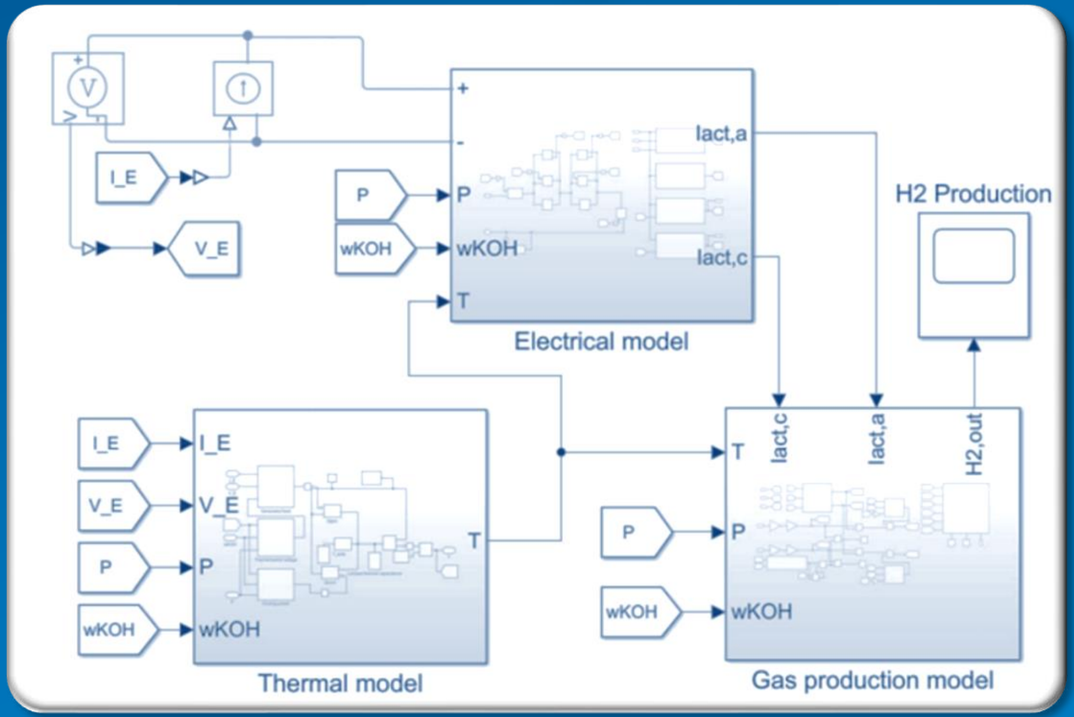
Digital Twins for New Energy Processes in MATLAB® & Simulink®

Chris R. Wells
Energy Resources

December 2023 (v1)



Artificial Intelligence | Big Data Analysis | Deep Learning | Machine Learning | Reinforced Learning | Predictive Analytics | Internet of Things | Process Optimization | Process Digitization | Process Automation | Value Chain Integration

Contents

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- Digital Twins in MATLAB and Simulink
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  – Multi-physics Digital Twins for Green Hydrogen Production
  – Modular Open-Systems Approach (MOSA) for Digital Twins
  – Optimizing Turbine Predictive Maintenance Scheduling
- MathWorks® Digital Twin Toolset

Background

The integration of new energy processes in the value chain requires a thorough understanding of time, cost, demand, and resources necessary to streamline these processes in the most effective and timely fashion

New energy processes comprise complex, multi-physics, dynamic systems that require comprehensive and continuous analysis and control steps to maximize data value using existing assets and allocated infrastructure

Digital twins and advanced process control (APC) are useful digital technologies for engineers, scientists, and decision makers to design, test, predict, and plan how to make the most out of a new energy process

MathWorks developed digital toolboxes in MATLAB and Simulink for organizations to build (i) digital twins that simulate dynamic systems and processes, and (ii) APC systems to maximize process performance, stability, and efficiency.

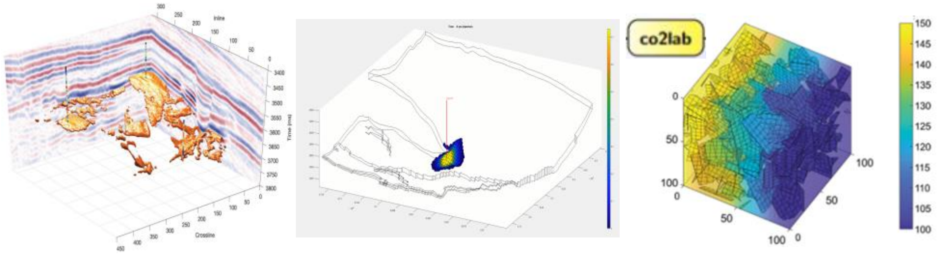
MathWorks®

Customizable Digital Products for Energy Upstream & Downstream

Process Modeling & Simulation

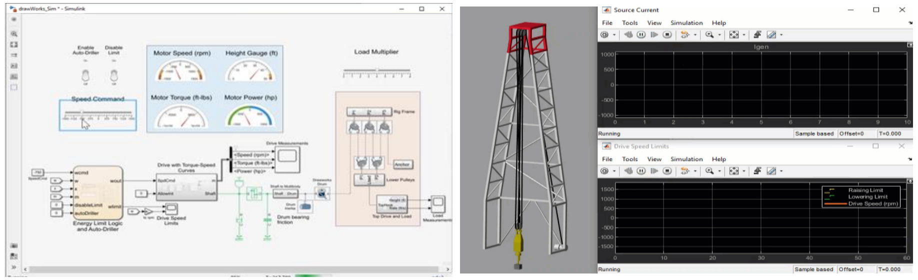
Subsurface

SeReM + MRST
MATLAB® Reservoir Modeling & Simulation

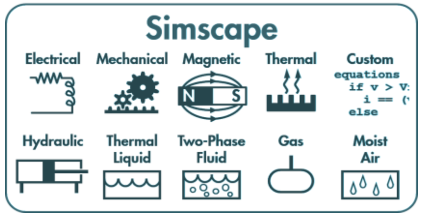


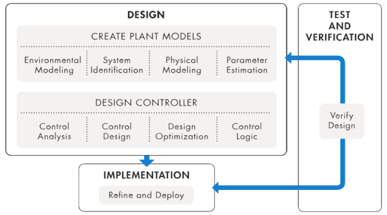
Oilfield

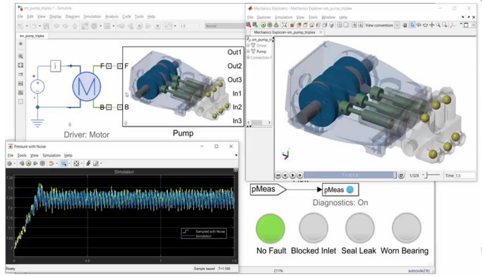
Oilfield & Plant Digital Twins
MATLAB® & Simulink®



Plant







Process Optimization & Automation

- MATLAB® Production Server
- MATLAB® Cloud Service
- MATLAB® Quantum Computing
- Parallel Computing Toolbox
- GPU Computing Toolbox
- Simulink® Simscape
- Image/Signal Processing Toolboxes
- Computer Vision Toolbox
- Machine Learning Toolbox
- Deep Learning Toolbox

MathWorks in Energy Resources

Digital Twins in MATLAB® & Simulink®

Digital Twin: A digital simulation of dynamic systems to predict outcomes and inform decisions

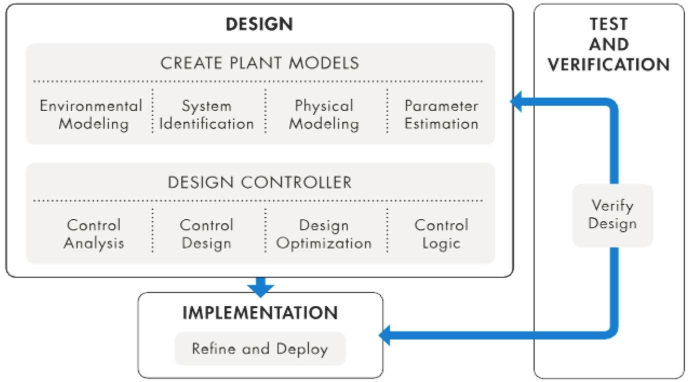
Subsurface | **Oilfields** | **Plants** | **Circularity**

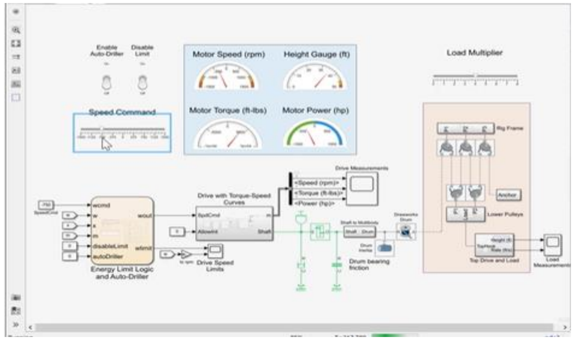
Asset

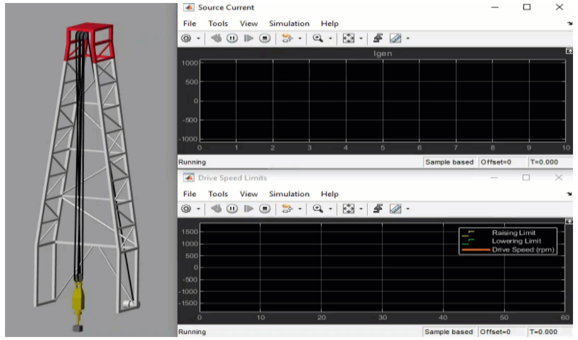
Process

Equipment

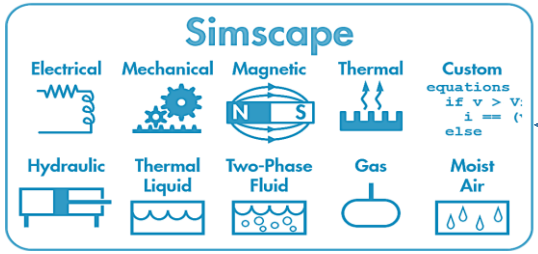
Component



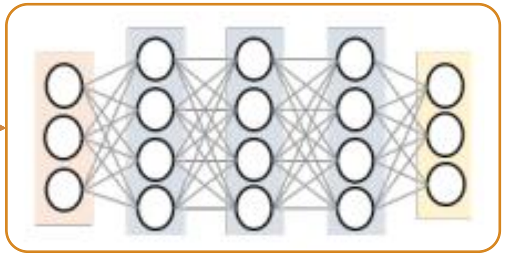


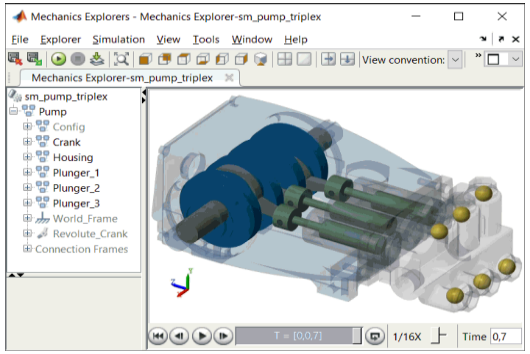


DATA ENGINEERING MODEL



DATA SCIENCE MODEL





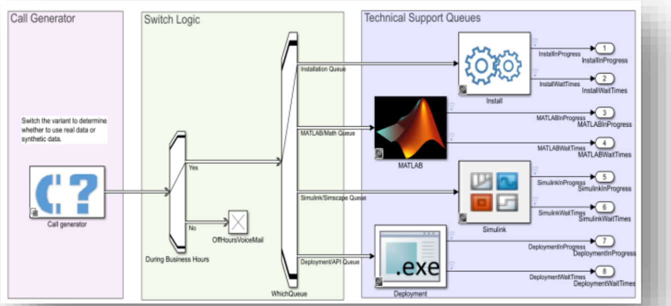
Types of Digital Twin Models

Build Digital Twin

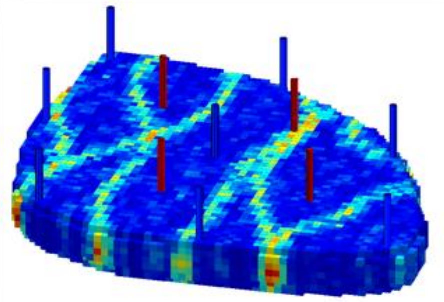
Leverage Digital Twin

Deploy Twin & Algorithms

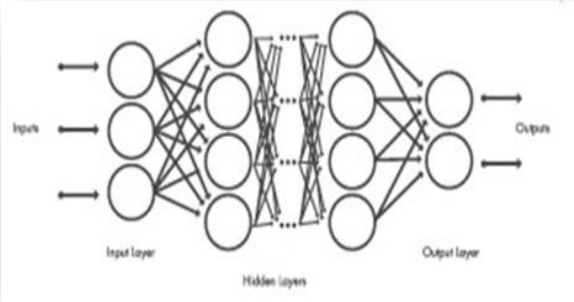
Process Model



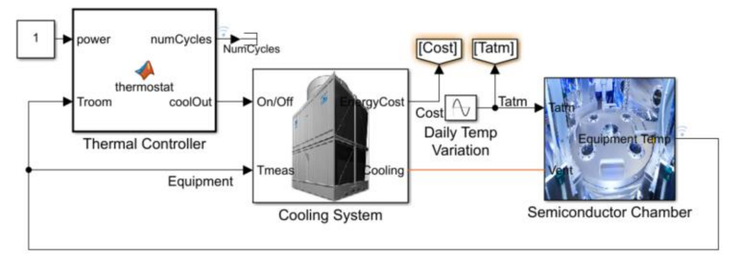
Parameter Estimation Reduced-Order Models



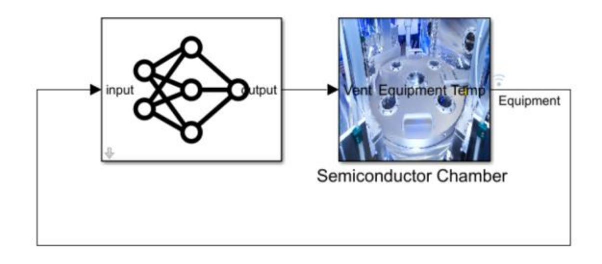
AI-based Models



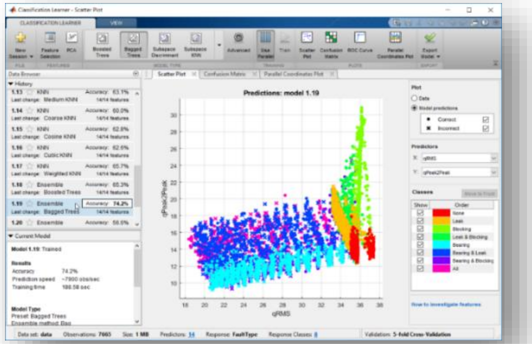
Physical Components



Hybrid Models



Machine Learning



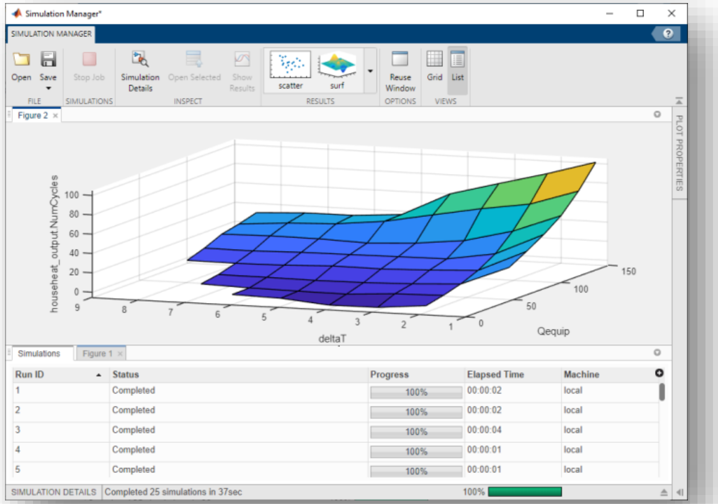
Physics-driven modeling

Data-driven modeling

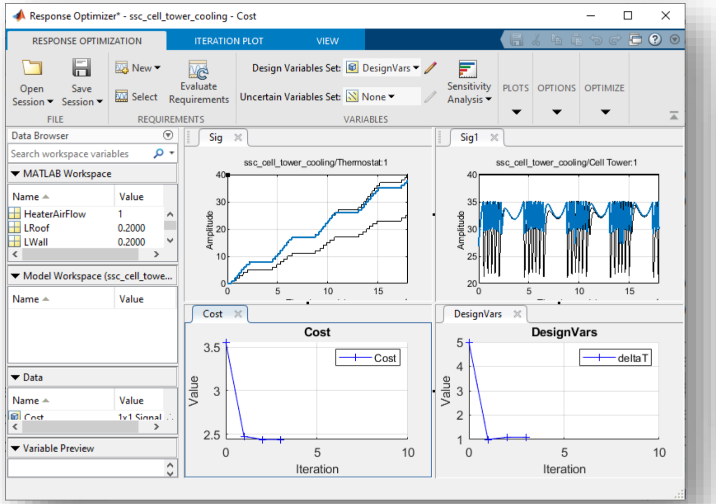
Common Digital Twin Applications

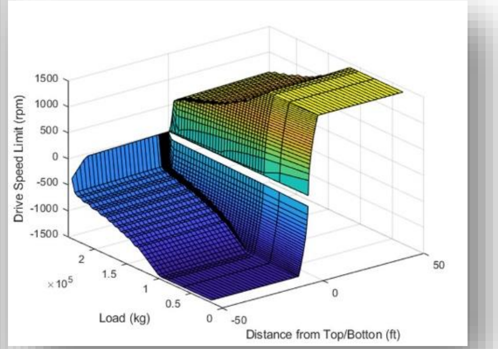
- Build Digital Twin
- Leverage Digital Twin
- Deploy Twin & Algorithms

Monte Carlo Simulations

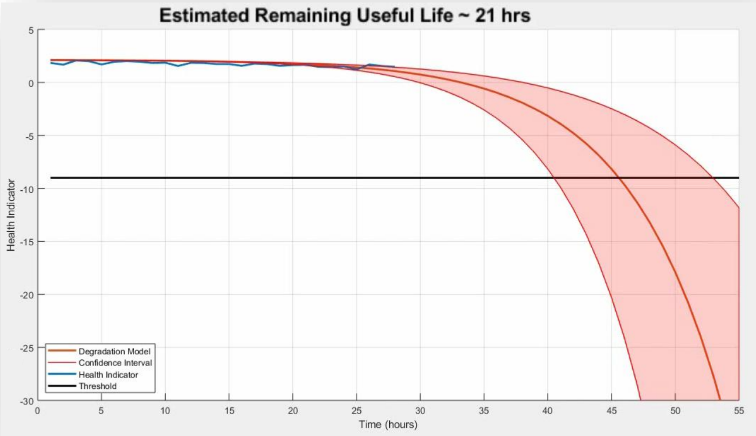


Operations Optimization

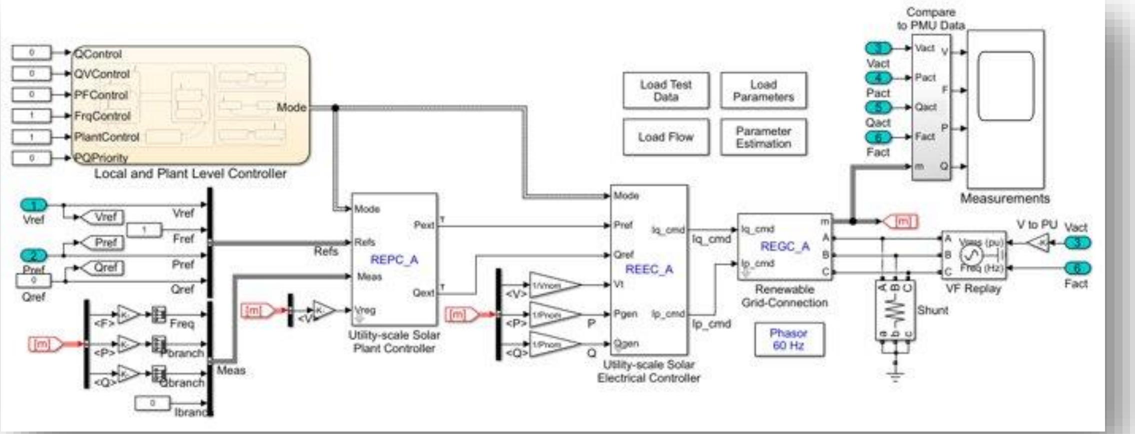




Predictive Maintenance



Fault Diagnostics

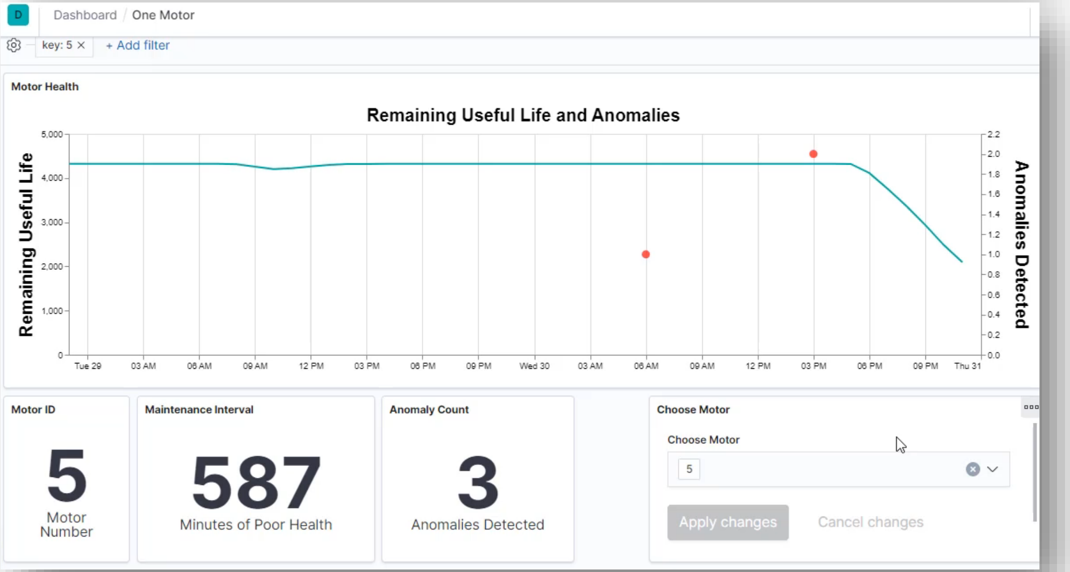


Digital Twin Deployment Options

Build Digital Twin

Leverage Digital Twin

Deploy Twin & Algorithms



Cloud-based Solutions

Standalone Application

Excel Add-in

Python

Desktop Users

Edge Devices

Digital Twins – AI-based modeling and system design workflow

1 Data Preparation

- Data cleansing and preparation
- Human insight
- Simulation-generated data

2 AI Modeling

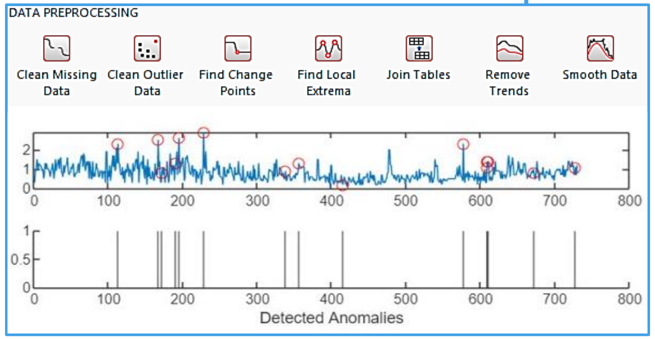
- Model design and tuning
- Hardware accelerated training
- Interoperability

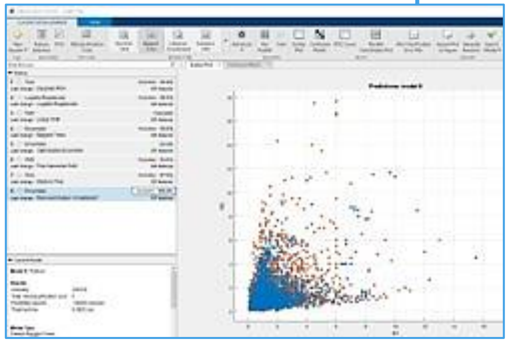
3 Simulation and Test

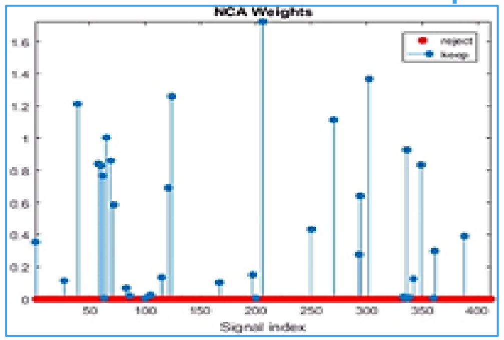
- Integration with complex systems
- System simulation
- System verification and validation

4 Deployment

- Embedded devices
- Enterprise systems
- Edge, cloud, desktop







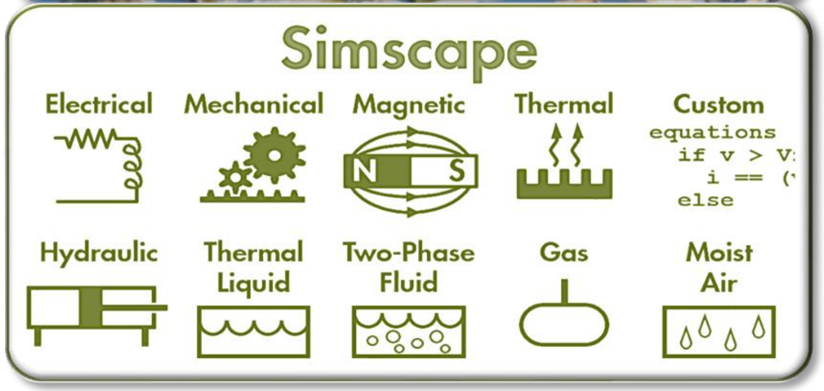
Simulink® Digital Twins for New Energies

Objectives

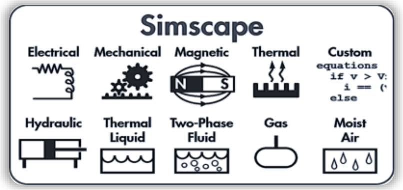
- Model chemical reaction kinetics, thermodynamics, and mass balance across a multi-physics system of equipment components
- Integrate machine learning to develop predictive model for process testing, prototyping, DevOps monitoring, and process optimization
- Incorporate advanced control systems (ACS: PLC, DCS) and digital sensors to simulate data flow across OT/IT infrastructure (e.g., SCADA)

Case Studies

- Iribarren *et al* (2023): *Dynamic modeling of a pressurized alkaline water electrolyzer: A Multiphysics approach*. IEEE Transactions on Industry Applications, Vol. 59, No. 3, May/June 2023.
- Sakas *et al* (2022). *Dynamic energy and mass balance model for an industrial alkaline water electrolyzer plant process*. International Journal of Hydrogen Energy, 47, 4328-4345.
- Randall (Sasol) and Mantji (Opti-Num). *Predictive maintenance of a steam turbine*. MathWorks Video.

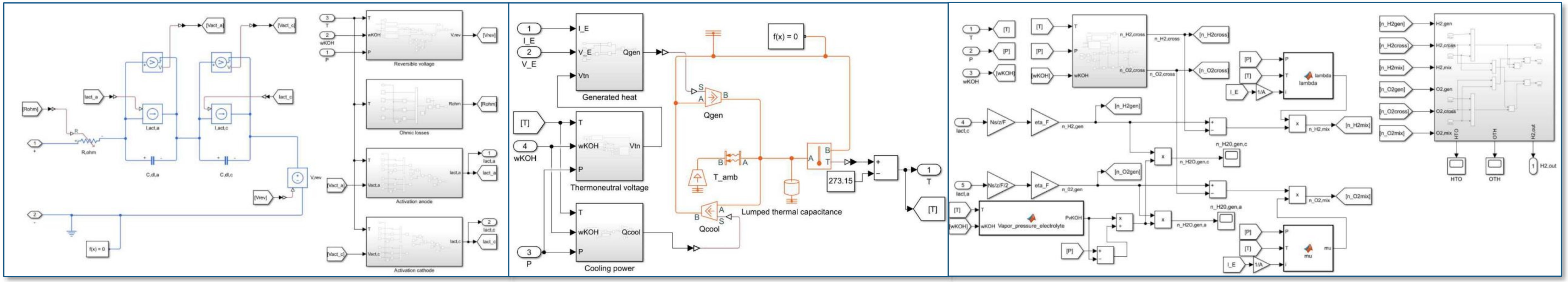


Simulink® Digital Twins for New Energies (Green Hydrogen)

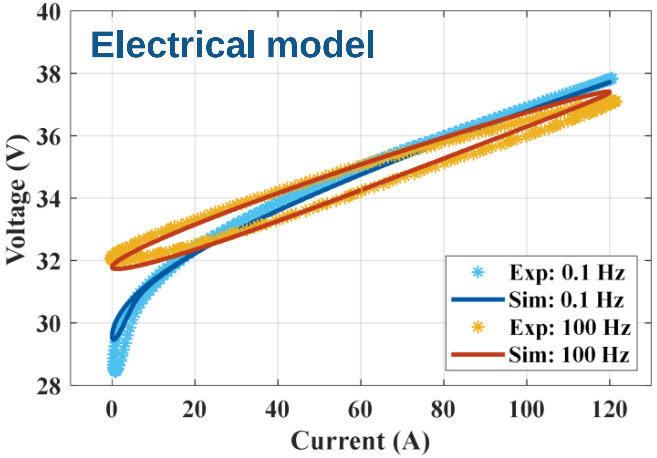


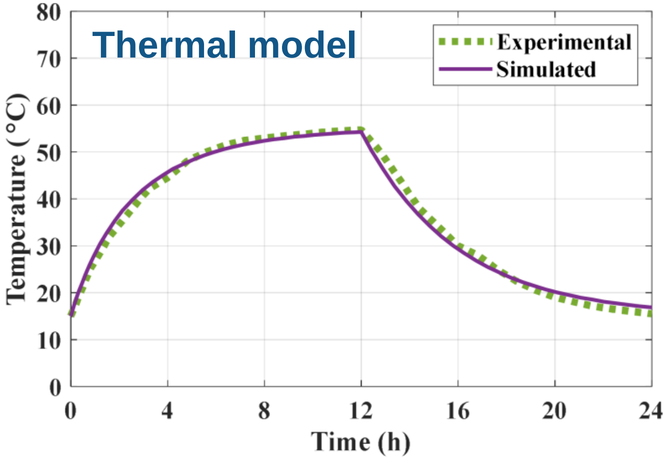
Multi-physics Digital Twin for Pressurized Water Electrolyzer ([Iribarren *et al*, 2023](#))

Electrical model + Thermal model + Green Hydrogen model

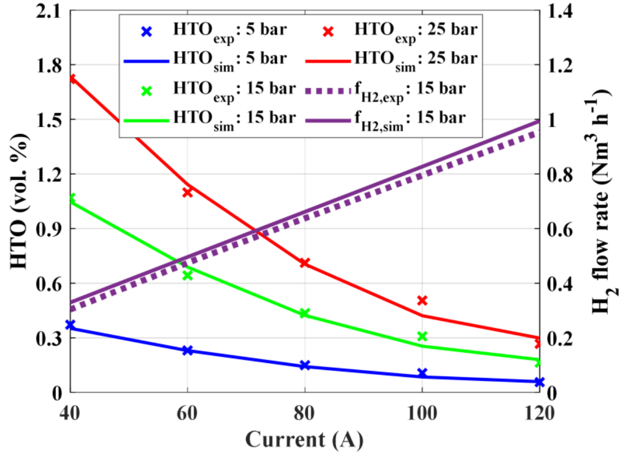


Multi-physics verification (experiments vs. simulations):

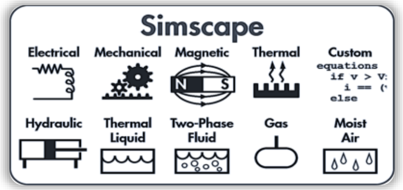




H2 production model

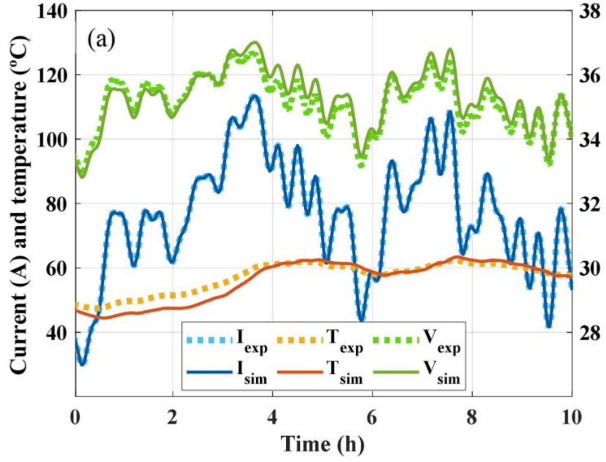


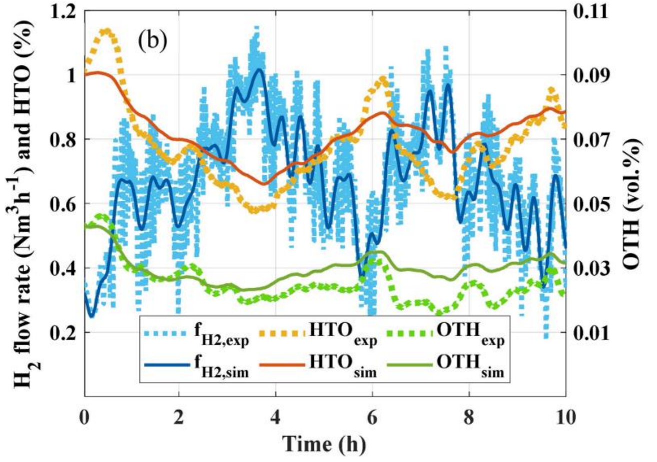
Simulink® Digital Twins for New Energies (Green Hydrogen)



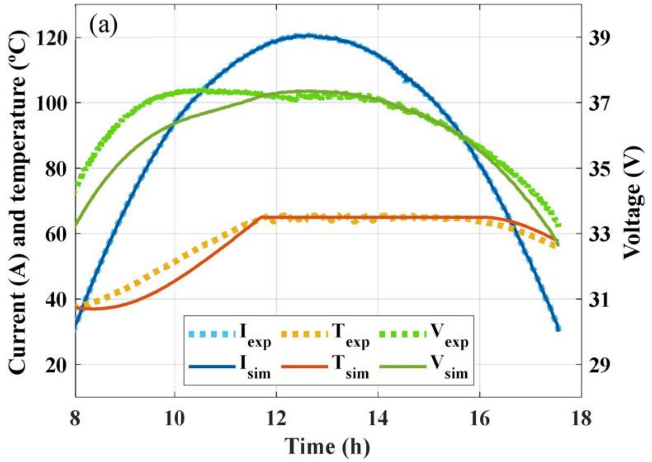
Multi-physics Digital Twin for Pressurized Water Electrolyzer (Iribarren *et al*, 2023)

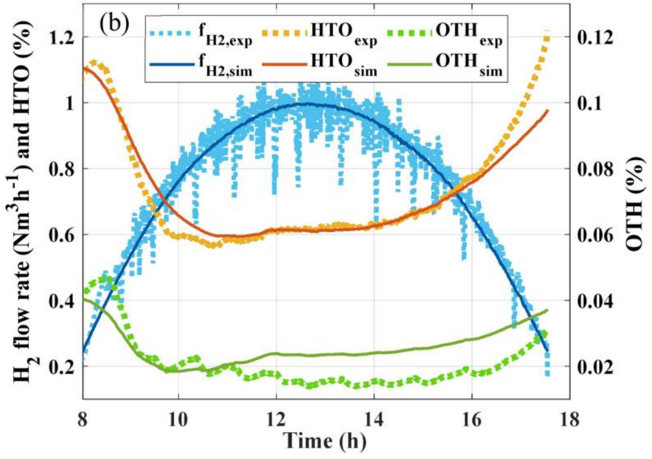
Digital twin validation – Wind Power Operation



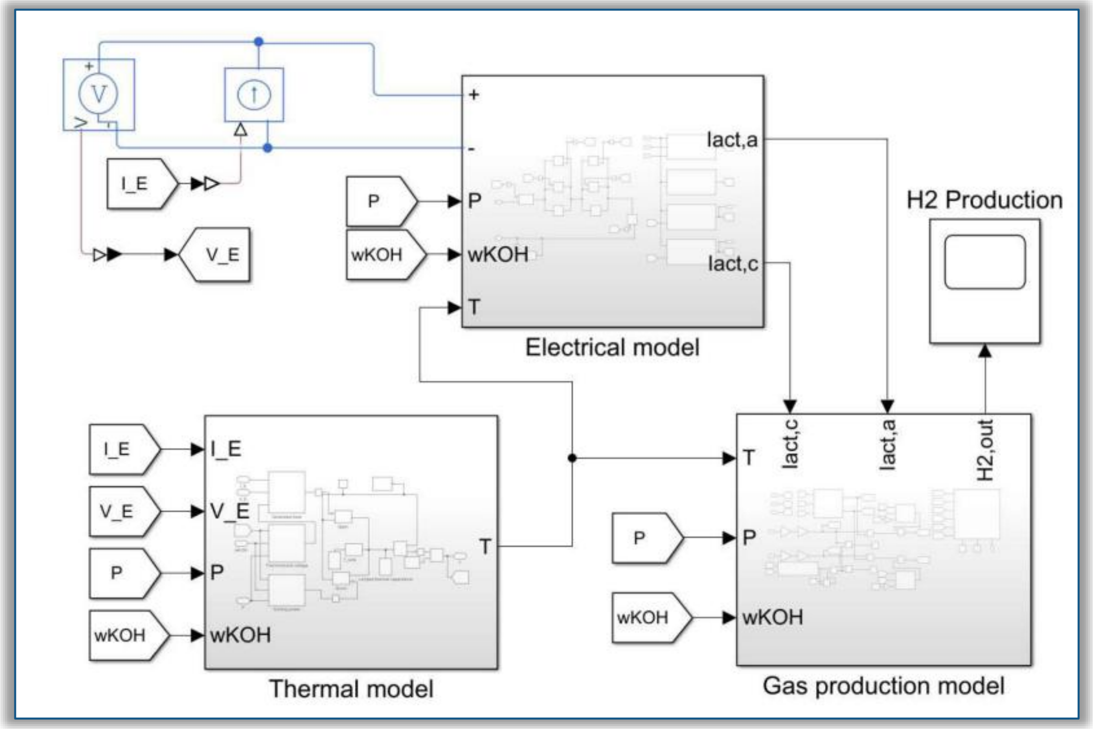


Digital twin validation – PV-based Operation



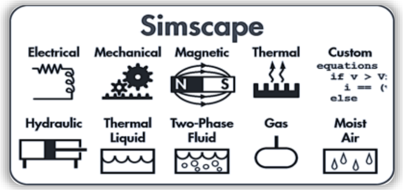


Digital Twin for Green Hydrogen Final Model

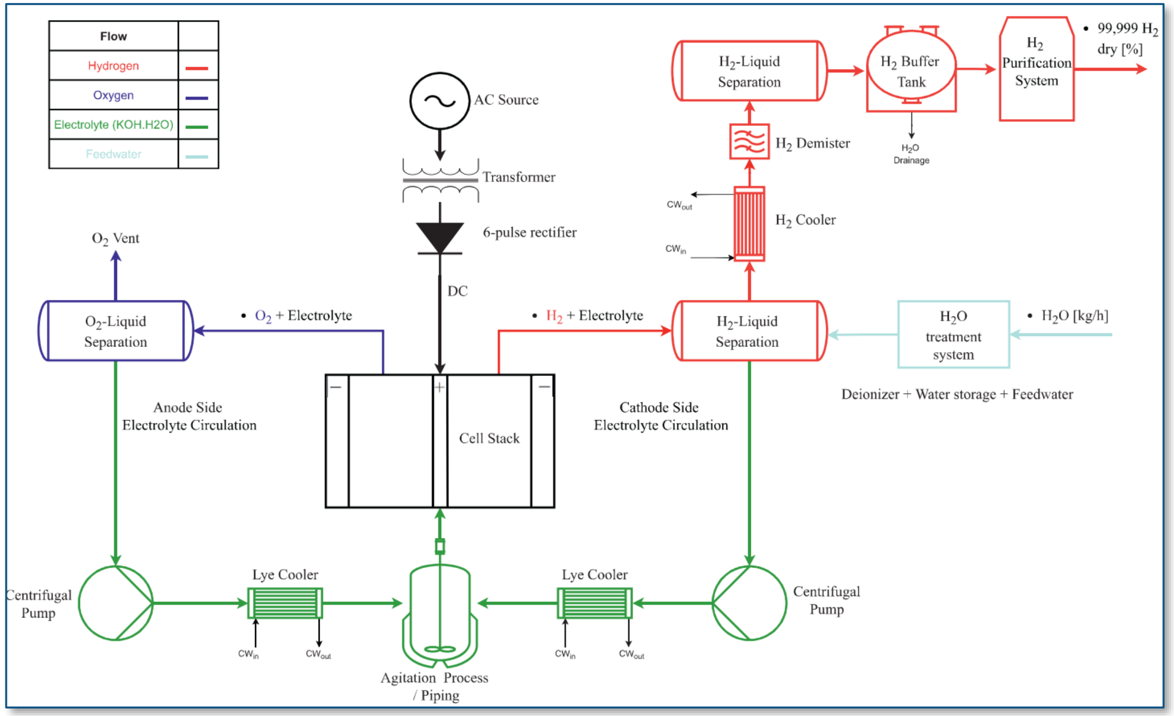


Simulink® Digital Twins for New Energies (Green Hydrogen)

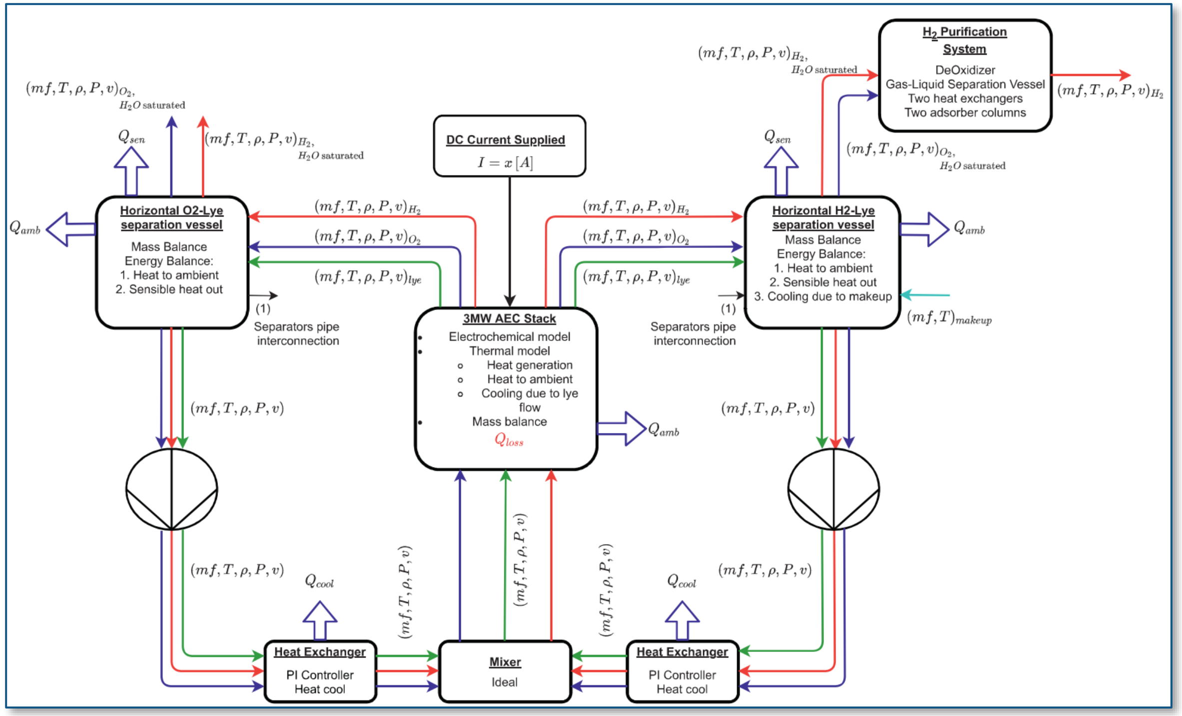
Multi-physics Digital Twin for Pressurized Water Electrolyzer (Sakas *et al*, 2022)



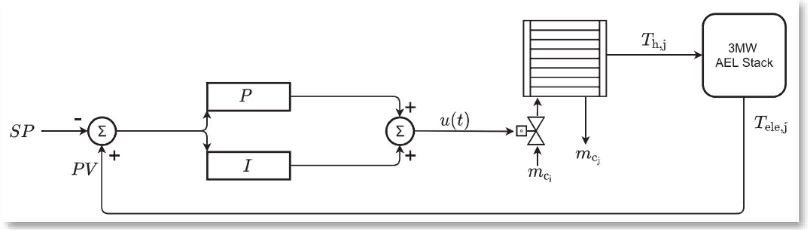
Alkaline water electrolizer process diagram



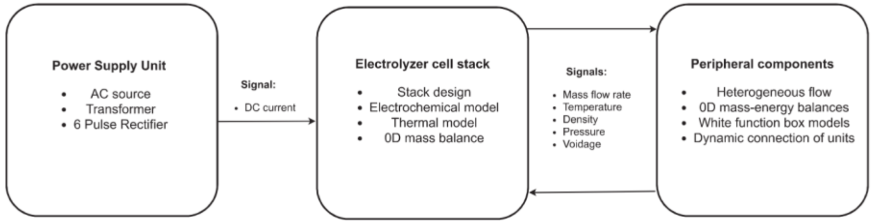
Alkaline water electrolizer – Simulink model



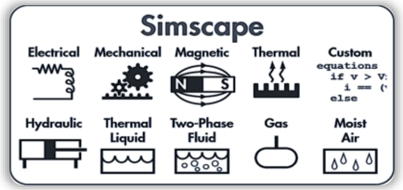
Simulink model – Cooling water feed valve control



Conceptual dynamic simulation model

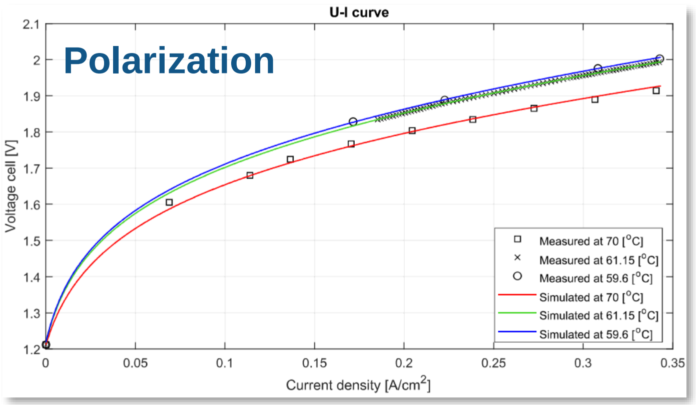


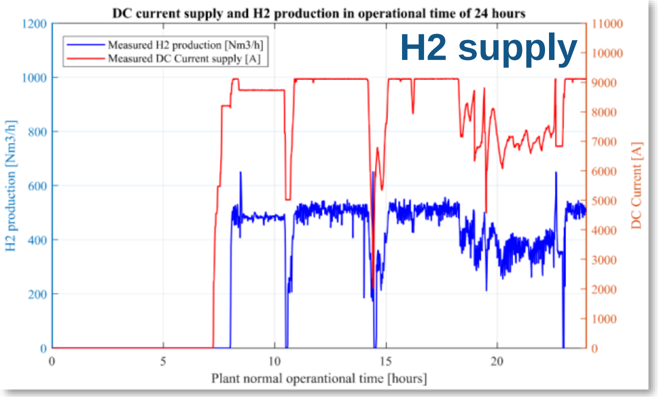
Simulink® Digital Twins for New Energies (Green Hydrogen)

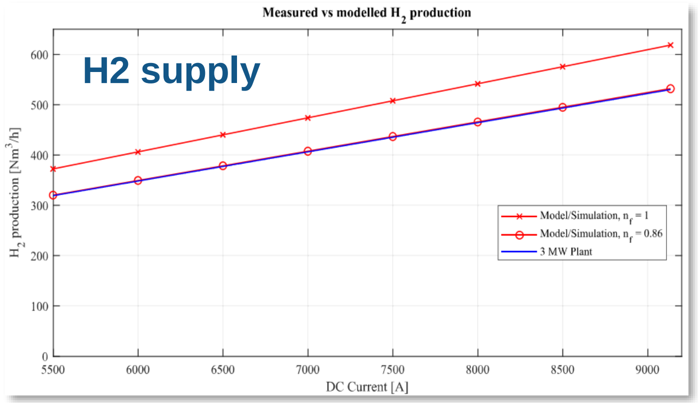


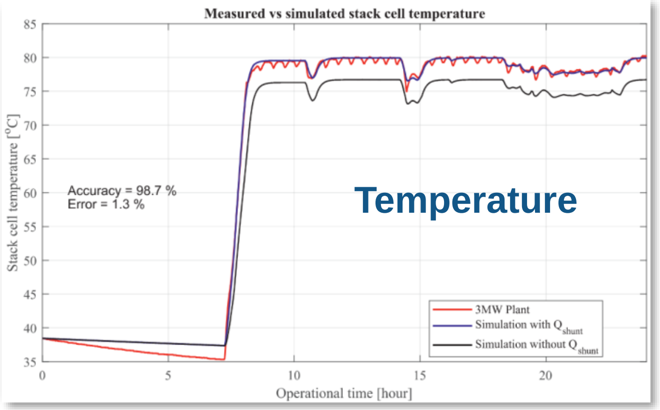
Multi-physics Digital Twin for Pressurized Water Electrolyzer (Sakas *et al*, 2022)

Multi-physics verification (measured vs. simulated):

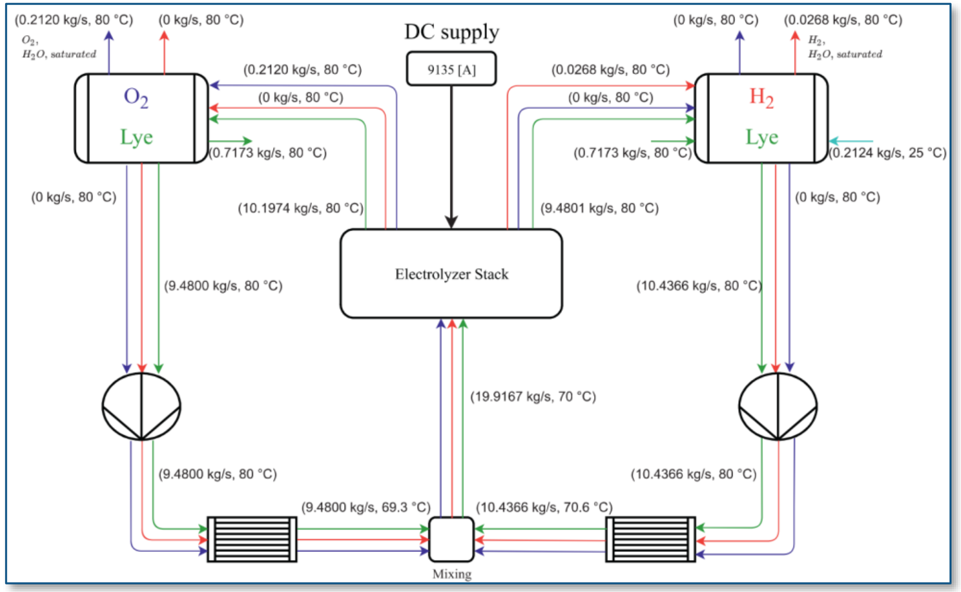




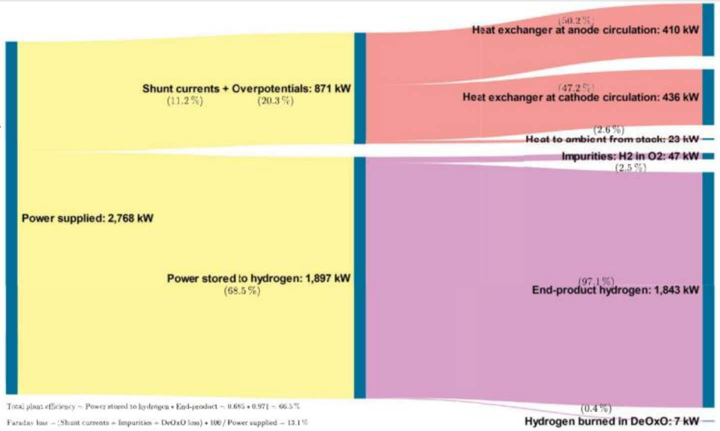




Digital Twin mass flow rates



Plant Efficiency *(Consumption vs Distribution)*

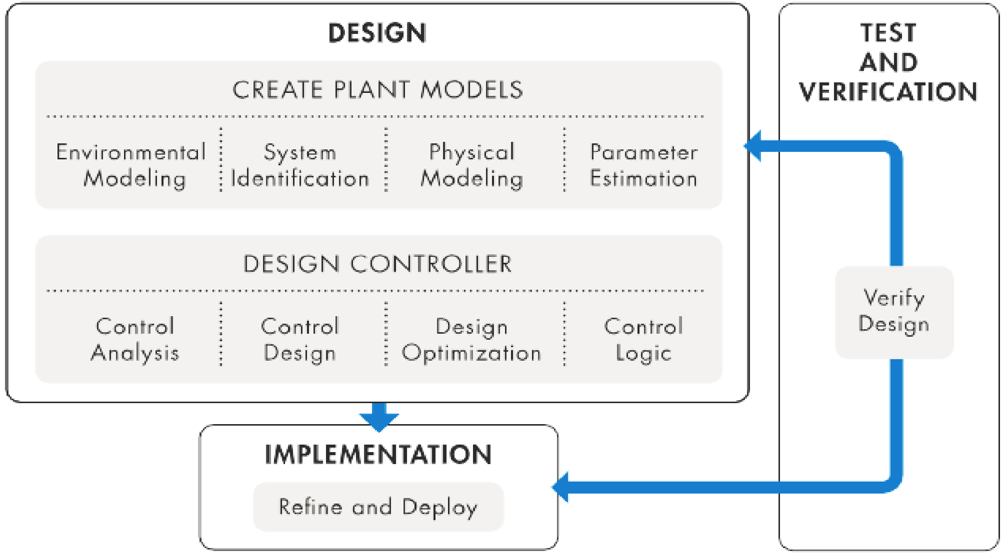


MathWorks® in Energy Resources
Modular Open-Systems Approach (MOSA) for Digital Twins

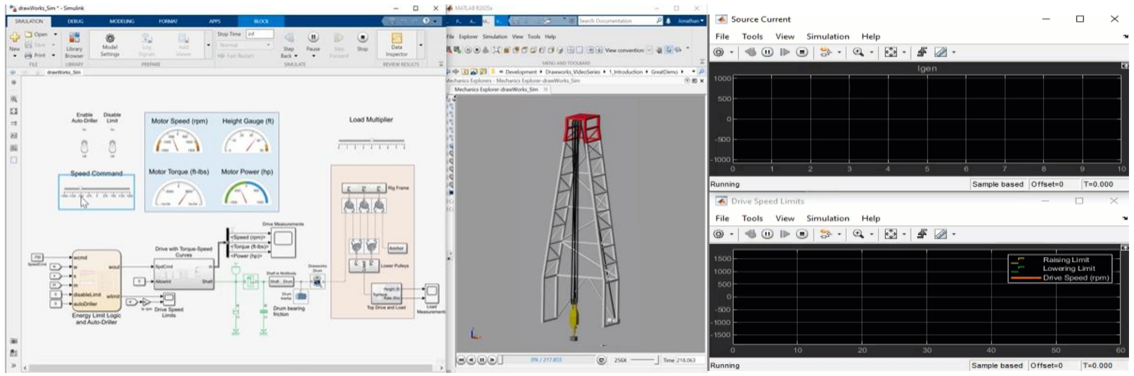
Objectives
- Monitor, predict, and automate IT/OT systems
- Integrate data science and engineering analytics

Advantages
- Full traceability and interoperability of DevSecOps
- Efficient, secure, and high-quality outputs
- Verify, adapt, and transform before you invest

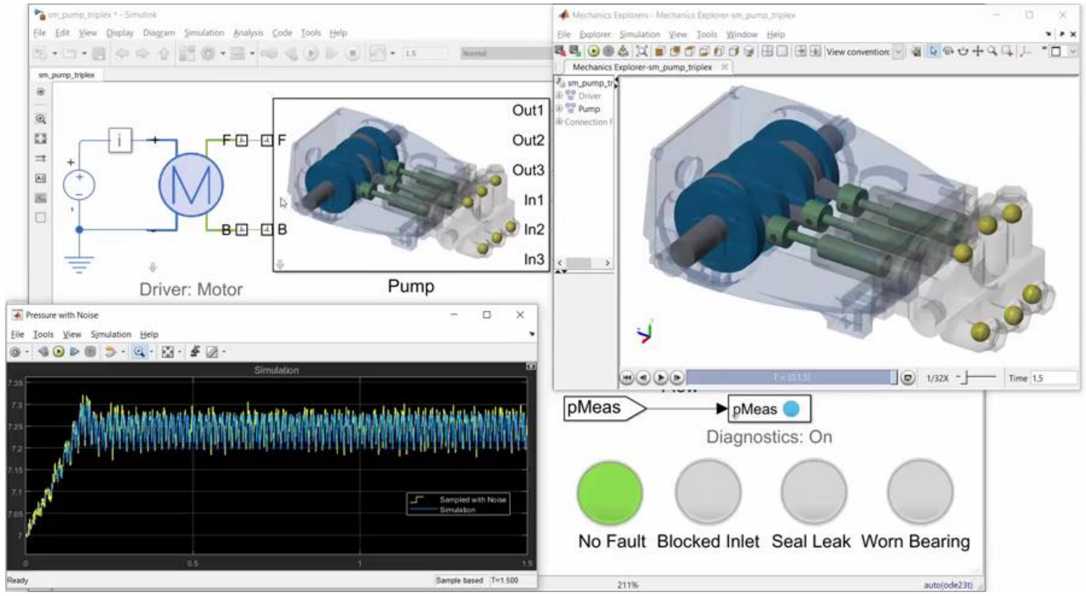
Modular Open-Systems Approach



Digital Twin for Drilling Rig Automation



Digital Twin for Pump Predictive Maintenance



Optimizing Turbine Predictive Maintenance Scheduling

Goal: Analyse performance of past maintenance and predict future efficiencies in only 100 engineering hours.

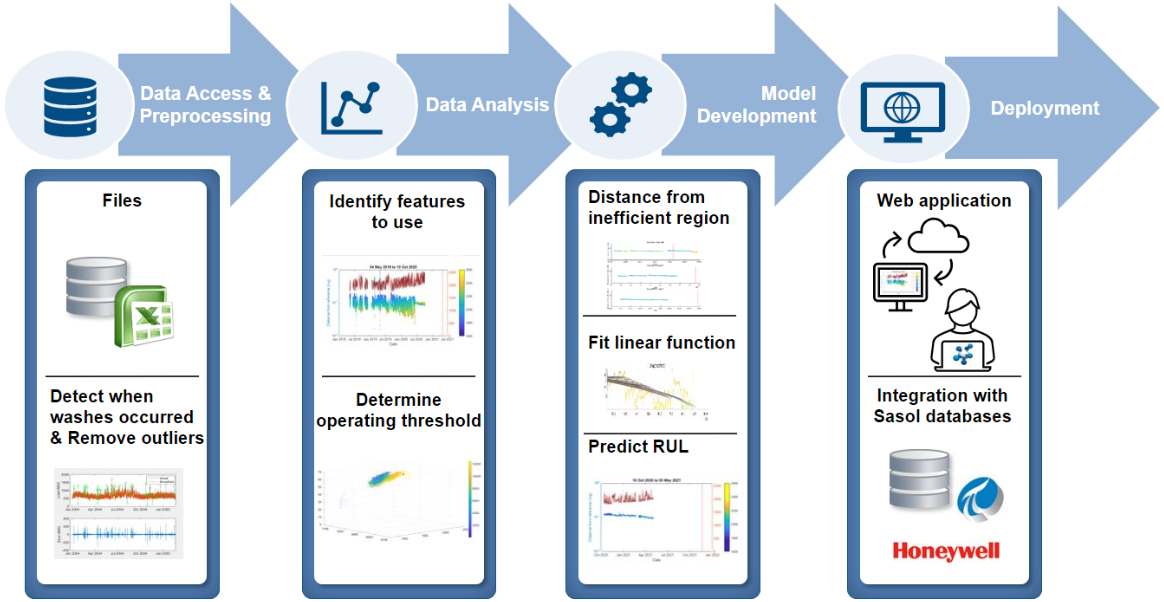
Challenges: Using historical data to detect unlogged maintenance and detect patterns that indicate efficiency of maintenance.

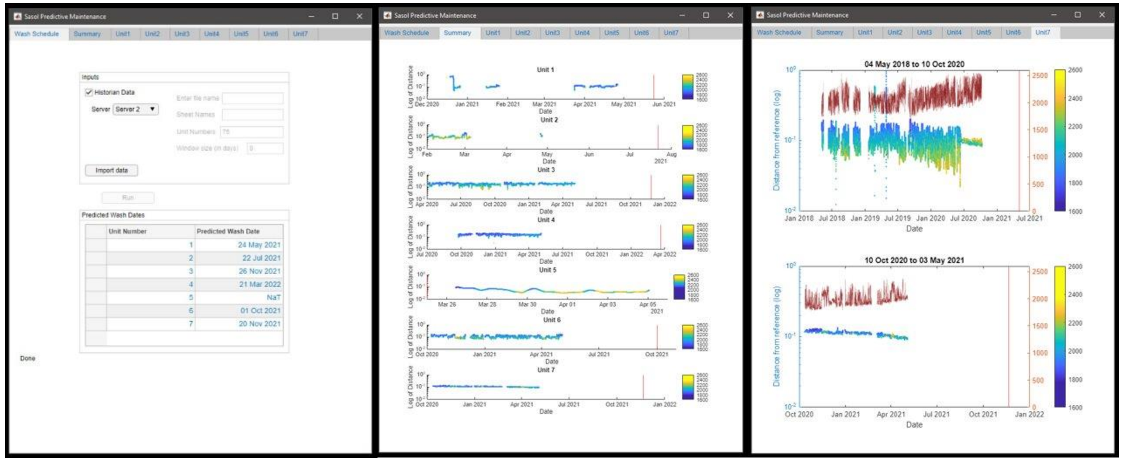
Solution: Predictive model to indicate an efficient maintenance schedule. Develop a frontend that allows operations staff to track the effects of inefficient maintenance.

Problem statements

- 13.5MW condensing steam turbine @ 6,700 rpm
- 7 compressor-turbine trains | WCP: 1,600-2,550 kPa
- Plan and predict fouling within a year
- Optimize turbine performance h-s & T-s

Predictive Maintenance Workflow and Deployment





MathWorks® Digital Twin Toolset

Digital Twin Process Optimization	**DevSecOps** Process Automation	**AI** Machine & Deep Learning	**HPC** CPU | GPU | Cloud | Quantum	**IPCV** Image Proc. | Comp. Vision

STEM Digital Science & Engineering Analysis	**BDIA** Big Data & Image Analytics

MATLAB® & SIMULINK®

Key technology differentiators

- Customizable STEM and BDIA toolboxes developed and fully interconnected on MATLAB® platform
- Model-based and data-driven science & engineering workflows to maximize data & image usage
- MathWorks® support, training, and development of data science, engineering, and analytics solutions
- Adaptive digital solutions to assess and integrate new energy processes using high-end technologies
- Low-cost, high-quality software solution to maximize technical expertise, IT infrastructure, and budget
- 200+ energy companies globally currently use MATLAB® solutions across upstream and downstream

Accelerating the pace of engineering and science