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Simplifying Green Hydrogen Production with Digital Twins and Software Suites

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An Executive Brief from: Siemens Industry, Inc.

Green hydrogen holds great potential in the global transition to low-carbon energy production and use. For achieving decarbonization initiatives, applications for green hydrogen are many. These include replacing conventional chemical process feedstocks for use as a zero-emission alternative to fossil fuels and powering fuel cell vehicles.

Another important use of green hydrogen is as an energy vector, meaning it can be used to store and transport renewable energy from solar power plants and wind farms. It can also be converted into vectors such as methane, methanol, or ammonia for transport or industrial use.

Using green hydrogen to replace existing feedstocks produced by carbon-intensive methods is an obvious advantage. It is estimated that conventional gray hydrogen production worldwide emits 1.3GTpa of CO2, with an average CO2 intensity of 12 tons/ton. Global production of hydrogen is around 110MTpa in 2023, of which c30% is for ammonia, 25% is for refining, c20% for methanol and c25% for other metals and materials[1]. This data-file estimates global hydrogen supply and demand, by use, by region, and over time, with projections through 2050. As such, replacing hydrogen stocks produced from natural gas with conventional technology offers clear opportunities to meet large-scale decarbonization goals.

Production Challenges

Producing green hydrogen comes with unique challenges that are present throughout the entire production cycle. These include:

- High cost of infrastructure, storage, and transportation.
- Balancing capacity and safety.
- Integration of complex technologies not proven for large scale use or in diverse operating environments.
- Complex and dynamic operations.
- Shortage of experienced operators.
- Highly variable demand for green hydrogen and supplies of renewable energy.

Failure to address and resolve each of these challenges can significantly increase hydrogen production times and levelized costs as well as negatively impacting the overall project. However, well-proven, cost-effective, and highly efficient solutions are available.

[1] https://thundersaidenergy.com/downloads/global-hydrogen-supply-demand-by-region-by-use-over-time/

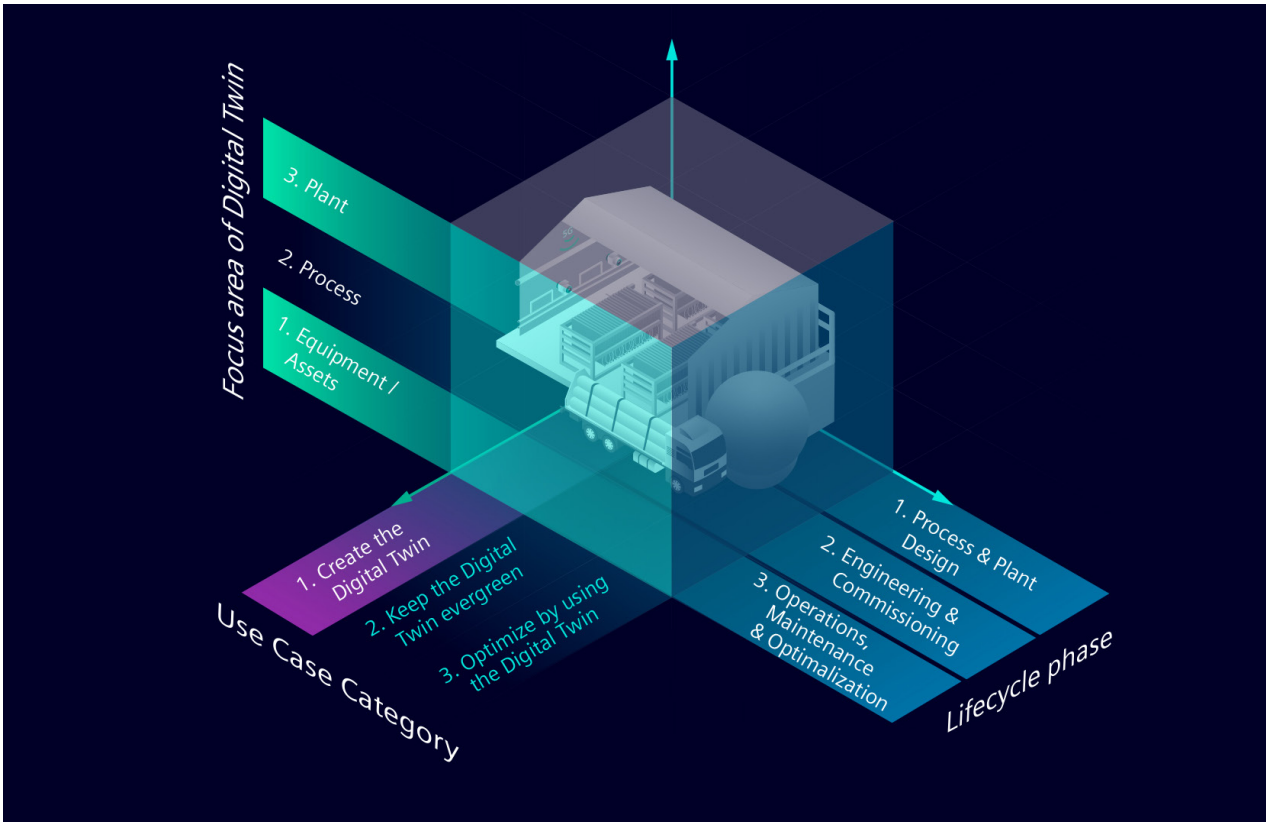
Solutions

The Digital Twin

One solution is to build a Digital Twin, which is a comprehensive virtual representation of the hydrogen production process. A Digital Twin is a model of the prospective or real-world system that is used for purposes such as equipment and system design, 'what-if' analysis, debottlenecking operator training, monitoring, production optimization, and maintenance.

Siemens Digital Twins are not just simulations of a system's processes or implementations of a single software. Instead, they represent a diverse range of tools, workflows, and features that virtualize all aspects of the process, creating a Digital Hydrogen Plant for the project. To apply the Digital Twin throughout the operational life of a plant, it must be deployed online and constantly updated with data from a wide range of areas of the process. Paired with modern compute capabilities with remote access, integrated Digital Twins offer significant capabilities to plant designers, engineers, and operators.

User-friendly dashboards that visualize information from Digital Twins and other sources allow system operators and other personnel to identify efficient operations, areas for improvement, and potential failures or safety hazards. Also, the Digital Twin enables proactive and optimized asset operation, making it a powerful tool for hydrogen and Power-to-X plants, which convert electricity, preferably from renewable sources, into chemicals and feedstocks.



The Digital Process Twin

The Digital Process Twin is a core element of the integrated Digital Twin. It provides an accurate representation of plant behavior using calibrated high-fidelity models of the key process units, such as electrolysers, heat exchangers, and compressors. When designing the plant, engineers can use the process model alongside powerful optimization and system analysis tools to accelerate the design process and reduce risk by removing uncertainty.

Implementing the Digital Process Twin in an online application allows plant owners to combine process simulation with real-time data feeds from the process, thereby unlocking unique capabilities. For example, online applications allow operators to leverage automated monitoring and optimization technology, which improves plant monitoring or enables off-taker demands to be met as efficiently as possible.

Siemens gPROMS software is an example of such Digital Process Twin technology that provides comprehensive modeling of the hydrogen production process throughout the entire plant lifecycle. It provides early-stage feasibility studies and detailed process design and real-time operational support once the plant is running. The software includes pre-built models for various hydrogen production technologies including Alkaline, PEM, and Solid Oxide electrolysers.

Bridging virtual and physical environments, the Digital Process Twin's capabilities enable manufacturers to achieve greater efficiencies and deeper insights at all stages of the project's lifecycle. Effective use delivers cost savings during development while also unlocking new sources of value from optimized plant operation and maintenance.

Key Benefits of the Digital Process Twin

1. **Optimized Design & Reduced Risk** – High-fidelity models improve plant design, minimize uncertainty, and streamline development.
2. **Real-Time Monitoring & Efficiency** – Live data integration enhances performance, detects issues early, and maximizes output.
3. **Cost Savings & Reliability** – Predictive analytics reduce maintenance costs, prevent failures, and improve long-term stability.

Siemens Hydrogen Performance Suite

The Siemens Hydrogen Performance Suite (HPS) is a process management and optimization application that enables plant owners and operators to access and derive benefits from a Digital Twin of their asset, known as the Digital Hydrogen Plant. The HPS uses several software modules to monitor, analyze, and optimize hydrogen production and plant performance.

The HPS is available to both current green hydrogen producers and those planning future projects. It addresses and resolves many challenges by equipping operators with advanced simulation, analytics, and decision-making support tools, which, when deployed in an online environment, can significantly reduce lifetime production costs.

The HPS can enhance hydrogen production in both single assets and fleets consisting of multiple plants. For instance, operators who fully utilize the HPS can achieve up to 15% savings in energy usage costs

The HPS consists of the following key components:

Process Simulation Module:

- Uses a calibrated Digital Process Twin of the plant including key process units and streams. The Digital Process Twin may be developed during the project design phase, ensuring continuity into operations.
- Leverages Siemens gPROMS modeling engine for steady-state and dynamic simulation.
- Enables model-based dynamic optimization of the process for real-time operation and scenario analysis.

Production Optimization Module:

- Uses data from the state estimation module and other inputs such as forecast information from third-party tools.
- Automatically runs regular and on-demand planning optimizations providing the flexibility to address diverse problems depending on project needs.
- Stores optimization results for auditing and analysis.

State Estimation Module:

- Retrieves real-time data from physical sensors, often via the plant control system or data historian. Siemens provides industry-standard connectors like OPC UA or REST to enable smooth transfers of information.
- Calculates equipment and process Key Performance Indicators (KPI)s and other unmeasured variables in near real-time.
- Provides continuous recalibration, ensuring the model is predictive even when operation deviates from the original design specifications. The module re-estimates model parameters, which can include performance curves.
- Saves calculation results for use in planning process optimization.

Data Validation Module:

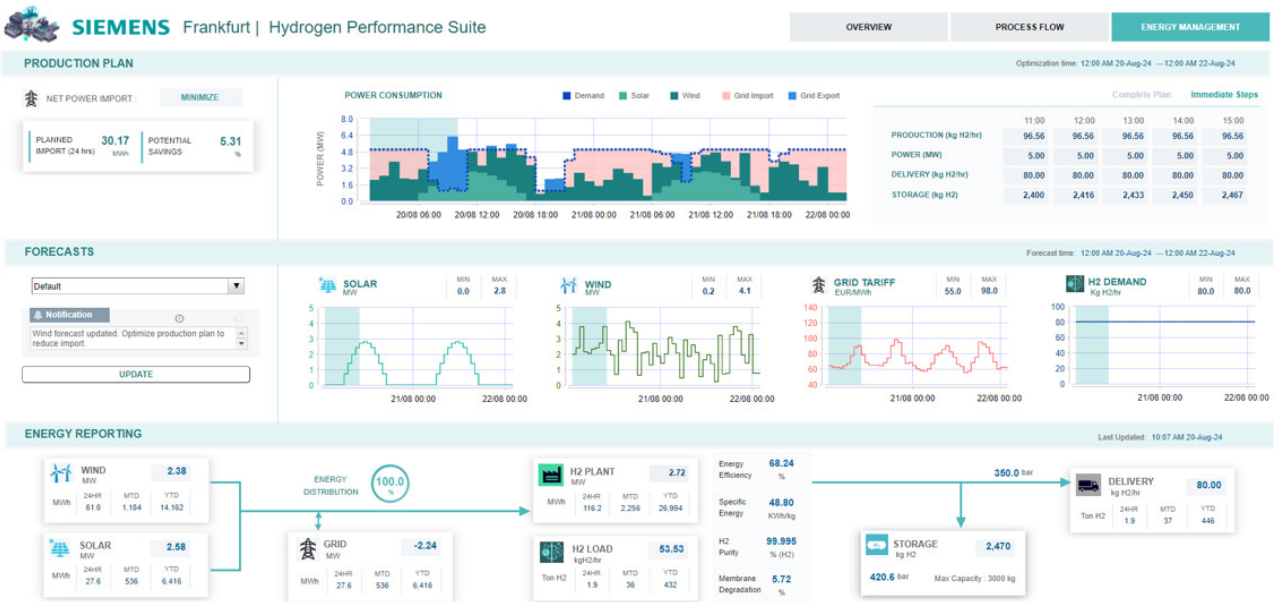
- Automatically validates all data exchanged between the optimizer and external data servers and internally between communication modules. Also handles cases of missing or invalid data.
- Automatically validates results of various computations before they pass to the External Data Manager.
- For optimization scheduling, data from past monitoring are visible in the dashboards, allowing operators to perform manual inspection and validation.

User-friendly dashboards, interfaces, and reporting:

- Outputs appear in a series of dashboards and are accessible via a web browser or secure private network. The dashboards refresh in real-time to display the latest results.
- Dashboards are configurable to include critical data/results and to be in accordance with a customer's design style.
- Dashboards provide summaries and plots of trends for a range of operating parameters, simulations, and optimization results.
- Offline reports outlining the main optimization results are produceable using SQL Server Reporting Services. Users can export these reports as a PDF for future analysis or auditing.

"What-if" Environment Module:

- This optional module provides the capability of running 'what-if' scenarios where users can execute an optimization event in an environment other than the online tool while using the current state of the plant.
- Users can alter a small set of input data and re-run the optimization from a dedicated dashboard within the same user interface. Results of 'what-if' optimizations are also visible within this dashboard.



Summary

As a fossil fuel substitute, green hydrogen is considered a key component of the migration to low-carbon energy. While green hydrogen performs well as a zero-emission fuel and chemical feedstock, its production comes with critical challenges that producers must address to enable this technology and avoid prohibitive costs. These include integrating highly complex technologies and managing dynamic operations, which are further complicated by a lack of extensive historical experience in operating such plants.

Solutions to these tough challenges start with the creation of a Digital Twin, which leverages advanced software tools to create a virtual replica of the key aspects of the hydrogen plant. The Digital Process Twin, a cornerstone of the Digital Twin, employs high-fidelity models and data to simulate a production system's behavior and optimize its performance.

Digital Process Twins built using Siemens gPROMS capture essential process data to create a calibrated model that can accurately simulate, optimize, and de-risk the process design. When deployed online and connected to a live plant, these models enable operators to track performance and optimize operating decisions in real time. Using the Digital Process Twin throughout the project lifecycle continually generates business value, thus helping to lower lifetime project costs and drive higher efficiencies.

Siemens Hydrogen Performance Suite paves the way for a promising and profitable future for green hydrogen production. This application monitors and optimizes the performance and operation of green hydrogen plants, tackling critical challenges such as high production costs, lack of experienced operators, and complex processes to ensure reliable and efficient operations.

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