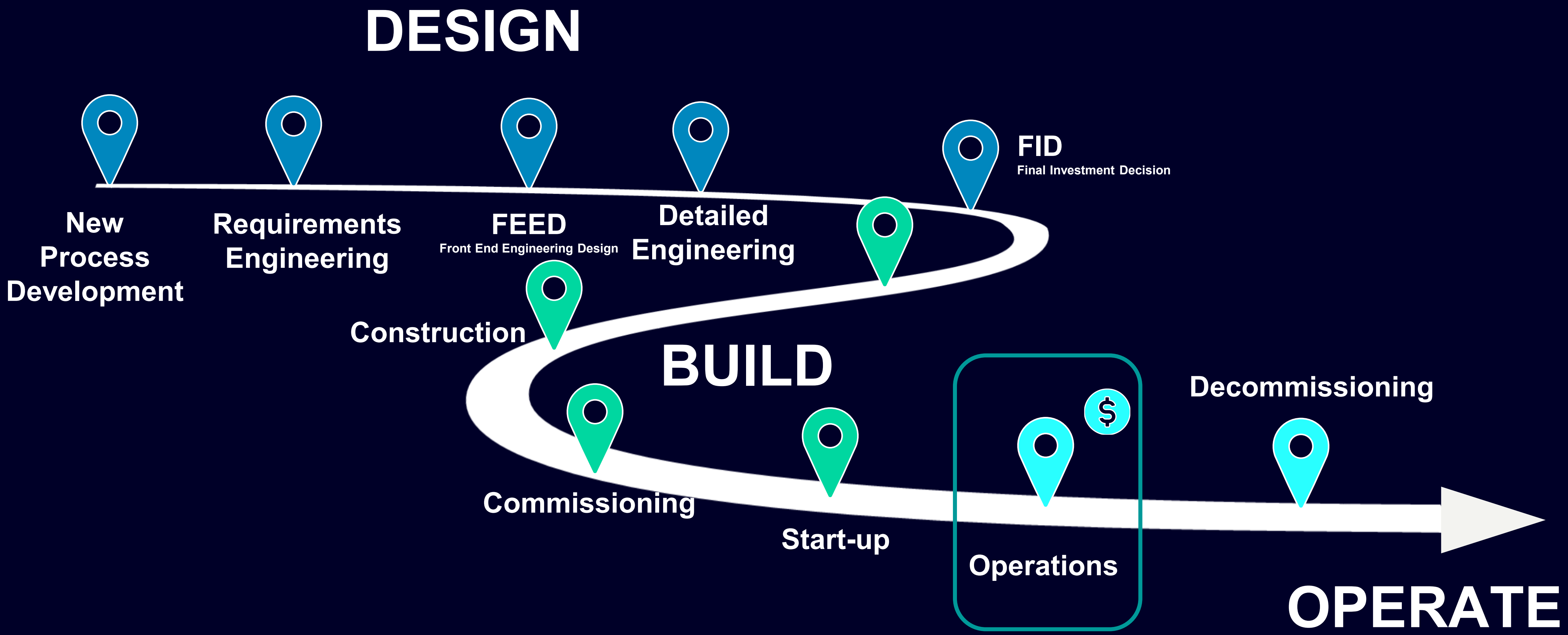
Digitalization in the product & process lifecycles



Biggest short-/medium-term opportunity
LARGE BENEFITS, LITTLE CAPEX

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Outline

1. Autonomy – what is it ?

2. Autonomy in Process Operations
    - Why do we need it ?
    - What is the scope ?
    - Impact of Deep Process knowledge

3. Conclusions and outlook

Autonomy

What is it?

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Autonomy is the ability to...

1. develop a well-defined, yet modifiable, plan towards the achievement of high-level goals, making use of all available resources and taking account of all relevant constraints

2. execute the plan, modifying it if necessary

3. react appropriately, if not optimally, to unexpected events

4. coordinate with human controllers.

[1] P.D. Watson, D. Scheidt, Autonomous Systems, *Johns Hopkins APL Technical Digest,* **26,** 368 – 376 (2005)

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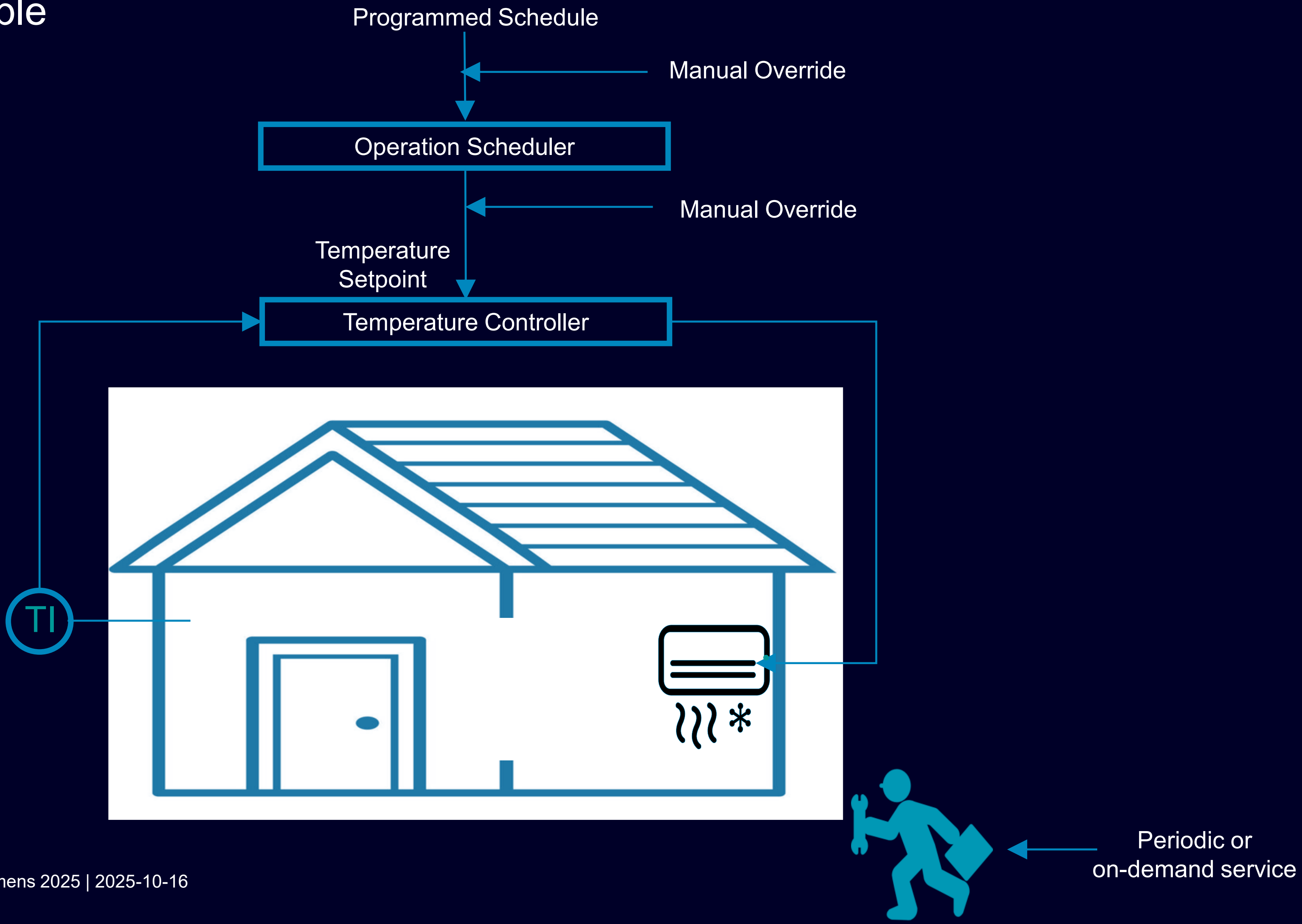
[1] Baldea, M., Georgiou, A.T., Gopaluni, B., Mercangöz, M., Pantelides, C.C., Sheth, K., Zavala, V.M. and Georgakis, C.: From automated to autonomous process operations
Computers & Chemical Engineering, 196, p.109064 (2025).

Automation vs. Autonomy

A simple example



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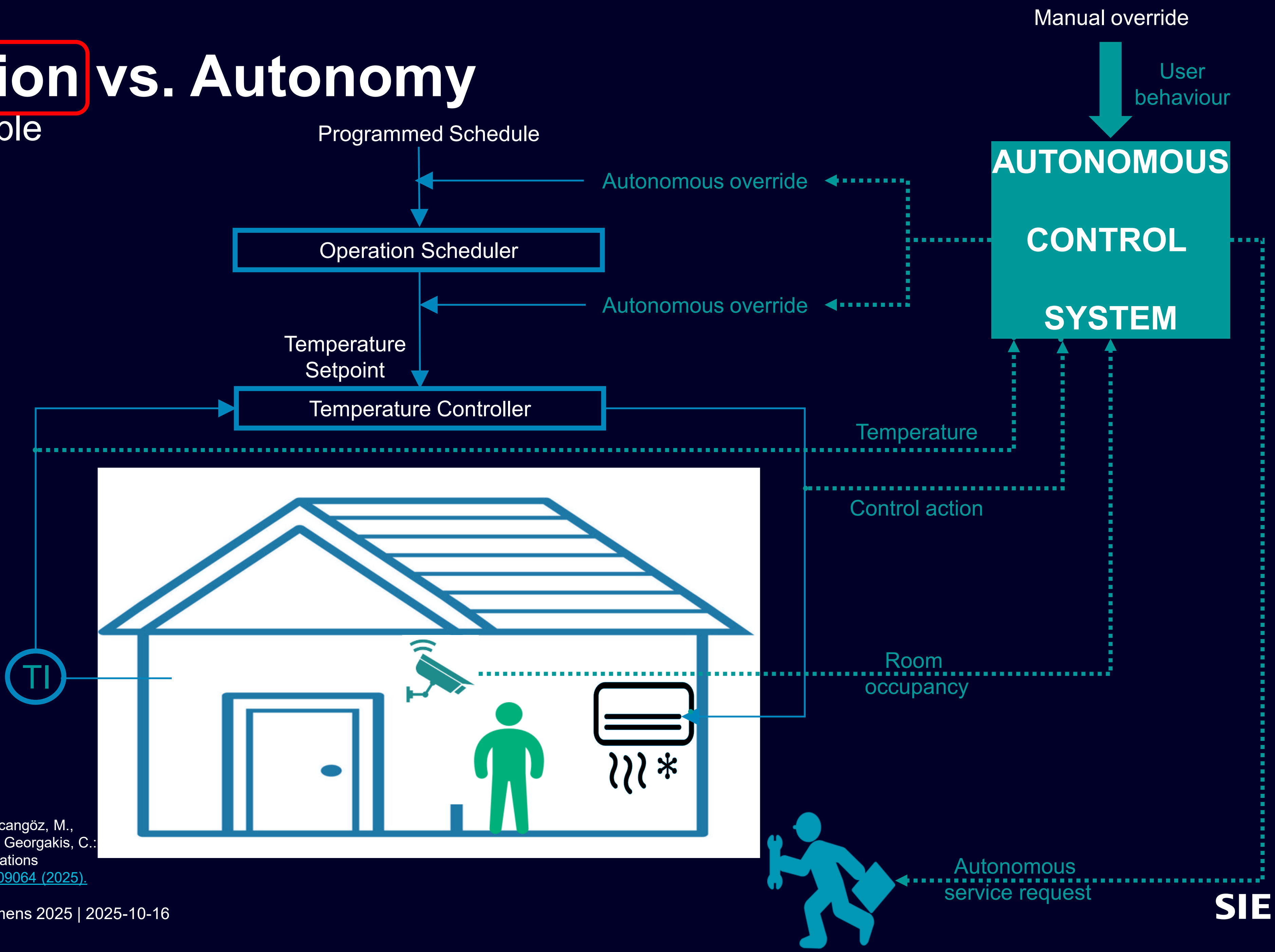
Automation vs. Autonomy

A simple example



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Autonomy in Process Operations

Why do we need it?

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Autonomy in Process Operations

Key drivers

01 Shortage of skilled personnel

02 Operations in hazardous/inhospitable environments

03 Multiple, geographically distributed plants

04 Improved process performance, safer & more consistent operations

Korn Ferry (2018). "Korn Ferry study reveals global talent shortage could threaten business growth around the world."
https://www.kornferry.com/content/dam/korn ferry/docs/pdfs/KF-Future-of-Work-Talent-Crunch-Report.pdf.
IndustryWeek (2021). "The skilled labor shortage threatens manufacturing sector’s full recovery.
https://www.industryweek.com/talent/article/21169565/the-skilled-lab or-shortage-threatens-manufacturing-sectors-fully-recovery-says-study.
Liberty Mutual Business Insurance (2022). "Labor shortage in manufacturing: causes, risks, and solutions."
https://business.libertymutual.com/insights/labor-shortage-in -manufacturing-causes-risks-and-solutions/.

Autonomy in Process Operations

A practical definition

Autonomy is the automation of important tasks which currently require significant human intervention and/or expertise

NOTE

- No hard boundary between “automation” and “autonomy”
  - Multi-layered systems in which today’s “*autonomy*” could be tomorrow’s “*automation*”

- Key deciding factors
  - Technological feasibility
  - Economic benefit

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Autonomy in Process Operations

What is the scope?

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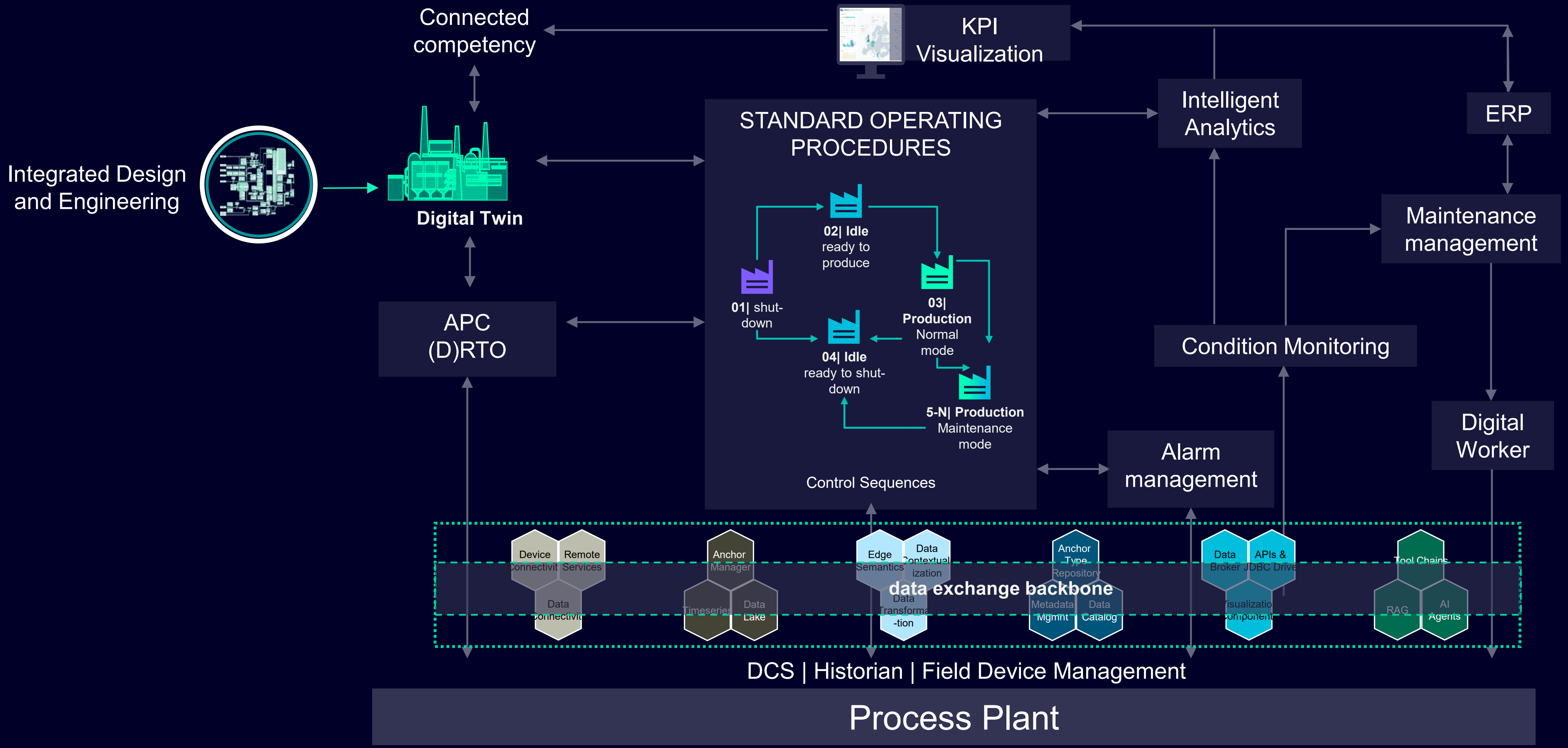
Integrated Process Operations



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Process Operations: from automation to autonomy
Reducing/eliminating human intervention in important tasks

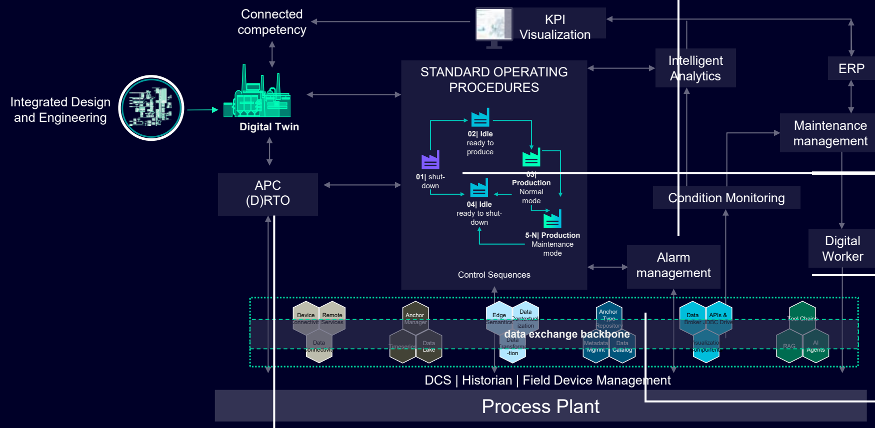
4 ADVANCED PROCESS & EQUIPMENT CONDITION MONITORING

Combined AI-based anomaly detection & model-based state estimation allow **reliable real-time monitoring** of plant operation ...including an **accurate assessment of the condition of processing equipment & field devices**, both now and in the near future

6 OPERATIONS CO-PILOTS

Operator's general workload is reduced via
- AI-assisted drafting of shift handover reports
- Chatbot answering queries on plant operation from interested parties

. . . . .



Current or predicted maintenance requirements **automatically trigger all necessary procedures, notifications & permits**, for field personnel to carry out the required **inspection & maintenance** work

5 COORDINATION WITH FIELD OPERATIONS

Next-generation APC technology combines deep engineering knowledge with machine learning to deliver **fully automatic control, both at steady state & under transient conditions** (e.g. transitions between operating points)

1 OPTIMIZED PLANT OPERATION

Standard Operating Procedure Executor combines state-based control with AI technology to ensure **ISA-106 compliant, flawless execution of SOPs** ...including **secure and reliable coordination with field personnel** via the Siemens Mobile Worker

2 OPERATING PROCEDURE EXECUTION

Intelligent AI-assisted alarm monitor handles alarm cascades and determines Root Causes

3 ALARM HANDLING

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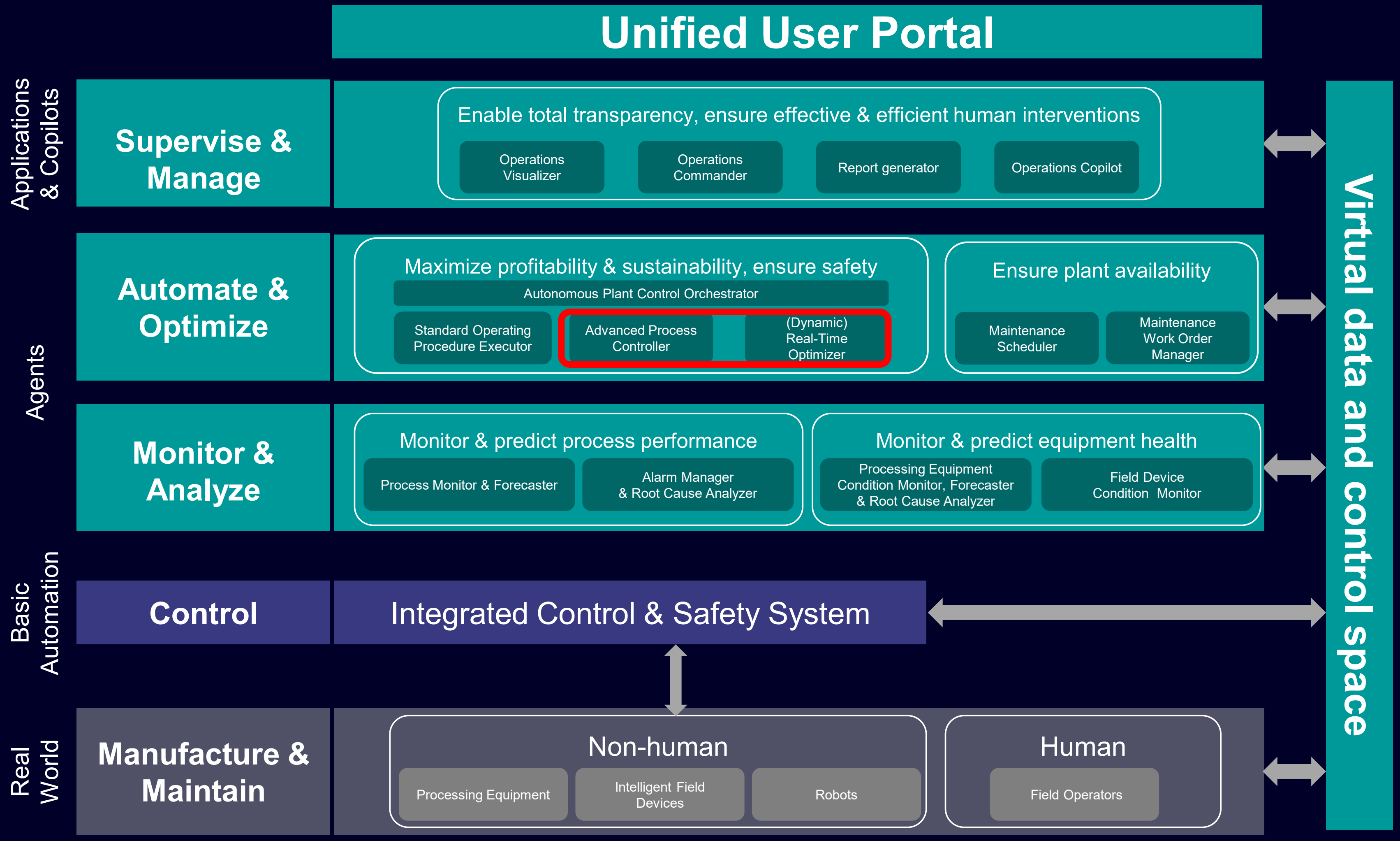
Siemens Autonomous Process Operations System



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Autonomy in Process Operations

The impact of deep process knowledge

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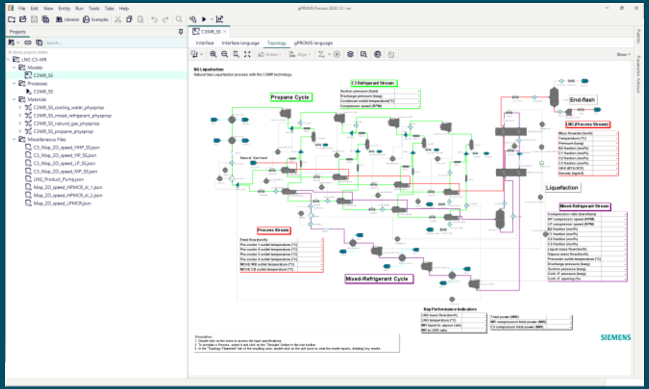
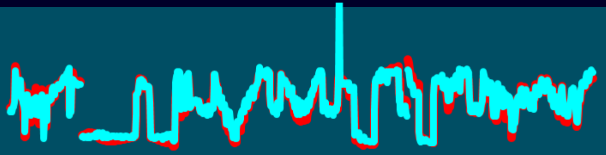
Deep process knowledge in Process Operations

Process Models



physics-based element

Hybrid Model



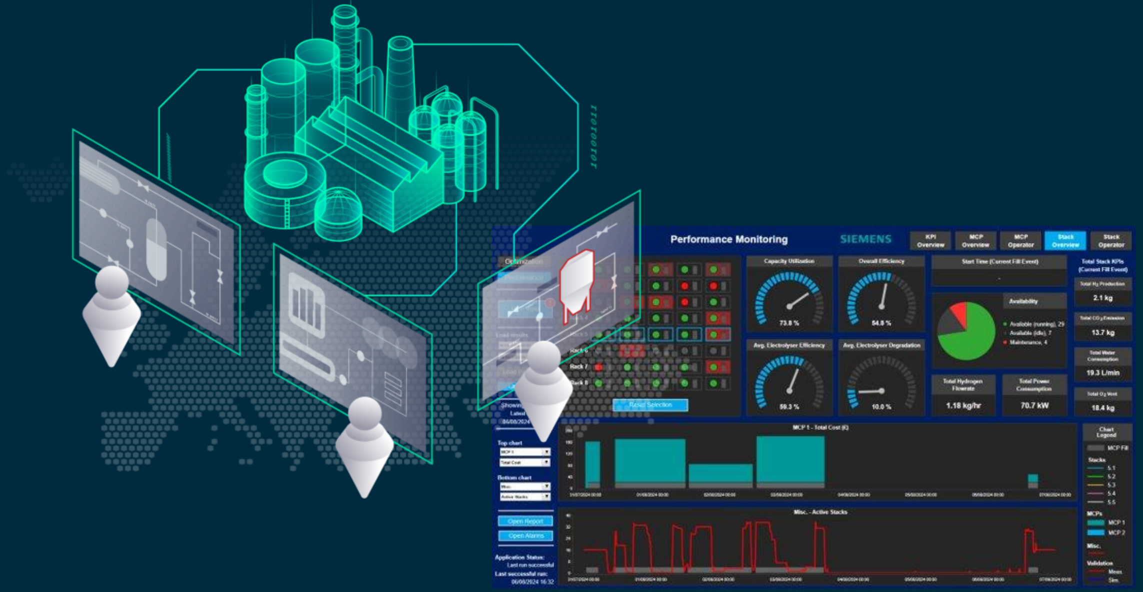
data-driven element

DESKTOP

ONLINE

Digital Applications

Advanced decision support & control in operations



Mathematics

simulation | state estimation | optimization | parameter estimation

+

AI technologies

surrogate modelling | anomaly detection | forecasting | LLMs | ...

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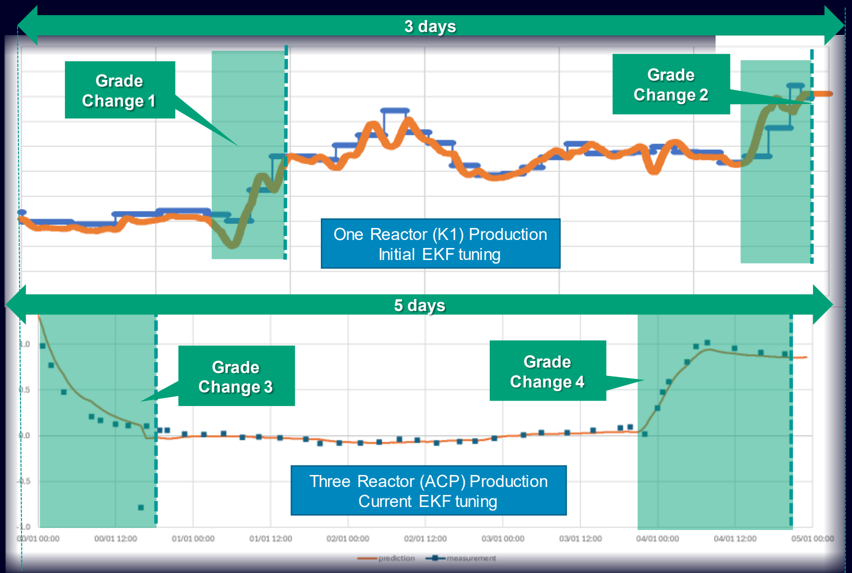
Deep knowledge in Advanced Process Control
Nonlinear Model Predictive Control – Polymerization



MFR - Laboratory measurements   MFR – Soft sensor

LyondellBasell Hostalen® HDPE process

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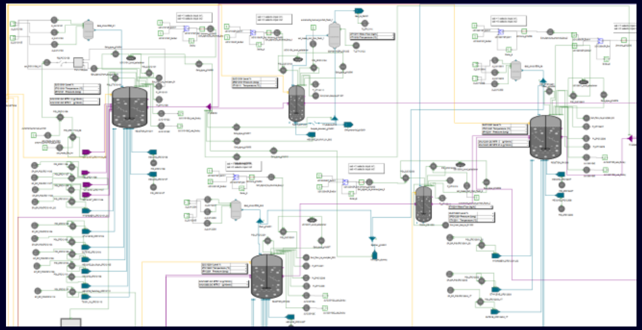
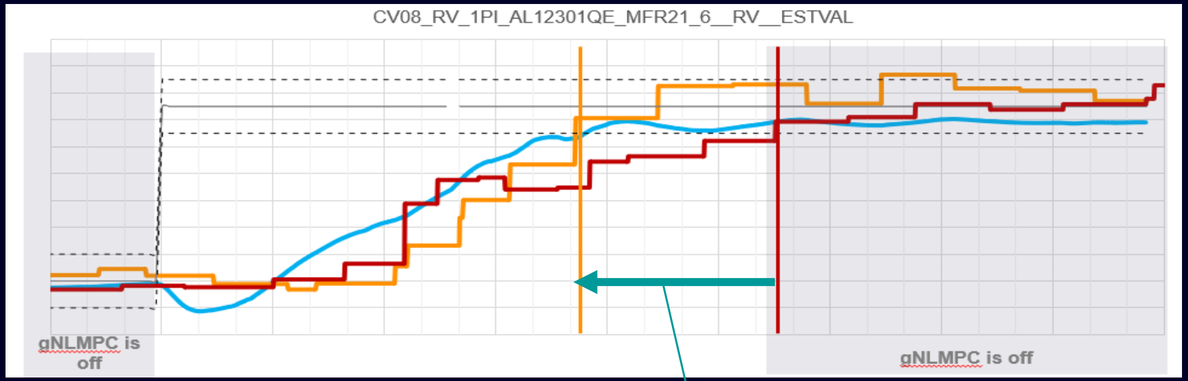
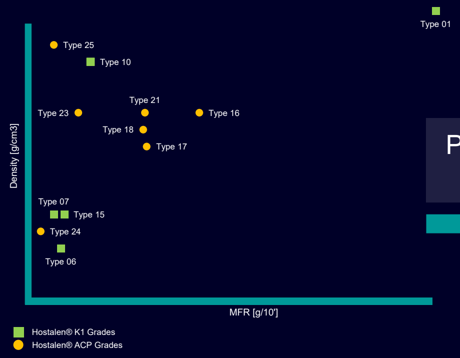
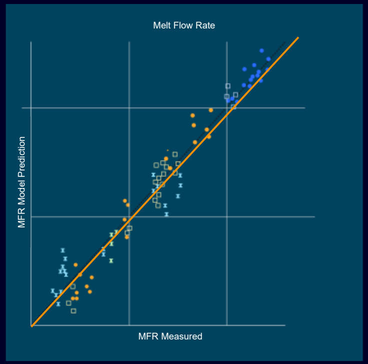






Plant model (gPROMS Process)
~50,000 equations



30% acceleration in grade transition

- MFR historical transition (actual lab measurement)
- MFR gNLMPC transition (actual lab measurement)
- MFR gNLMPC transition (online estimate)

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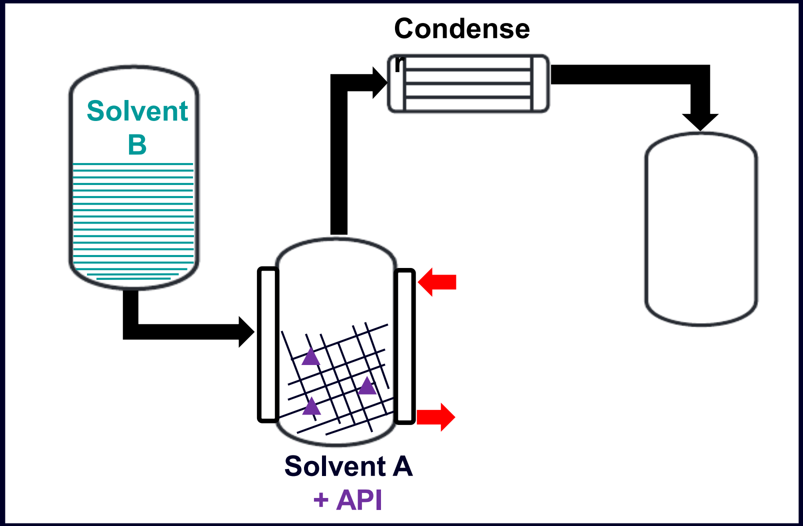
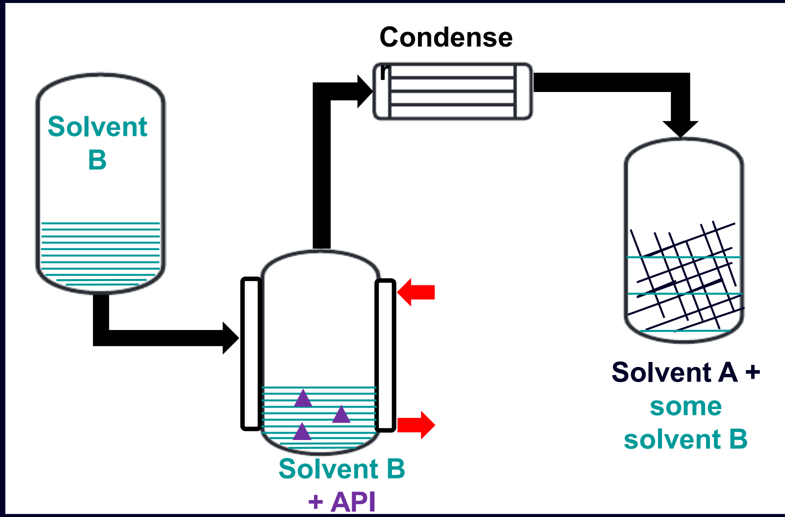
Deep knowledge in Advanced Process Control
Nonlinear Model Predictive Control – Solvent Swap

Start of batch



End of batch



Challenge

- High energy and loss of solvent ➔ costly, poor sustainability
- Batch process ➔ conventional APC not applicable
- Need for frequent manual intervention from operators to keep plant on track

Nonlinear MPC

- Solvent loss reduced by 28%
- Batch duration reduced by 66%
- Total savings up to €500,000 per year per line
- No additional capital expenditure

Pantelides, C.C. and Pereira, F.E. (2024). The future of digital applications in pharmaceutical operations. *Current Opinion in Chemical Engineering*, 45, p.10103

Digital Process Twin Reduces Production Time and Costs (2020) https://www.linkedin.com/pulse/digital- process-twin-reduces-production-time-costs-jj-catrysse-b7cwf/

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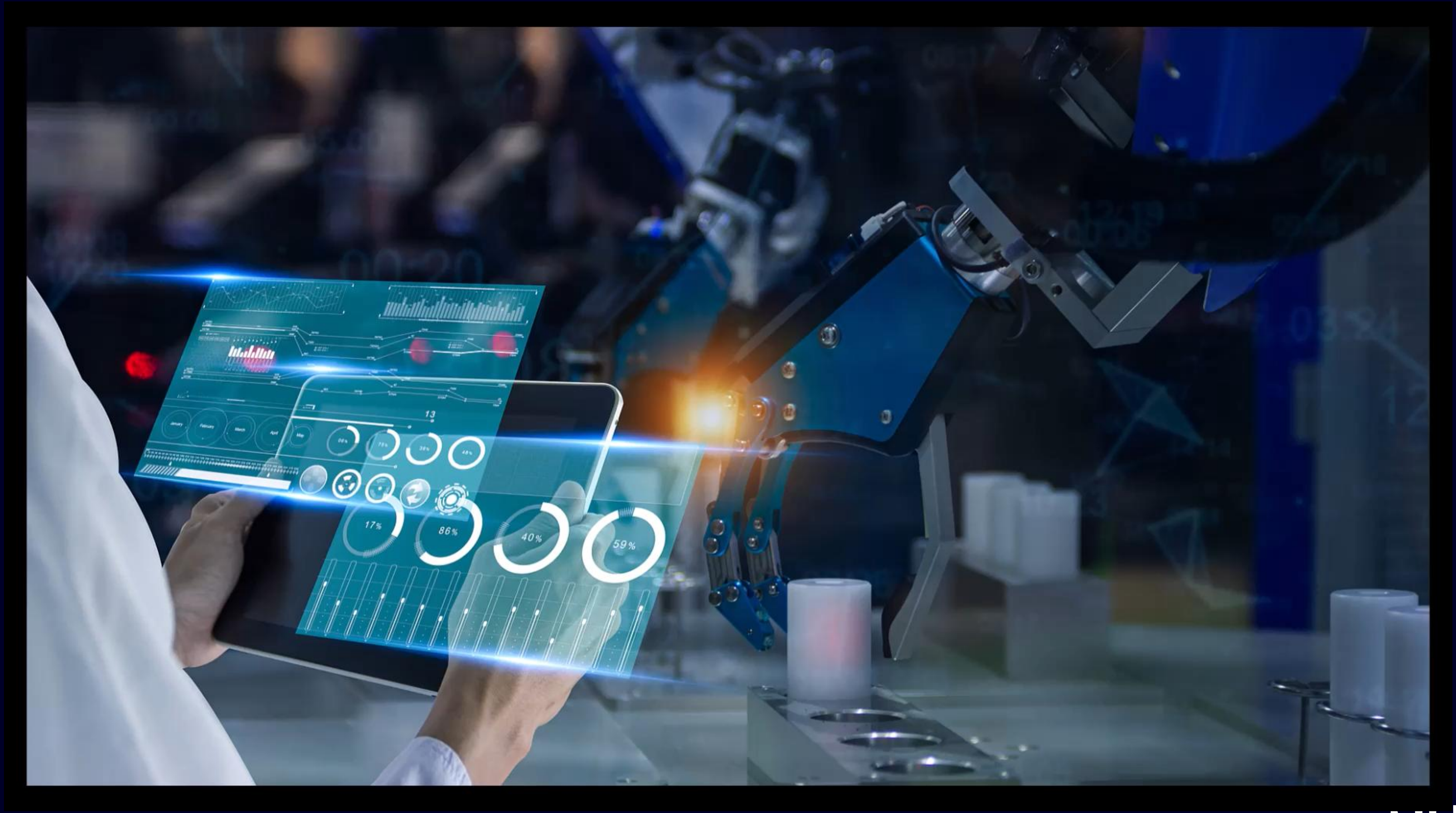
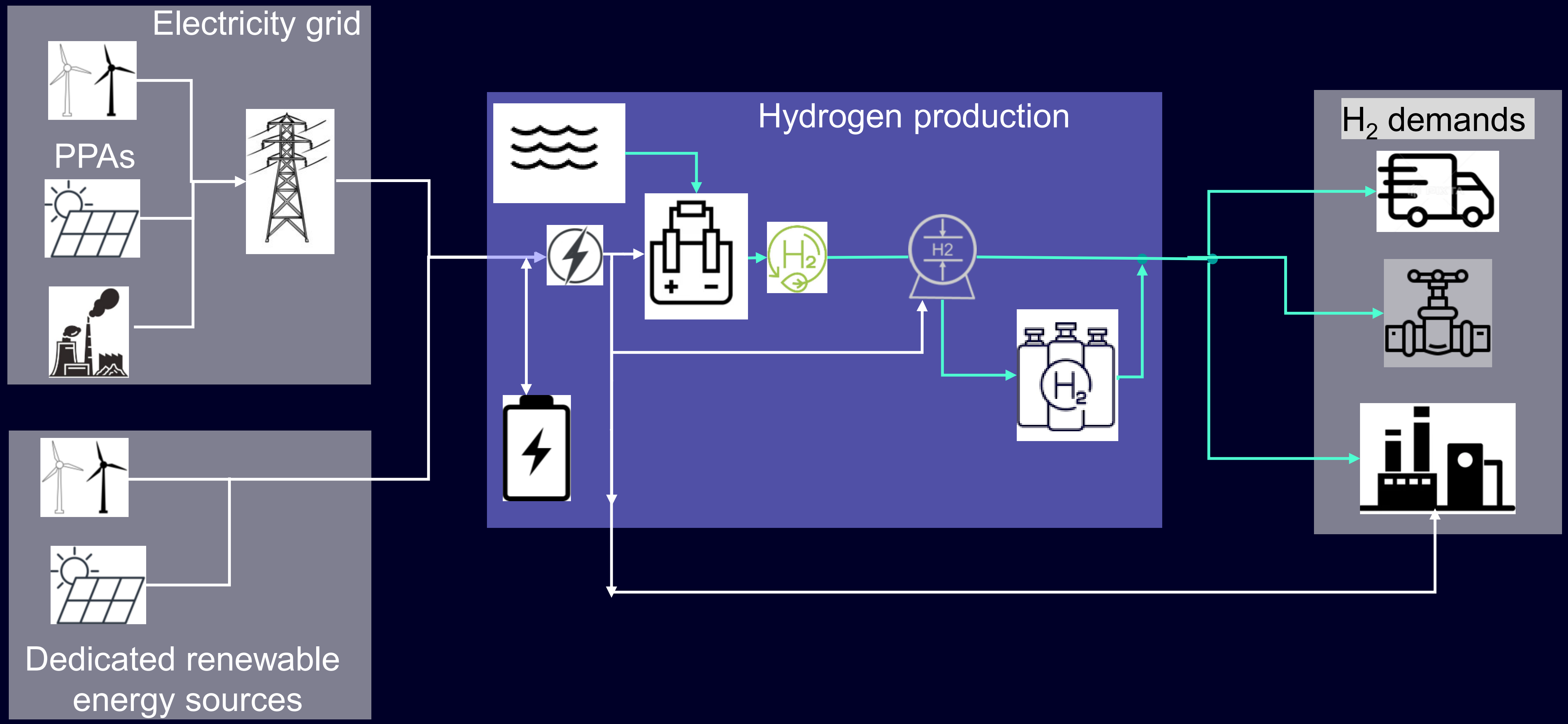
gPROMS Nonlinear Model Predictive Controller

Applications in Pharmaceuticals: Solvent Swap



Deep knowledge in Advanced Process Control
Dynamic Real-Time Optimization – Green Hydrogen



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Deep knowledge in Advanced Process Control
Dynamic Real-Time Optimization – Green Hydrogen

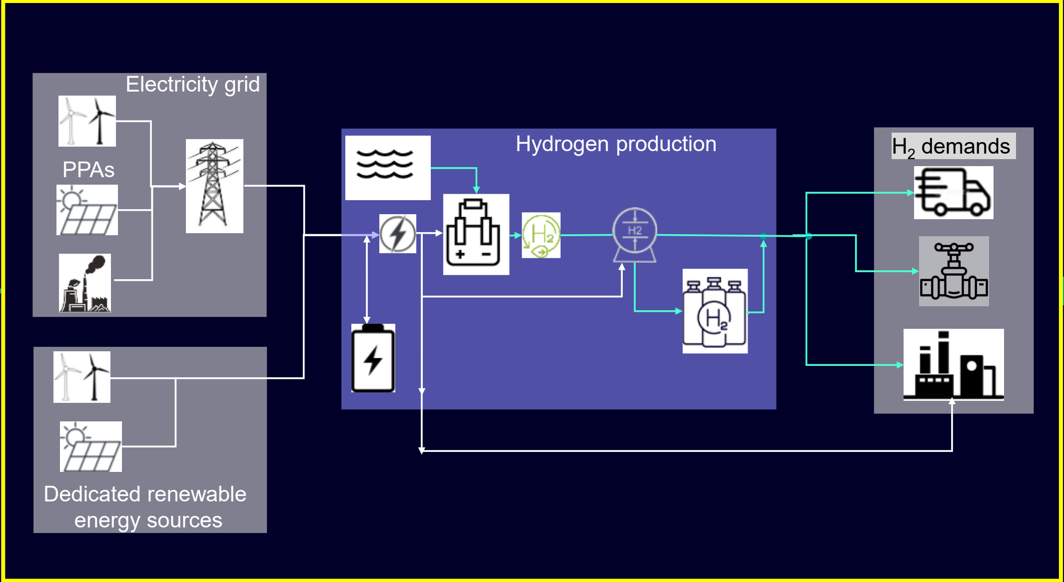
Inputs

Current

- ✓ H_2 inventory
- ✓ Battery state

Forecasts @15' intervals over 24h:

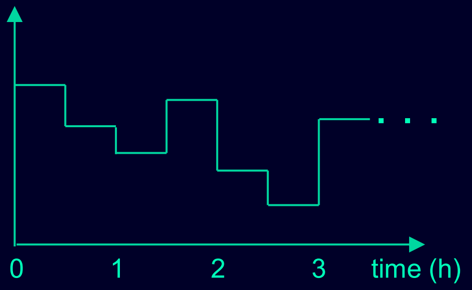
- ✓ RE (wind/solar) supply
- ✓ Non-RE (grid) price & availability
- ✓ Equipment availability
- ✓ H_2 demand



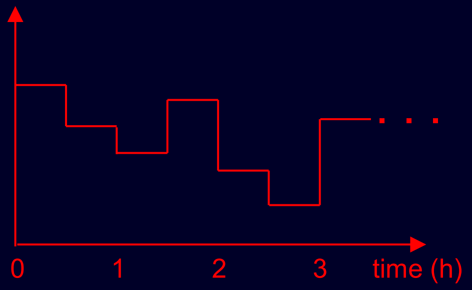
Outputs

Operating schedule @15' intervals over 24h:

- ✓ Electrolyzer stack operation (ON/OFF; throughputs)
- ✓ H_2/electricity storage levels
- ✓ Water consumption
- ✓ Energy requirements
- ✓ H_2 delivery plan to off-takers
- ✓ Energy sold to grid



Day-ahead scheduling of operations



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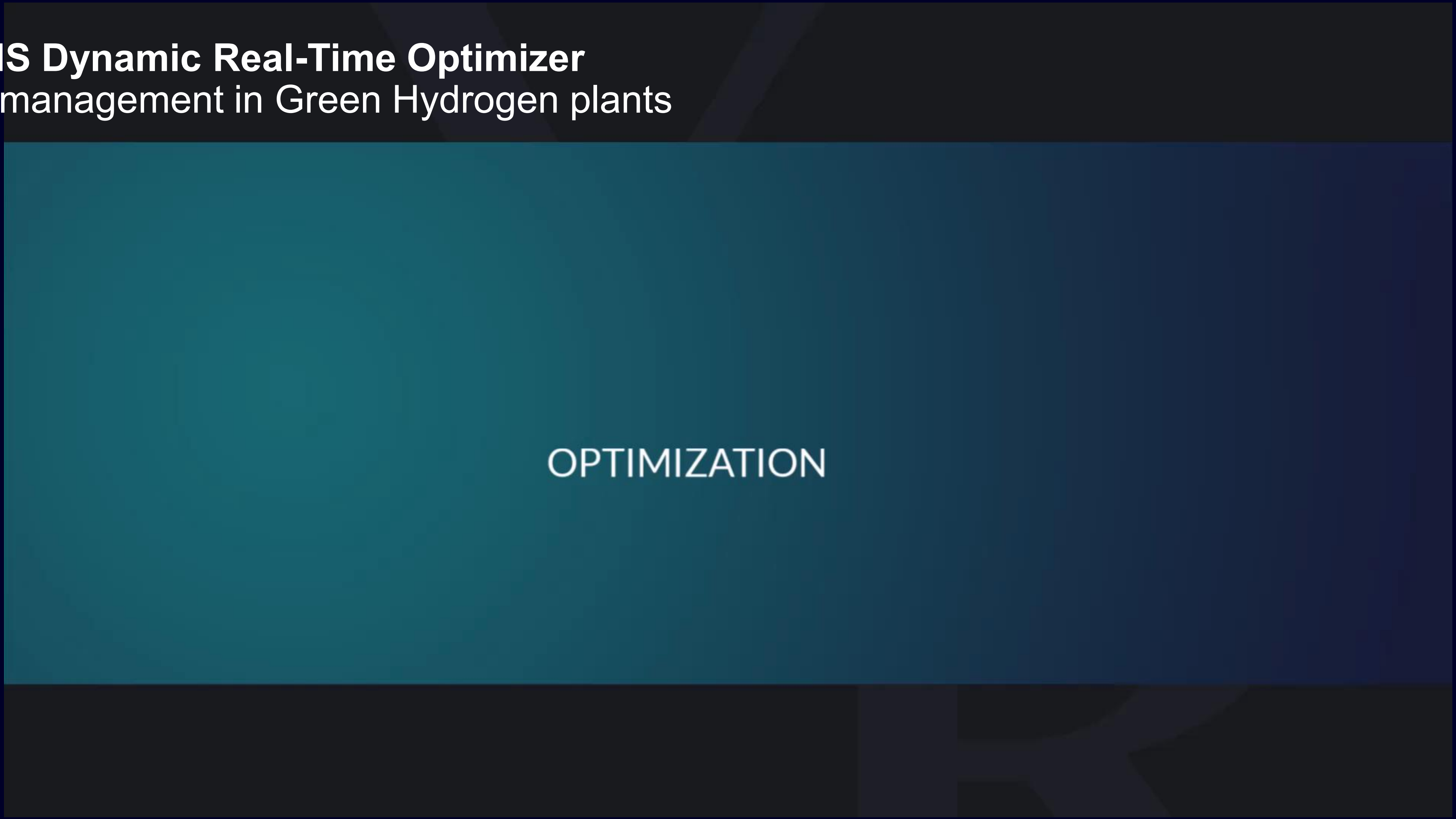
gPROMS Dynamic Real-Time Optimizer
Energy management in Green Hydrogen plants



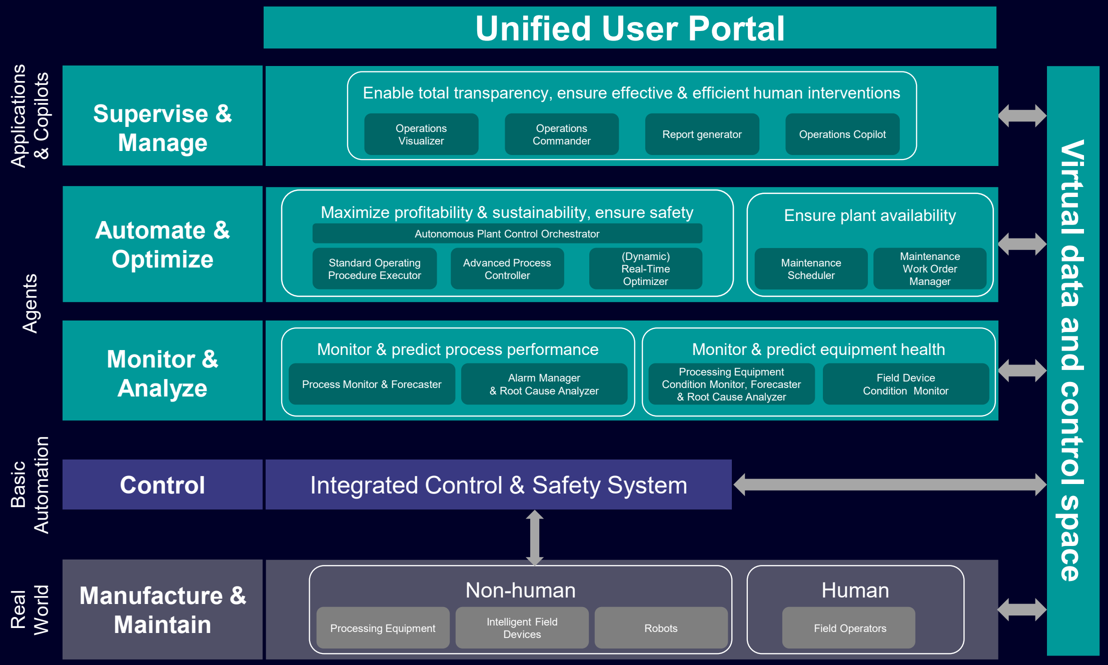
Conclusions & outlook

In conclusion...

1. Autonomous process operations are essential for
    - ensuring for long-term viability of process industries
    - enabling new processes & processing paradigms

2. Delivering the required functionality requires the tight integration of new AI technologies with more conventional Process Systems methodologies

3. Significant software challenges will need to be overcome
    - scalability
    - orchestration
    - data integration
    - . . . .



Now progressing from a general vision
to concrete requirements & use cases, software designs and implementations

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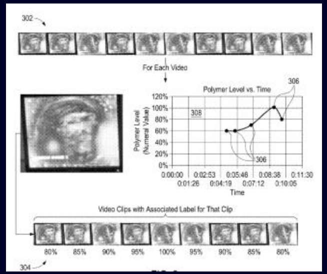
Autonomous Process Operations
Longer-term perspective

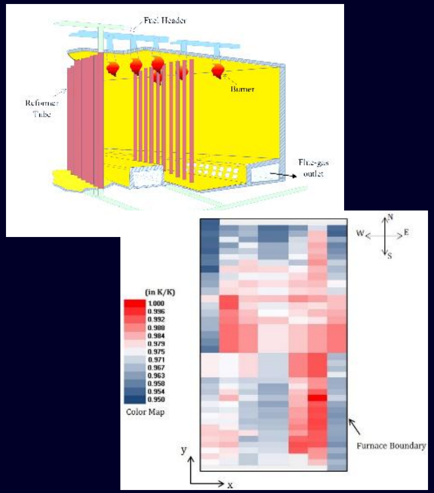
EFFECTIVE HANDLING OF UNANTICIPATED SITUATIONS

...will require substantial investment in new technologies

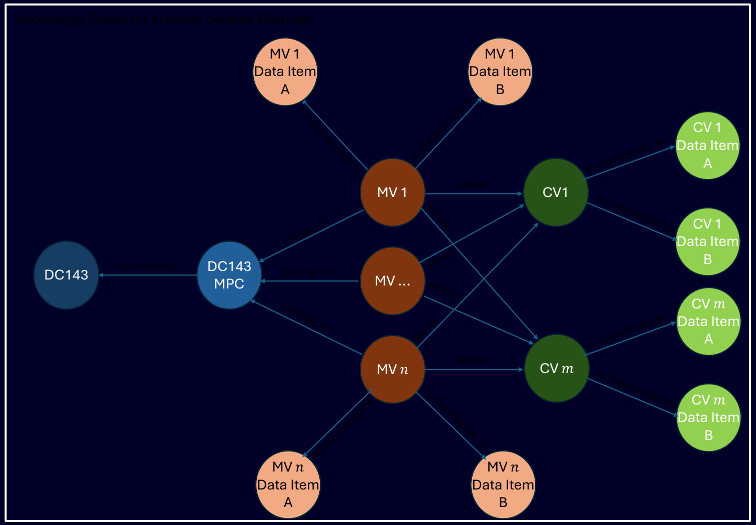
- improved situational awareness via advanced sensors
  - Vibration/acoustic sensors
  - Imaging technologies (visible spectrum/thermal/hyperspectral)
  - Artificial noses
  - . . . .
- wider range of models
  - e.g. semantic models based on Knowledge Graphs
- decision support methodologies
  - e.g. Reinforcement Learning
- . . . .



ExxonMobil (2020).
Systems and Methods of Monitoring and Controlling an Industrial Process.
United States Patent 11,513,496 B2.



Kumar, A., Baldea, M., Edgar, T.F. (2016)
Real-time optimization of an industrial steam- methane reformer under distributed sensing.
Control Eng. Practice **54**, 140–153.



Knowledge Graph for Process Control System[1]

[1] Baldea, M., Georgiou, A.T., Gopaluni, B., Mercangöz, M., Pantelides, C.C., Sheth, K., Zavala, V.M. and Georgakis, C.: From automated to autonomous process operations
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Questions ?

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