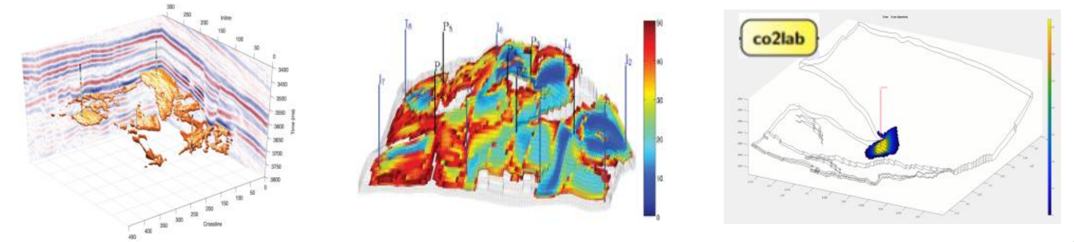
MathWorks®

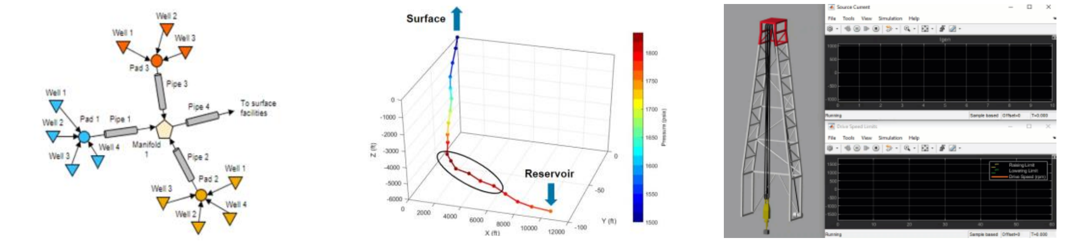
Industrial Solutions for Energy Resources in MATLAB® & SIMULINK®

(v. 1Q25)

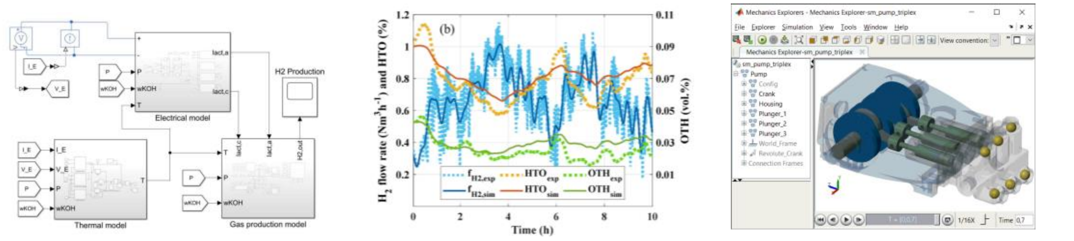
Subsurface



Oilfield



Plant



Artificial Intelligence

Big Data Analysis

Deep Learning

Machine Learning

Reinforced Learning

Predictive Analytics

Internet of Things

Process Optimization

Model-Based Design

Process Automation

New Process Integration

MathWorks®

Accelerating the pace of engineering and science

MathWorks®

The creators of

MATLAB® & SIMULINK®

Americas
United States
Brazil

Middle East
UAE

Asia-Pacific
Australia
China
India
Japan
Korea
Malaysia

Europe
Finland
France
Germany
Ireland
Italy
Netherlands
Poland
Spain
Sweden
Switzerland
UK

6,500+ staff
in 34 offices around the world

140+ Toolboxes
for STEM applications

40 years in business
and profitable every year

MathWorks

Industrial Solutions for Energy Resources

Artificial Intelligence (AI)

Predictive analytics and machine learning for data-driven modeling, anomaly detection, failure prediction, and real-time optimization

Improve reliability, safety, decision-making

Petroleum **Minerals**

Chemicals **Materials**

Model-based Design (MBD)

Dynamic process simulation and optimization for process control design, digital twin development, real-time monitoring, and predictive analytics

Improve efficiency, safety, profitability

Signal & Image Processing (SIP)

Seismic data analysis and interpretation with advanced filtering, denoising, spectral analysis, and machine learning-based feature extraction

Enhance subsurface imaging & characterization

Advanced Process Control (APC)

Model predictive control (MPC) for real-time process optimization, dynamic modeling & simulation, and control system design

Improve efficiency, stability, performance

Optimization & Finance (O&F)

Asset investment planning, risk analysis, and supply chain optimization for capital allocation, portfolio management, and pricing strategies

Maximize profitability and reduce uncertainties

Upstream → **Midstream** → **Downstream**

Software Development Kit (SDK)

Custom and interactive engineering applications for data analysis, visualization and decision support across enterprise systems and clouds

Prompt analysis, optimization, predictability

E&P EOR

CCS Circularity

Geothermal H_2 | Li

Upstream Energy | MathWorks Solutions in MATLAB & SIMULINK

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Enablers

MRST — Customized Subsurface Modeling

Rapid prototype custom models for unconventional, fractured, geological storage, and geothermal reservoirs

+

HPC — High-Performance Computing

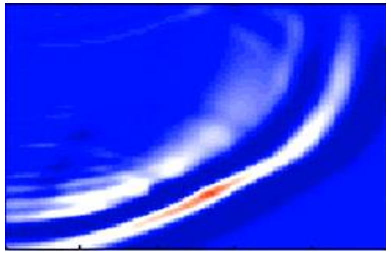
Accelerate large-scale data processing and simulation with GPU computing on-prem or on-cloud

+

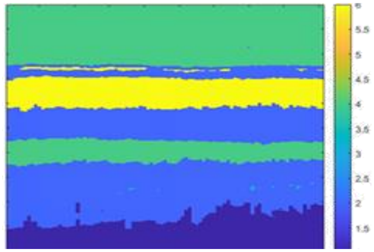
AI & SIP — Predictive Analytics of Big Data and Signals

Streamline data analytics to extract value of information (VOI) timely with built-in AI/ML workflows

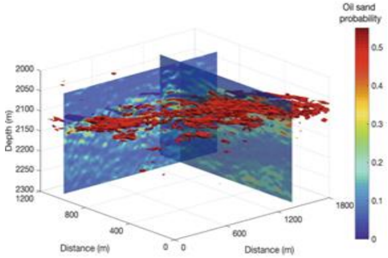
Workflows



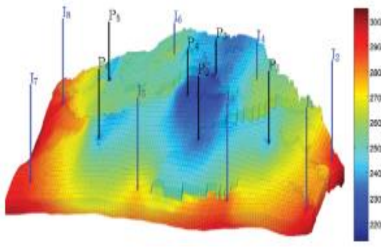
IMAGING



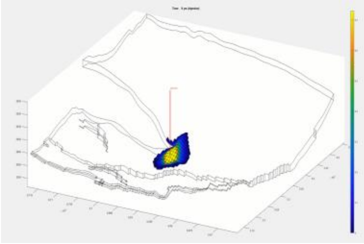
CLASSIFICATION



CHARACTERIZATION

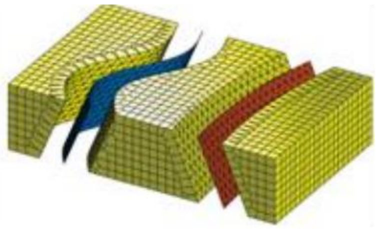


MODELING

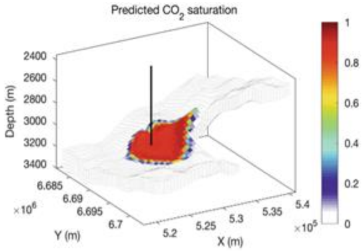


SIMULATION

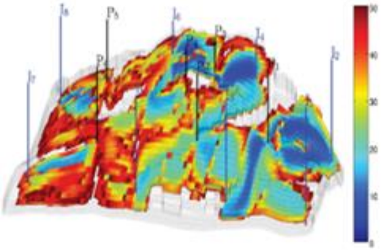
Applications



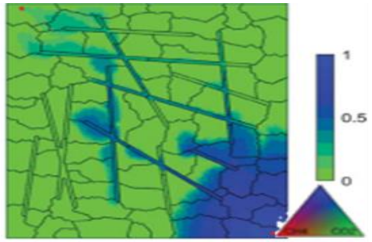
Subsurface Modeling



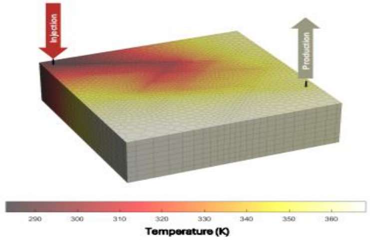
Geological Storage



Enhanced Recovery



Fractured Reservoirs



Geothermal Reservoirs

Midstream Energy | MathWorks Solutions in MATLAB & SIMULINK

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Enablers

MBD — Cost-Effective Model-Based Design

Rapid prototype, test, and verify models to reduce downtime and costs and ensure safe and reliable operations

+

OPC — Data Integration & Process Optimization

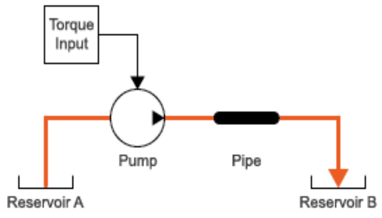
Integrate sensor data from PI & SCADA to streamline production data analytics and optimize operational processes

+

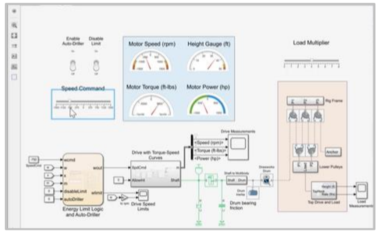
SLRT — Real-Time Analytics & Digital Twins

Develop digital twins for real-time monitoring, predictive maintenance, and dynamic process control

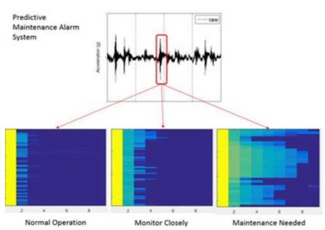
Workflows



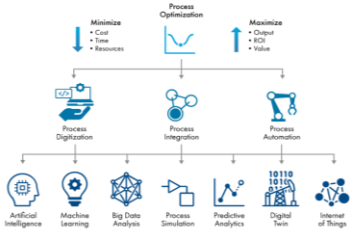
MODELING



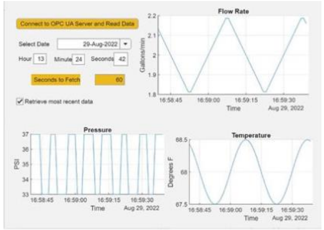
MONITORING



ANALYSIS

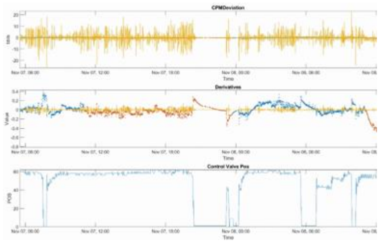


OPTIMIZATION

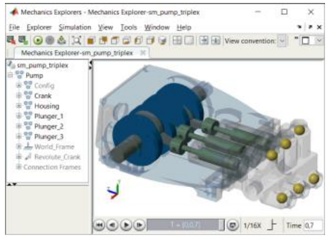


RT ANALYTICS

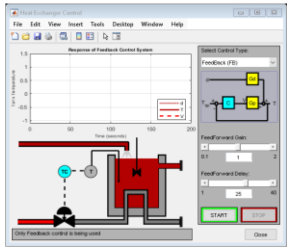
Applications



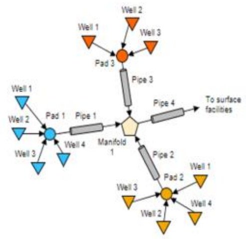
Pipeline Integrity



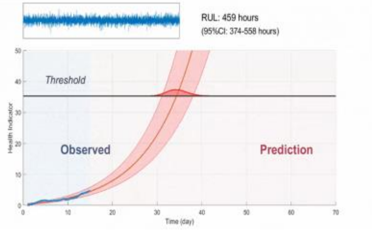
Predictive Maintenance



LNG Processing



Production Optimization



Process Reliability

Downstream Energy | MathWorks Solutions in MATLAB & SIMULINK

Enablers

APC — Advanced Process Control & Model-Based Design

Enhance design, modeling, and control of complex production processes to ensure safety and reliability more cost-effectively

+

OPC — Data Integration & Process Automation

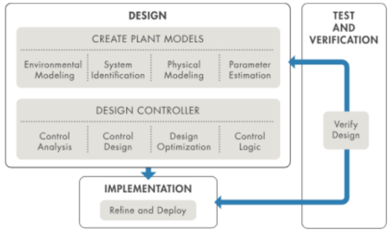
Integrate sensor data from PI & SCADA to streamline production data analytics and optimize process performance

+

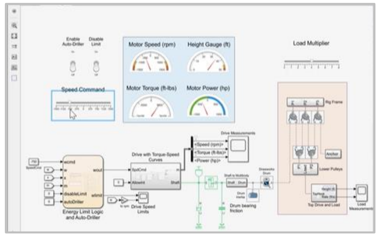
SLRT — Real-Time Analytics & Digital Twins

Develop digital twins for real-time monitoring, predictive maintenance, and dynamic process control

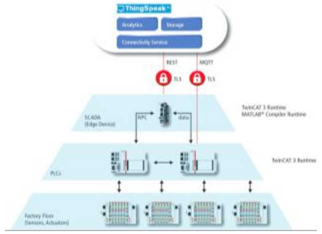
Workflows



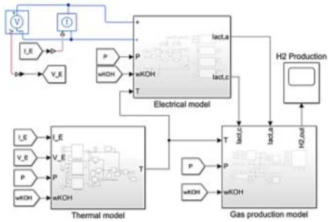
MODELING



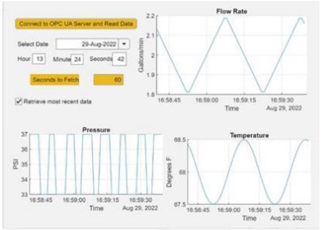
MONITORING



AUTOMATION

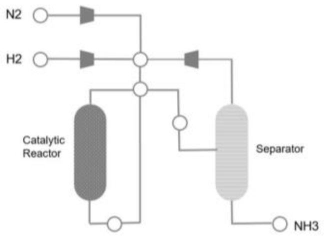


DIGITAL TWIN

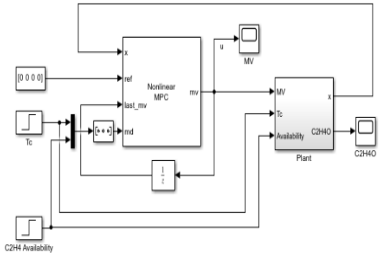


RT ANALYTICS

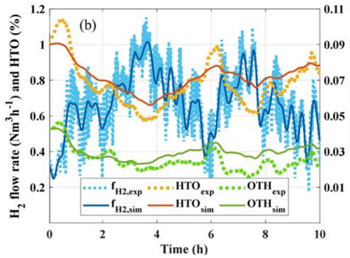
Applications



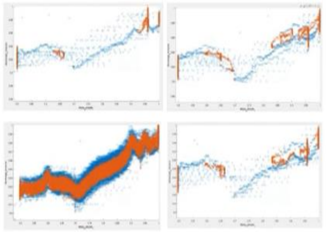
Process Modeling



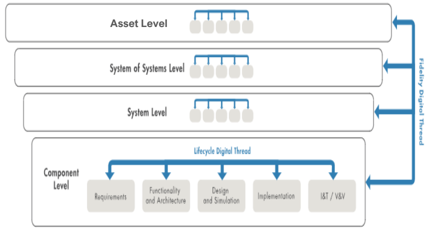
Process Control



Process Optimization



Process Monitoring



Process Scalability

What Upstream customers have achieved using MathWorks products

Customer	Objective	Outcome	MathWorks solutions
ExxonMobil	**Drilling Modeling, Simulation, and Control** Model drill string dynamics for operational surveillance, diagnosis, and automation	**Improved drilling performance and automation** • Continuously improve drilling automation process • Save time selection and optimizing drilling systems	**MATLAB & Simulink** • Simscape + Stateflow • Control Systems
aramco	**Natural Fracture Prediction and Analysis** Perform key structural geomechanics analysis in a computational and cost-efficient manner	**Efficient geomechanical modeling & simulation** • Accelerated reservoir geomechanics workflow for elastic dislocation and fracture prediction analysis	**MATLAB** • Math & Optimization • App Deployment
Chevron	**Reduced-Order Reservoir Simulation** Simulate reservoir and surface conditions in a mature oilfield to optimize production recovery	**Accelerated reservoir management decisions** • Integrated LSTM-CRM reservoir models • Supported real-time decision making	**MATLAB** • Reservoir Modeling & Simulation • Optimization & App Deployment
Shell	**Microseismic Monitoring of Carbon Storage** Design measuring-monitoring-verifying (MMV) plan for CO_2 storage using microseismic data	**Accelerated CCS surveillance decisions** • Developed a risk-based MMV app for microseismic analytics to assess containment at CCS complex	**MATLAB** • Image & Signal Processing • Data Analytics +App Deployment
BR PETROBRAS	**Oil Production Modeling and Control** Model oil production processes, dynamic responses, and advanced control structures	**Integrated process control theory and practice** • Production methods for data processing, modeling, and simulation of oilfield control systems	**MATLAB & Simulink** • Math & Optimization • Control Systems
HALLIBURTON	**Borehole Image Processing and Analysis** Model and process distributed acoustic sensor (DAS) datasets to enhance borehole images	**Enhanced DAS survey modeling & VSP imaging** • Integrated seismic models to design DAS surveys • Design migration algorithms for VSP images	**MATLAB** • Image & Signal Processing • Math & Optimization
slb	**Adaptive Multi-Domain Controller Design** Model, simulate, and deploy multi-domain controller systems for operational optimization	**Improved wireline logging operations** • Customized control system model, generated embedded code, and test automation in DevOps	**MATLAB + Simulink** • Simscape + Stateflow • Control Systems + Simulink Test

How Energy companies benefits from MathWorks technology

MATLAB® & SIMULINK®

- Accelerate advanced data analytics
- Real-time modeling and simulation of complex production systems

→ **Optimize** exploration, production, and refining operations

- Simulate process control systems
- Analyze large-scale sensor data
- Predictive maintenance algorithms

→ **Improve** asset reliability

Reduce operational costs

- Design multi-physics digital twins
- Integrate with existing IT/OT systems
- Execute agile, data-driven workflows

→ **Accelerate** process efficiency

Drive innovation across upstream, midstream, and downstream

MathWorks®

Accelerating the pace of engineering and science

INITIATE

INNOVATE

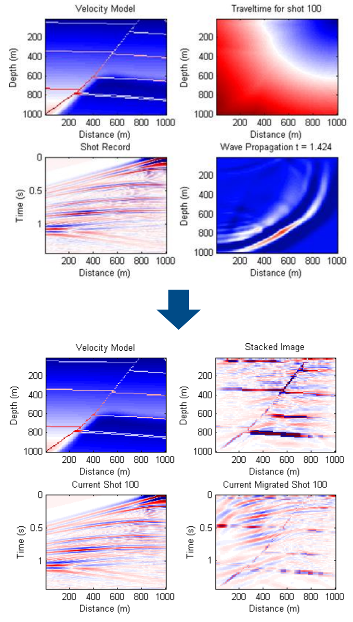
INSPIRE

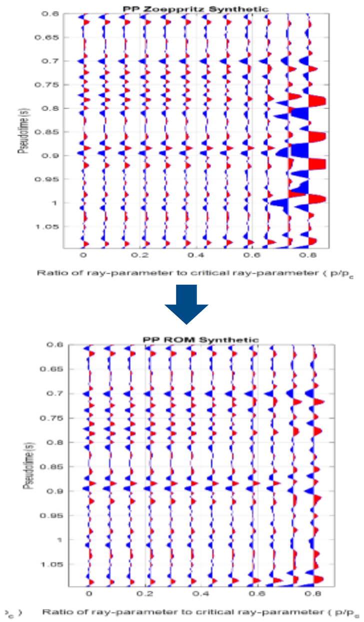
MATLAB® & SIMULINK®

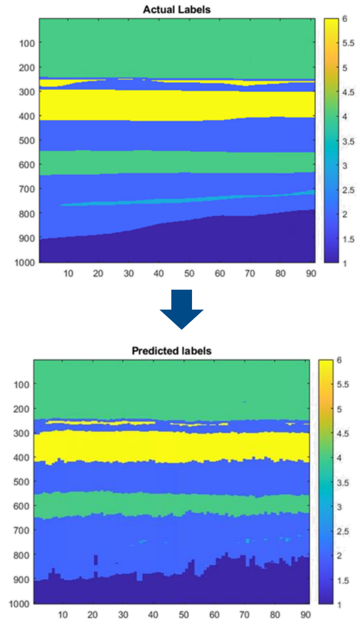
Upstream Geosciences | Big Data Science Workflows

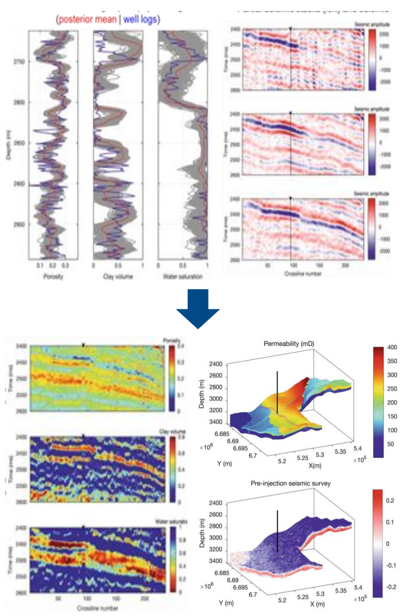
Workflow	Imaging	Conditioning	Classifying	Inverting	Predicting
Inputs	Prestack seismic gathers Seismic velocity model	Prestack migrated gathers (after NMO or NHMO)	Seismic migrated stacks Seismic inversion volumes	Prestack conditioned AVO-compliant gathers	Seismic inversion volumes Subsurface property vols.
Key features	**Prestack imaging** (RTM, LSM, FWI) Parallel computing (CPU, GPU)	**Reduced order modeling** (AVO, AVA, AVAz) Gather flattening Spectral balancing	**Structural / Stratigraphic classification** Spectral decomposition PINNs (CNN, RNN)	**Rock physics modeling** **Petroelastic inversion** Geostatistical modeling Bayesian classification	**Sweet spot classification** **Petroelastic/Geomechanical** Petroelastic classification PINNs (CNN, RNN)
MATLAB® Toolboxes	Seismic Imaging GPU Computing GIS Mapping	Signal Processing Deep Learning GPU Computing	Signal Processing Deep Learning GPU Computing	Rock Physics Geophysical Inversion GPU Computing	Signal Processing Deep Learning GPU Computing
Outputs	Prestack migrated gathers Prestack migrated stacks	Prestack conditioned AVO-compliant gathers	Structural class. volume Stratigraphic class. volume	Seismic inversion volumes Subsurface property vols.	Sweet spot geobodies Property class. volumes

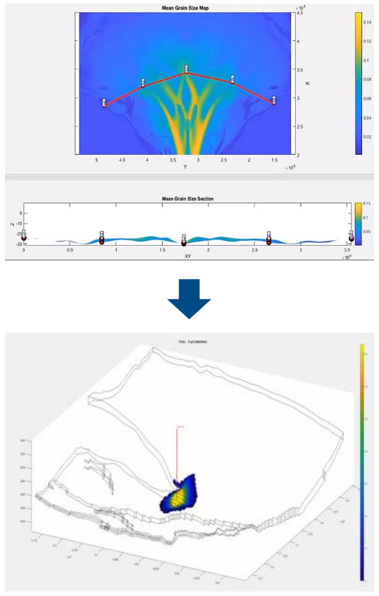
Examples







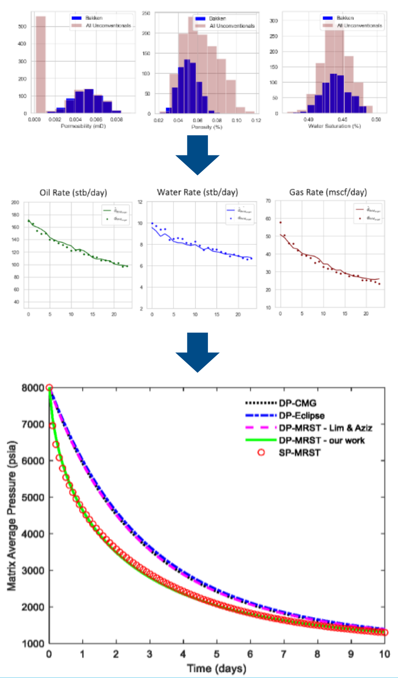


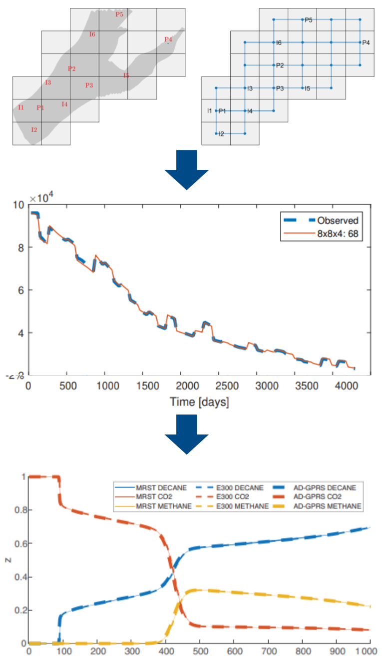


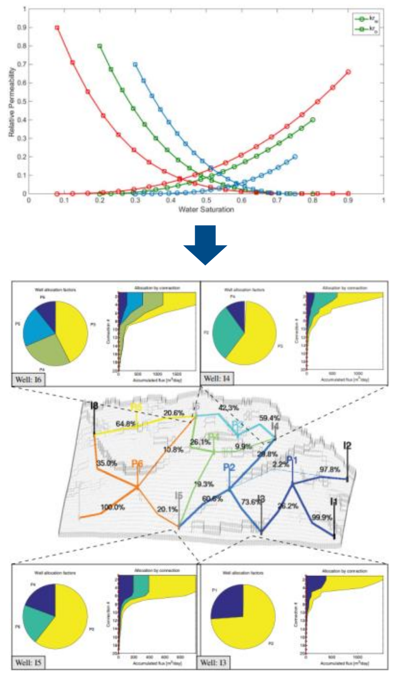
Upstream Engineering | Production Optimization Workflows

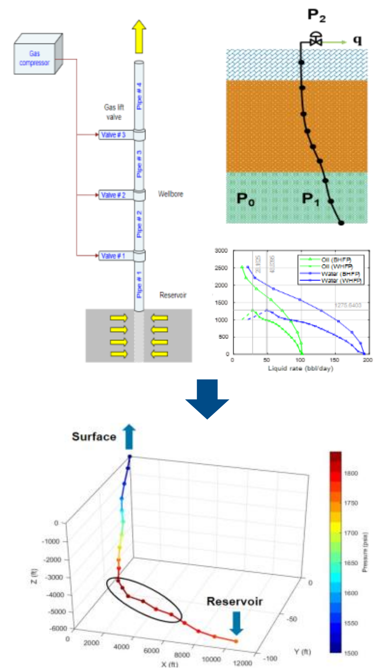
Workflow	Modeling	Simulating	Automating	Monitoring	Optimizing
Inputs	Reservoir property grids Production history data	Reduced order models Dynamic model decks	Production history data Reservoir model updates	Borehole and surface pipeline sensor data	Production history data IPR & VLP data
Key features	**Reduced order modeling** **CRM modeling** Dual-porosity modeling	**Geomechanical simulation** **Compositional fluid sim.** Sensitivity analysis	**Automatic history matching (AHM)** Machine learning model	**Subsurface-to-surface nodal analysis** Steady-state analysis	**Multi-domain production optimization** Steady-state analysis
Toolboxes	Subsurface Simulation Deep Learning GPU Computing	Subsurface Simulation Global Optimization GPU Computing	Subsurface Simulation Machine Learning GPU Computing	Subsurface Simulation Simscape GPU Computing	Global Optimization Computational Finance GPU Computing
Outputs	History matching outputs Reservoir model updates	History matching outputs Reservoir model updates	History matching outputs Reservoir model updates	Borehole and surface dynamic properties	Production history outputs

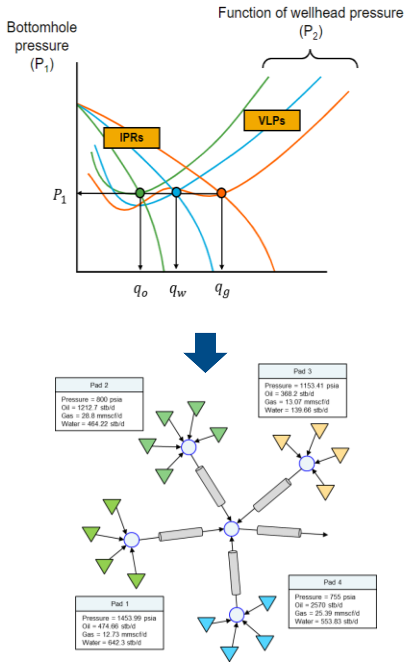
Examples









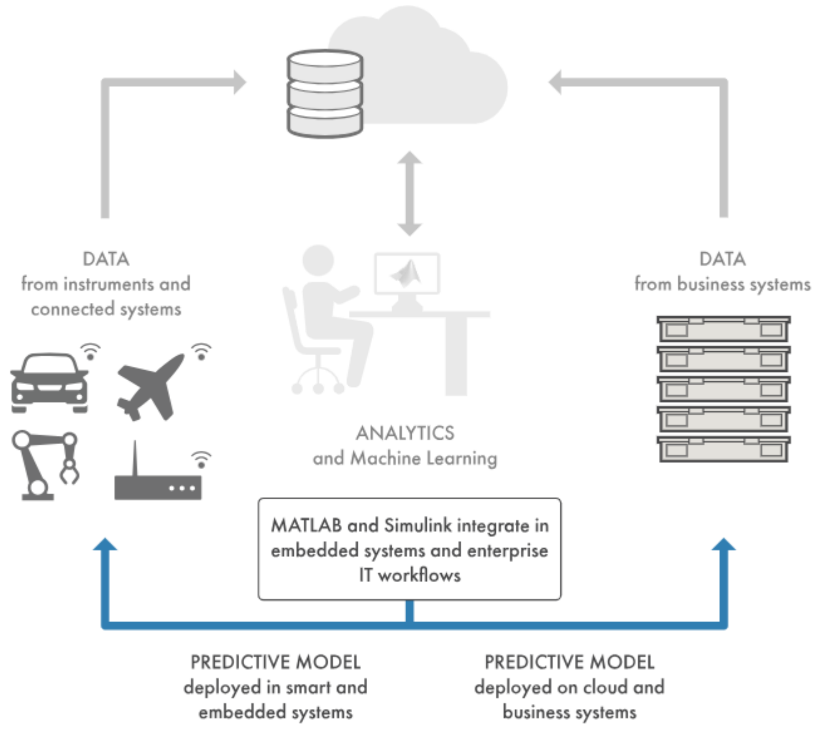


MathWorks® in Energy Resources

Industrial Workflows for Midstream and Downstream Energy

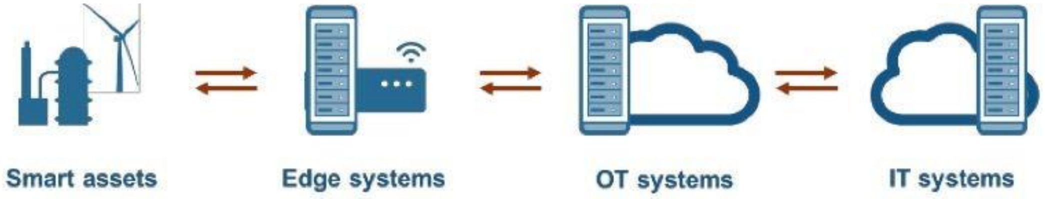
Real-Time Analytics (AI, IPCV, HPC)

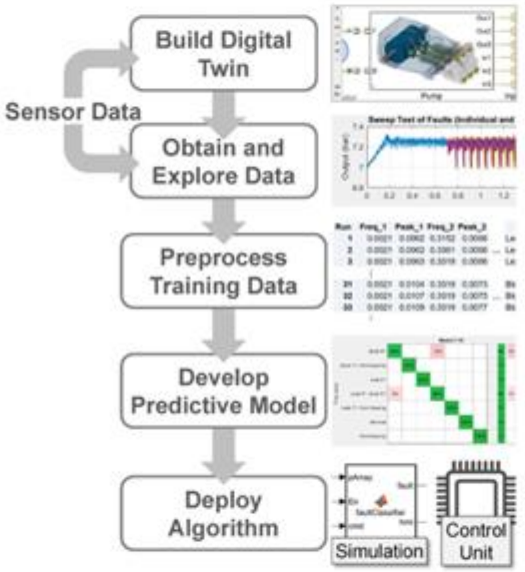
Sensor data analysis for production surveillance, and machine learning for predictive analytics

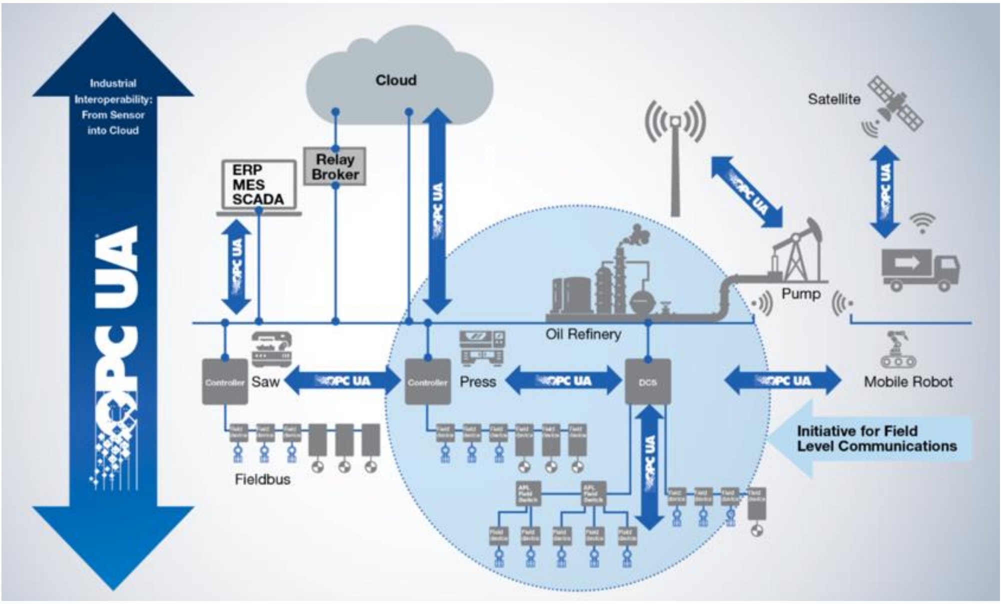


Process Control and Automation (APC, DCS, PLC, SCADA)

Multi-physics digital twins (MBD) for fast prototyping of complex processes integrated with process control systems and IIoT sensors







MathWorks solutions for Midstream Asset Management

Workflow	Key Solutions	Main Objectives	Major Applications	Examples
System Design & Simulation	Simulink & Simscape	• **Design and model** digital twins of complex multi-domain LNG infrastructure • **Simulate and optimize** LNG facilities design before construction • **Visualize and analyze** dynamic interactions between LNG subsystems	➢ Fluid dynamics, thermodynamics, control systems ➢ Predictive, real-time operational optimization ➢ Gas processing and compression, LNG cooling	• Optimize and Automate Energy Assets with Digital Twins in MATLAB and Simulink • Optimize Oil & Gas Production Assets with Simscape - MATLAB & Simulink
Control System Development	MPC, Control Systems & PLC Coder	• **Design** advanced control systems essential for LNG processes • **Generate** structured text to deploy on PLCs and embedded controllers	➢ Gas liquefaction, storage, and transportation ➢ Safe and efficient temperature & pressure control ➢ LNG facility process automation	• Digital Twins for Industrial IoT - MATLAB & Simulink • Developing Energy Systems from Tank to Fuel Cell - MATLAB & Simulink
Predictive Maintenance & Reliability Analysis	Pred. Maintenance, Machine & Deep Learning	• **Design** predictive algorithms using sensor data from LNG facility equipment • **Predict** operational performance using data-driven models and data analytics	➢ Proactive maintenance to avoid unplanned downtime ➢ Optimize maintenance schedules (compressors, pipelines, tanks) ➢ Predict equipment degradation	• Introduction to Predictive Maintenance with MATLAB • Digital Twins for Predictive Maintenance of Oil & Gas Processes - MATLAB & Simulink
Process Optimization & Safety Assessment	Optimization & Planning	• **Optimize** facility layouts, pipeline routing and LNG processing parameters • **Quantify** risks in complex LNG operations • **Model** safety-critical LNG systems	➢ Enhanced operational efficiency, safety, and cost effectiveness ➢ Assess potential failures in pipelines, tanks, or processes	• Optimizing Operational Processes with Reinforcement Learning in MATLAB
Scalability & Enterprise Systems Integration	App Deployment Servers & Industrial Communications	• **Process** historical and real-time data from PI systems to fine-tune operations • **Integrate** SCADA, ERP, and PI historians to analyze and optimize operational data • **Deploy** enterprise-wide applications	➢ Advanced process analytics to improve energy efficiency ➢ Run complex analysis, visualize data trends, and make data-driven decisions in real time	• MATLAB Production Server – MATLAB • MATLAB Web App Server – MATLAB • Industrial Communication Toolbox - MATLAB

MathWorks® in Energy Resources

Modular Open-Systems Approach for Digital Twins

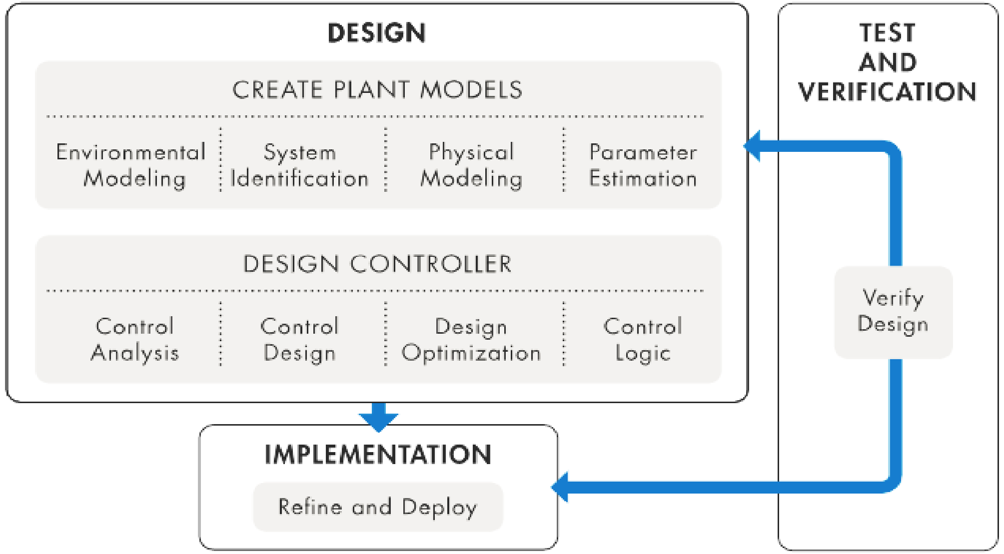
Objectives

- Monitor, predict, and automate IT/OT systems
- Integrate data science and engineering analytics

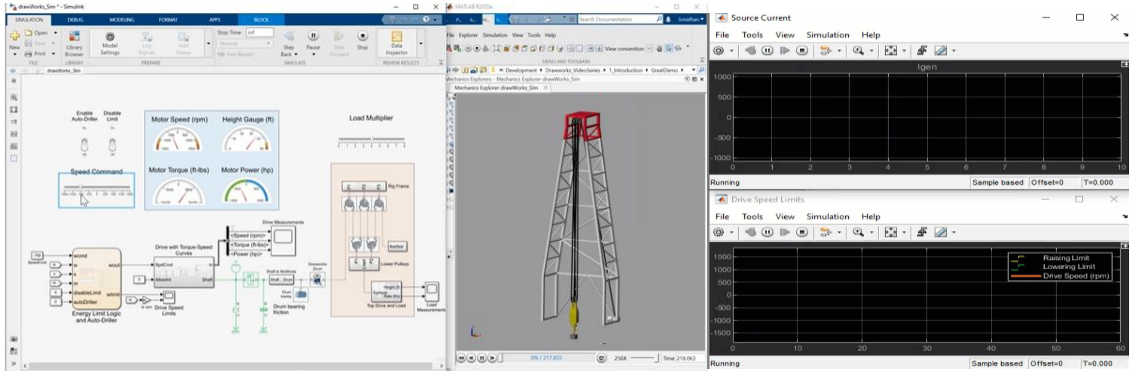
Advantages

- Efficient, secure, and high-quality outputs
- Verify, adapt, and transform before you invest

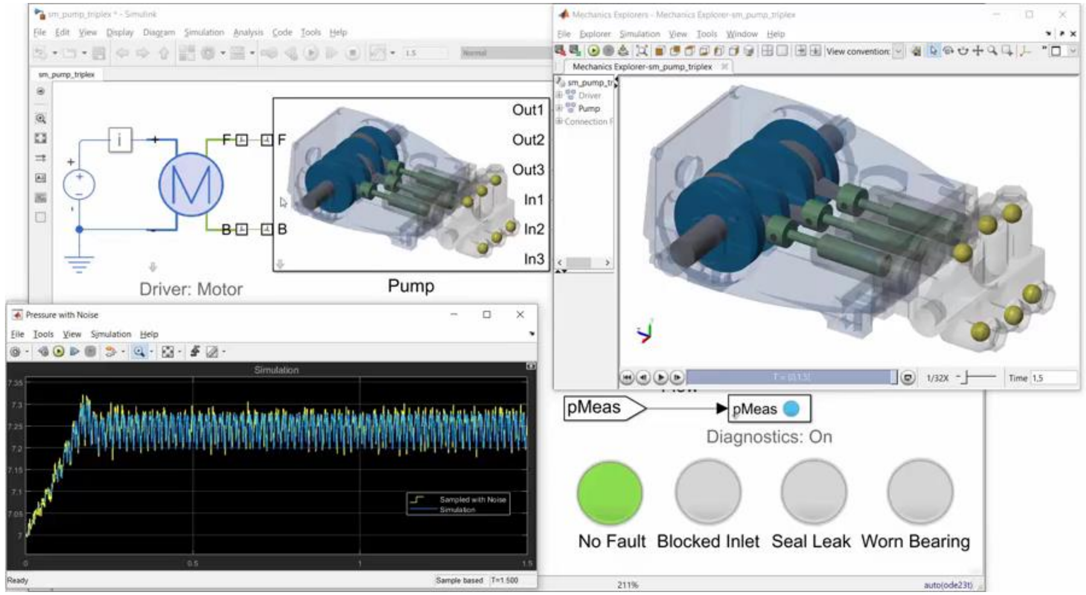
Modular Open-Systems Approach



Digital Twin for Drilling Rig Automation



Digital Twin for Pump Predictive Maintenance



MathWorks solutions for Digital Twin Modeling of Oilfield Processes

	Product	Objective	Functions	Applications	Examples
Process Simulation	Simulink	Model dynamic systems with block diagrams to represent physical processes and control systems	• Model thermal flow systems • Model oilfield infrastructure • Model control systems	Oilfield assets: • Borehole sensors • Pipelines • Oilfield equipment • Processing facilities • Storage facilities	Optimize and Automate Energy Assets with Digital Twins in MATLAB and Simulink
	Simscape	Model multi-physics processes	• Model gas and fluid flow dynamics • Model condensation / evaporation • Model liquefaction / regasification		Optimize Oil & Gas Production Assets with Simscape - MATLAB & Simulink
	Sim. Real-Time	Test and deployment of models in real-time environments	• Hardware-in-the-loop (HIL) testing • Testing digital twins in real-time • Process safety and reliability		Electro-Mechanical System Optimization using Simulation - MATLAB & Simulink
Process Control	Pred. Maintenance	Analyze equipment data from sensors, predict performance, and forecast maintenance	• Detect process anomalies • Predict equipment failure • Optimize maintenance schedule	• Pressure control • Temperature control • Flow rate regulation • Faulty conditions • Healthy conditions	Digital Twins for Predictive Maintenance of Oil & Gas Processes - MATLAB & Simulink
	Control Systems	Design, analyze, and implement process controls in digital twins	• Model Predictive Controls (MPC) • Advanced Control Systems (APC) • Distributed Control Systems (DCS)		Digital Twins for Industrial IoT - MATLAB & Simulink
	PLC Coder	Deploy control algorithms onto field devices including PLCs and embedded controllers	• Automatic PLC code generation • Automatic C/C++ code from Simulink model for hardware	• Multi-brand PLCs • Multi-brand RTUs • Embedded controllers	Developing Hydrogen Systems from Tank to Fuel Cell - MATLAB & Simulink
Data Analytics	MATLAB	Develop scripts, algorithms, and predictive models to perform real-time data analysis from sensors	• Data preprocessing and analysis • Real-time signal processing • Data postprocessing	S&H Integration with: • Big data stores • PI historians • CaaS and SaaS • RT dashboards • 3rd-party applications • Control systems	Digital Twins for New Energy Processes – MATLAB & Simulink
	Machine Learning	Develop predictive models using machine learning algorithms	• Process optimization, anomaly detection, and data analysis • Real-time predictive analytics		Optimizing Operational Processes with Reinforcement Learning in MATLAB

MathWorks® in Energy Resources

Digital Transformation of Interconnected Asset Processes

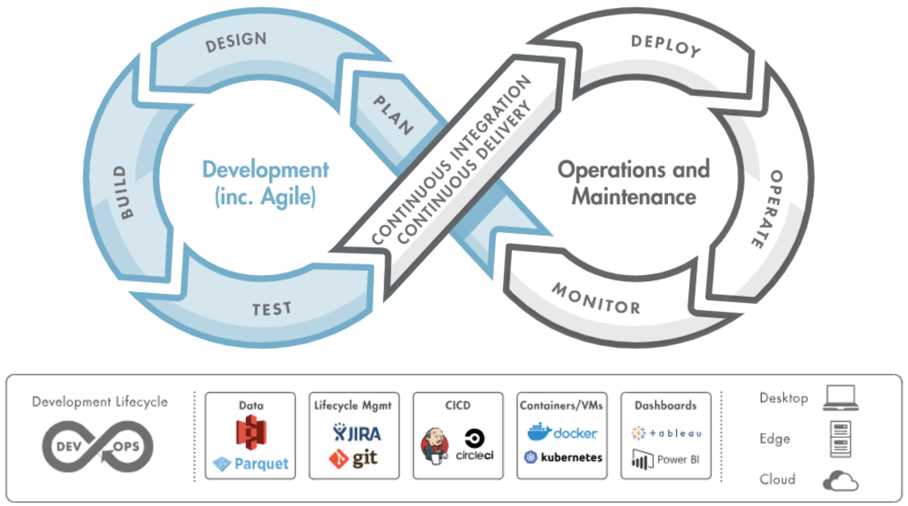
Objectives

- Optimize life-cycle of core business processes
- Simulate cost-effective operations before FIDs

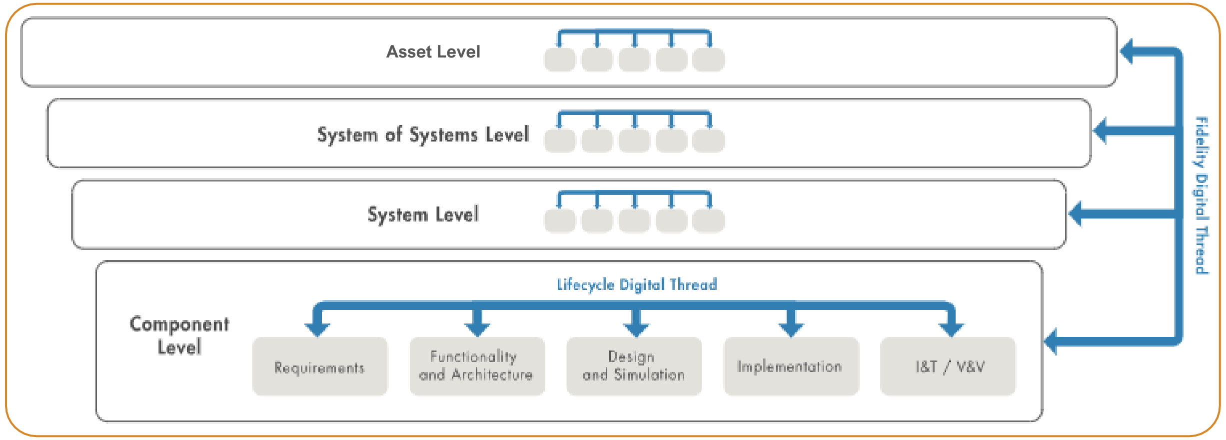
Advantages

- Integrate new and complex processes
- Scale, customize, and adapt process interactions
- Virtualize potential dynamic scenarios
- Simulate, automate, and streamline CI/CD processes

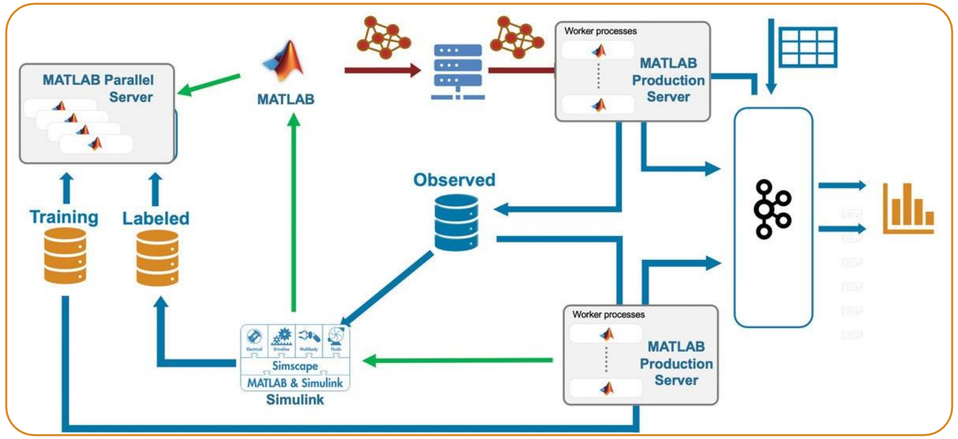
Automated, Agile, Iterative DevOps



Accelerated Systems Monitoring – Digital Thread



Scalable and Customizable MLOps Architecture



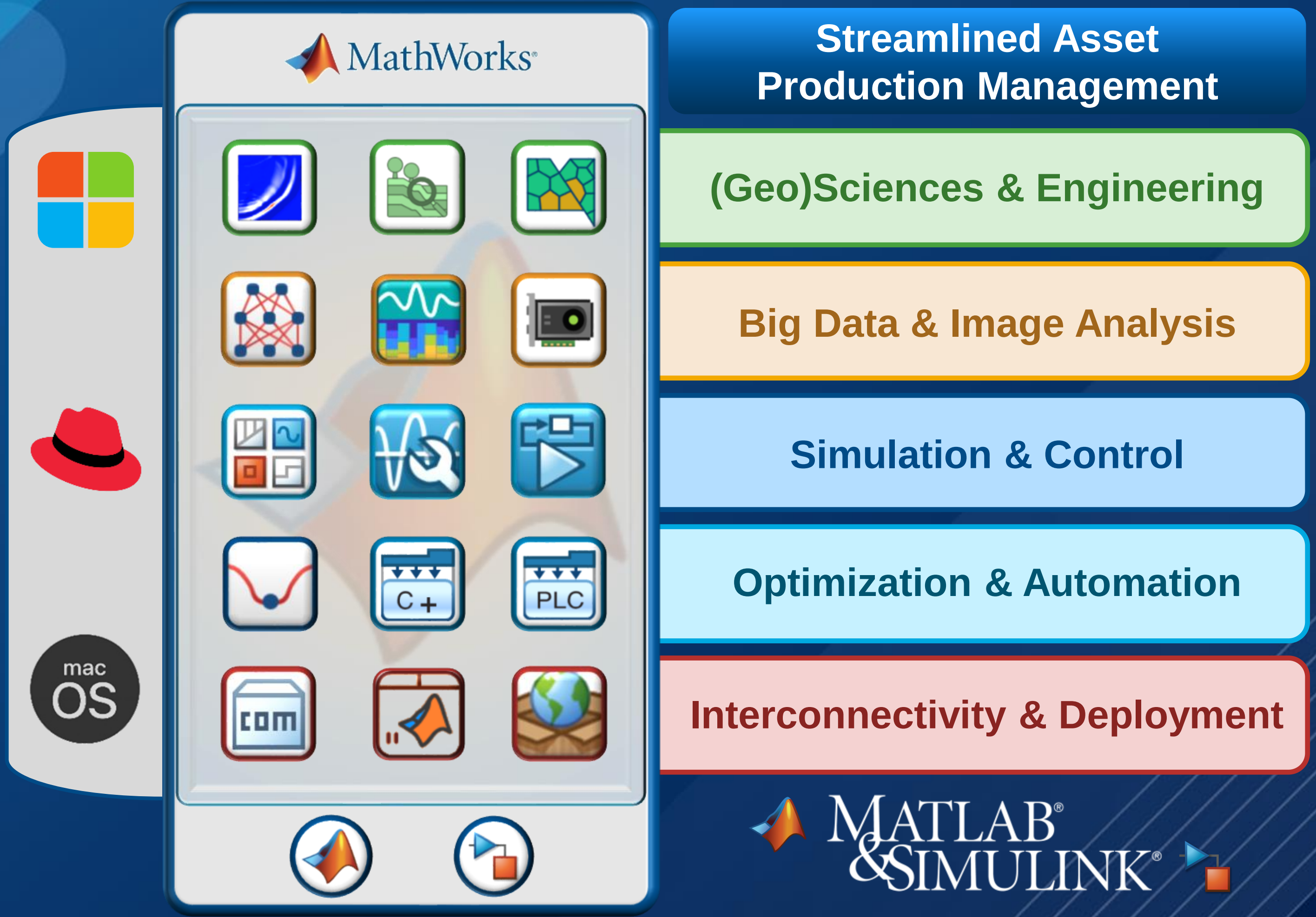
MathWorks solutions for Downstream Process Optimization

- Flexible and scalable simulation of large-scale plant designs and unit-specific optimizations
- Advanced predictive analytics using data science and AI to optimize process operations
- Industry-compliant tools to ensure safe and sustainable production processes

Workflow	Key Solutions	Main Objectives	Major Applications	Examples
Process Modeling & Simulation	**MATLAB, Simulink & Simscape**	• **Build** dynamic models of chemical reactors, distillation columns, and heat exchangers • **Simulate and optimize** nonlinear and time-dependent petrochemical processes • **Visualize and analyze** dynamic interactions between petrochemical subsystems	➢ **Optimize** process design and operations ➢ **Analyze** energy and mass balances ➢ **Troubleshoot** processing and production bottlenecks	• Chemicals and Materials - MATLAB & Simulink • Selection of Optimum Chemical Reactor Design • Controller for Distillation Column • Heat Exchangers
Process Control & Automation	**MPC, Control Systems & Simulink Real-Time**	• **Design and tune** advanced controllers (MPC, PID) for distillation towers, compressors, and polymerization reactors • **Develop and integrate** real-time models for predictive analytics using control systems • **Implement** closed-loop control systems	➢ **Enhance** process safety and reliability ➢ **Automate** fault-tolerant processes and operations ➢ **Integrate** DCS and SCADA systems and PI historians	• Nonlinear Model Predictive Control of Exothermic Chemical Reactor • Adaptive MPC Control of Nonlinear Chemical Reactor • Use OPC UA Data to Test Binary Distillation Column Plant Model
Process Safety & Reliability	**Pred. Maintenance, Machine & Deep Learning**	• **Develop** risk assessment models (HAZOP) supported by software-in-the-loop (SIL) tests • **Simulate** critical process scenarios • **Create** logical alarm management frameworks • **Monitor** equipment health in real time using machine learning	➢ **Simulate** and mitigate hazardous scenarios for critical process units ➢ **Analyze** historical alarm data to identify nuisances ➢ **Predict** and prevent equipment failure and anomalies	• Digital Twins for Predictive Maintenance of Oil & Gas Processes - MATLAB & Simulink • Optimizing Operational Processes with Reinforcement Learning in MATLAB
Process Design & Optimization	**Optimization & Planning**	• **Optimize** feedstock blending and reaction conditions • **Improve** throughput and reduce waste using data-driven modeling • **Evaluate** economic and environmental performance of alternative processes	➢ **Enhance** operational efficiency, safety, and cost effectiveness ➢ **Assess** potential failures in petrochemical facilities	• Multivariate Analysis for Process Monitoring | Fault Detection and Diagnosis in Petrochemical Processes, Part 1 • HYSYS-MATLAB LINK - File Exchange - MATLAB Central

Industrial Solutions for Energy Resources

MathWorks
Accelerating the pace of engineering and science

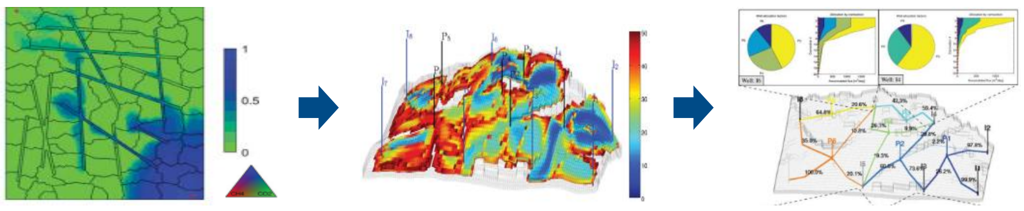


Subsurface Geosciences & Engineering

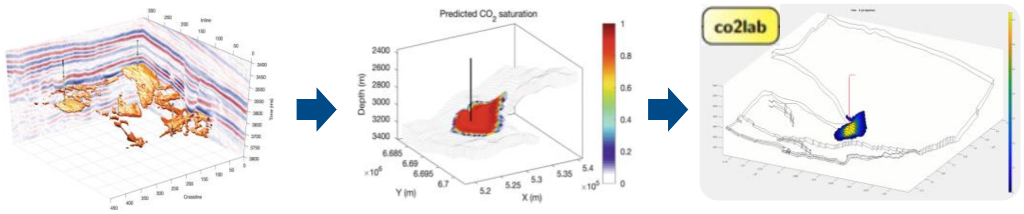
● Customize & optimize subsurface processes with integrated solutions developed in MATLAB & Simulink to maximize asset value ●

Key Applications

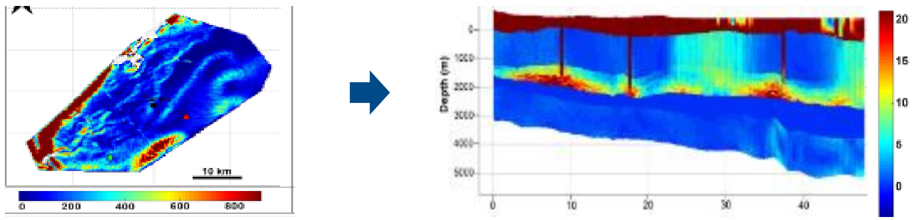
Enhanced Recovery (EOR | IOR)



Carbon Capture & Storage (CCS | GCS)



New Energies (Hydrogen | Geothermal)



Solution		Key Features
S3I	Seismic Migration & Imaging	• 3D prestack migration (Kirchhoff, RTM, LSM) • 3D elastic full waveform inversion (FWI) • Multi-CPU and multi-GPU parallel processing
SeReM	Seismic Modeling & Inversion	• Seismic convolutional and geostatistical modeling • Rock-physics-informed Bayesian facies inversion • Elastic, mechanical, and petrophysical properties
MRST	Reservoir Modeling & Simulation	• 3D reservoir modeling and fluid flow simulation • Multi-fluid, multi-physics geodynamics • Automatic differentiation & reduced order models

Upstream Big Data & Image Analysis

● Accelerate processing and analysis of large-scale and real-time data and images to make prompt and informed asset decisions ●

Key Applications

Seismic Migration & GPU Computing

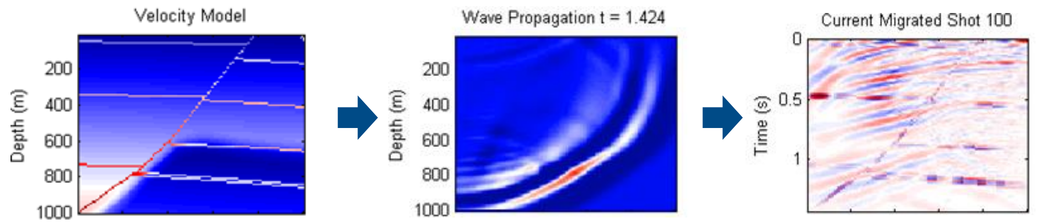
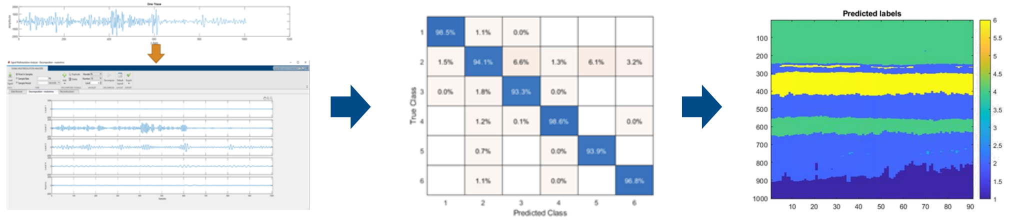
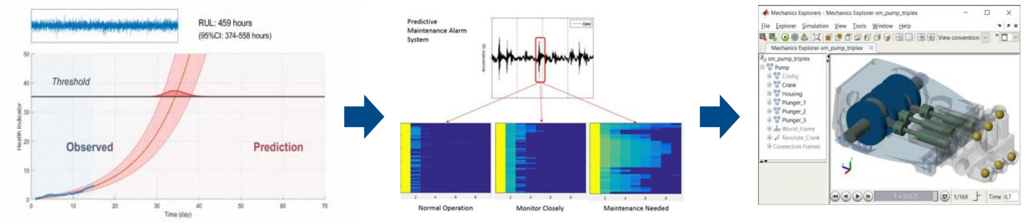


Image Classification using PINNs (RNN | CNN)



Predictive Maintenance & Anomaly Detection



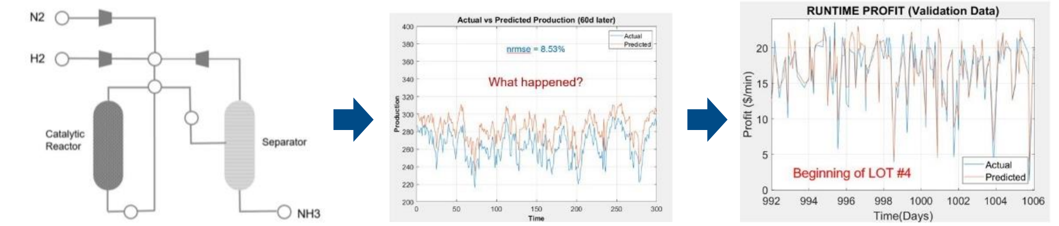
Solution	Key Features
Machine & Deep Learning	• Classification, regression & clustering algorithms • Deep neural networks (NN) & transfer learning • Reduced order modeling & physics-informed NNs
Signal & Wavelet Processing	• Signal and wavelet analysis (time, space, freq.) • Time series analysis and wavelet decomposition • Multi-scale analysis for physics-informed NNs
High Performance Computing	• Multi-CPU, multi-GPU cluster & cloud computing • GPU CUDA code generation & cloud deployment • Run real-time analytics for process automation

Midstream & Downstream Data & Image Analysis

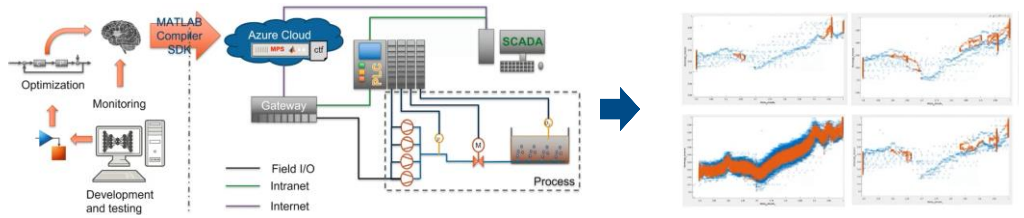
● Accelerate processing and analysis of large-scale and real-time data and images to make prompt and informed asset decisions ●

Key Applications

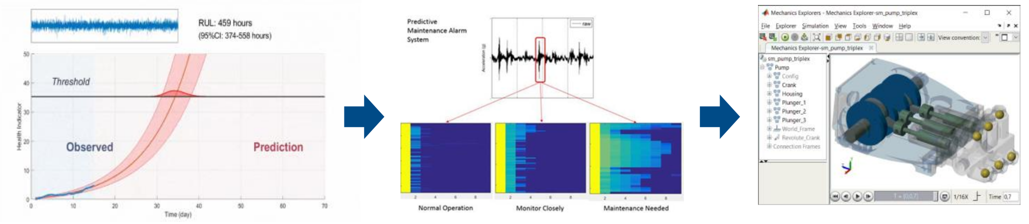
Chemical Production Data Analytics



Plant Production Monitoring and Optimization



Predictive Maintenance & Anomaly Detection



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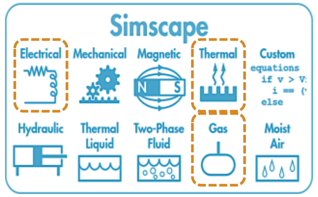
High Performance Computing	• Multi-CPU, multi-GPU cluster & cloud computing • GPU CUDA code generation & cloud deployment • Run real-time analytics for process automation

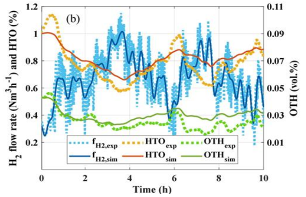
Process Simulation & Control

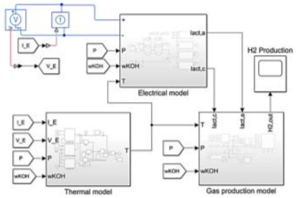
● Model, simulate, and monitor production processes using Simscape and Control Systems for cost-effective asset performance ●

Key Applications

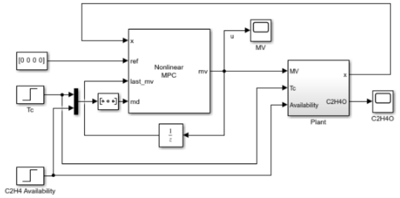
Green Hydrogen Production Digital Twin

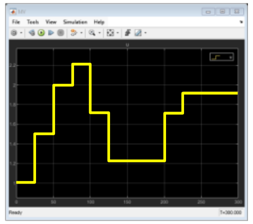


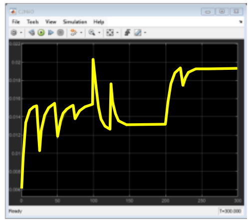




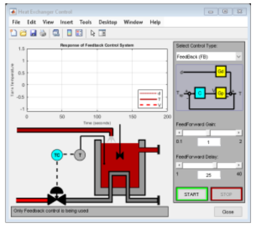
MPC for Nonlinear Chemical Process Simulation

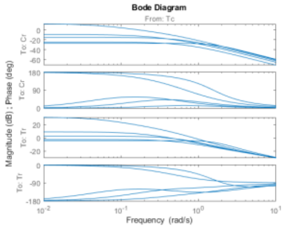


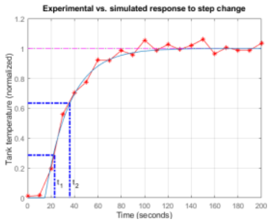




Thermal/Fluid Process Predictive Control







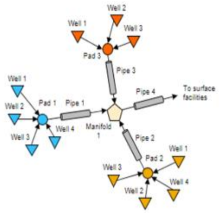
Solution	Key Features
Simscape Process Simulation	• Multi-domain process modeling and simulation • Fluid, chemical, thermal, electromechanical model • Model-based Design (MBD) of digital twins
Control Systems Design	• Design dynamic systems and controller response • Tune PID controller & SISO/MIMO compensators • Detect anomalies & diagnose feedback controls
Model Predictive Control	• Design advanced process controls (ACS | DCS) • Linear & nonlinear MPC design and optimization • Control production process & remote surveillance

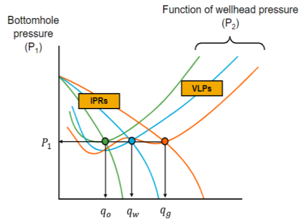
Upstream Process Optimization & Automation

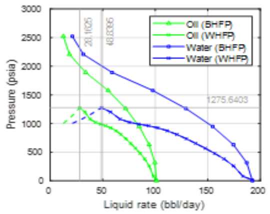
● Perform techno-economic assessments and generate embedded code to optimize and automate reliable production processes ●

Key Applications

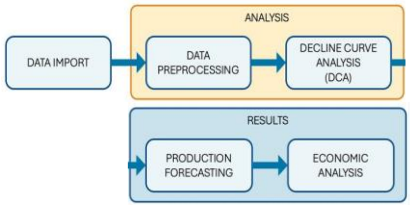
Multi-pad, multi-well production optimization

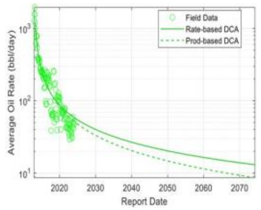


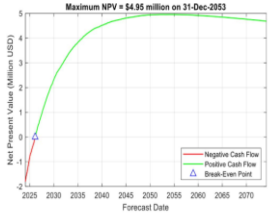




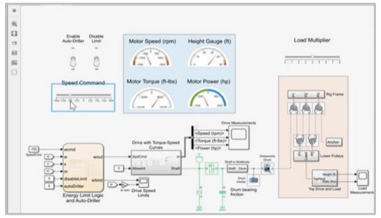
Oil & gas production forecasting & economics

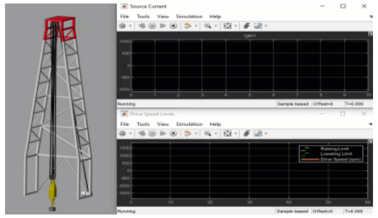






Drilling rig system simulation & automation





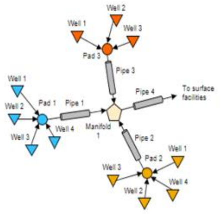
Toolbox	Key Features
Optimization & Financial Computing	• Multi-variate process optimization and forecasting • Technical and economic production optimization • New energy risk and investment management
MATLAB Coder & Compiler	• C/C++ embedded code generation from MATLAB • Customize, optimize, trace SIL & PIL processes • Deploy on control systems for process automation
Simulink PLC Coder	• PLC & PAC structured text and ladder diagrams • Support code generation for third-party IDEs • Agnostic production surveillance with IIoT devices

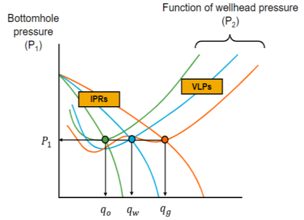
Mid/Downstream Process Optimization & Automation

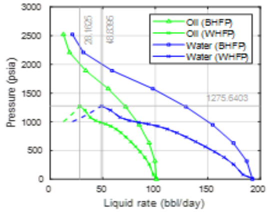
● Perform techno-economic assessments and generate embedded code to optimize and automate reliable production processes ●

Key Applications

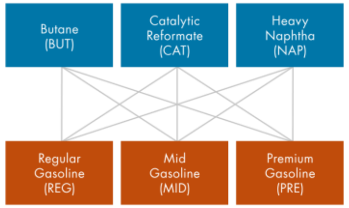
Multi-pad, multi-well production optimization







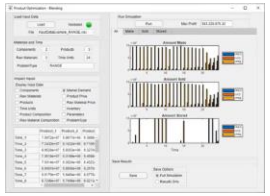
Supply chain optimization & economics



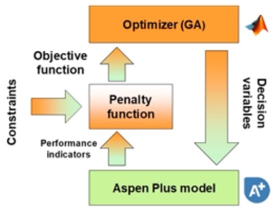
Linear Programming (LP)

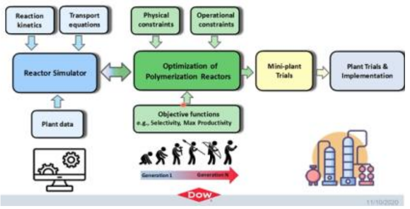
$$\min_x f^T x \quad \text{s.t.} \quad \begin{cases} A_l x \le b_l \\ A_g x \ge b_g \\ A_e x = b_e \\ lb \le x \le ub \end{cases}$$

Objective	Constraints	Bounds
$\max_x (2x_1 + 3x_2)$	$6x_1 + x_2 \le 19.5$	$0 \le x_1$
	$-3x_1 + 5x_2 \le 15$	$0 \le x_2$



Chemical process optimization & co-simulation





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App Interconnectivity & Deployment

• Create, interconnect, and deploy software and hardware applications across asset's IT, OT, and IIoT infrastructure •

Key Applications

Interconnectors with 3rd-party software

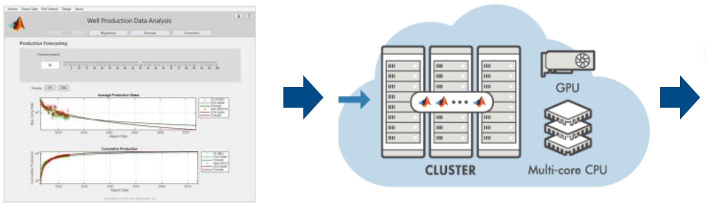
Upstream: Petrel, Eclipse, Vista

Downstream: Ansys, Honeywell, AVEVA, COMSOL

Interconnectors with IIoT devices (PLC | DCS | RTU)

SIEMENS, YOKOGAWA, BECKHOFF, OMRON, EMERSON, Schneider Electric, MITSUBISHI ELECTRIC

App & Microservice Deployment in the Cloud

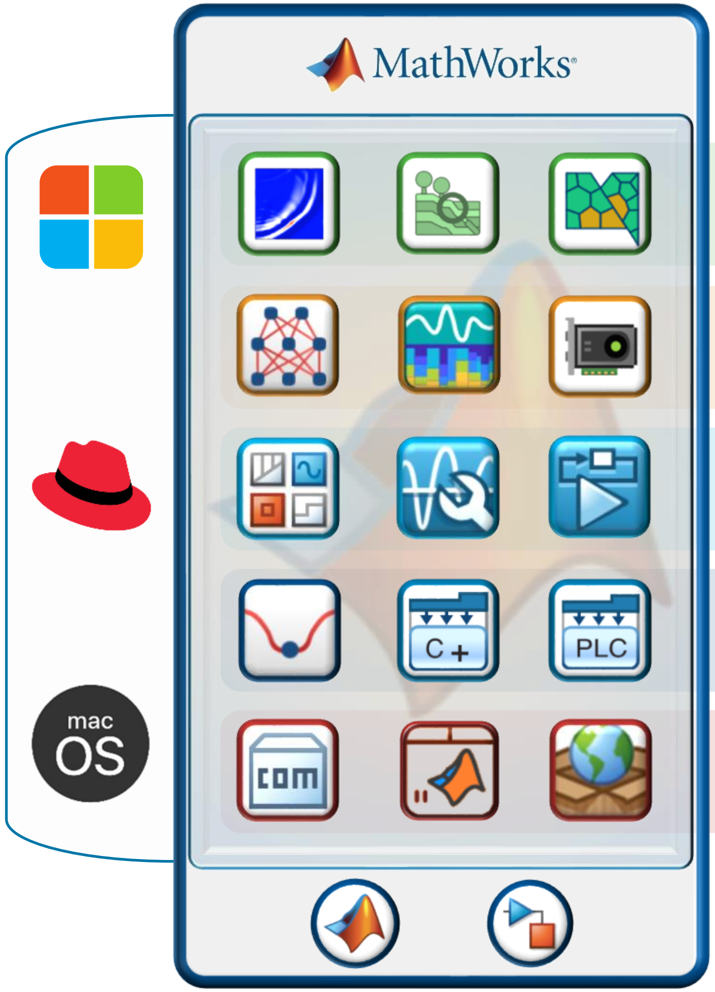


Amazon SNS, Azure HDInsight, Amazon SQS, Databricks, Apache Spark, Google BigQuery, Amazon RDS, Google Storage, AWS Athena, Hadoop, Amazon S3, Azure Data Lake, Azure Blob Storage, AWS DynamoDB, Azure Cosmos DB

Solution	Key Features
Industrial Comms	• Exchange data with OPC UA, MQTT protocols • Interconnect IIoT devices (PLC, DCS, RTU) • Support distributed control systems (SCADA)
MATLAB Compiler SDK	• Build standalone and web apps from MATLAB • Build Python, .NET, C++, and Docker packages • Deploy in OT & edge devices for IIoT surveillance
MATLAB Web App Server	• Use MATLAB App Designer to create Web GUIs • Deploy and host MATLAB & Simulink web apps • Control access using OpenID Connect & LDAP

How to Accelerate Big Data & Image Analysis with MATLAB® & SIMULINK®

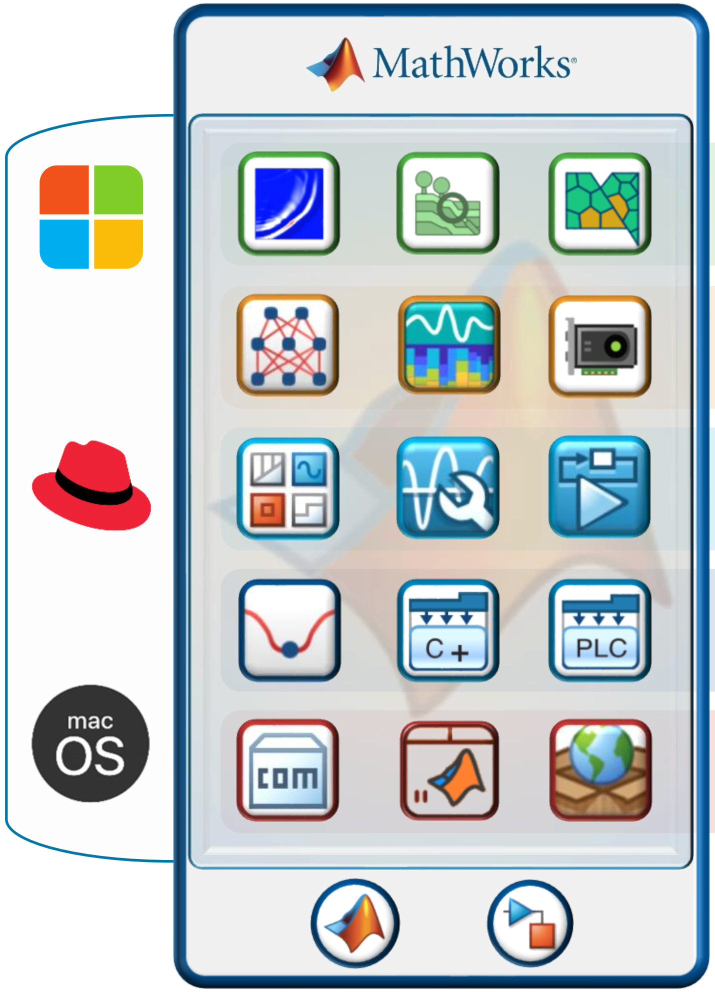
Industry-compliant toolboxes, technical documentation, and dedicated customer support on science & engineering applications with customized services and specialized training



- (Geo)Sciences & Engineering
- Big Data & Image Analysis
- Simulation & Control
- Optimization & Automation
- Interconnectivity & Deployment

- **Built-in big data scalability** using tall arrays and integration with Hadoop and Spark datastores
- **Advanced toolboxes** to rapidly process, analyze, and visualize large-scale data, signals, and images
- **Automated code generation** to integrate software and hardware systems for enhanced performance
- **Just-in-time (JIT) compilation** with optimized numerical analysis and matrix-based performance
- **Built-in parallel computing** using on-prem or cloud-based CPU or GPU cluster infrastructures

How to Streamline Real-Time Data Analysis with MATLAB® & SIMULINK®



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- (Geo)Sciences & Engineering
- Big Data & Image Analysis
- Simulation & Control
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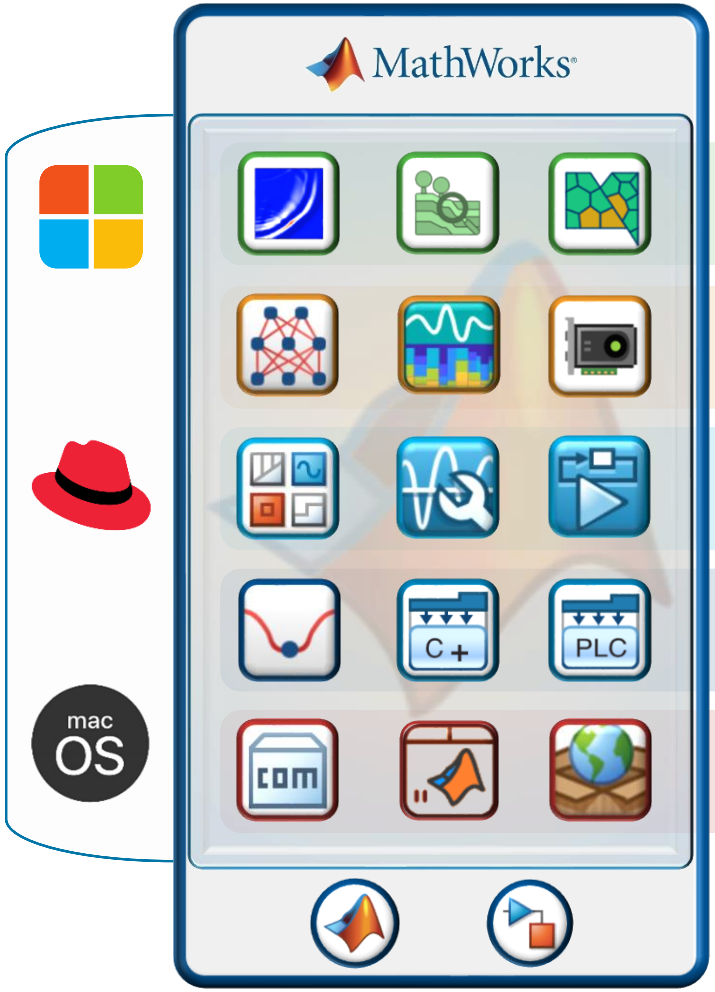
- Interconnectivity & Deployment

- **Easy-to-use and scalable platform** with high-level language, intuitive syntax, and low coding
- **Engineering workflows** to optimize & accelerate signal processing, control systems, and AI tasks
- **Specialized toolboxes** for real-time analysis, testing & validation of mission-critical operations
- **Automatic C/C++ code generation** to deploy on embedded systems and real-time platforms
- **Supports OPC, MODBUS & CAN protocols** for real-time analysis using OT and IIoT devices

How to Ensure Process Safety & Compliance with MATLAB & SIMULINK



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- Optimization & Automation
- Interconnectivity & Deployment

- **Built-in industry-compliant tools** for automated verification, validation, and documentation generation following NIST, ISO, ICE, DO, and EN standards
- **Sensitive data security & access control** based on encrypted data storage, user authentication, and role-based access control (RBAC) cybersecurity standards
- **Automated regulatory document generation** for code, models, and data traceability and auditability
- **Automated code & model testing & validation** to comply with industry regulations prior to deployment

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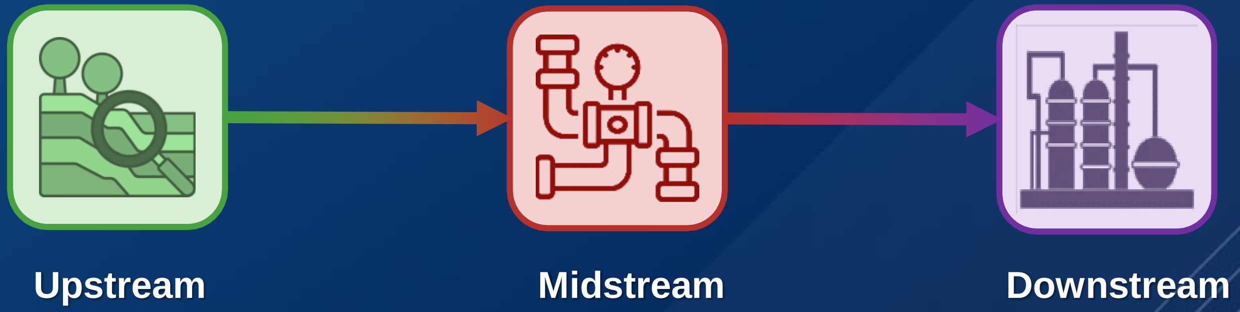
Accelerating the pace of engineering and science

Applications for Energy Resources in MATLAB® & SIMULINK®



Accelerated seismic depth imaging using MATLAB GPU computing

Challenge

- Accelerate seismic migration workflows in S3I using parallel computing (GPU-based).

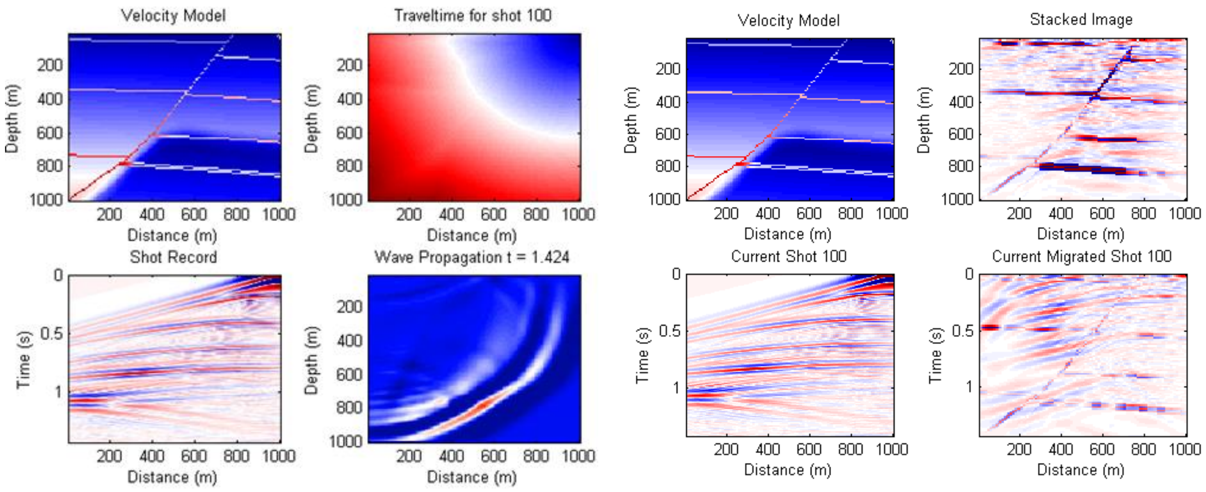
Solution

- Implemented a MATLAB workflow for seismic migration using both Kirchhoff and reverse time algorithms and a GPU extension based on a CUDA kernel to compare CPU & GPU solutions

Benefit

- The custom CUDA kernel solution to the seismic wave equation using PDE finite differences was 1.6X faster than the vectorized CPU solution
- This early implementation of parallel computing in S3I helped to accelerate big data analysis.

Seismic pre-stack wave model | **Seismic RTM migration stack**



MATLAB Seismic migration & GPU computing workflow

3D seismic dataset (40Tb)

- Seismic waveform modeling
- Kirchhoff and reverse time migrations
- CPU (vectorized) vs. GPU (CUDA) solution

RTM workflow runs 1.6X-1.8X faster on GPU

MATLAB®

S3I Seismic Migration

Parallel Computing

Source: S. Kozola. Large data in MATLAB: A seismic data processing case study. MATLAB Central File Exchange. https://www.mathworks.com/matlabcentral/fileexchange/30585-large-data-in-matlab-a-seismic-data-processing-case-study

Enhanced prestack seismic quality with ROMs in MATLAB

Challenge

- Enhance and accelerate prestack seismic quality for quantitative interpretation using a short-time, minimum-resource, physics-informed solution

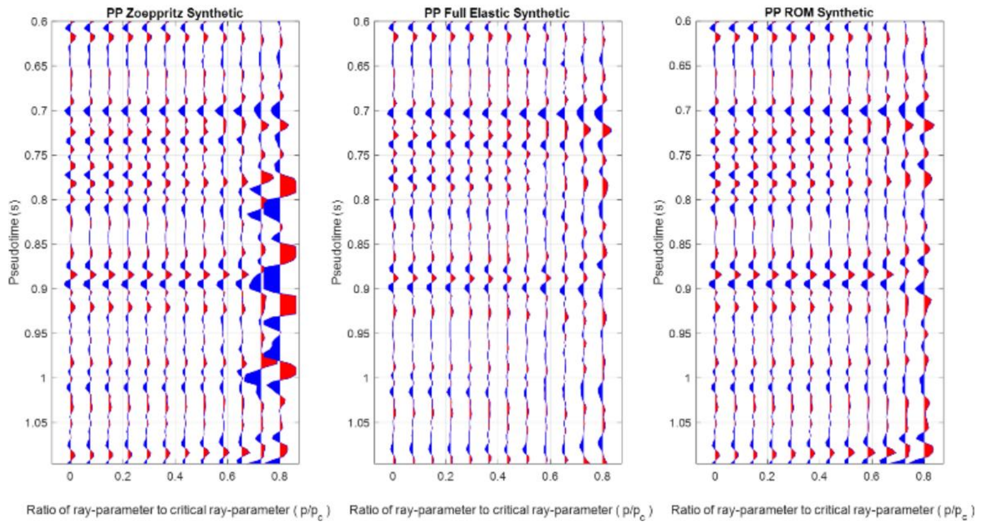
Solution

- Developed a MATLAB transfer learning workflow for a multi-scale reduced order model (ROM) of wave propagation in the ray-parameter domain (p)

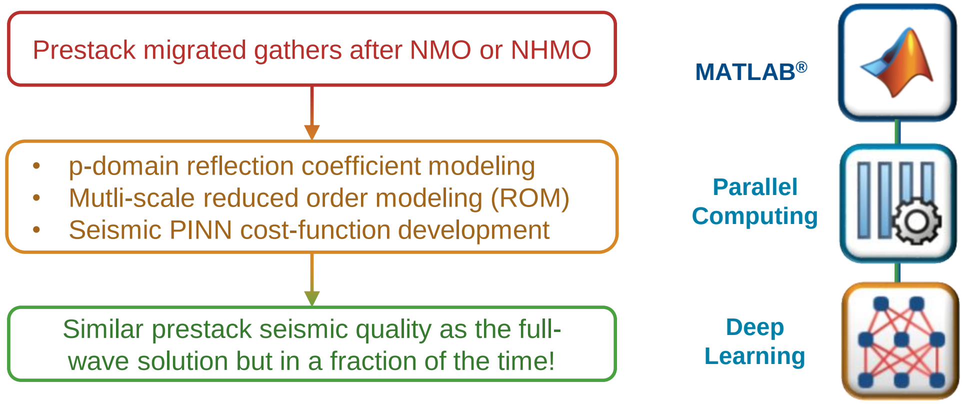
Benefit

- The ROM output shows similar quality as the full-wave elastic solution but in a fraction of time
- The ROM model is suitable to include in physics-informed neural network (PINN) models

Seismic gathers (plane wave (left); full-wave (middle); ROM (right)



MATLAB seismic reduced order modeling workflow



Source: *A. Dey.* Introducing Seismic Reduced Order Modeling with MATLAB. MATLAB and Simulink Seminars. The MathWorks, Inc.

Accelerated seismic facies classification using PI-RNNs

Challenge

- Accelerate and enhance facies classification from large seismic datasets using PINNs and HPC.

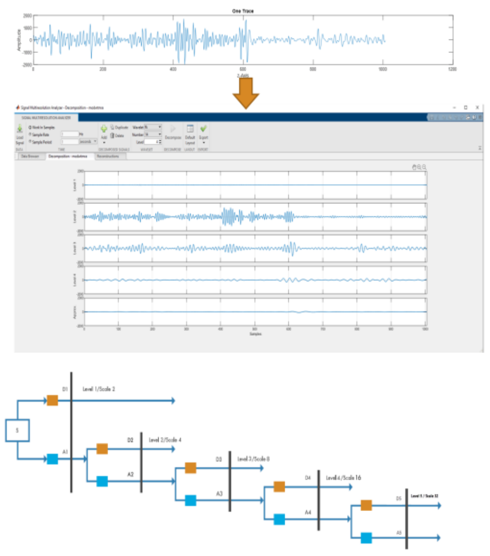
Solution

- Implemented a MATLAB workflow for seismic signal processing based on a physics-informed recurrent neural networks (PI-RNN) using GRU and LSTM with discrete wavelet decomposition to accelerate and enhance seismic facies classification using a GPU CUDA kernel solution.

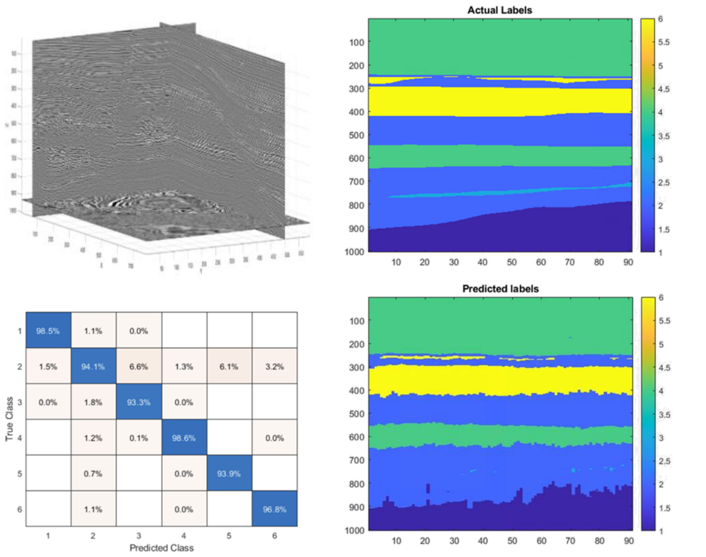
Benefit

- The PI-RNN workflow predicted seismic facies with 76% correlation, ~2X higher than CNN
- The CUDA kernel solution was ~70X faster (~3min) than a vectorized CPU solution (~3 hrs).

Discrete wavelet transform



Seismic facies labels and PI-RNN prediction

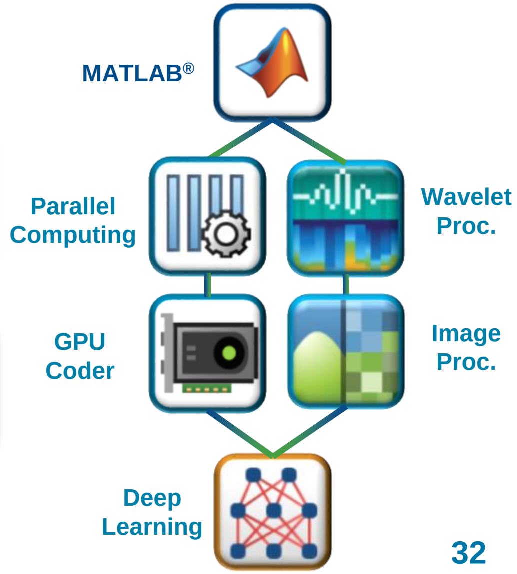


MATLAB Seismic facies classification & GPU computing workflow

3D seismic dataset (200Gb)

- Signal-based RNN model using GRUs
- Discrete Wavelet Transform (DWT)
- CPU (vectorized) vs. GPU (CUDA) solution

Facies correlated 76% with 93% trained data
RNN correlation ~2X higher than CNN (40%)
GPU time: 2.5 min vs. CPU time: 3 hours



Source: Mishra, A. (2018). Facies Classification with Wavelets and Deep Learning. MATLAB Energy Conference 2021. MathWorks.

Rock Physics and Seismic Petrophysics Modeling using MATLAB

Challenge

- Automate sensitivity analysis of prestack seismic response to changes in petrophysical properties

Solution

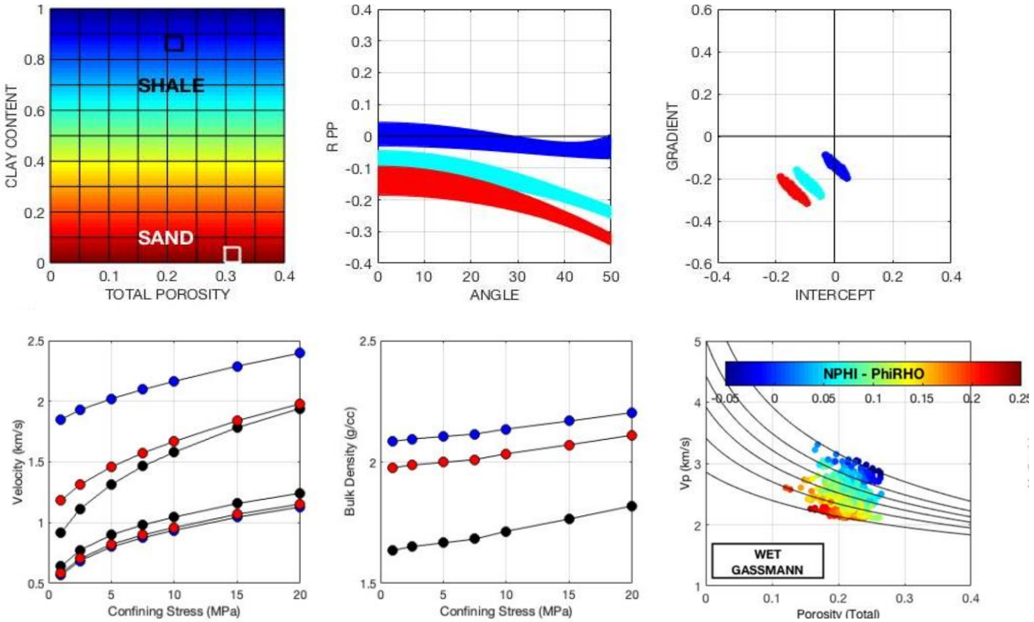
- Developed a MATLAB app to interactively assess seismic responses to changes in petrophysical properties to quantify variations in seismic inversion
- Incorporated geomechanical properties to assess compressibility and rigidity under compaction (mechanical, chemical) mechanisms

Benefit

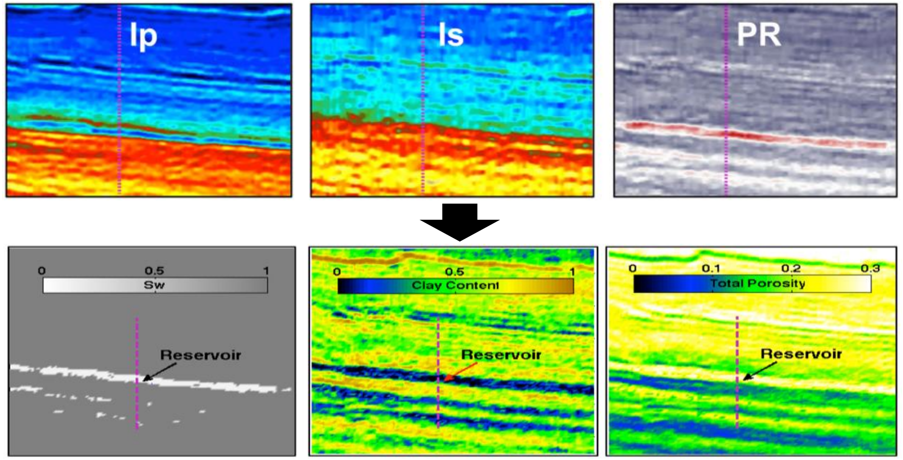
- Enhanced sensitivity analysis of seismic changes in rock properties and missing log prediction
- Workflow was fully implemented in MATLAB using SeReM & MRPI toolboxes.

Source: J. Dvorkin. MRPI: A MATLAB solution for Rock Physics Analysis. Personal notes.

Seismic Petrophysics (above) and Rock Physics (below) Modeling



Seismic Elastic (above) and Petrophysical (below) Inversion



Integrated CO2 storage monitoring and simulation

Challenge

- Integrate 4D seismic monitoring and CO2 flow simulation workflows in one software platform.

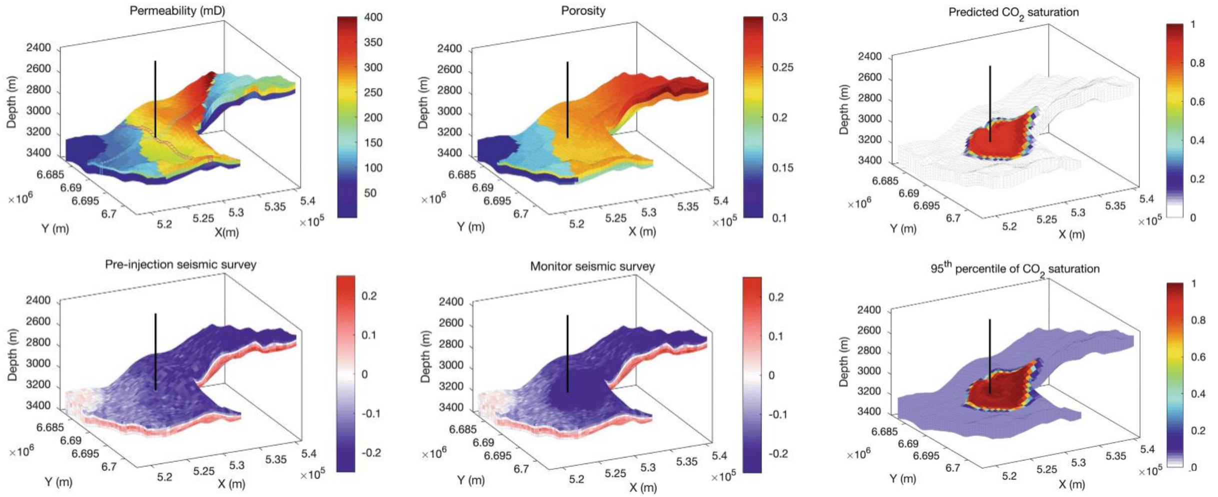
Solution

- Implemented an integrated MATLAB workflow for seismic inversion and CO2 flow simulation using an ensemble smoother with multiple data assimilation and a convolutional autoencoder from SeReM to compare against CO2 saturation simulated in MRST

Benefit

- Modeled CO2 saturation was predicted from 4D seismic data with a correlation of 92%.
- Workflow was fully implemented in MATLAB using SeReM & MRST toolboxes.

Reservoir Properties & 4D Seismic Volumes | **CO2 Simulation Prediction**



MATLAB 4D Seismic Inversion & CO2 Flow Simulation workflow

4D seismic + CO2 well injection datasets

- Ensemble smoother & convolutional model
- FFT-MA for rock and fluid property models
- CO2 dynamic injection simulation

CO2 plume (model vs data): R = 0.92

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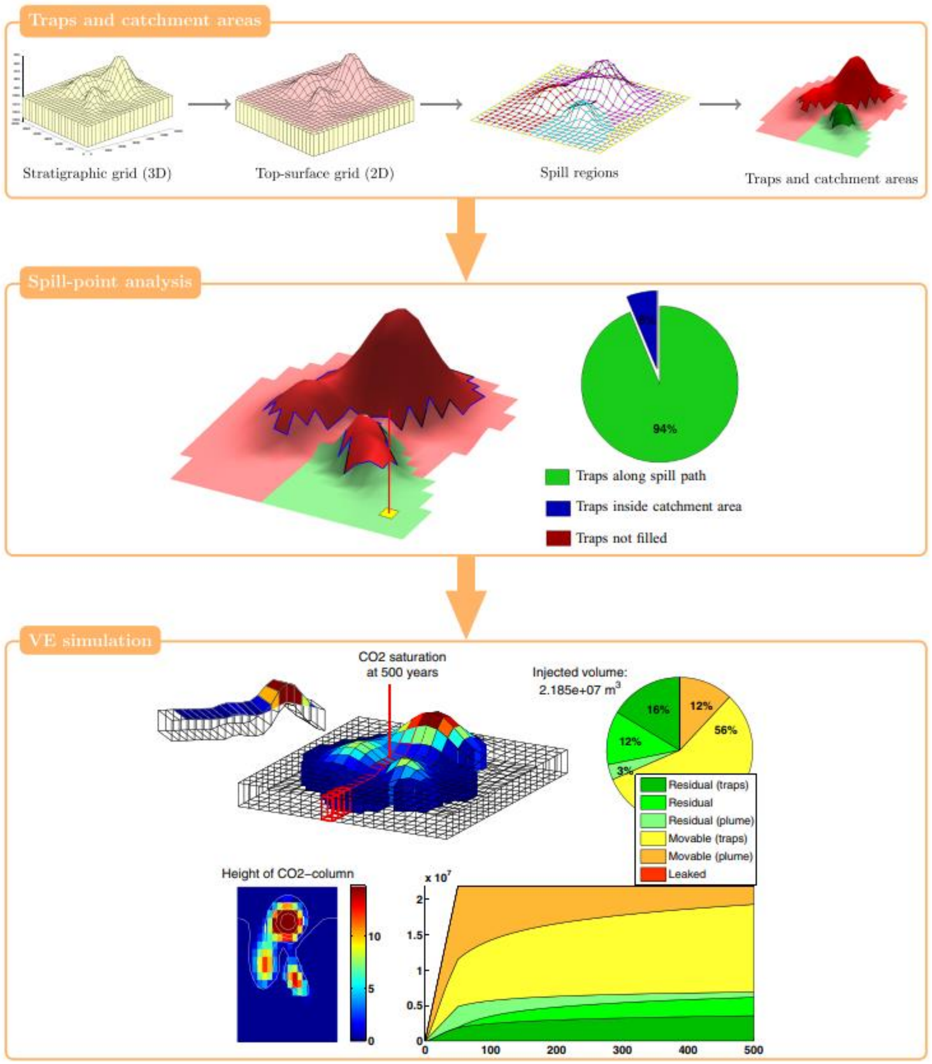
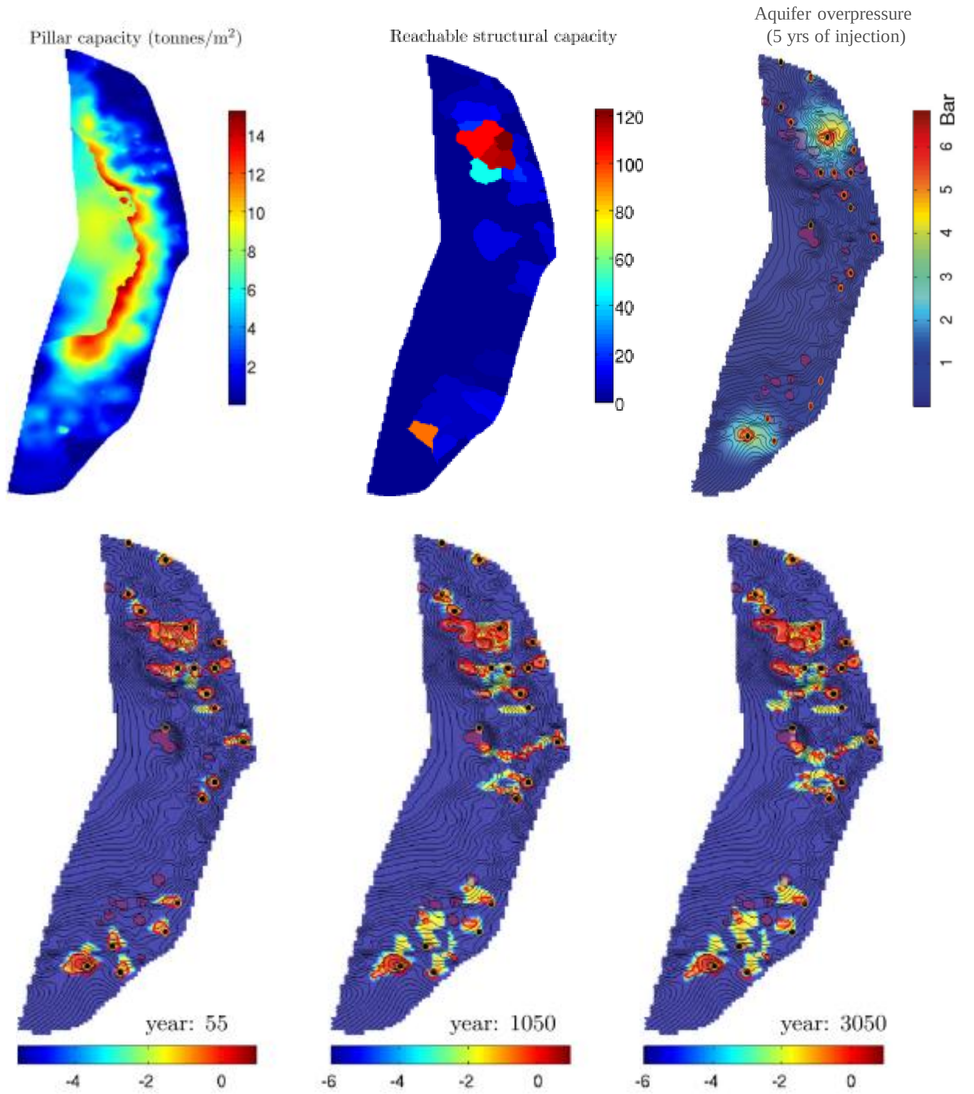
SeReM Subsurface Modeling

MRST Subsurface Simulation

Source: Liu, M. and Grana, D. (2020). Petrophysical characterization of deep saline aquifers for CO2 storage using ensemble smoother and deep convolutional autoencoder. Advances in Water Resources, Vol. 142, No. 103634.

Large-scale CO2 storage simulation in Norwegian North Sea





Lie et al (2016). *A simulation workflow for large-scale CO2 storage in the Norwegian North Sea*. Computer Geosciences, Vol. 20, pp. 607-622. Springer International Publishing. SINTEF (NOR).

Accelerated Digital Stratigraphic Modeling with MATLAB

Challenge

- Conventional reservoir modeling tools lack interactive visualization and analysis of stratigraphic models and depositional systems

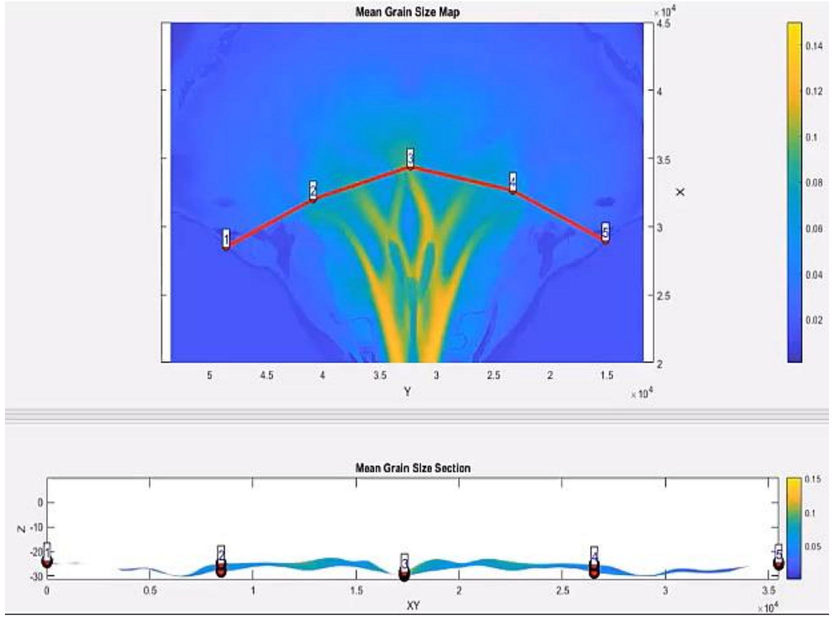
Solution

- Developed an interactive application in MATLAB to analyze geologically-plausible reservoir analogues by simulating sediment transport and deposition, and generating reservoir N/G and thickness analogues
- Deployed both executable applications and dynamic libraries to read in other applications like PETREL

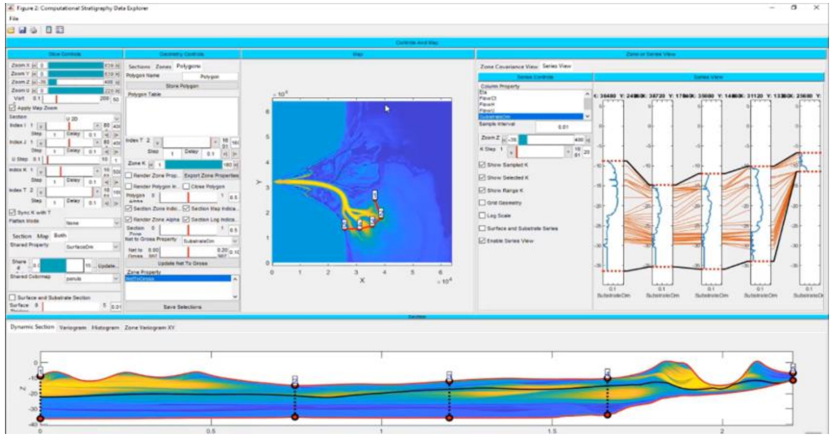
Benefit

- Efficient software development using MATLAB
- Integration of geoscience disciplines using one app
- Iterative software improvement

Computational Stratigraphy Explorer (CSE)



Computational Stratigraphy Explorer (CSE) App GUI



Source: Hern, B., Willis, B., Li, M., and Sun, T. (2020). Exploring digital stratigraphy using Computational Stratigraphy Explorer (CSE). Chevron USA.

Accelerated Reservoir Characterization with Image Learning

Challenge

- Reduce oil and gas exploration costs and increase well production by constructing accurate models of the subsurface
- Sharing algorithms so they can be used worldwide

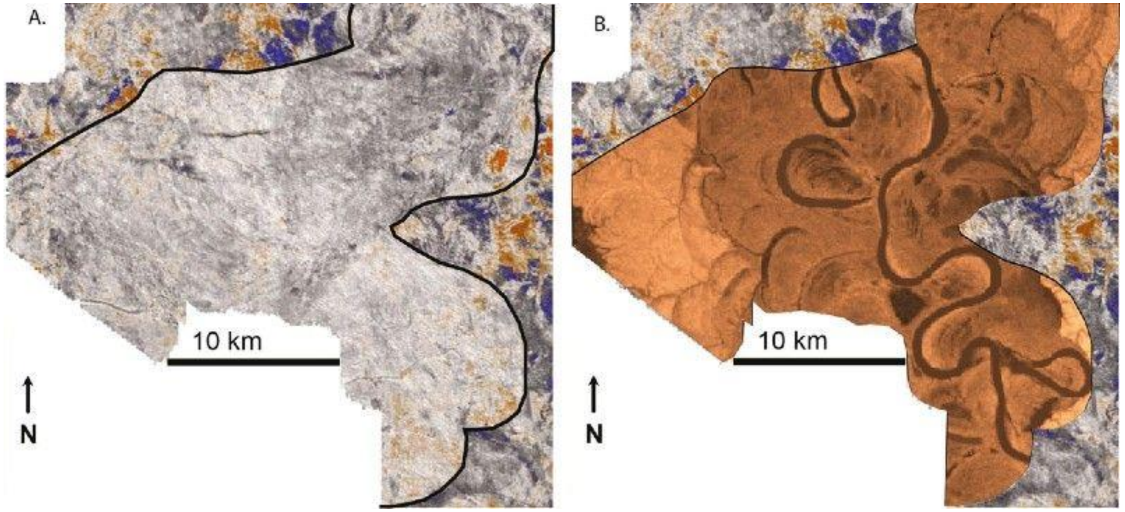
Solution

- Use machine learning to develop and deploy algorithms that use seismic data, known scaling relationships, and a database of geologic metrics to quantitatively characterize subsurface features with MATLAB

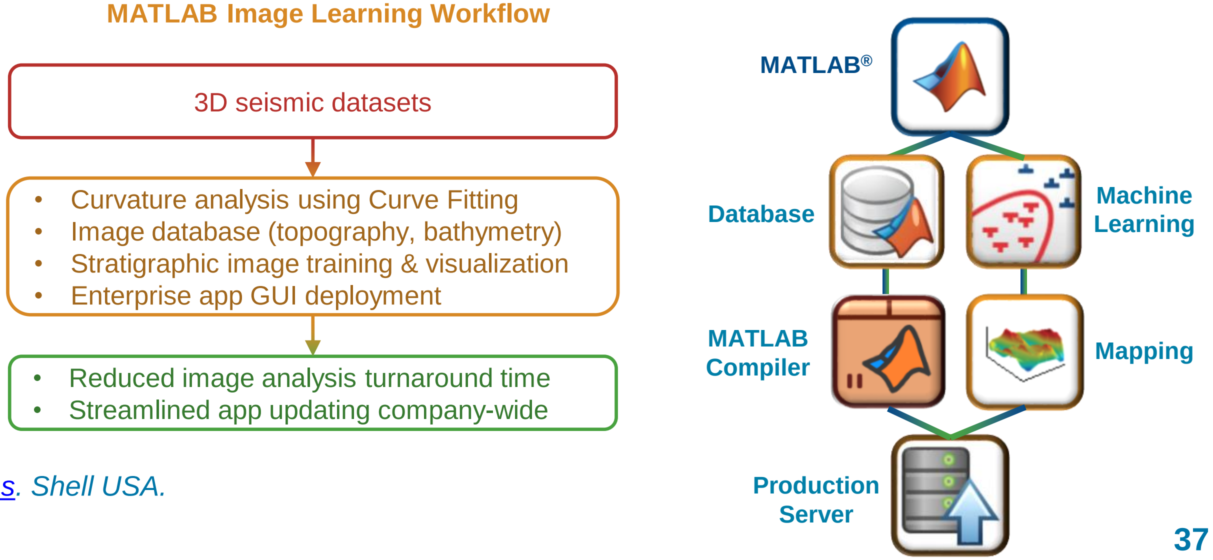
Benefit

- Month-long projects replaced by simple queries
- Drilling prognosis accuracy substantially improved
- Software updates instantly deployed

3D seismic image slices before (left) and after (right) Image Learning



MATLAB Image Learning Workflow



Source: Howes, N. (2012). Software deployment for predicting subsurface geological features. Shell USA.

High Accuracy Intelligent Seismic Inversion with Deep Learning

Challenge

- Seismic has limited resolution for thin-bed imaging
- Seismic inversion methods assume zero-phase data

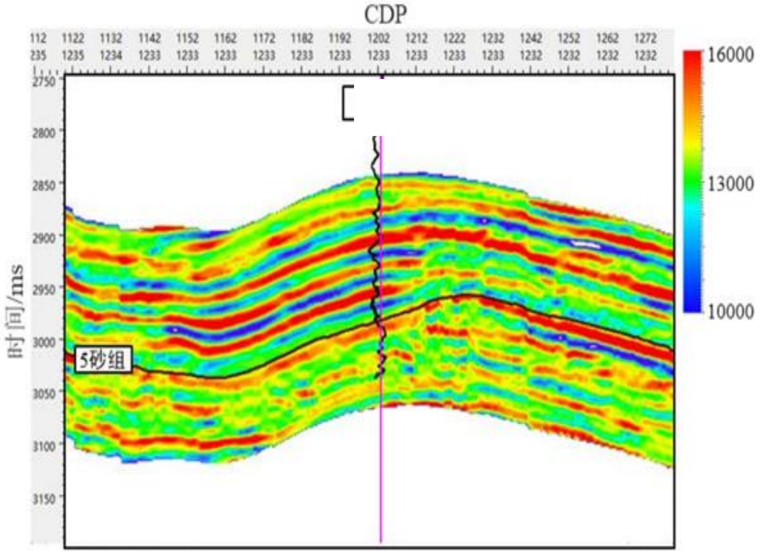
Solution

- Developed a frequency-phase intelligent seismic inversion algorithm combined with deep learning
- Use MATLAB signal processing and optimization toolboxes to construct, optimize, and train models

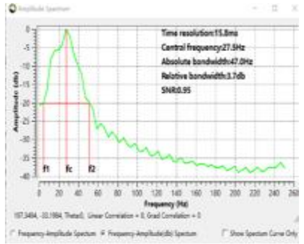
Benefit

- Seismic frequency-phase intelligent inversion results showed a broader bandwidth compared to input data
- Thin beds beyond seismic resolution were resolved in the seismic impedance inversion result

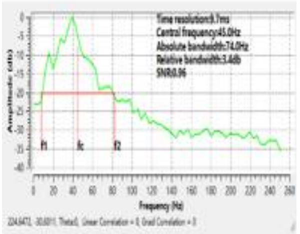
Intelligent seismic impedance inversion result



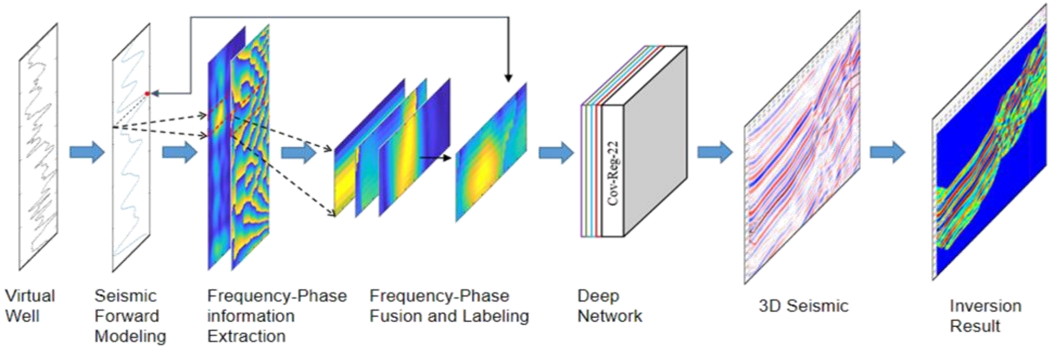
Input Spectrum



Output spectrum



Intelligent frequency-phase seismic inversion workflow



Source: Peijie, Y. (2022). [MATLAB deep learning for intelligent seismic inversion](). Sinopec Shengli Oilfield Geophysical Research Institute. MATLAB Expo 2022.

Reservoir Capacitance-Resistance Model (CRM) using PINNs

Challenge

- Simulate reservoir and surface conditions (well shut-in, plug-in & abandonment, new infills) in a mature oilfield to optimize production recovery.

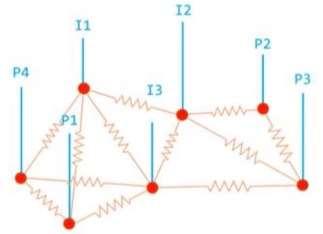
Solution

- Developed an integrated MATLAB workflow for reservoir simulation using a physics-informed neural network (PINN) based on long-short term memory (LSTM) and optimized with a capacitance-resistance model (CRM) using the MATLAB Reservoir Simulation Toolbox (MRST)

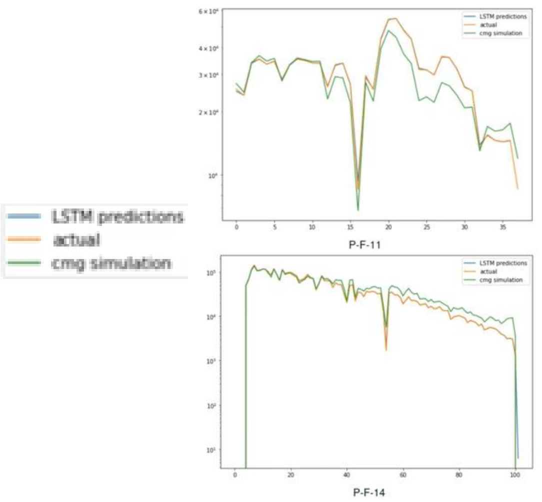
Benefit

- This reduced-order PINN model (LSTM+CRM) accelerated reservoir simulation and supported real-time decision making using a workflow fully implemented using MATLAB capabilities.

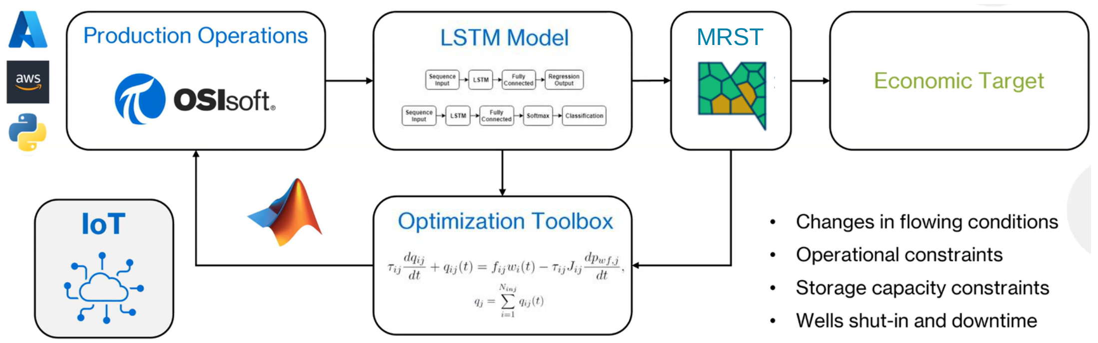
Injector-Producer Pairs & Correlation Matrix



Reservoir Simulation Results



MATLAB Reduced-Order Modeling & Real-Time Decision-Making workflow



Source: Behl, M., Tyagi, M., and Molina, O. (2022). Development of CRM for Reservoir Simulations using PINNs. MathWorks Energy Conference 2022.

Geomechanical simulation of CO2 flow in a fractured reservoir

Challenge

- Simulate a discrete fracture network with compositional flow dynamics to simulate fluid transmissibility through structural faults to assess sealing integrity after CO2 storage.

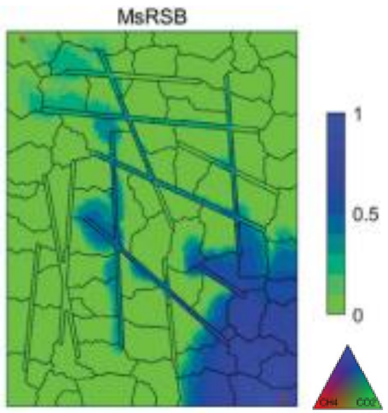
Solution

- Implemented a MATLAB workflow for fracture-bound compositional fluid dynamics under miscible CO2 conditions to model both matrix and fracture saturations and assess fault-bound fluid transmissibility using MRST.

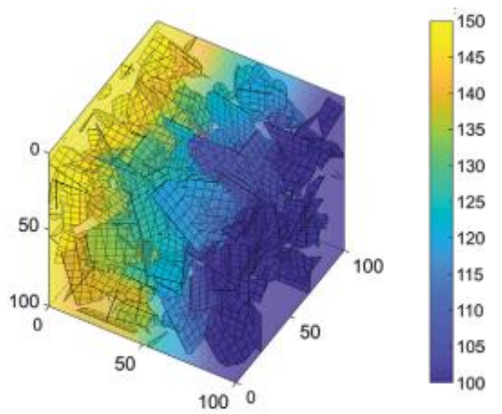
Benefit

- MRST outputs matched fault-bound saturations predicted by Eclipse (E300) and AD-GPRS.
- Workflow was fully implemented in MATLAB.

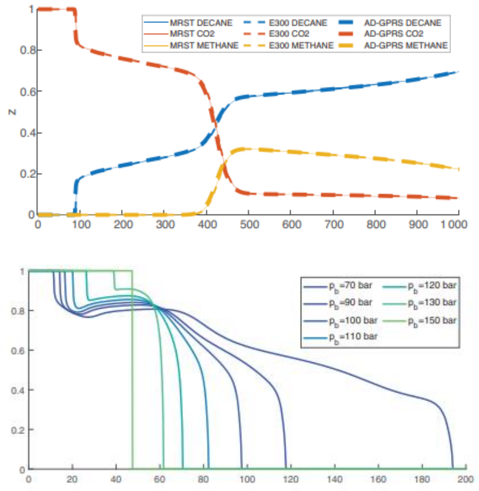
Fault-bound fluid saturation section



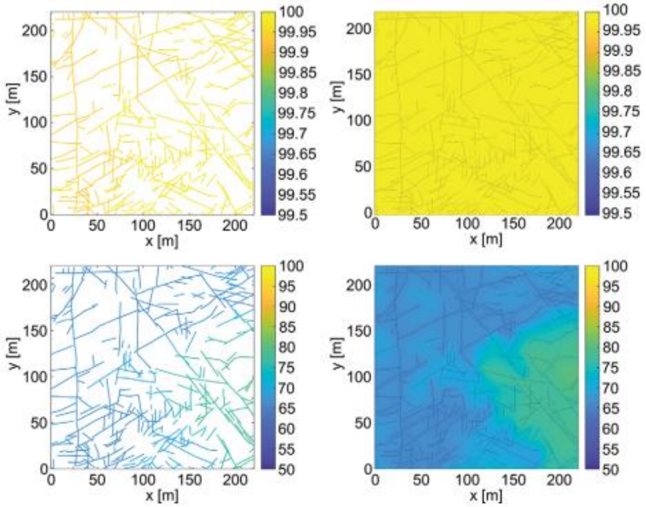
Discrete fracture model



CO2+CH4+CH10 miscible properties



Matrix and Fracture fluid saturations



Source: K.A. Lie and O. Moyner. (2021). [Numerical modeling of fractured unconventional oil]. Advanced Modeling with the MATLAB Reservoir Simulation Toolbox, Chapter 10.Cambridge University Press.

Accelerated reservoir simulation with reduced order models

Challenge

- Sensitivity analysis of dynamic parameters for reservoir simulation is a time-consuming task.
- Data-driven models using machine learning methods do not guarantee results accuracy.

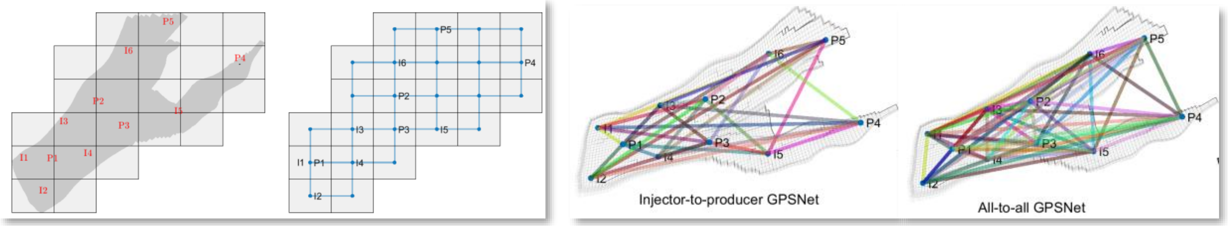
Solution

- Designed a data-driven proxy model in MRST (MATLAB reservoir simulator) via reduced-order modeling to accelerate simulation time.

Benefit

- The proposed CGNet model is easy to setup and runs faster than most simulation models.
- CGNet model is quick to calibrate and fast to evaluate for parameter optimization purposes.

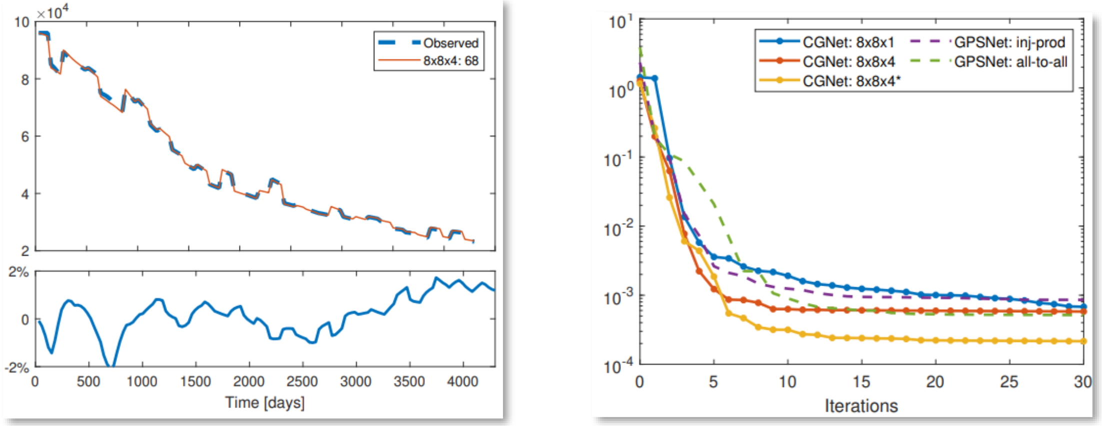
CGNet model & grid mesh (left) vs GPSNet models (injector-to-producer & all-to-all) (right)



	CGNet			GPSNet	
setup	$8 \times 8 \times 1$	$8 \times 8 \times 4$	$8 \times 8 \times 4^*$	inj–prod	all-to-all
# parameters	99	305	204	71	121
# nodes	35	94	68	300	550

$*$ – mesh cells containing 70 fine-cell centroids or less are culled

CGNet oil production rates & misfit (left) and Levenberg-Marquardt minimizations (right)



Source: K. Lie and S Krogstad, 2022. Data-driven modelling with coarse-grid network models. European Conference on the Mathematics of Geological Reservoirs, EAGE.

Unconventional production prediction using transfer learning

Challenge

- Enhance prediction of fluid flow in tight oil, hydraulically fractured formations using unconventional reservoir simulation models.

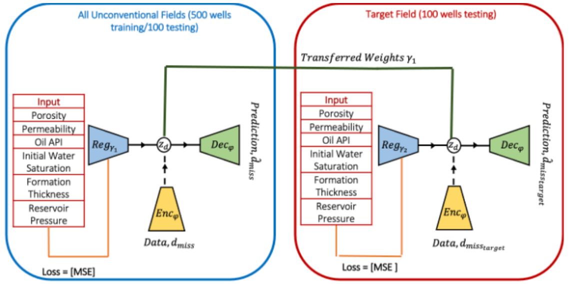
Solution

- Used MATLAB to develop a physics-assisted transfer learning methodology combining both physics-based and data-driven models.
- Used MRST (MATLAB reservoir simulator) to model a horizontal hydraulically-fractured well to compare results against average data from several unconventional plays.

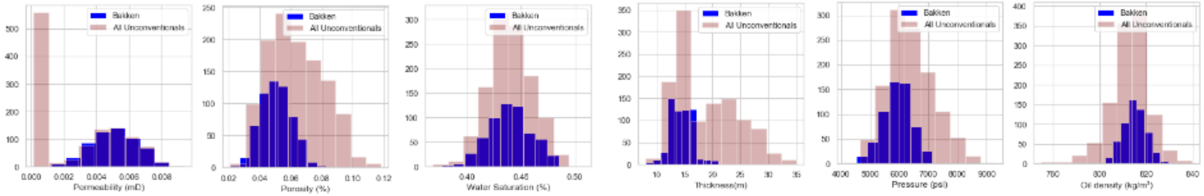
Benefit

- A robust transfer learning model provided a more reliable, consistent fluid flow prediction.

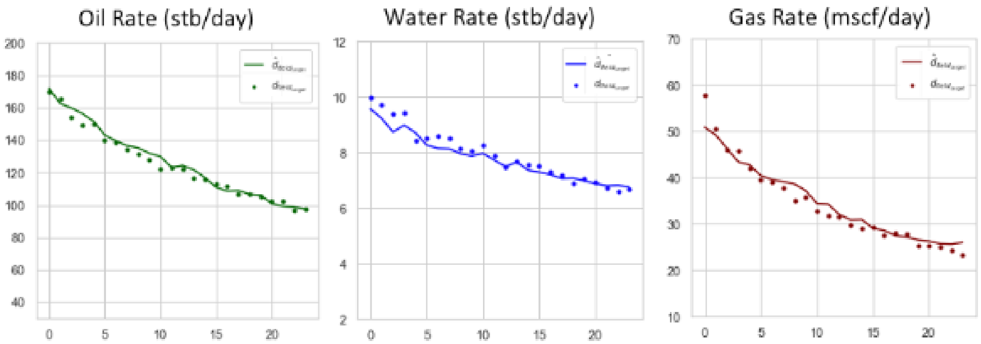
Transfer learning workflow in MRST



Reservoir property distributions (all fields in light red; target field in blue)



Fluid flow prediction in MRST (lines) compared to field data (dots)



Source: *Cornelio, J., Razak, S., Jahandideh, A., Cho, Y., Lui, H., Vaidya, R., and Jafarpour, B. (2021). Physics-Assisted Transfer Learning for Production Prediction in Unconventional Reservoirs. URTeC: 5688. SPE, AAPG, SEG.*

Electrical Submersible Pump (ESP) Digital Twin

Challenge

- Develop a digital EPS system for artificial lift equipment monitoring and failure prediction.

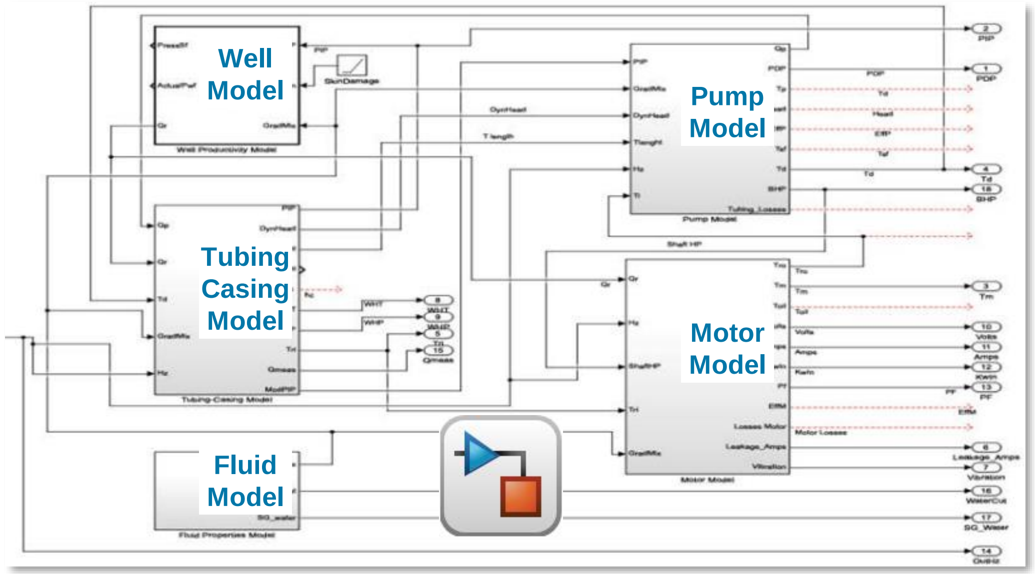
Solution

- Used Simulink to design and model simulations of multi-domain dynamic systems: heat transfer, electrical, hydraulic, and mechanical (vibration).
- Added digital controls to capture and visualize outputs from downhole & wellhead sensors, VSD, and flowmeter using AI-driven outputs.

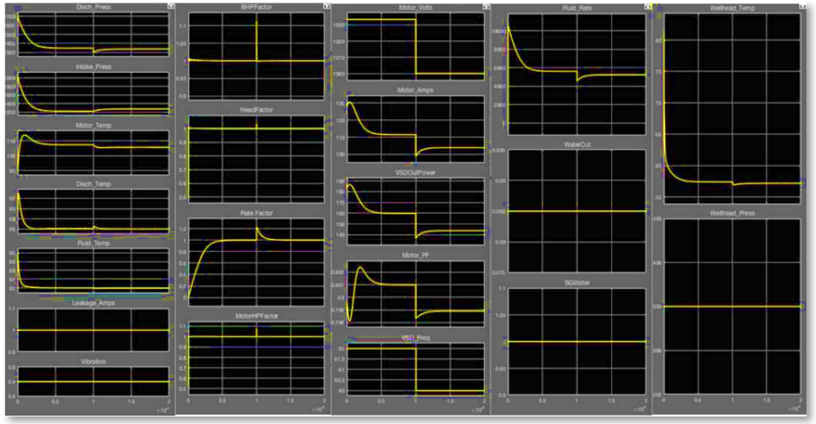
Benefit

- Digital twin was calibrated with physical model, allowing automatic equipment sizing, virtual well modeling, and capture deviations related to failure detection and performance diagnostics.

Simulink® ESP Digital Twin



Simulink® ESP Borehole & Welhead Sensor Outputs



Source: R. Lastra. Electrical Submersible Pump Digital Twin, the Missing Link for Successful Condition Monitoring and Failure Prediction. SPE-197156-MS

Dynamic transfer simulation in ultra-tight, dual-porosity systems

Challenge

- Enhance mass transfer dynamics in dual-porosity reservoirs to predict pressure response under ultra-tight conditions.

Solution

- Compared MATLAB reservoir simulator (MRST) with CMG and ECLIPSE outputs based on three fracture geometry models to describe different diffusion-type processes.

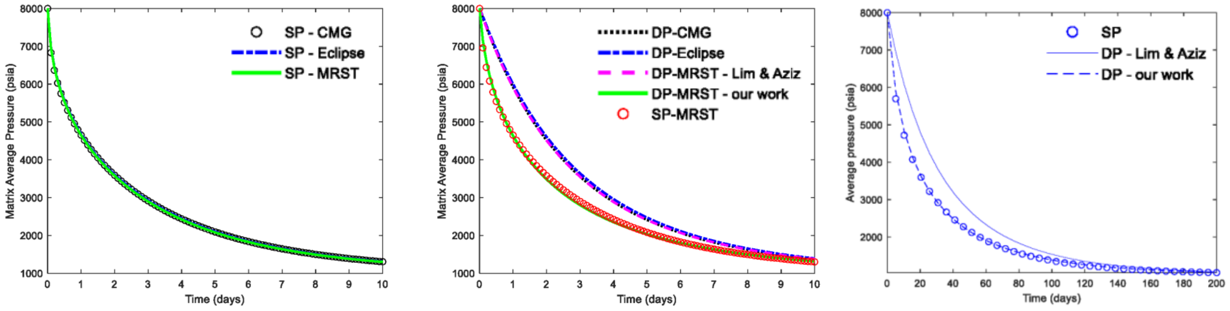
Benefit

- The Vermeulen dynamic transfer function predicts early and late pressure accurately in ultra-tight, dual-porosity reservoirs.
- MRST outputs fully resemble the dynamic outputs from ECLIPSE and CMG models.

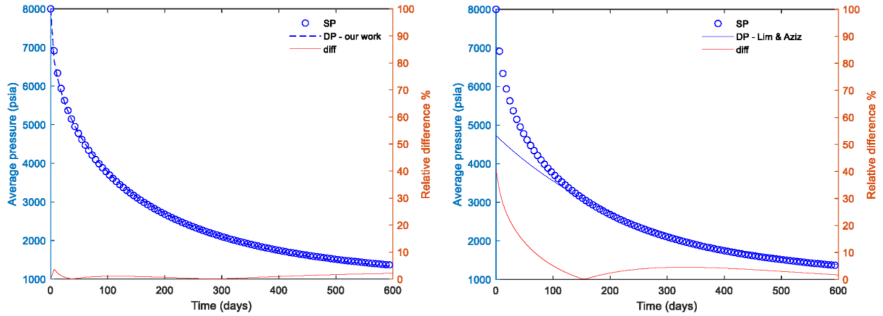
Vermeulen dynamic transfer model: Processes, parameters, and applications

	D	Ψ	Application
Viscous flow	Hydraulic diffusivity	Pressure	Tight oil/gas
Diffusion	Diffusion coefficient	Concentration	Unconventional EOR
Heat conduction	Thermal diffusivity	Temperature	Geothermal

MATLAB® MRST vs. ECLIPSE and CMG comparisons
Pressure predictions based on Single (SP) and Dual (DP) porosity models



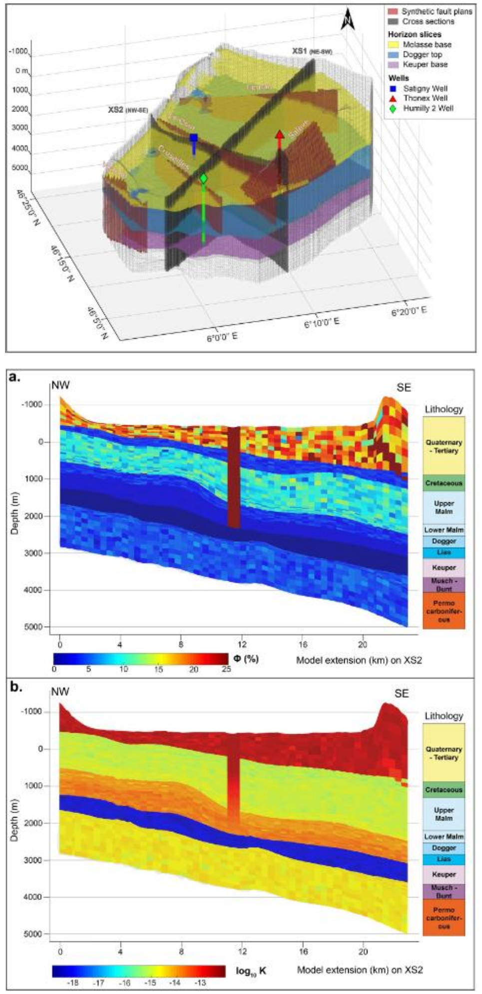
Pressure predictions in irregular matrix models



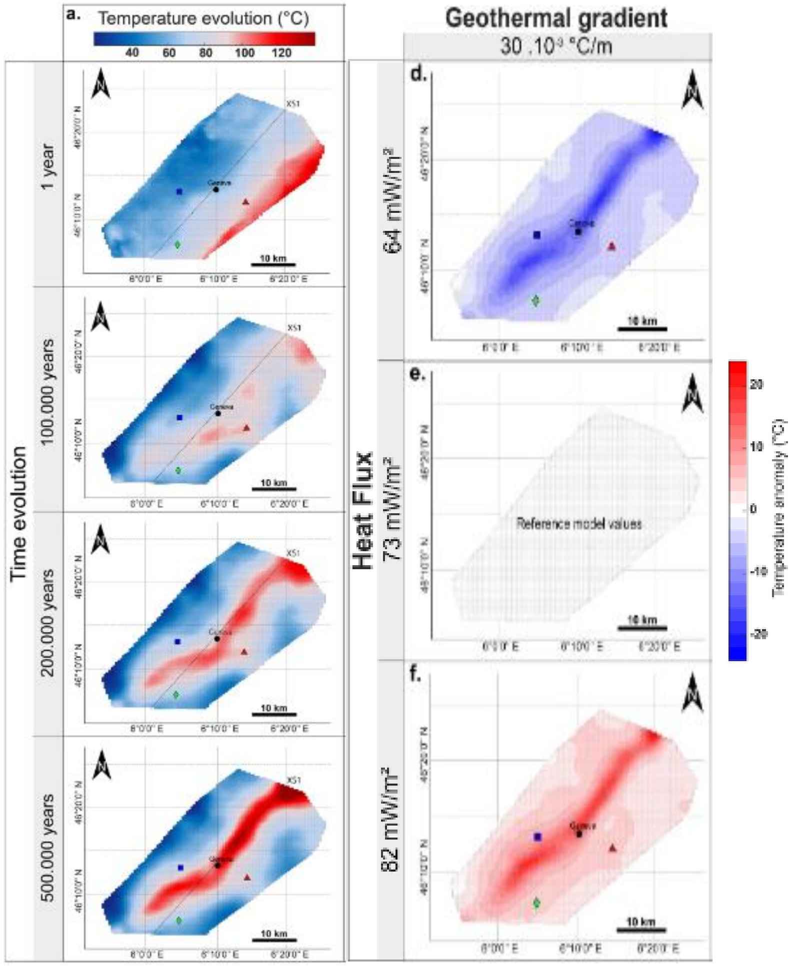
Source: *Zhang, J., Raslan, M., Wu, C., and Jessen, K., 2022. A generalized dynamic transfer function for ultra-tight dual-porosity systems.* [SPE-209324-MS]

Geothermal Reservoir Simulation in MATLAB

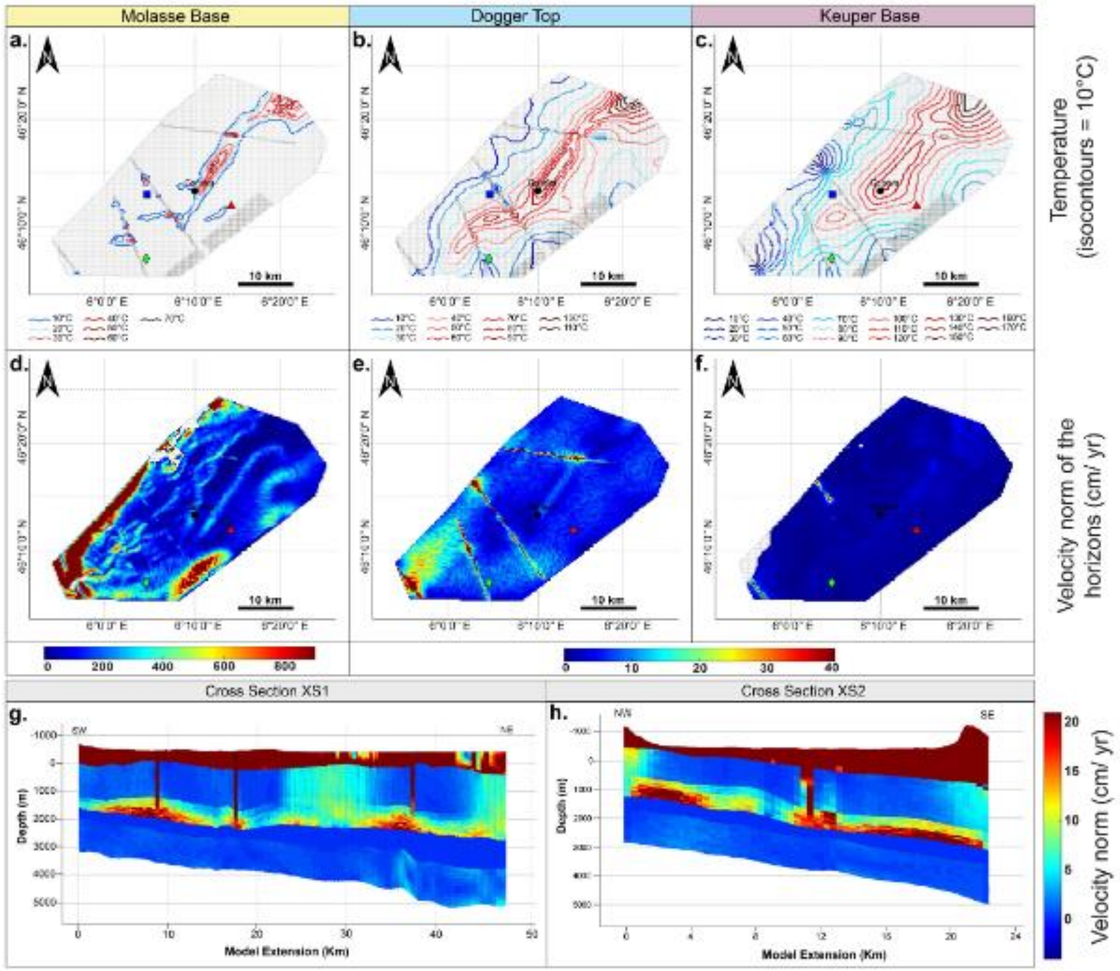
3D Geological Model
(0.5M cells)



Geothermal Gradient & Heat Flow Models
(4,000 time stamps, 3 formations)



Final Geothermal Simulation Models
(thermal, structural, and petrophysical parameters)



Source: Alcanie, M., Collignon, M., Moyner, O., and Lupi, M. 2021. 3D Basin-Scale Groundwater Flow Modeling for Geothermal Exploration. Geochemistry, Geophysics, Geosystems, Vol. 22, e2020GC009505. https://doi.org/10.1029/2020GC009505

Real-time Sensor Signal Processing of Energy Systems in Simulink

Challenge

- Model, simulate, and test real-time digital signal processing (DSP) from energy sources.

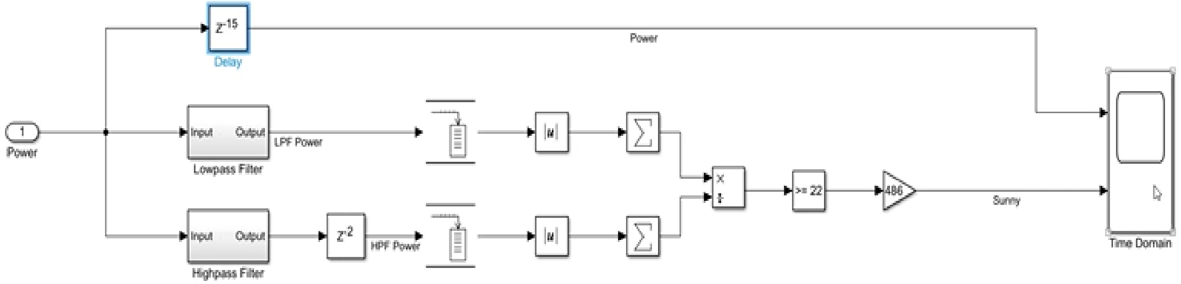
Solution

- Used Simulink to design a signal processing system to predict multiple energy conditions and optimize power generation from a solar grid.
- Used DSP Toolbox to analyze sensor signals, design filters, and generate embedded code for hardware deployment.

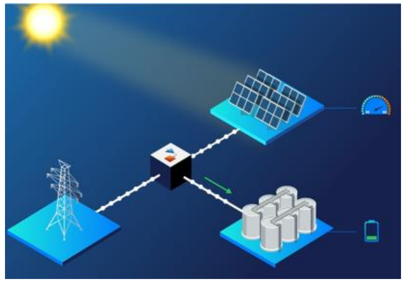
Benefit

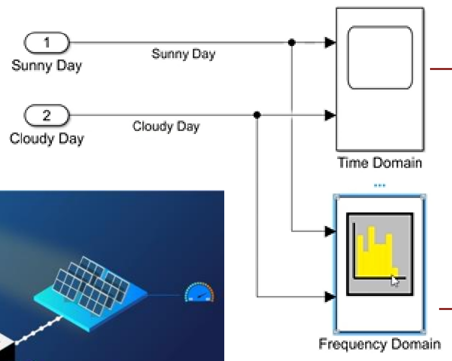
- Simulink enabled the design of an integrated system to analyze real-time signals from energy sensors and deploy code on embedded systems automatically.

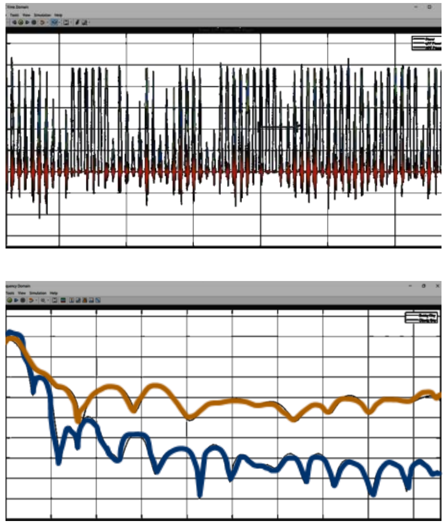
Digital Signal Processing (DSP) Simulink model



Comparison between energy signal responses in Time (above) and Frequency (below) domains







Source: R. Panah, G. Theunick, D. Vickery, and Joey Storer. Process Optimization by Integrating MATLAB with Aspen Plus. The MathWorks, Inc.

Event detection in chemical plants with predictive analytics

Challenge

- Detect events and abnormalities from big data in real time using predictive analytics.

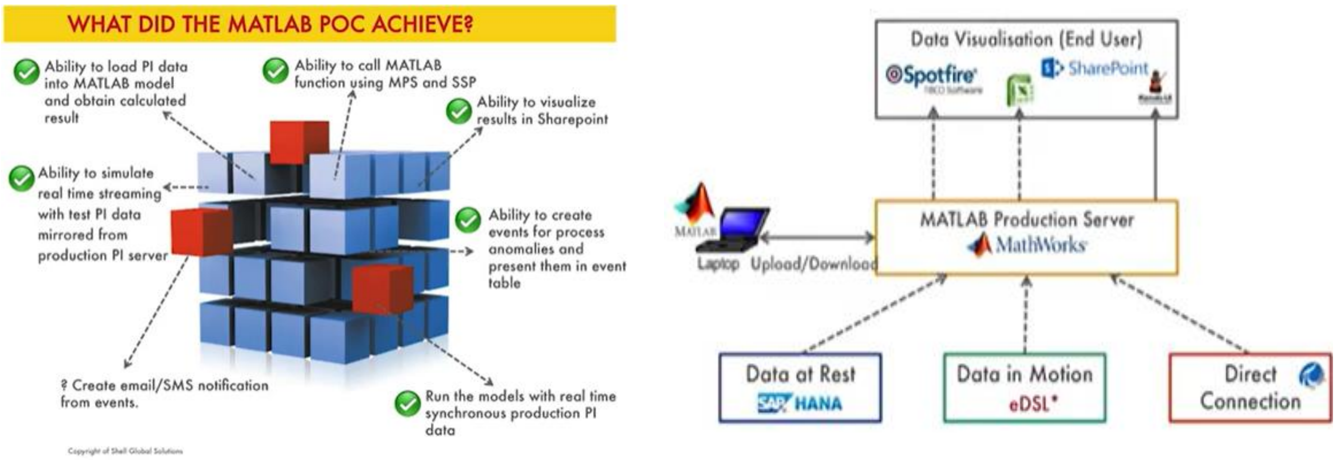
Solution

- Used MATLAB toolboxes for data extraction, processing, analysis, modeling, diagnostics, monitoring, and detection in real time.
- Supported real-time streaming of data from PI server, created events for process anomalies, and modeled real-time production data.

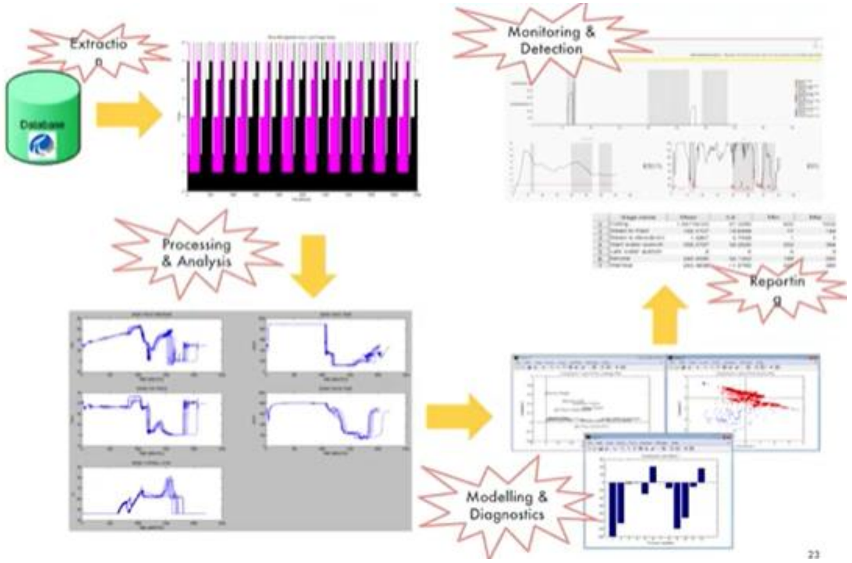
Benefit

- MATLAB helped to integrate production data from PI server for synchronous predictive analytics in real time.
- MATLAB enabled generating notifications of process anomalies and visualize events in end user applications and dashboards.

MATLAB for Real-Time Predictive Analytics



MATLAB-supported Real-Time Predictive Analytics Workflow



Source: Chaudry, A. Big data and predictive analytics at Shell – In Depth. MathWorks Videos and Webinars.The MathWorks, Inc.

Optimized predictive maintenance of Steam Turbines

Challenge

- Analyze performance of past maintenance to detect patterns and predict future efficiencies.

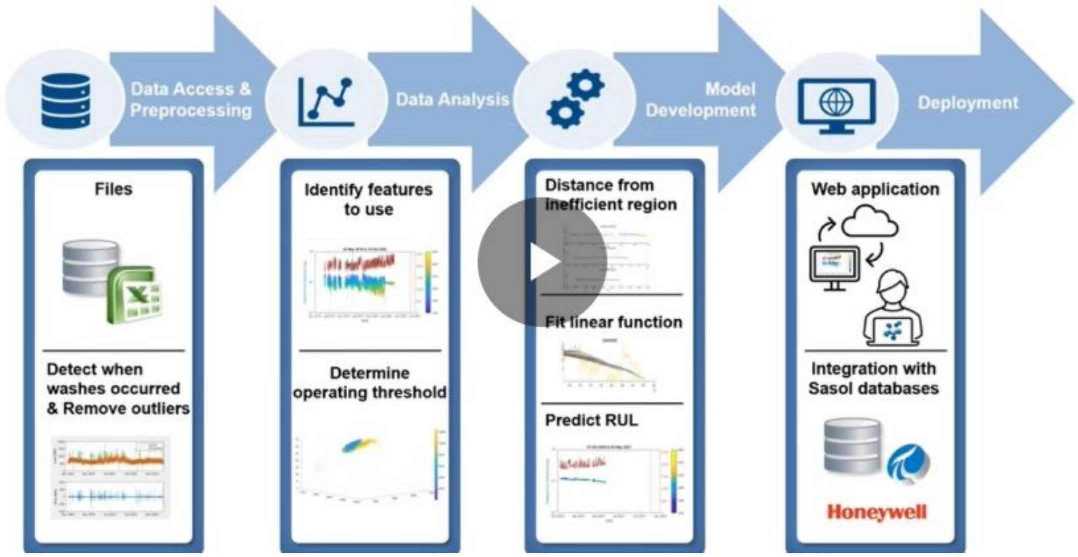
Solution

- Used MATLAB Machine Learning to develop a predictive model for efficient maintenance scheduling.
- Developed a MATLAB app for operations to identify ineffective maintenance outcomes.

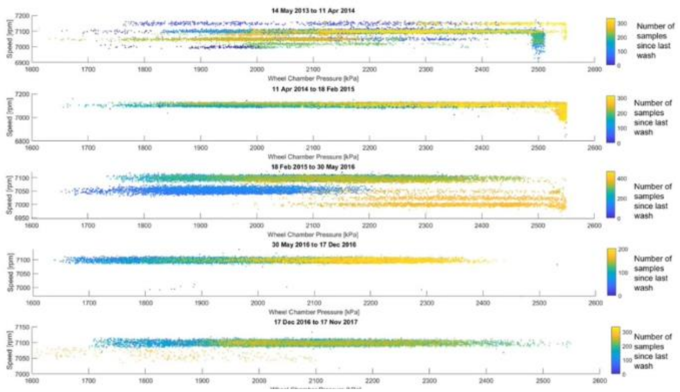
Benefit

- MATLAB predictive model established a new best practice to schedule maintenance.
- MATLAB app supported closer monitoring of steam turbine operations, limitations, and anomalous conditions in production.

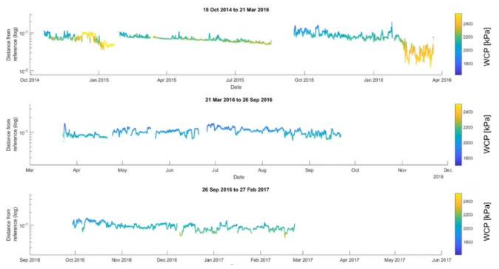
MATLAB-supported workflow for Predictive Maintenance



Steam Turbines Data Analysis



Predictive Model Development



Source: S. Miller. Digital Twins for Predictive Maintenance (eBook). Predictive Maintenance Using a Digital Twin (Technical Article). The MathWorks, Inc.

Equipment Fault Detection and Predictive Maintenance

Challenge

- Detect and anticipate potential equipment failure conditions for predictive maintenance.

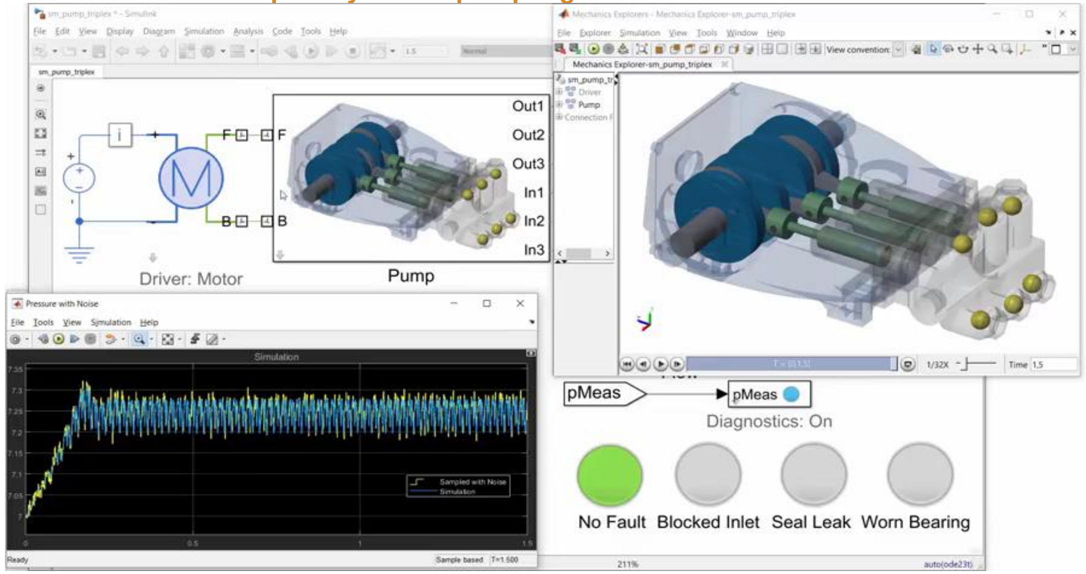
Solution

- Used Simulink to detect leak, blocking, and bearing faults in a triplex reciprocating hydraulic pump using a multi-class classifier.
- Simulated datasets as time and frequency signals for multiple fault combinations and healthy conditions.

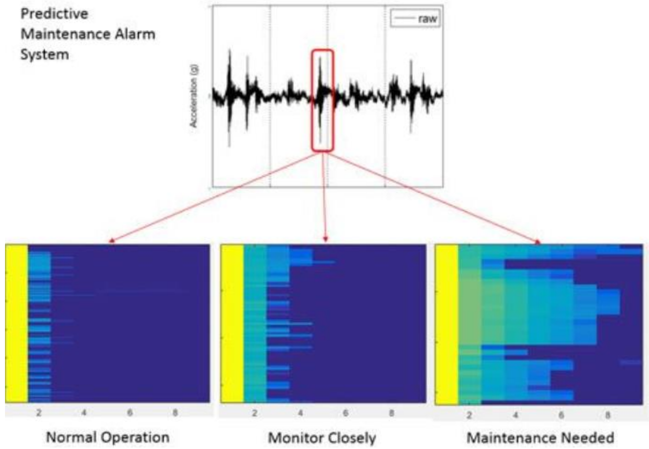
Benefit

- The Simulink model successfully detected and predicted simulated pump responses under both faulty and healthy conditions to use for predictive maintenance.

Triplex hydraulic pump digital twin in Simulink



Predictive Maintenance Alarm System



Pump faults detection
actual (vertical) vs. predicted (horizontal)

Actual leak fault \ Predicted fault	None	Leak	Blocking	Leak & Blocking	Bearing	Bearing & Leak	Bearing & Blocking	All
None	27	0	0	0	1	0	0	0
Leak	0	20	0	0	0	0	0	0
Blocking	0	0	27	0	0	0	4	0
Leak & Blocking	0	0	0	10	0	0	1	1
Bearing	0	0	1	0	32	0	0	0
Bearing & Leak	0	0	0	0	0	9	0	0
Bearing & Blocking	0	0	2	0	2	0	12	1
All	0	0	0	1	0	1	0	8

Source: S. Miller. Digital Twins for Predictive Maintenance (eBook). Predictive Maintenance Using a Digital Twin (Technical Article). The MathWorks, Inc.

Electrolyzer simulation of the world's largest PEM hydrogen plant

Challenge

- Assess power consumption from proton exchange membrane (PEM) technology in large-scale, green-hydrogen electrolyzers.

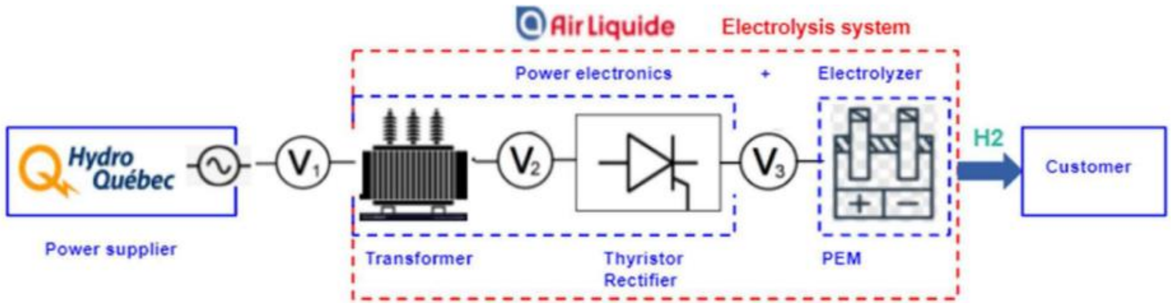
Solution

- Used Simulink and Simscape to model multiple topologies from an industrial 20 MW PEM water electrolysis system.
- Compared simulated results against existing 20 MW PEM with AC and DC power supply.

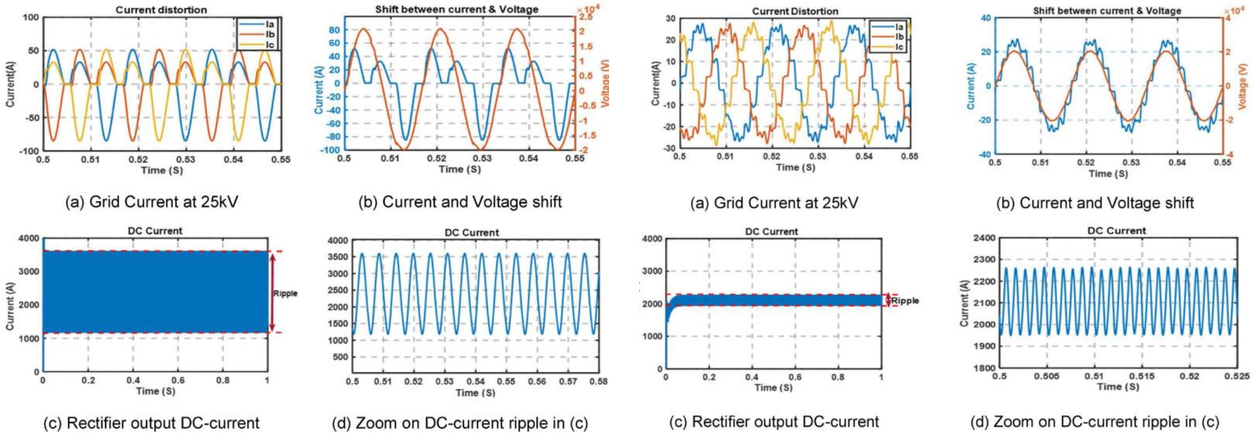
Benefit

- Simulink model resembled experimental results under multiple topologies and enabled reducing power losses under partial loads to support efficiencies during industrial design.

Water electrolysis processes modeled in Simulink



Thyristor outputs with 20% load with 6 pulses (left plots) and 3-phase buck rectifier (right plots)



Source: Keddar et al (2022). Power quality improvement for 20 MW PEM water electrolysis system. International Journal of Hydrogen Energy. Elsevier.

Polymerization Process Co-Simulation & Optimization in MATLAB

Challenge

- Model complex polymerization process to optimize production under multiple scenarios.

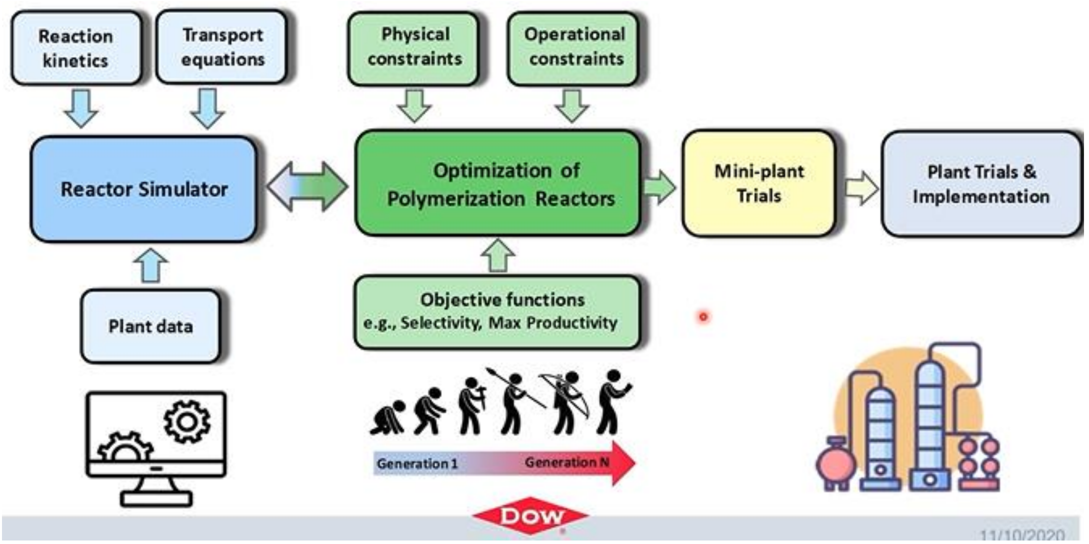
Solution

- Used Aspen Plus to define a distillation model for polymerization reactor optimization.
- Used MATLAB to execute a genetic algorithm, to optimize process parameters running multiple simulation realizations automatically.

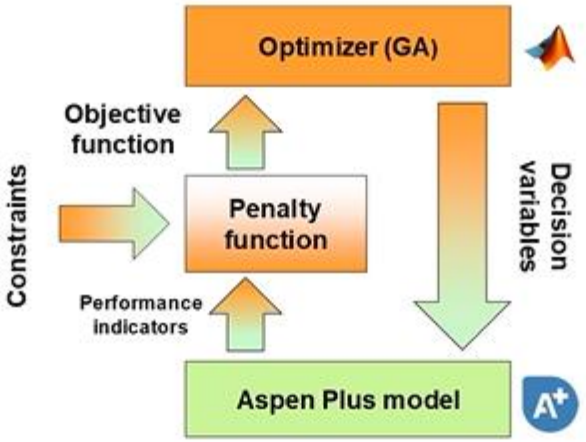
Benefit

- MATLAB interconnection with Aspen Plus enabled running thousands of co-simulations to optimize the process in a few hours.
- Results enhanced equipment designs and optimized asset performance at minimum cost

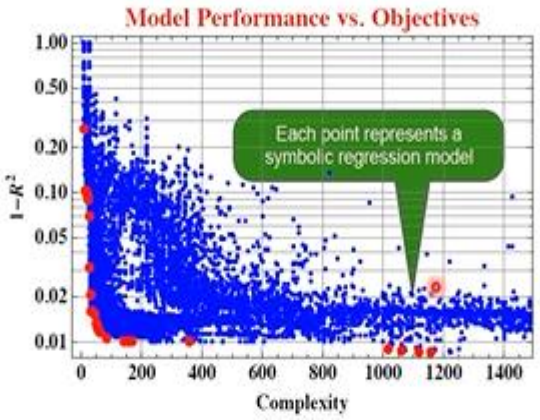
Process Simulation and Optimization Workflow for Polymerization Reactor



Multi-variate Optimization with Genetic Algorithm



Pareto plot
(Accuracy vs. Complexity)



Source: R. Panah, G. Theunick, D. Vickery, and Joey Storer. Process Optimization by Integrating MATLAB with Aspen Plus. The MathWorks, Inc.

Control and automation of polymer manufacturing processes

Challenge

- Simulate and control an exothermal process to avoid material damage during phenol-formaldehyde manufacturing.

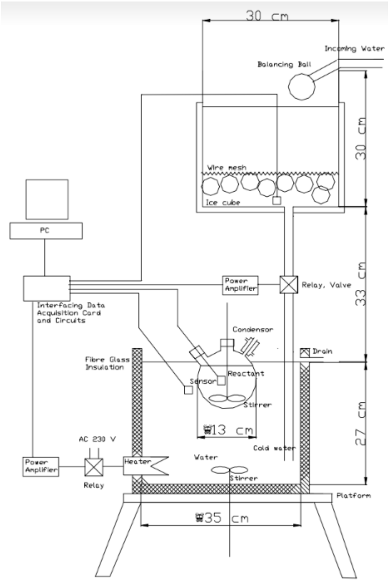
Solution

- Used Simulink and Fuzzy Logic (FLC) toolbox to simulate the process and design a sensor-based process control system.
- Compared a predictive FLC structure against a PID model to assess temperature control.

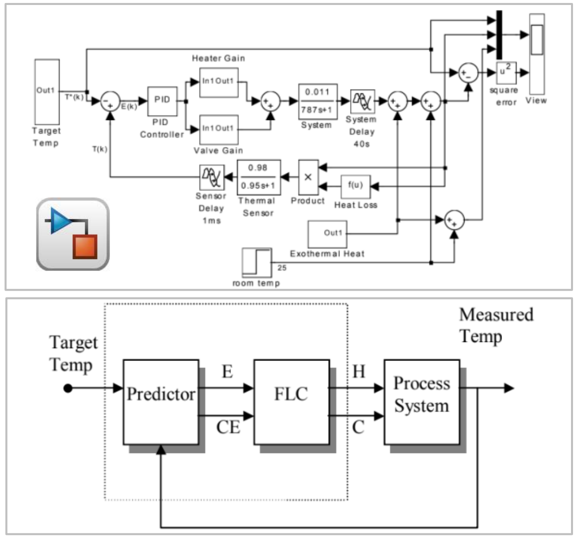
Benefit

- The FLC model developed in Simulink was reliable and useful to control, predict, and automate temperature changes during polymer manufacturing.

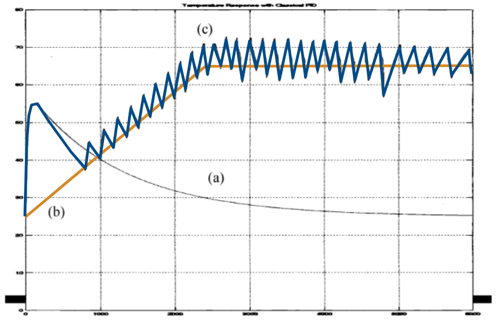
Reactor System Model



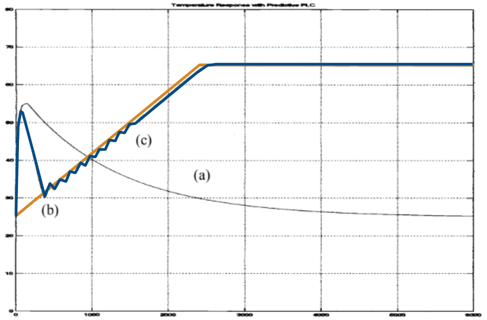
Simulink: Fuzzy Logic Control (FLC) model (above) and PID model (below)



PID Simulated (b) vs. Actual (c) responses



FLC Simulated (b) vs. Actual (c) responses



Source: Yaacob, S., Nagarajan, R., and Kenneth, T. Predictive Fuzzy Logic to Control Temperature in Phenol-Formaldehyde Manufacturing. SPIE, Vol. 4565. ISDM IV.

Simulation of Water Electrolyzer for Green Hydrogen Production

Challenge

- Maximize hydrogen production using multiple renewable energy sources (wind, solar)

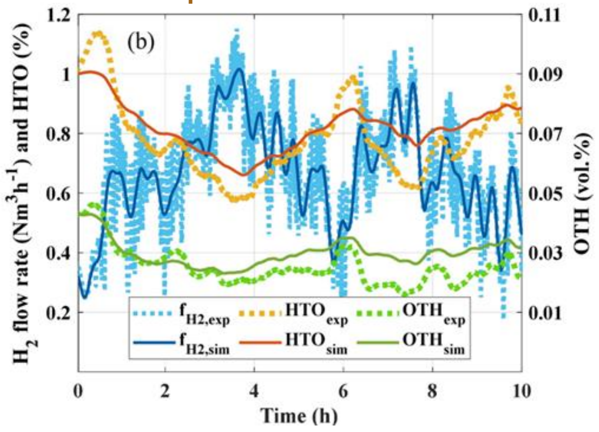
Solution

- Used Simulink and Simscape to model a multi-physics digital twin (electrochemical, thermodynamics, multi-fluids) for water electrolysis with intermittent energy sources.

Benefit

- Simulink results replicated actual green hydrogen production process with high accuracy and predictability.
- Digital twin enabled fast prototyping of what-if scenarios of a water electrolyzer for green hydrogen ahead of plant modifications.

Wind power model validation



Hydrogen Production Profiles

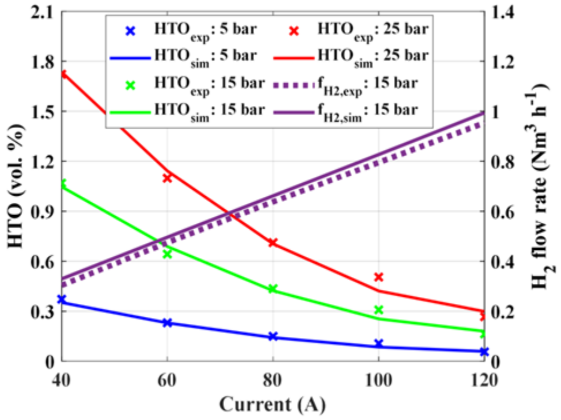
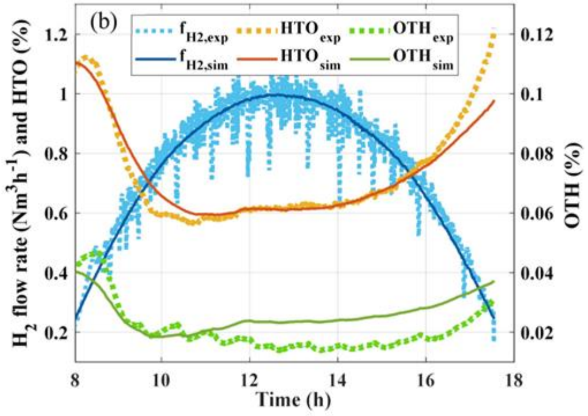
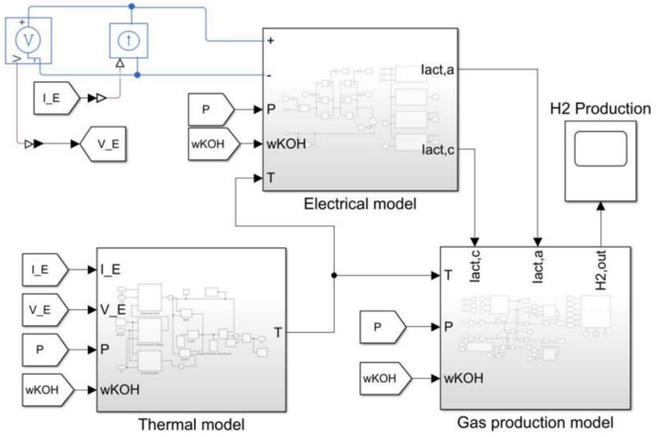


Photo-voltaic-based model validation



Multi-physics Green Hydrogen Digital Twin



Source: Iribarren, A. et al. Dynamic Modeling of a Pressurized Alkaline Water Electrolyzer: A Multiphysics Approach. IEEE, Vol. 59, No. 3.., pp. 3741-3753.

Model predictive control (MPC) of vinyl chloride monomer process

Chinprasit et al | Kasetsart University (TH)

Challenge

- Control and predict vinyl chloride monomer (VCM) process with complex nonlinear interactions between reactors and separators.

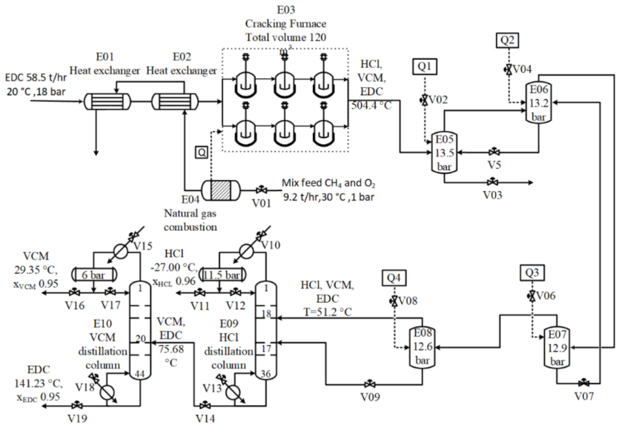
Solution

- Used Simulink, MPC & System Identification toolboxes with AspenPlus to co-simulate the VCM process using a multivariate model.
- Assessed proportional-integral-derivative (PID) and MPC controller performance under multiple input/output configurations.

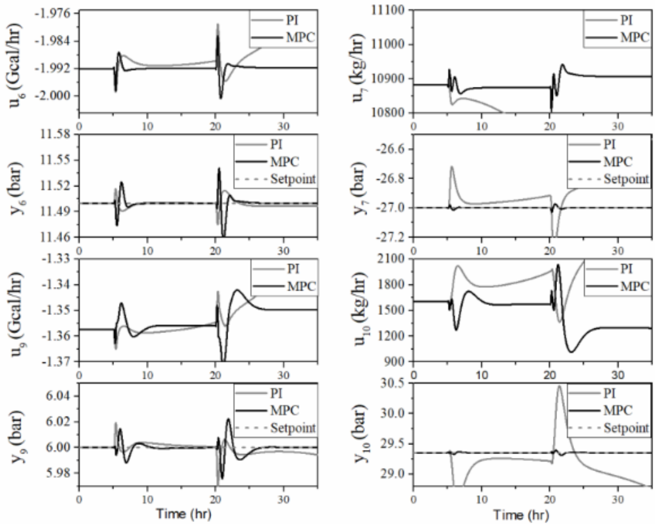
Benefit

- Simulink enabled performing a thorough sensitivity analysis of the VCM process.
- MPC showed better performance than PID.

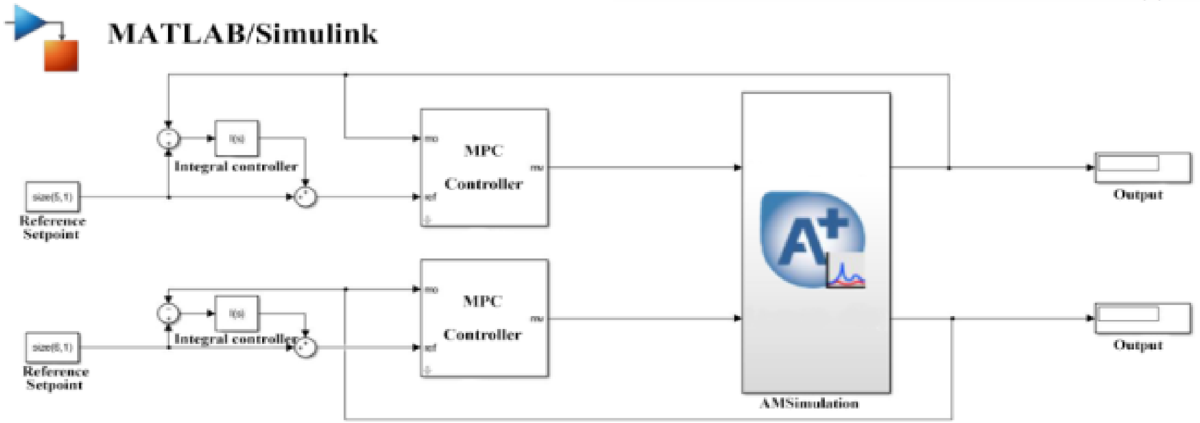
VCM process diagram



Results of PID vs MPC controller outputs



Simulink and Aspen Plus co-simulation model



Source: Chinprasit, J., and Panjapornpon, C.. (2019). MPC of vinyl chloride monomer process. IOP Conference on Materials Science and Engineering, Vol. 778, No. 012080.

Lithium Recovery Optimization from Geothermal Brine

Challenge

- Optimize lithium recovery by simulating a multi-stage system of distillation, evaporation, crystallization, and precipitation processes and assessing membranes performance.

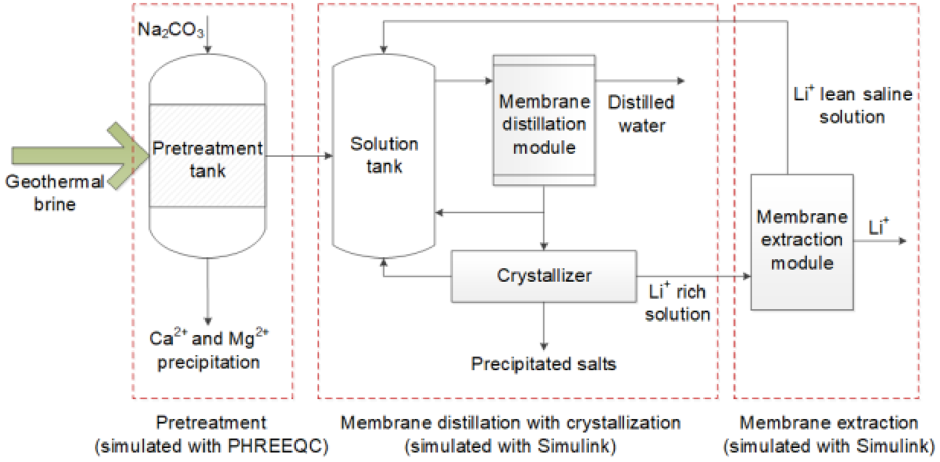
Solution

- Used Simulink and Simscape to simulate membrane distillation and crystallization for lithium extraction using thermal and fluid sub-systems of polynomial equations.

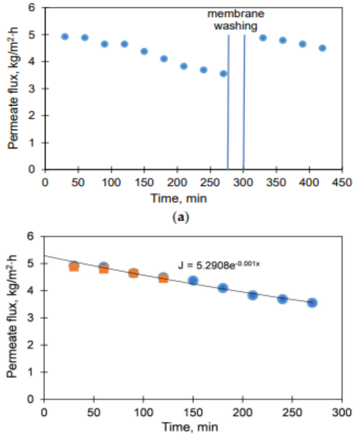
Benefit

- Simulink enabled the simulation of complex geothermal processes for effective lithium extraction and confirmed experimental results about optimal membrane design and fluid thermodynamic conditions.

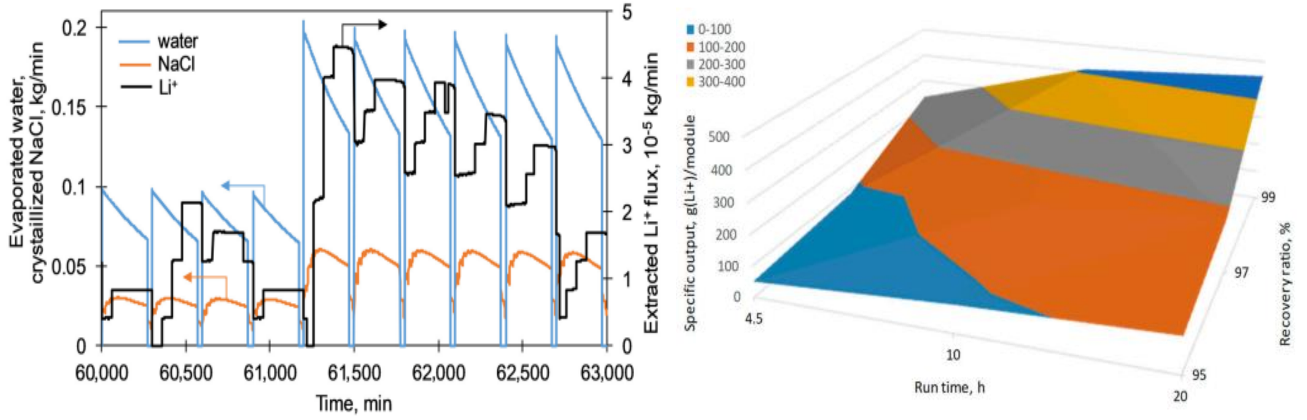
Geochemical (PHREEQC) & Geothermal (Simulink) Digital Twin



Geochemical fluxes (PHREEQC)



Geothermal simulation outputs (left) and Lithium recovery optimization (right)



Source: *Kalmykov, D., Makaev, S., Golubev, G., Eremeev, I., Vasilevsky, V., Song. J., He. T., and Volkov, A. (2021). [Operation of Three-Stage Process of Lithium Recovery from Geothermal Brine: Simulation](). MDPI Membranes, Vol. 11, No. 175.*

Technoeconomic assessment of blue hydrogen plant using CO2 hydrogenation

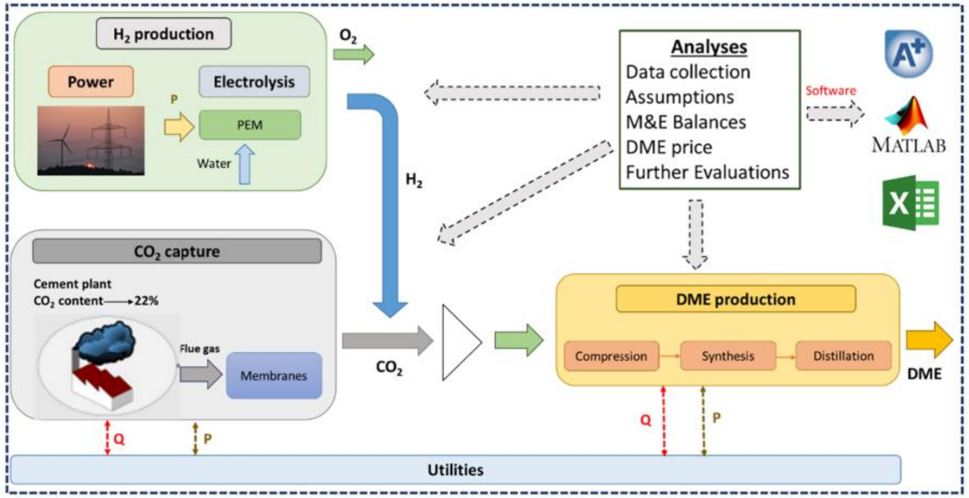


Fig. 1. System elements and boundaries of the proposed DME plant.

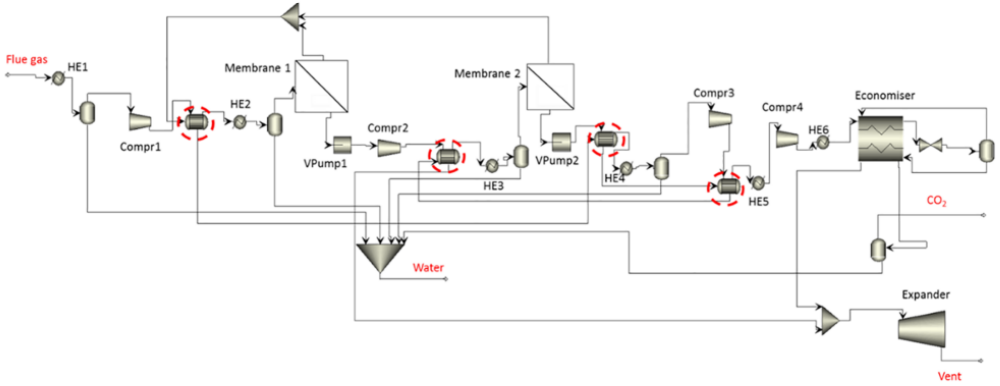


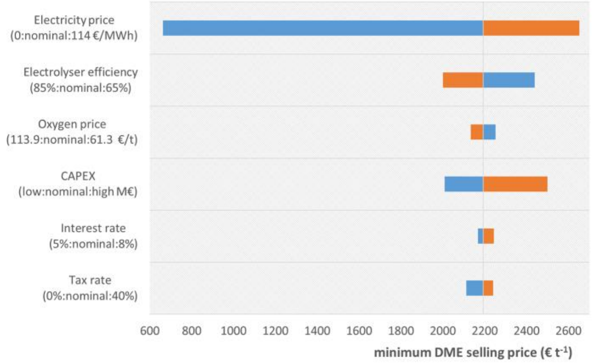
Fig. 2. Process flow diagram for CO_2 capture though multistage membrane and cryogenic separation.

MATLAB was interconnected with Aspen Plus via COM to:

- Model both sensitivity and probabilistic analyses
- Solve nonlinear equations for CO2 membrane separation
- Control stream flowrates on Aspen black box in real time

Economic indicator results of the plant.

	CO_2 capture plant	Electrolysis	DME synthesis	Utilities	Total
CAPEX (M€)	237	197	488	272	1195
OPEX (M€)	17	382	23	13	436
CAPEX per tonne of DME (€ t^{-1})	106	88	218	121	533
OPEX per tonne of DME (€ t^{-1})	71	1556	96	51	1774
DME Production cost (€ t^{-1})	177	1644	313	173	2307
Revenues from O_2 (€ t^{-1})	–	–	–	–	195
Net DME production cost (€ t^{-1})	–	–	–	–	2112
Minimum DME selling price (€ t^{-1})	–	–	–	–	2193



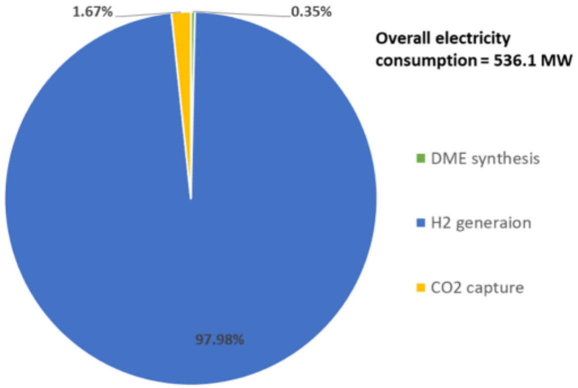


Fig. 10. Electricity cost breakdown.

Source: Michailos et al (2019). Dimethyl ether synthesis via captured CO2 hydrogenation within the power to liquids concept: A techno-economic assessment. Energy Conversion and Management, Vol. 184, pp. 262-276. https://doi.org/10.1016/j.enconman.2019.01.046.

CO2 recycling model for syngas production based on chemical looping

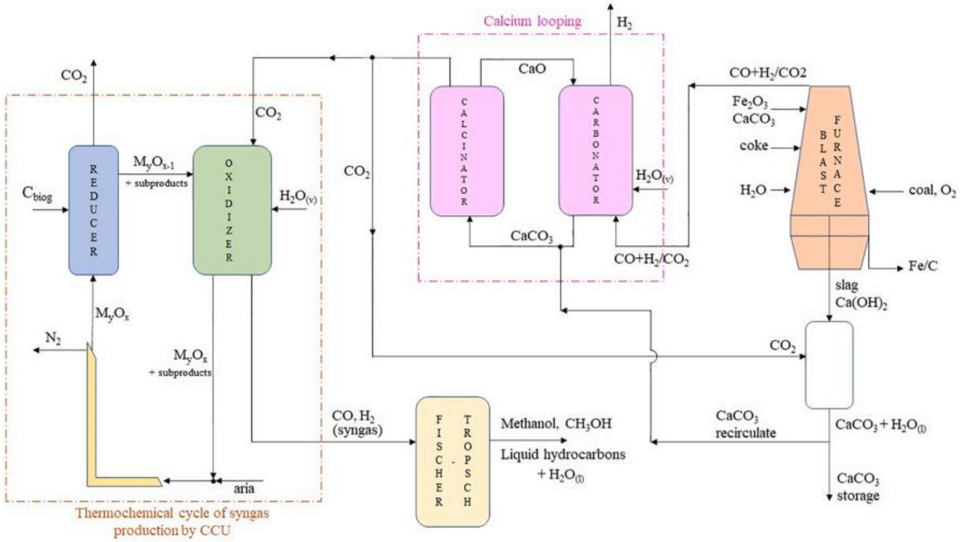


Fig. 1. Industrial integration scheme for a syngas production cycle coupled with CO_2 treatment.

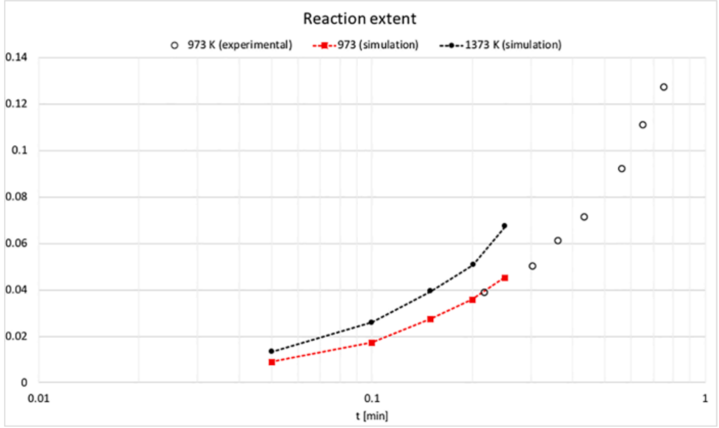


Fig. 4. Reaction extent comparison between experimental values and simulation results.

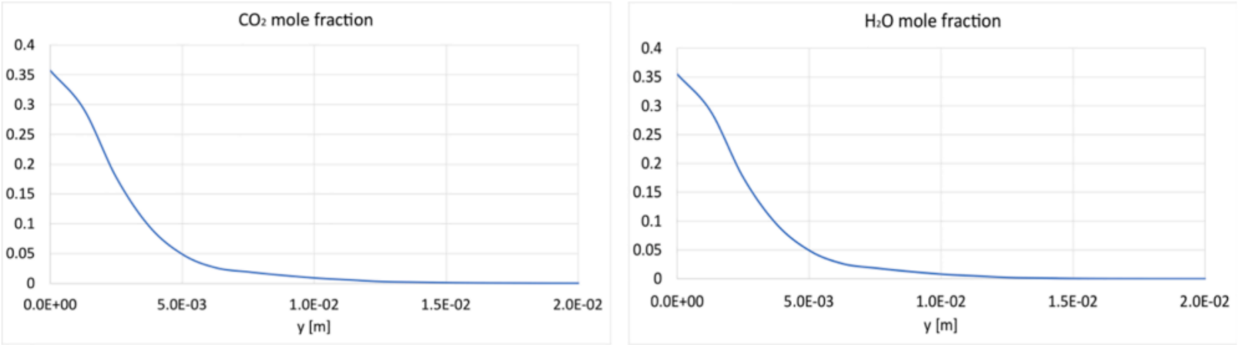


Fig. 5. Gases mole fractions of H_2O and CO_2 at t = 15 s along oxidizer's centerline.

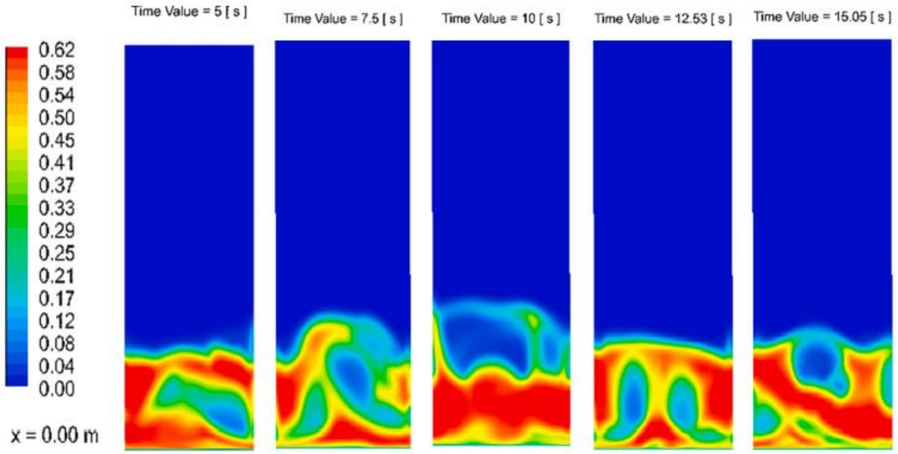


Fig. 7. Solids (FeO and Fe_3O_4) volume fraction for $t = 5s, 7.5s, 10s, 12.53s$ and $15.05s$ in the $x = 0$ plane.

Source: Hoxha et al (2022). Development of a novel carbon capture and utilization approach for syngas production based on a chemical looping cycle. Fuel, Vol. 325, No. 124760. https://doi.org/10.1016/j.fuel.2022.124760.

CO2 post-combustion capture modeling & optimization using machine learning

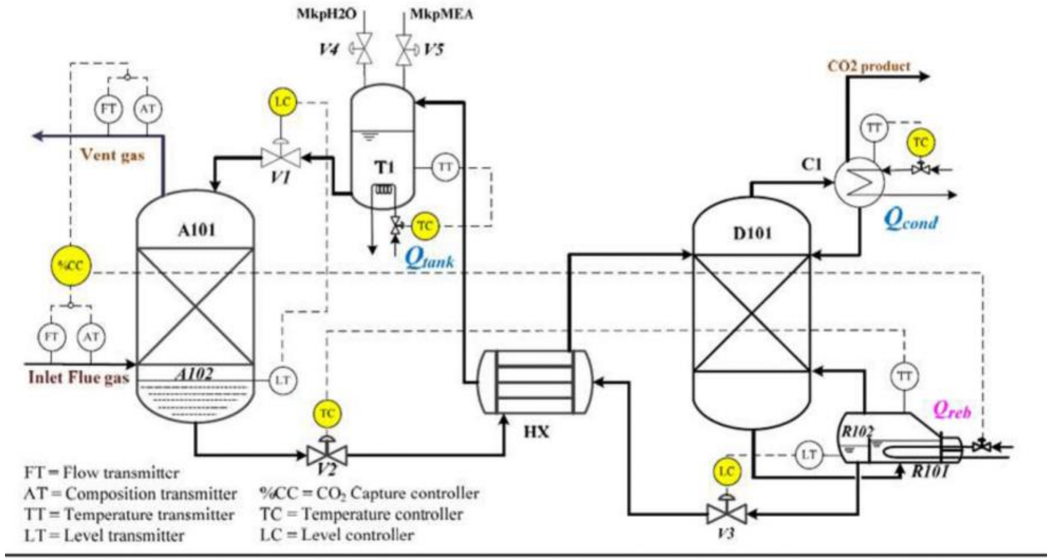


Fig. 1. Post-combustion unit.

Variable	Variable Name
x_1	Flow Rate (mol/s)
x_2	Temperature (K)
x_3	Pressure (kPa)
x_4	Reboiler Pressure (kPa)
x_5	Reboiler Duty (W)
x_6	Condenser Duty (W)
y_1	System Energy Requirements (kJ/kg CO_2)
y_2	Capture Rate (%)
y_3	Purity

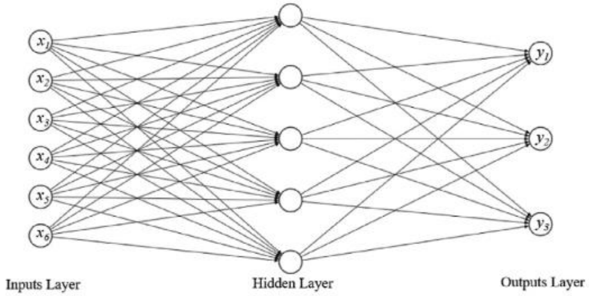


Fig. 2. Feed-forward neural network structure.

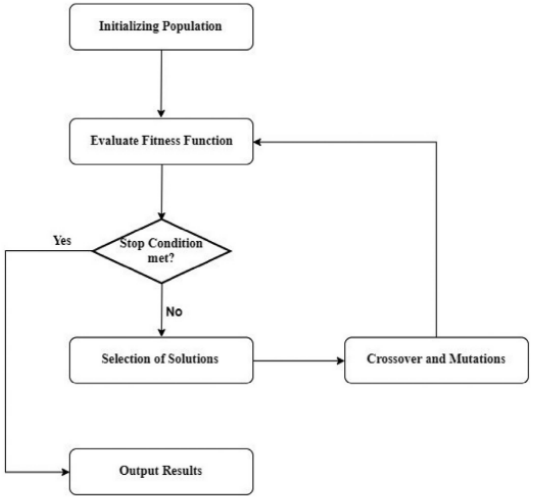


Fig. 4. Genetic algorithm flow chart.

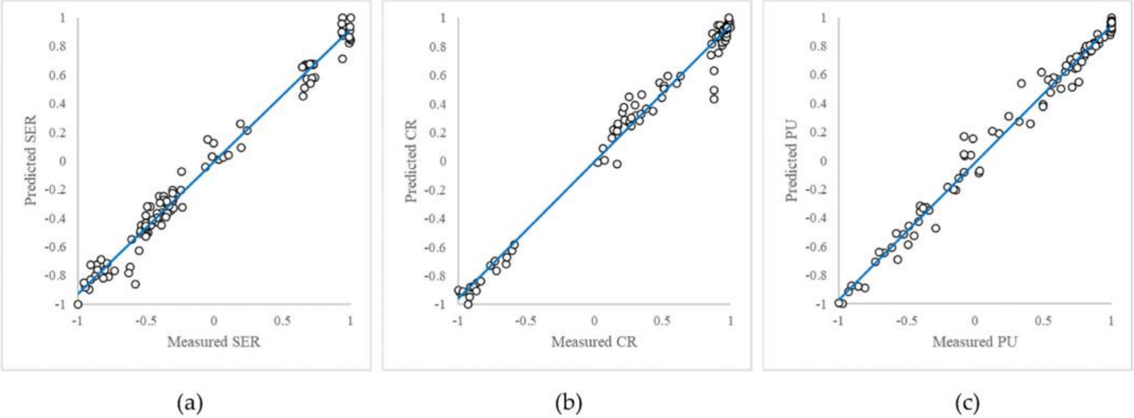


Fig. 3. Predictions vs. measured outputs of the developed models: (a) ANN model predicting SER; (b) ANN model predicting CR; (c) ANN model predicting PU;

Source: Shalaby et al (2021). A machine learning approach for modeling and optimization of a CO2 post-combustion capture unit. Energy, Vol. 215, No. 119113. *https://doi.org/10.1016/j.energy.2020.119113*.

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