WHITE PAPER

Optimize and Automate Energy Assets with Digital Twins in MATLAB and Simulink

MathWorks®

Introduction

The energy sector, like most industrial sectors, is continuously adapting to global changes in energy supply and demand. Climate regulations aimed at reducing carbon emissions, along with the development of carbon and hydrogen storage and the establishment of new energy facilities, are among the most pressing demands for energy organizations interested in adopting sustainable, adaptive, efficient, and safe technologies to compete and grow. However, these organizations face challenges when making final investment decisions (FIDs) to support the implementation of new processes across the energy value chain: FIDs require thorough assessments and forecasting of plausible technical, operational, and economic outcomes, sometimes in the absence of historical data or prior successful outcomes, to ensure positive returns on investment (ROI) on implementing those new processes (Chronis et al., 2024; WEF, 2017).

With the advent of Industry 4.0 technologies, energy organizations have embraced digital transformation strategies to support FIDs and core business plans with industrial solutions focused on streamlining the prototyping and integration of new processes, the optimization of resources across existing processes, and the minimization of operating costs and production turnaround times (Potts, 2021; WEF, 2017). For this purpose, MathWorks[1] has developed industrial software tools to support the energy sector's digital transformation with *digital twins* that enable the modeling and simulation of complex dynamic systems and accelerate industrial processes across new or existing IT/OT infrastructures at the component, process, asset, and mission levels.

For the energy sector, the Energy Production team at MathWorks has incorporated software product groups for upstream, midstream, and downstream assets focused on adaptive and cost-effective solutions to customize, optimize, control, and automate processes at the subsurface, oilfield, and plant levels (Figure 1). The big data science capabilities of MATLAB® and Simulink® integrate data and image analysis, process control, high-performance computing, and predictive analytics to rapidly develop and deploy customized digital twins that support subsurface modeling and simulation, as well as the control, optimization, and automation of field and plant production processes.

[1] *MathWorks is the developer of MATLAB and Simulink, and it has been one of the top global providers of industrial software technologies for science and engineering applications across more than fifteen industries for more than 40 years.*

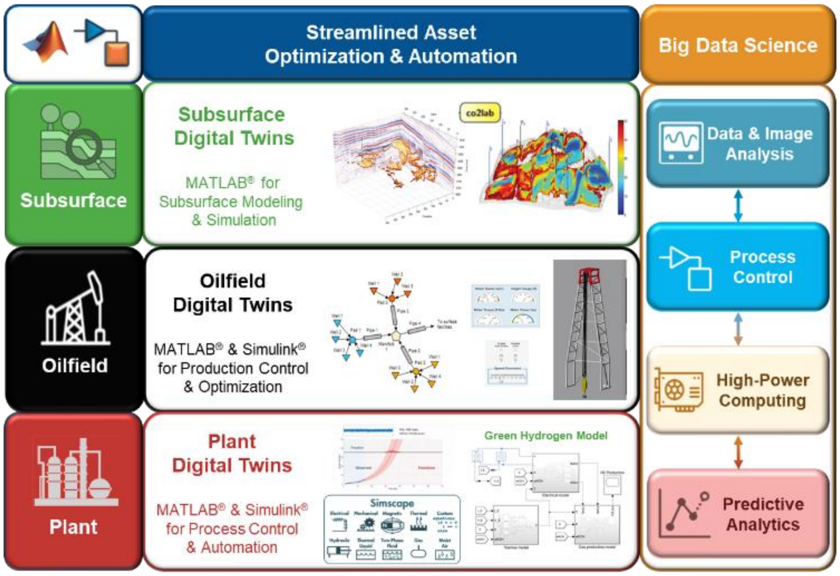

Figure 1. Digital twins for energy resources with MATLAB and Simulink.

Upstream Digital Transformation Solutions

Upstream energy assets invest in studies, projects, and operations to explore and develop energy resources from subsurface reservoirs with commercial hydrocarbon, hydrogen, geothermal, and critical mineral accumulations (Chronis et al., 2024). To achieve a successful outcome from upstream investments, an integrated teamwork among geoscientists and engineers is essential. This collaboration involves creating subsurface and oilfield models to derisk prospective resources and developing contingent resources with minimum uncertainty and high commerciality before making investment decisions (SPE, 2008).

To support upstream energy assets, the Energy Production team at MathWorks has integrated an **Upstream Asset Product Group** with adaptive software toolboxes developed in MATLAB and Simulink for geoscientists, engineers, operations staff, and IT/OT professionals. These toolboxes allow them to customize, analyze, optimize, and deploy *subsurface and oilfield digital twins* (Figure 2). The product group also enables the interconnection of MATLAB and Simulink with third-party software applications and IT/OT devices, which transforms and accelerates major upstream processes including:

- Seismic and well data analysis
- Geological and geomechanical modeling
- Reservoir simulation and monitoring
- Oilfield surveillance and IT/OT interconnectivity
- Data science and real-time analytics
- High-performance computing
- Application deployment

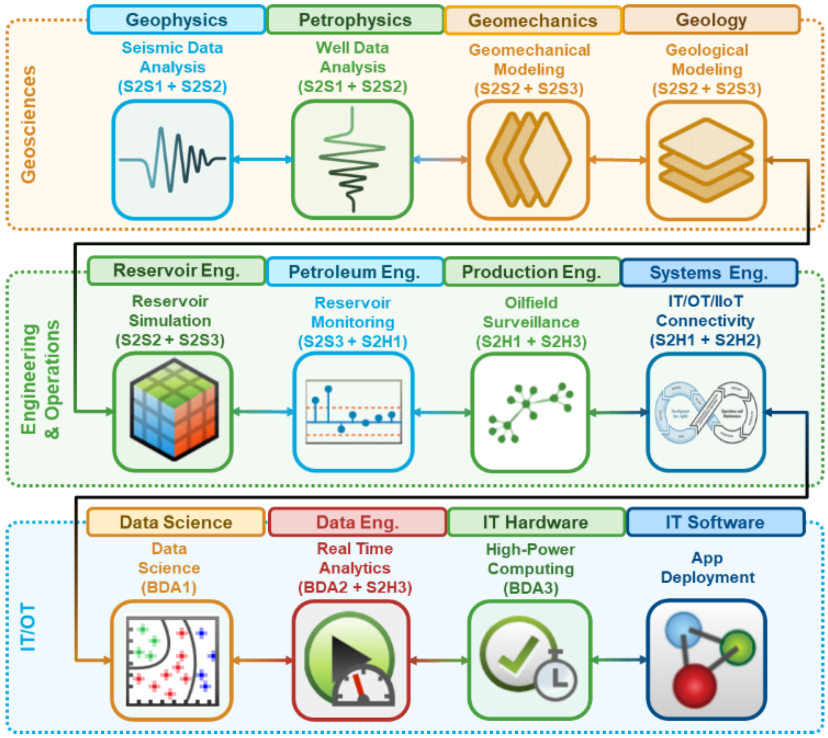

Figure 2. Upstream asset product groups from MathWorks.

Upstream Digital Twins

The following examples highlight digital twins developed in MATLAB and Simulink that support FIDs across key upstream processes, which require sustainable, cost-effective solutions involving complex processes and new core business areas such as:

- Unconventional well simulation
- Geological carbon storage (GCS)
- New energies (e.g., geothermal, natural hydrogen)

Figure 3 shows an upstream digital twin designed for the rapid prototyping of unconventional well simulation. It aims to assess production performance with and without geomechanical input using an enhanced reservoir simulation methodology that integrates MATLAB Reservoir Simulation Toolbox (MRST) with Optimization Toolbox™ and Statistics and Machine Learning Toolbox™.

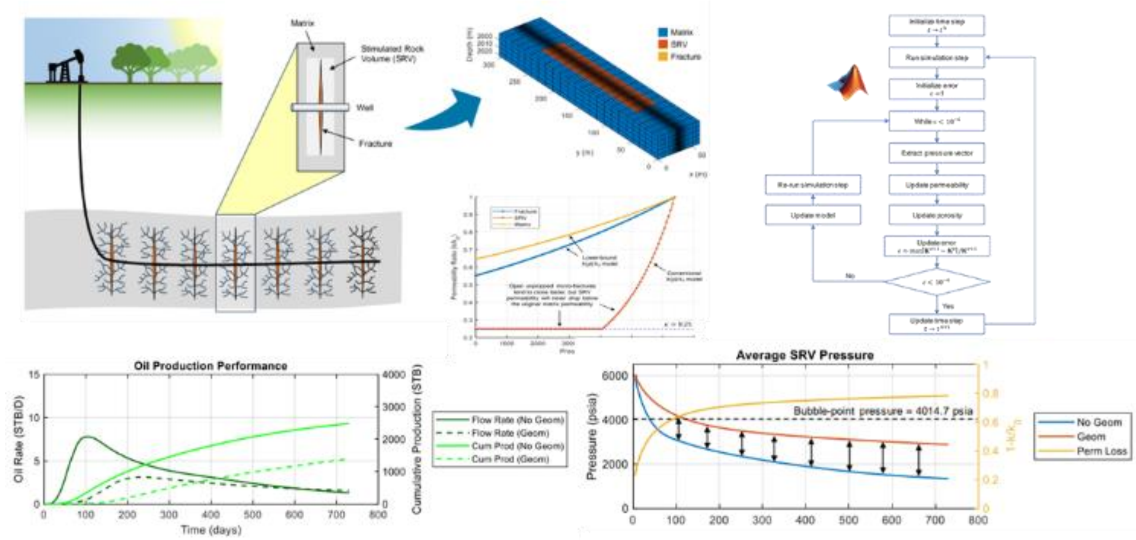

Figure 3. A digital twin made in MATLAB for unconventional well simulation.

Figure 4 shows an upstream digital twin designed to simulate the geological carbon storage (GCS) process in a fractured aquifer using compositional fluid dynamics coupled with a geomechanical model that assesses fluid transmissibility across faults and fractures (Lie et al., 2021). This integrated reservoir simulation methodology compares engineering capabilities from MRST against SLB's Eclipse and Stanford's AD-GPRS reservoir simulators.

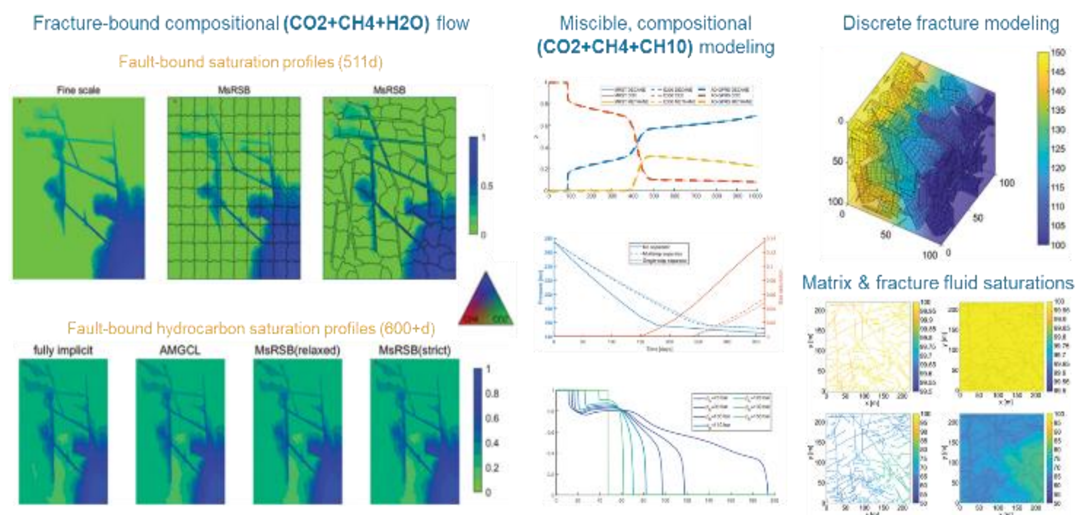

Figure 4. A digital twin in MATLAB for GCS.

Figure 5 shows an upstream digital twin designed to simulate a geothermal gradient and heat flow process using a multiphysics (i.e., thermal, geomechanical, petrophysical) model, which identifies sweet spots for geothermal drilling across deep subsurface layers (Alcanie et al., 2021). This integrated reservoir simulation uses the dynamic simulation capabilities of MRST.

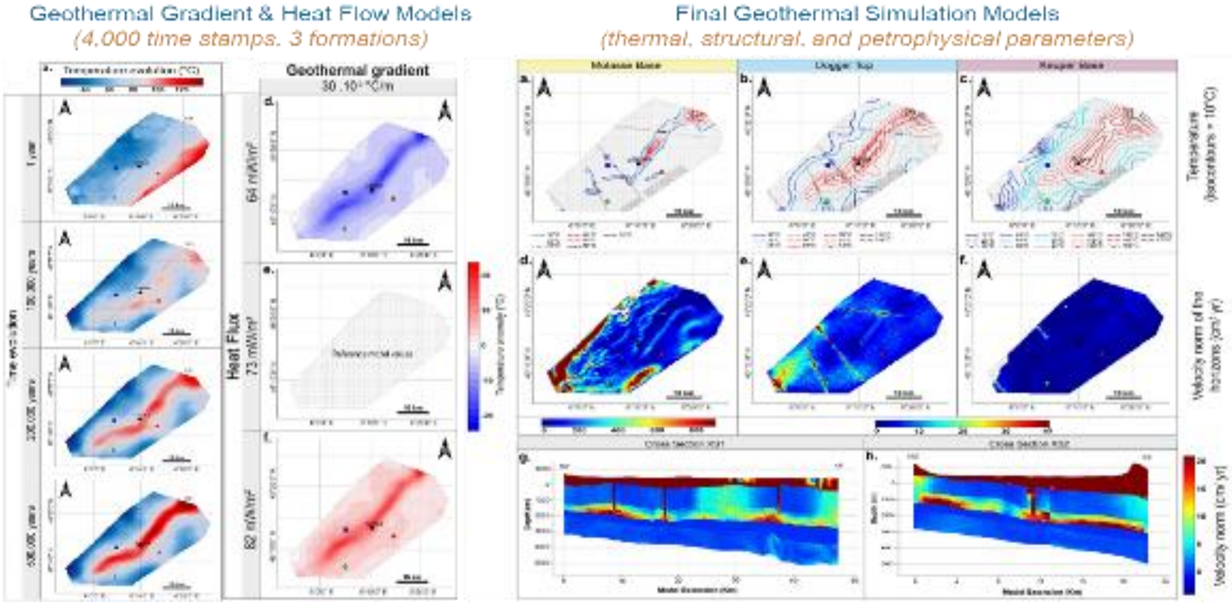

Figure 5. A digital twin in MATLAB for geothermal reservoir simulation.

Midstream Digital Twins

The following examples highlight digital twins developed in MATLAB and Simulink to support FIDs related to:

- Subsurface-to-surface production optimization
- Drilling system automation
- Equipment failure detection and predictive maintenance

Figure 6 shows a midstream digital twin designed to prototype the artificial gas lift performance of a producing well by comparing dynamic pressure and fluid rate data extracted from oilfield sensors at both the reservoir and surface levels. This integrated subsurface-to-surface process uses Optimization Toolbox, Parallel Computing Toolbox™, and network-modeling code to assess production performance via digital nodes and pipes.

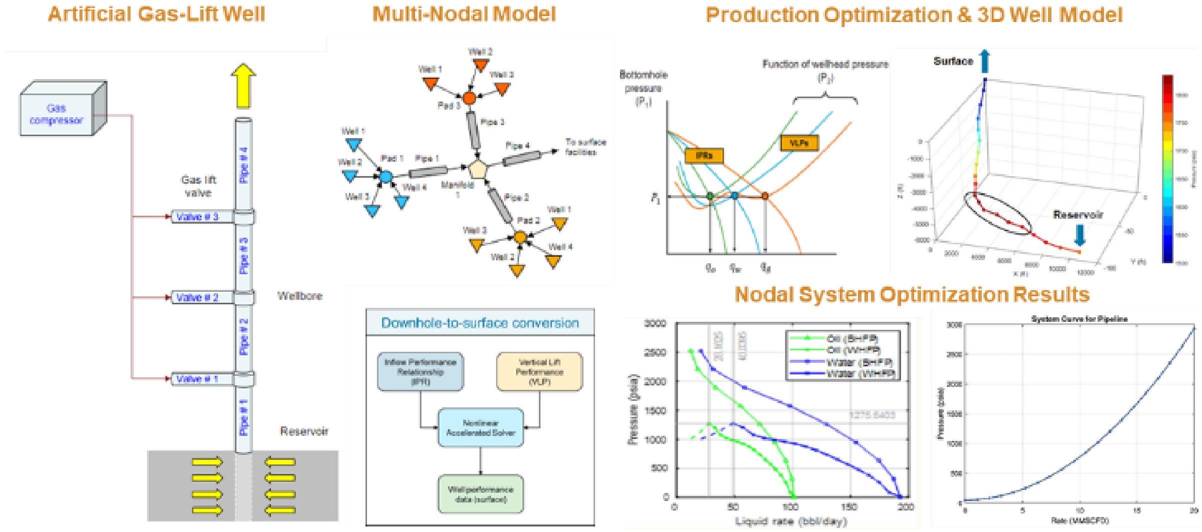

Figure 6. A digital twin in MATLAB for artificial lift optimization.

Figure 7 shows a midstream digital twin designed to optimize a multiphysics system of electrical, mechanical, and hydraulic components that control and automate a drilling drawworks system. This integrated multiphysics process uses Optimization Toolbox, Simulink PLC coder™, Simulink Control Design™, Simscape™, and Stateflow® to interconnect IT/OT sensors and simulate autonomous operating conditions.

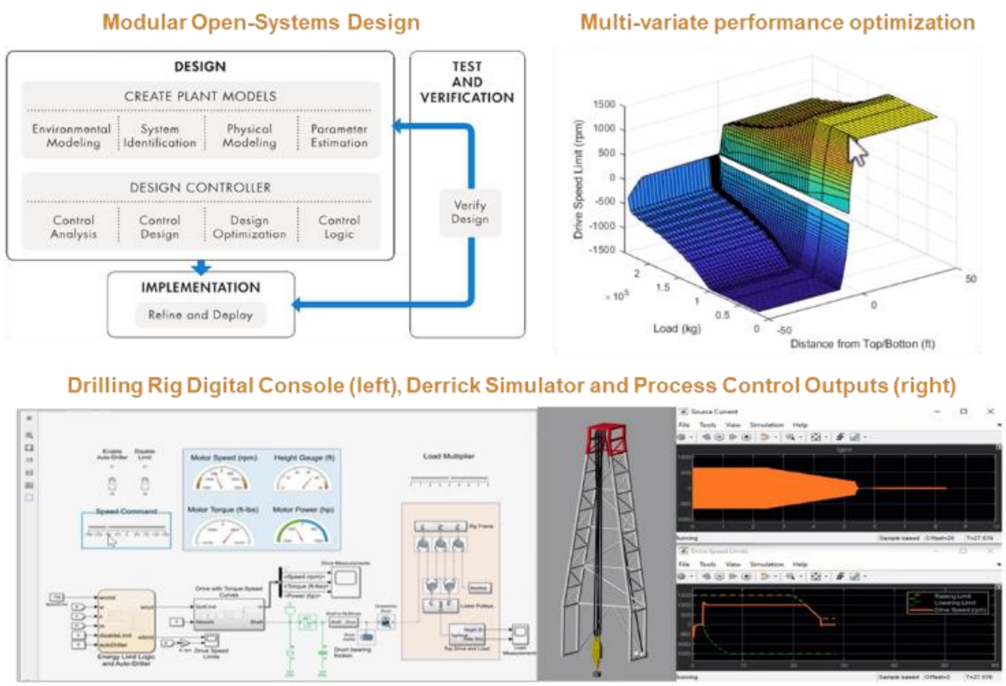

Figure 7. A digital twin in Simulink for drilling systems automation.

Figure 8 shows a midstream digital twin designed to simulate a multiphysics system of electrical, mechanical, and hydraulic components that control and automate an electrical submersible pump (ESP) system (Lastra, 2019). This integrated multiphysics process uses Optimization Toolbox, Simulink PLC Coder, Simscape, Statistics and Machine Learning Toolbox, and Industrial Communication Toolbox™ to automate equipment sizing, failure detection, and performance diagnostics from borehole sensors and flowmeters.

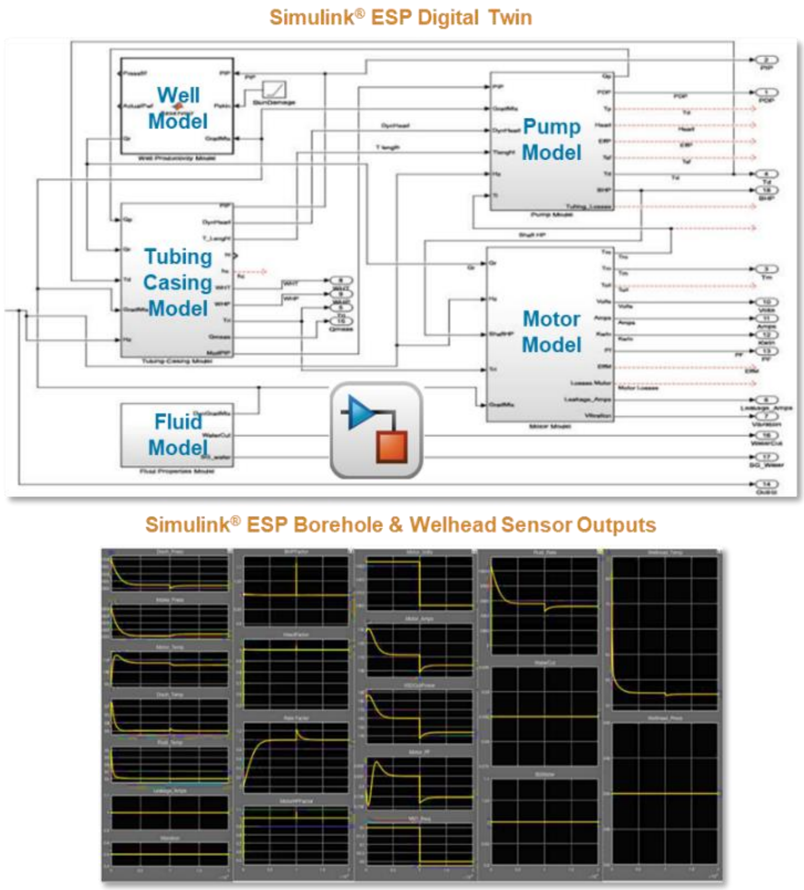

Figure 8. A digital twin in Simulink for an ESP.

Figure 9 shows a midstream digital twin designed by Baker Hughes to predict the failure and required maintenance of positive displacement pumps used for hydraulic fracturing in unconventional wells. Using Statistics and Machine Learning Toolbox and Deep Learning Toolbox™ to develop a multiclass classifier, Baker Hughes collects data from pressure, vibration, and timing sensors to predict failures and maintenance requirements. Also, a Simulink block diagram shows the digital twin from the triplex pump multiphysics system. This integrated approach for analyzing nearly 1 TB of data has helped reduce equipment costs by 30–40%, or $10 million per year.

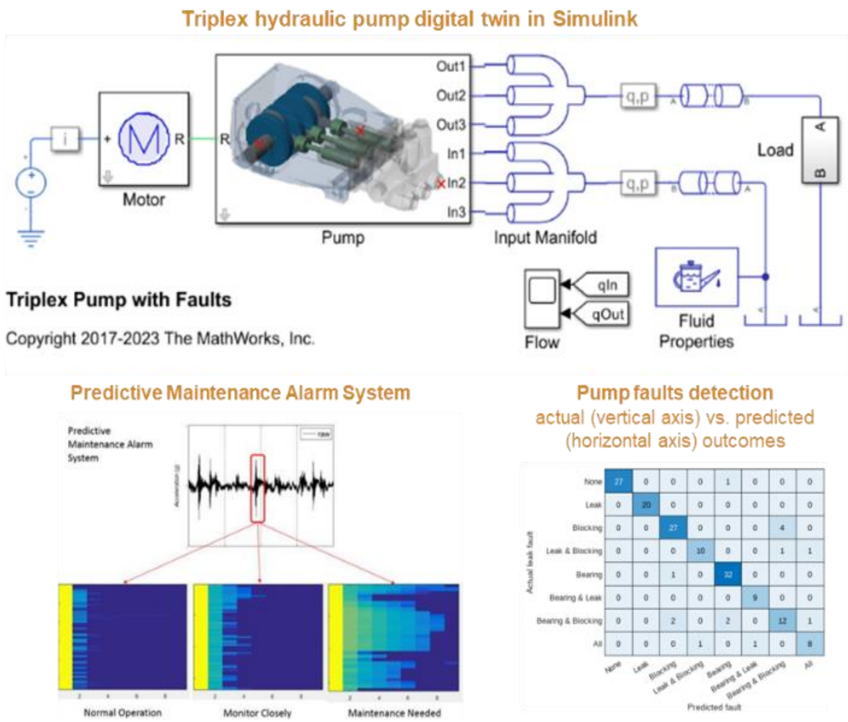

Figure 9. A digital twin in MATLAB for predictive maintenance.

Downstream Digital Transformation Solutions

Downstream energy assets invest in studies, projects, and operations to produce, commercialize, and supply energy resources following standard industrial procedures and best practices for processing, refinement, production, transportation, delivery, and storage (Chronis et al., 2024). A successful outcome from downstream investments usually requires integrated teamwork among scientists and engineers. This collaboration involves creating digital plant models that depict production scenarios for new and existing processes and products on an industrial scale. These models help to evaluate commerciality before investment decisions are made for plant commissioning or refurbishing.

To support downstream energy assets, the Energy Production team at MathWorks has integrated a **Downstream Asset Product Group** with adaptive software toolboxes for scientists, engineers, operations staff, and IT/OT professionals. These toolboxes help them customize, analyze, optimize, and deploy *plant digital twins* (Figure 10). The product group also enables the interconnection of MATLAB and Simulink with third-party applications and IT/OT devices to accelerate:

- Multiphysics, chemical, and R&D modeling
- Process modeling and simulation
- Production surveillance and IT/OT interconnectivity
- Process optimization and automation
- Application deployment

Downstream Digital Twins

The following examples highlight digital twins developed in MATLAB and Simulink to support FIDs related to new energy and chemical manufacturing processes, including:

- Blue and green hydrogen production and CO_2 removal
- Lithium recovery from geothermal sources
- Model predictive control (MPC) of chemicals and materials
- Real-time analytics and process automation

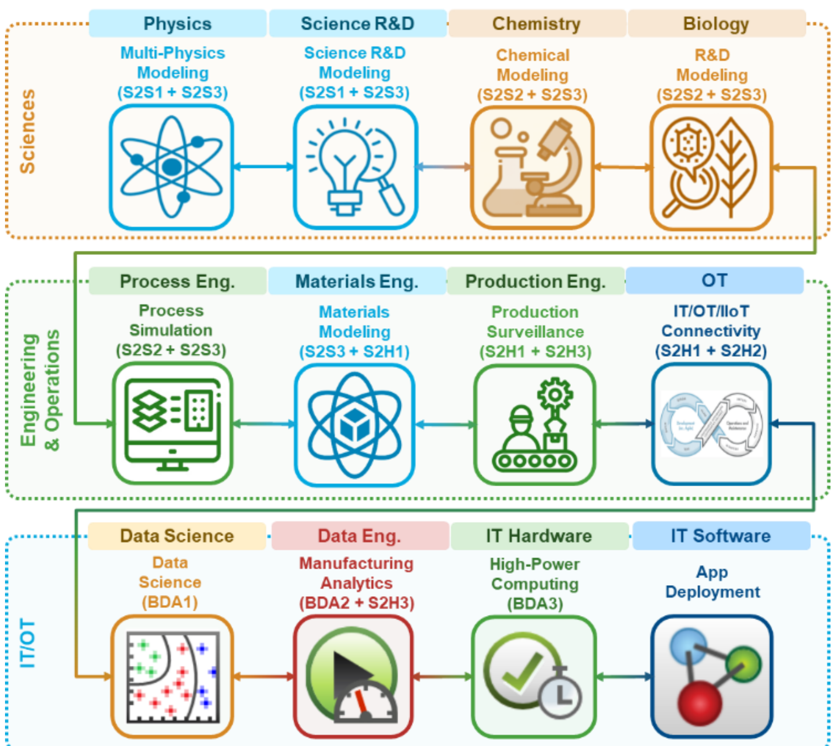

Figure 10. Downstream asset product groups.

Figure 11 shows a downstream digital twin designed to simulate blue hydrogen production and CO_2 hydrogenation by integrating a multiphysics system composed of renewable energy sources (biomass and solar photovoltaic), multifluid processing, and thermal systems (Herdem et al., 2020). This integrated multiphysics process uses MATLAB and Simulink toolboxes, including Simscape and Industrial Communication Toolbox, to parameterize components and monitor chemical, electrical, and thermodynamic performance.

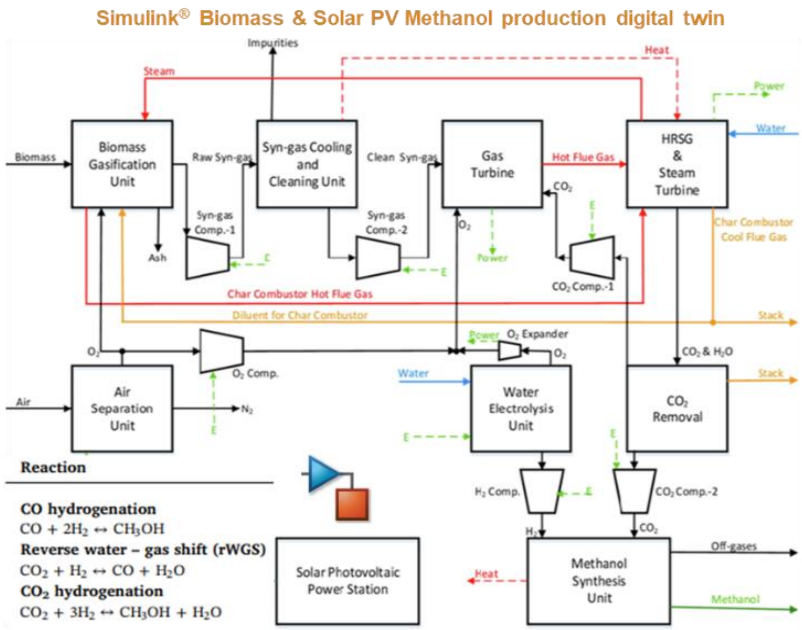

Figure 11. A digital twin in Simulink for blue hydrogen production.

Figure 12 shows a downstream digital twin designed to simulate green hydrogen production by integrating an alkaline water electrolyzer with a multiphysics system composed of renewable energy power (wind and solar photovoltaic), multifluid processing, and thermal systems (Iribarren et al., 2023). This integrated multiphysics process uses MATLAB and Simulink, including Simscape, to optimize hydrogen production using multiple power sources and monitor chemical, electrical, and thermodynamic performance.

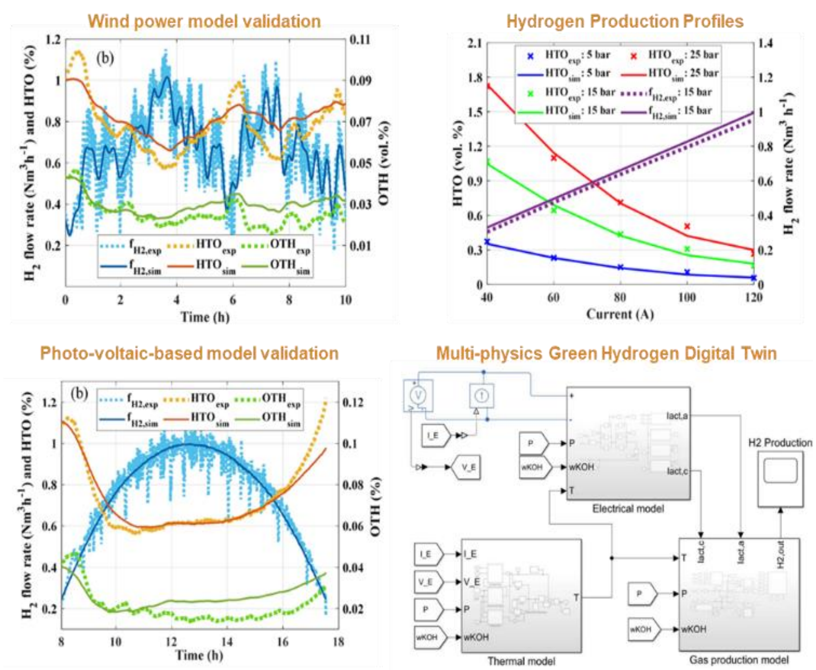

Figure 12. A digital twin in Simulink for green hydrogen production.

Figure 13 shows a downstream digital twin designed to control and predict vinyl chloride monomer (VCM) production across chemical process equipment, including reactors and separators (Chinprasit et al., 2019). This integrated multiphysics process uses MATLAB and Simulink connected to Aspen Plus for cosimulating the VCM process. It involves employing a multivariate model to conduct a sensitivity analysis in Simulink. Additionally, PID and MPC controllers are utilized based on multiple input/output configurations to optimize process performance.

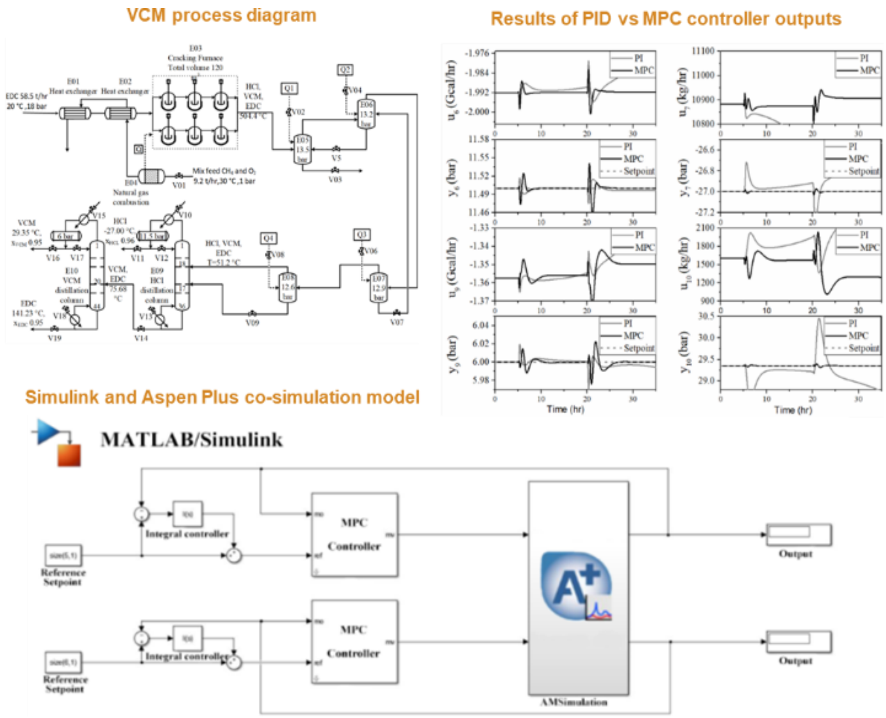

Figure 13. A digital twin in Simulink for MPC.

Figure 14 shows a downstream digital twin designed to control and predict failure in a polymer manufacturing process by tracking uncontrolled exothermal responses during phenol-formaldehyde production (Yaacob et al., 2001). This integrated process uses MATLAB, Simulink, and Statistics and Machine Learning Toolbox to compare fuzzy logic (FLC) and Proportional-Integral-Derivative (PID) structures and design a sensor-based process control system that automates a safe exothermal chemical process.

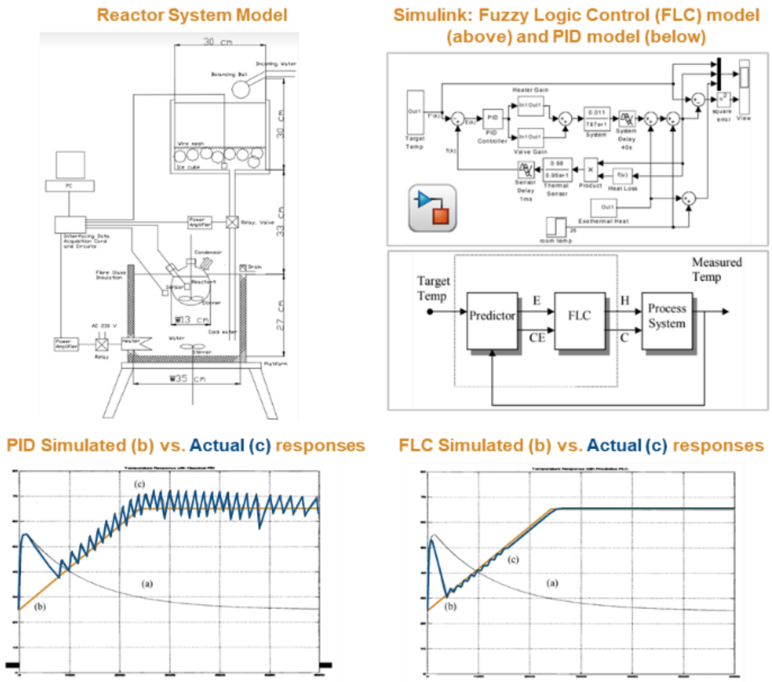

Figure 14. A digital twin in Simulink for process control and automation.

Figure 15 shows a downstream digital twin designed to optimize lithium recovery by assessing the performance of separation membranes involved in distillation, evaporation, crystallization, and precipitation processes (Kalmykov et al., 2021). This integrated process uses Simulink and Simscape to cosimulate a multiphysics system of geochemical and geothermal processes using geochemical properties extracted from a PHREEQC simulator, designing separation membranes for optimal geothermal production.

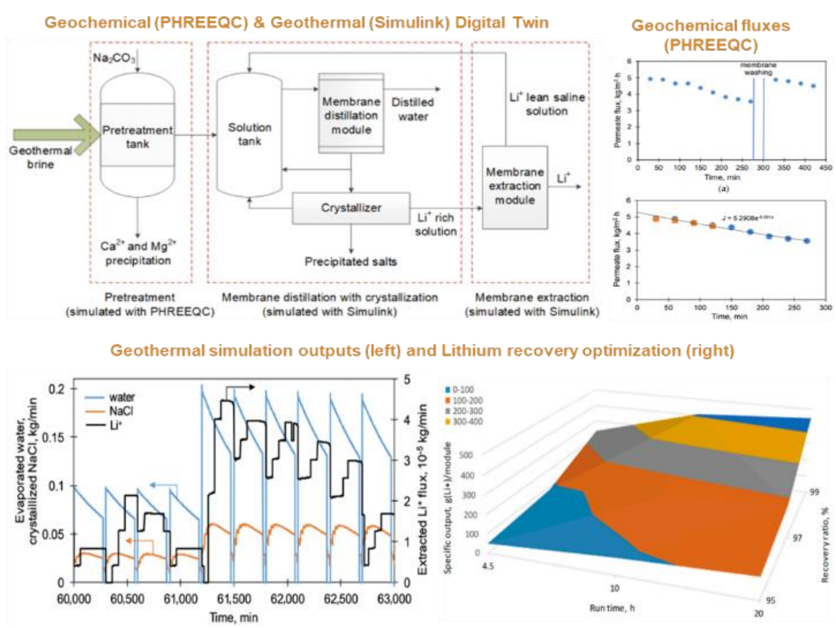

Figure 15. A digital twin in Simulink for geothermal lithium recovery.

Conclusion

Digital twins enable predictive maintenance, production optimization, and process automation to enhance decision-making, improve asset performance, reduce operational downtime, and ensure process safety and reliability.

Building digital twins in MATLAB and Simulink offers significant value by optimizing and automating production processes across the energy value chain. By creating virtual models to mirror multi-physics operations, you can simulate, analyze, and optimize complex production processes in real time.

Leveraging the powerful analytics and dynamic system modeling capabilities of both MATLAB and Simulink platforms, you can effectively develop robust and precise digital twins to drive efficiency, reduce costs, and generate sustainable outcomes across your upstream, midstream, and downstream energy assets.

Learn More

Learn more:

MATLAB and Simulink for Process Optimization and Automation in Energy Resources

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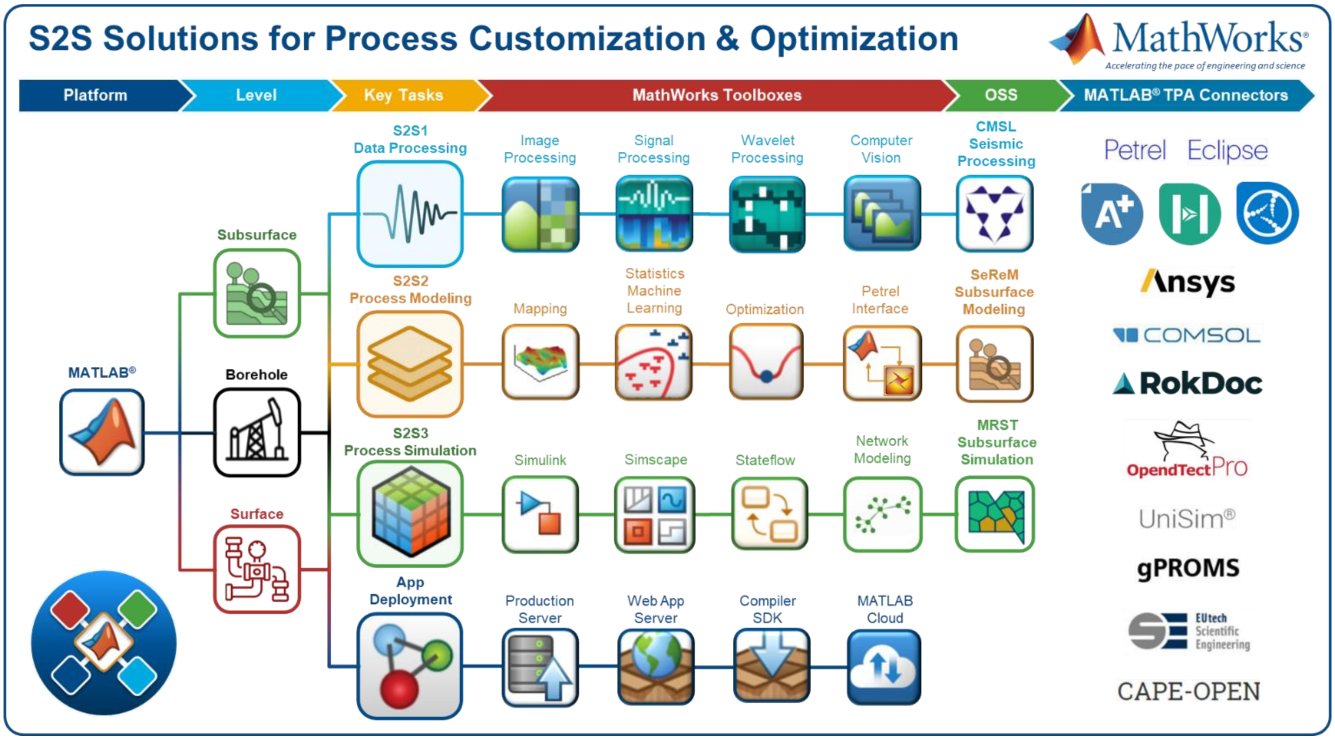
Appendixes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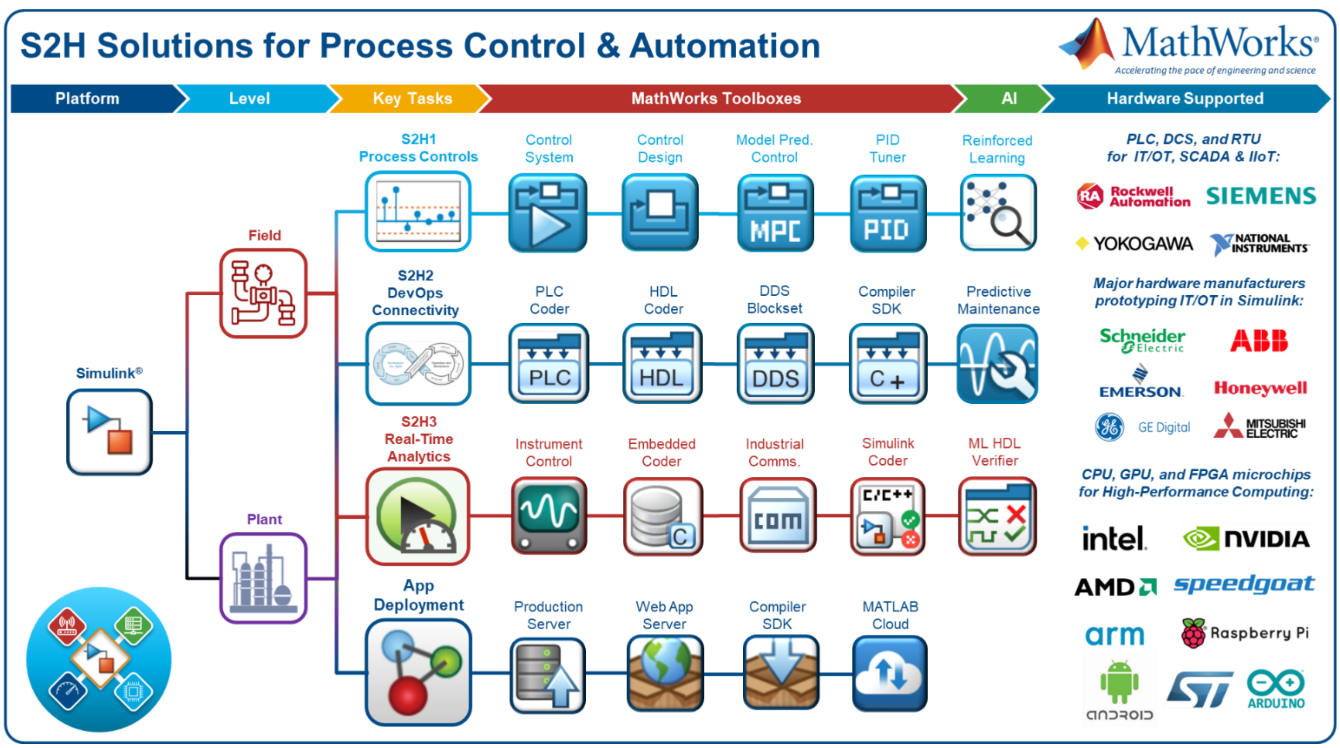
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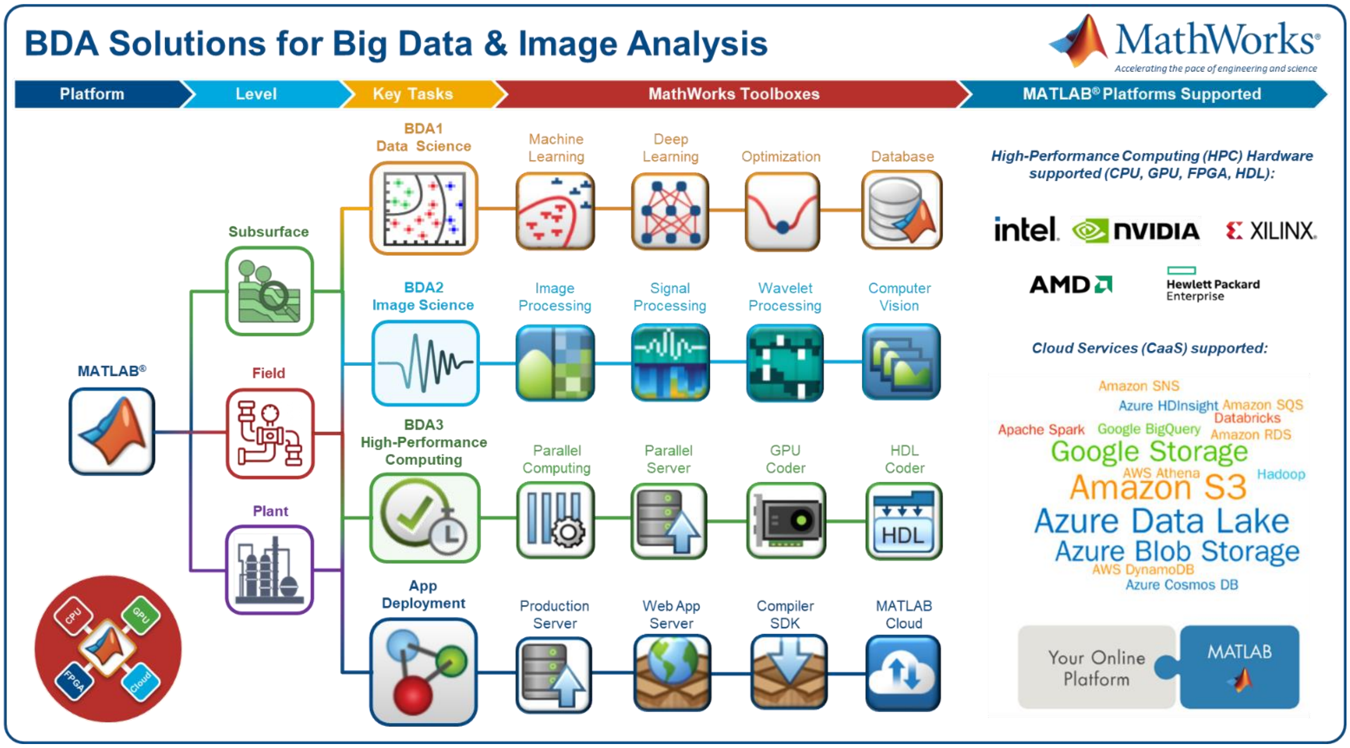
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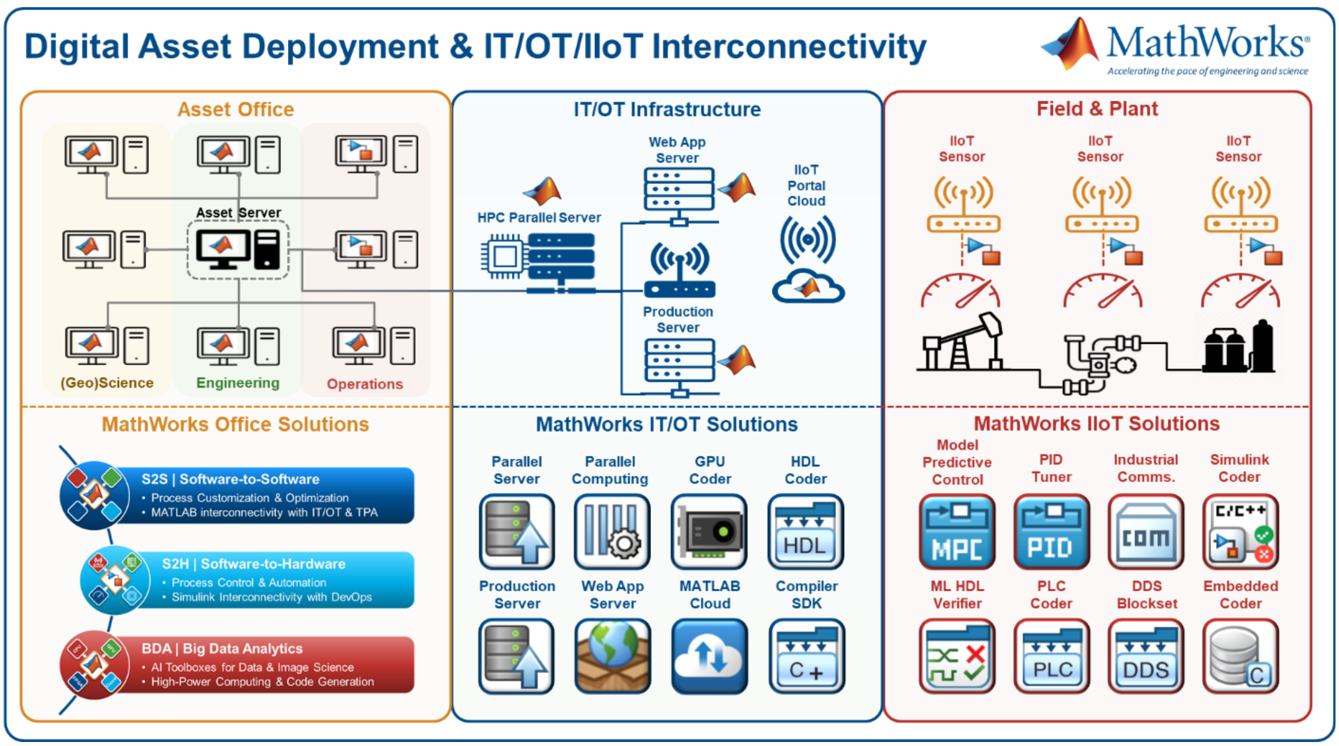
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