Topic -1 Digital Twins

Beyond the Buzzword: Grounded Insights on Digitalization in Energy Series

Digital Twins have become a strategic enabler for the energy sector, offering real-time insights, predictive capabilities, and simulation-based optimization. Despite the promise, many organizations struggle to extract tangible value due to excessive costs and misalignment between digital models and business needs.

Understanding the distinct types of digital twins and aligning them with business objectives is crucial. By clearly defining the scope, purpose, and functional requirements, companies can ensure that digital twins deliver scalable value and support operational, safety, and sustainability goals.

Before embarking on a digital twin initiative, organizations must define the business case and use cases clearly. **(Table-A/C)**

Table-A : Business Cases:

Need	Description
Enhanced Asset Reliability and Maintenance	Digital twins help monitor asset health and predict failures
Operational Efficiency and Optimization	They optimize operations by simulating real-time process conditions and recommending adjustments.
Safety and Risk Management	Digital twins enhance hazard identification, incident response, and safety compliance.
Emission Reduction and Environmental Compliance	Enable real-time emissions tracking and optimization to meet regulatory targets.
Lifecycle Asset Management	Provide a unified view of assets from design through decommissioning for better planning and upgrades.
Predictive and Prescriptive Analytics	Allow operators to forecast equipment and system behavior under varying conditions.
Improved Decision-Making	Support faster and more informed operational and investment decisions.
Simulation and Scenario Planning	Enable what-if simulations to evaluate the impact of operational or market changes.
Remote Monitoring and Control	Provide visibility into remote assets, reducing the need for on-site personnel.
Training and Knowledge Transfer	Support immersive training environments using real system data and scenarios.
Integration of Renewables and Grid Stability	Support integration of variable renewable energy and ensure system reliability.
Cost Reduction and ROI Improvement	Reduce unplanned outages, improve asset utilization, and increase financial returns.

Whether targeting predictive maintenance, energy optimization, or emissions monitoring, the twin's type and scale must align with operational realities. Successful deployments often combine multiple twin types within an integrated architecture. **(Table-B)**

Table-B: Types of Digital Twins

Type of Digital Twin	Scope	Example Applications
Component Twin	Individual parts or devices	Pump impellers, compressor blades, valves
Equipment or Asset Twin	Full equipment units combining multiple components	Compressors, separators, heat exchangers, turbines
System Twin	Interconnected systems or process units	Gas treatment trains, crude distillation units, flare systems
Process Twin	Entire processes or workflows	Oil separation, gas dehydration, refining processes (e.g., FCC)
Field or Facility Twin	Integrated modeling of a full production or refining site	Offshore platform, refinery, FPSO, FLNG
Pipeline and Network Twin	Flow and integrity modeling of pipelines and distribution networks	Onshore/offshore pipeline monitoring, leak detection, corrosion monitoring
Enterprise Twin	End-to-end value chain and business operations	Supply-demand planning, asset performance management

Table-C: Some Use Cases of Digital Twins in the Energy Sector

Use Case	Description	Applicable Twin Type(s)
Predictive Maintenance	Anticipate equipment failures using condition monitoring	Component, Asset
Process Optimization	Optimize parameters like flow, pressure, and temperature for efficiency	Process, System
Production Forecasting	Simulate reservoir behavior and surface facility performance	Field, Process
Energy Efficiency Management	Monitor energy use and identify areas for savings	System, Facility
Emission Monitoring & Reduction	Track GHG emissions, detect flaring anomalies	Process, Facility, Enterprise
Operator Training Simulators	Train personnel using real-world, scenario-based simulations	System, Process
Incident Simulation & Response	Model safety incidents and test emergency procedures	Facility, Process
Supply Chain Optimization	Balance feedstock availability, processing, storage, and product distribution	Enterprise, Facility
Asset Performance Management	Analyze equipment performance across lifecycle	Asset, Enterprise
Digital Commissioning	Validate and simulate plant behavior before physical startup	System, Facility

Clearly articulating the functional requirements of a digital twin is a critical step often overlooked. Poorly scoped or ambiguously defined requirements lead to missed expectations and underperforming solutions. Our experience highlights the importance of early stakeholder alignment, data strategy development, and technical rigor. **Table-D provides a snapshot of a typical definition of functional requirements**.

Table-D: Defining Functional Requirement

Attribute	Description
Purpose/Objective	What the twin is meant to achieve (e.g., monitoring, optimization, simulation)
Physical Scope	Scale and boundary—component, asset, system, facility, or enterprise
Data Sources & Availability	Sensors, control systems, lab data, IoT, historical records
Modeling Requirements	Physics-based, data-driven, hybrid models
Update Frequency	Real-time, near real-time, batch
Integration Needs	Interfaces with SCADA, DCS, ERP, CMMS, historians
Visualization Capabilities	Dashboards, 3D models, VR/AR interfaces
Analytics and AI	Predictive analytics, diagnostics, anomaly detection
Security & Compliance	Data security, access control, regulatory compliance
Scalability	Ability to expand from single units to large-scale systems
User Roles & Access	Engineers, operators, maintenance, planners—role-based interfaces

For successful implementation, a phased and structured approach is recommended. This includes objective setting, functional definition, infrastructure assessment, vendor evaluation, pilot deployment, and progressive scaling. Upfront investment in planning significantly enhances success rates and ROI.**(Table-E)**

Summary:

Digitalization in the energy sector holds the potential to unlock significant value across the asset lifecycle. However, success depends not only on the adoption of innovative technologies but also on a structured and disciplined approach. Clear definition of objectives, thoughtful alignment of digital solutions with operational needs, and rigorous front-end planning are essential.

Organizations that approach digital transformation with a strong engineering foundation, cross-functional collaboration, and an emphasis on measurable outcomes are better positioned to realize long-term benefits. As digital twins and other technologies continue to evolve, the ability to scale intelligently and adapt over time will distinguish those who achieve lasting impact from those who do not.

Table-E: Implementing a Digital Twin

Step	Description
Define Objectives and Scope	Clarify business goals (e.g., predictive maintenance, optimization) and determine the scale—component, system, or enterprise.
Identify Use Cases and Stakeholders	Engage relevant teams (operations, engineering, IT) and prioritize use cases with measurable value.
Assess Existing Infrastructure and Data	Evaluate available sensors, control systems, data historians, and IT/OT readiness.
Select Digital Twin Type and Architecture	Choose the appropriate twin type (component, process, etc.) and define the system architecture (cloud, edge, hybrid).
Define the functional and technical requirements	Determine required data sources and system integrations. Specify fidelity needs (physics-based vs. data-driven vs. hybrid models).Decide on visualization, simulation, and analytics capabilities.
Develop or Acquire Modeling Capabilities	Create or license models (physics-based, AI/ML, hybrid) relevant to the assets and processes.
Develop a procurement guide and vendor check list, KPI, ROI, vendor selection	Should include General Strategy and Architecture, Data and Integration, Modeling and Simulation Capabilities, Visualization, Analytics, and User Experience, Scalability and Lifecycle Support, Security, Compliance, and Ownership, Cost, Licensing, and ROI
Develop pilot scale digital twin	Implement a pilot on a critical asset (e.g., pump, compressor, specific units like CDU). Measure improvements in reliability, performance, and cost savings. Document lessons learned and scaling considerations.
Develop road map for scaling up	Create a roadmap for expanding from pilot to process units, systems, and enterprise level. Budget for incremental expansion and integration work. Ensure vendor support for updates and evolution of the twin.
Integrate Data Sources and Systems	Connect real-time and historical data sources using standard protocols and APIs.
Build and Validate the Digital Twin	Evaluate the twin against operational scenarios and validate its accuracy and performance.
Deploy and Train Users	Roll out to users with training, dashboards, and change management strategies.
Monitor, Maintain, and Iterate	Continuously monitor digital twin performance and update models/data as needed.(against the ROI, KPI etc.)
Scale and Expand	Expand implementation to other assets, processes, or sites, guided by initial success.