WHITEPAPER

Engineering the hydrogen transition

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Executive summary

Corporations and governments see the hydrogen economy as a key enabler of the transition to a carbon-neutral world. Though already an important industrial commodity, hydrogen demand is forecasted to skyrocket as it gains major new applications in hard-to-abate industries and in the global clean energy market. By 2030, capital projects worth more than $500Bn[1] must come online to meet demand for low-carbon hydrogen. Engineering teams face the major challenge of conceiving, designing, and executing brownfield and greenfield projects on time and within budget while both technology and markets undergo rapid change. From first concept to capital project execution and operations, engineering the hydrogen plant of the future requires innovation, agility, and collaboration. AVEVA's engineering solutions build comprehensive digital twins that help engineers turn bold promises into results.

This whitepaper will examine the trends shaping the industry and the technological challenges that engineers must overcome to deliver a net-zero hydrogen economy.

Promises have been made. Promises of gigatons. Promises of terawatts. Most importantly, promises of zero. As in, net-zero carbon emissions by 2050. One after another, leaders from industry and government have announced bold visions for carbon-neutral economies. In the industry that used to call itself oil and gas, the word on everyone's lips is now hydrogen. This colorless gas is the key to a green future for industries that are otherwise difficult to decarbonize. With pressure from investors and regulators, CEOs have committed to capturing this opportunity. Now it falls to engineering to translate commitments into designs, projects, and an operational hydrogen economy.

A gray commodity with a colorful future

Hydrogen is already an important industrial commodity. The largest demand comes from the chemicals industry for ammonia production and from the refining industry for desulphurization. Hydrogen has more uses in metals, semiconductors, glass, and several other industries. Demand from these applications may be growing solidly, but it is not the cause of the hydrogen boom. Current hydrogen production is dominated by gray hydrogen (see sidebar[2]) produced by steam methane reforming (SMR) fed with natural gas.

The booming hydrogen forecast is contingent on industry's ability to scale up low- or no-carbon processes for hydrogen production. Though there are many potential colors of hydrogen, blue and green are the primary targets of industry roadmaps. Blue hydrogen takes existing SMR processes and adds a carbon capture and storage (CCS) process, thus creating a low-carbon hydrogen source. Green hydrogen relies on electrolysis powered by renewable energy to produce a zero-carbon commodity.

Cost-competitive blue or green hydrogen unlocks a wide range of decarbonization applications in industries that have few options, such as cement and steel. It is a viable transportation fuel, especially for heavy transport. Hydrogen can also act as an energy carrier so that renewable electricity can be stored, transported, and traded regardless of today's weather.

The Hydrogen Spectrum

Black
Produced by gasification of black coal

Gray
Produced from natural gas via steam methane reforming

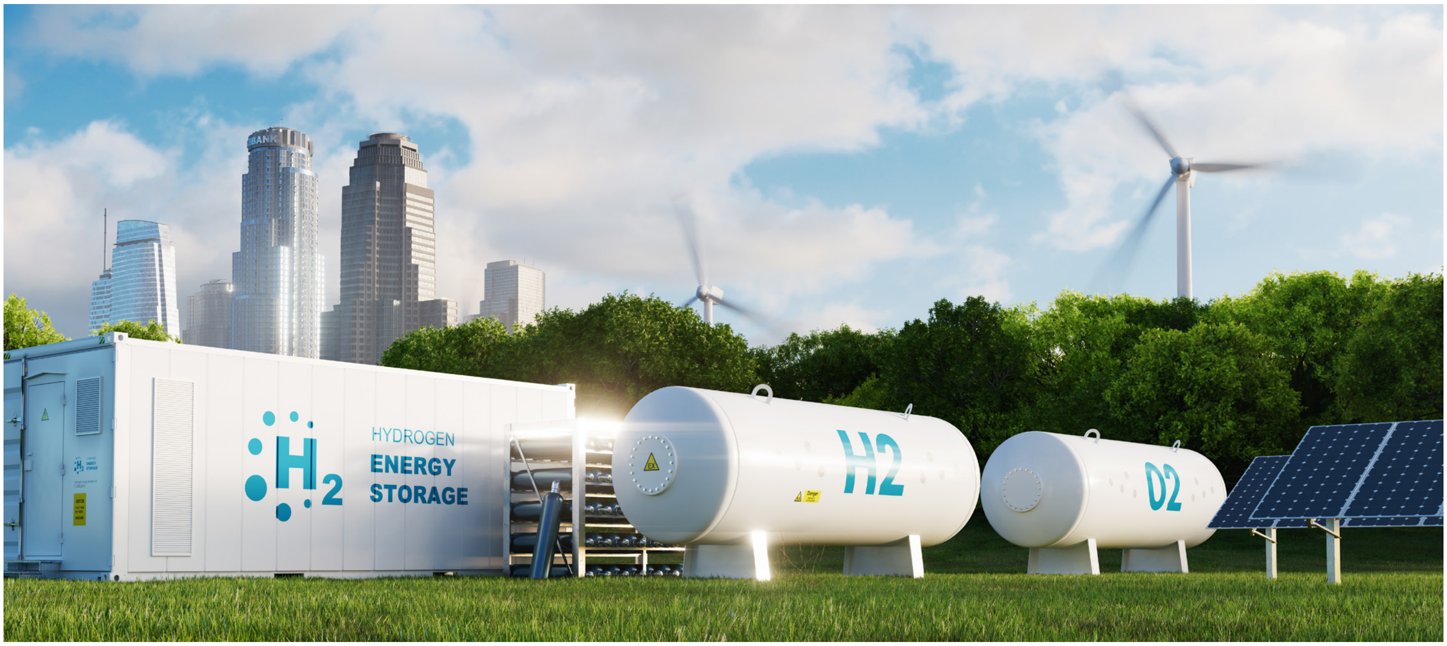
Blue
Gray hydrogen with carbon capture and storage

Turquoise
Produced by methane pyrolysis

Pink
Produced by water electrolysis using nuclear energy

Yellow
Produced by water electrolysis using grid power

Green
Produced by water electrolysis using renewable energy



Opportunity stokes investment

With such a huge opportunity available, companies and governments have committed extraordinary sums of money in a very short time. According to McKinsey & Company,[3] investments through 2030 amount to roughly $500 billion, $150 billion of which are mature investments in planning, construction, commissioning, or operations. More than 350 large-scale hydrogen projects have been announced, including 28 giga-scale production projects. Announced projects see a 70/30 split between green and blue hydrogen.

The influx of capital presents a challenge. Engineering teams must conceive, design, and execute a wide range of major capital projects for both brownfield and greenfield hydrogen assets. To accelerate the transition, projects must be delivered on time and within budget.

Unfortunately, heavy industry has a well-earned reputation for projects that are late and expensive. The average capital project schedule lags by 20 months and goes over budget by 80%.[4]

And hydrogen projects face more obstacles – rapidly changing technology and market conditions. Many of the process technologies required for the hydrogen economy have not been deployed beyond the pilot scale. Unexpected problems and surprise efficiencies will arise. Technologies will reach economies of scale at different times. All of this will occur in a market environment where the prices of inputs and outputs swing significantly as complementary or competing projects succeed, delay, or fail. The hydrogen transition will be disruptive.

Digital transformation unlocks innovation, agility, and collaboration

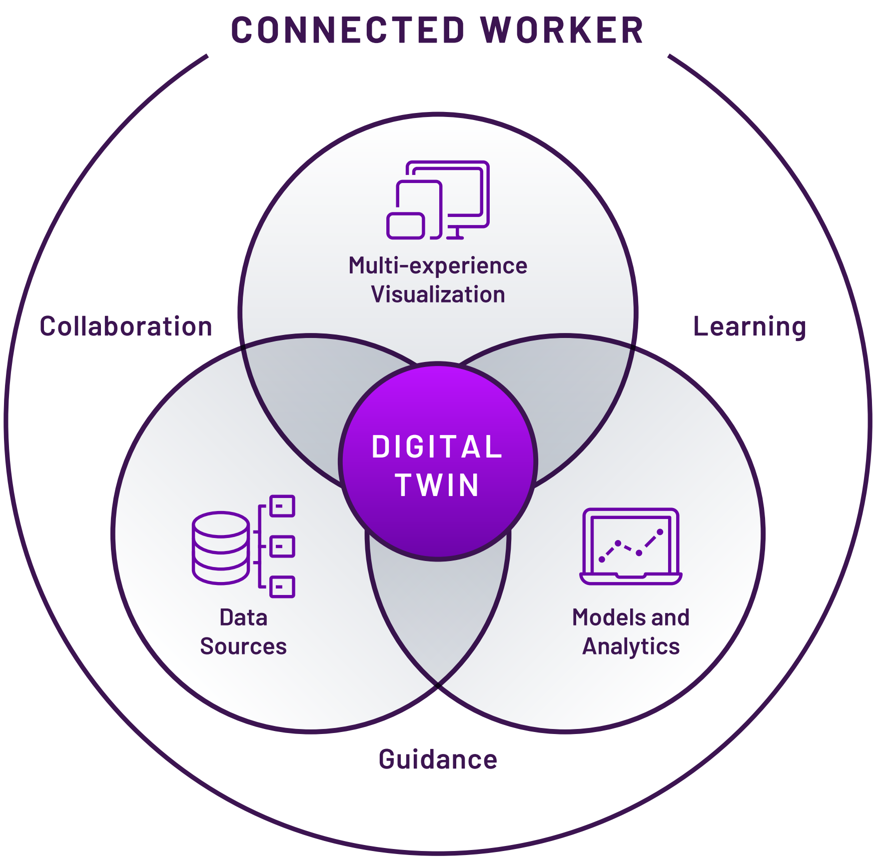
To overcome the challenges of the hydrogen transition, engineering teams must embrace digital transformation starting from conceptual design to engineering, project execution, startup, and operations. Digital transformation is the key to unlocking innovation, agility, and collaboration across the project lifecycle.

Digital transformation enables the creation of the digital twin, which is a digital representation of a real-world entity. The digital twin can be a model that mirrors a greenfield asset to be built or an existing brownfield asset. The digital twin includes:

- **Data sources:** The engineering design data and real-time plant data
- **Simulation models:** First principles, physics-based models, data analytic models, and hybrid models
- **Visualization:** The tools necessary for connected workers to access and visualize data so they can make informed decisions

In the hydrogen industry, engineers can use AVEVA digital twin solutions to:

- Accelerate innovation and scale-up of process technologies
- Rapidly evaluate design concepts against project KPIs
- Optimize processes for capacity, profitability, and carbon emissions
- Enable collaboration among engineers across disciplines and organizations
- Decrease project risk through a data-centric approach to engineering information
- Start up without surprises and with a workforce that is ready to go
- Hand over to operations with a comprehensive digital twin for ongoing decision support and operational excellence



From conceptual design to FEED

In the early phases of a hydrogen project, engineers face a wide range of possible designs with tremendous technical and economic uncertainty. Effective decision-making requires a quantitative analytical framework. The digital twin organizes project data and enables the visualization of complex issues.

Incorporating a process simulation model as part of the digital twin reduces risk and ensures projects are much more likely to be delivered on schedule and within budget.[5] The hydrogen transition will drive a new set of process modeling requirements including but not limited to:

- Improved process equipment models for gray and blue hydrogen generation
- Environmental calculations to design processes that meet production and quality goals with minimum environmental impact
- Equipment models for green hydrogen generation, including renewable power sources, electrical grids, and electrolyzers
- Accurate thermodynamics for modeling hydrogen liquefaction and other sustainable processes
- Capabilities to simulate liquid organic hydrogen carrier (LOHC) processes that facilitate transportation

A standalone simulation package is not an enabler of digital transformation. Legacy process simulators are typically poorly integrated into the engineering workflows beyond the process world. Unlike legacy simulation platforms, AVEVA™ Process Simulation was developed from the ground up to deliver the process digital twin to the next generation of process engineers. AVEVA Process Simulation is differentiated from legacy platforms in three ways:

1. One process model can be used throughout the project lifecycle
2. Next-generation ease-of-use and connectivity reflect its conception and development in today's computing environment
3. Applicable to the full hydrogen value chain including gray, blue, and green processes

Gray hydrogen

This example flowsheet (see fig. 1) demonstrates a typical process to produce hydrogen via SMR. Natural gas and high-pressure steam are reacted over a catalyst to produce H_2, CO, and CO_2. The CO and H_2O in the outlet stream are then further refined in high-temperature and low-temperature water gas shift reactors. These reactors convert much of the remaining CO and H_2O into H_2 and CO_2. The final step of the process (not modeled here) separates H_2 from the remaining components using pressure swing adsorption (PSA).

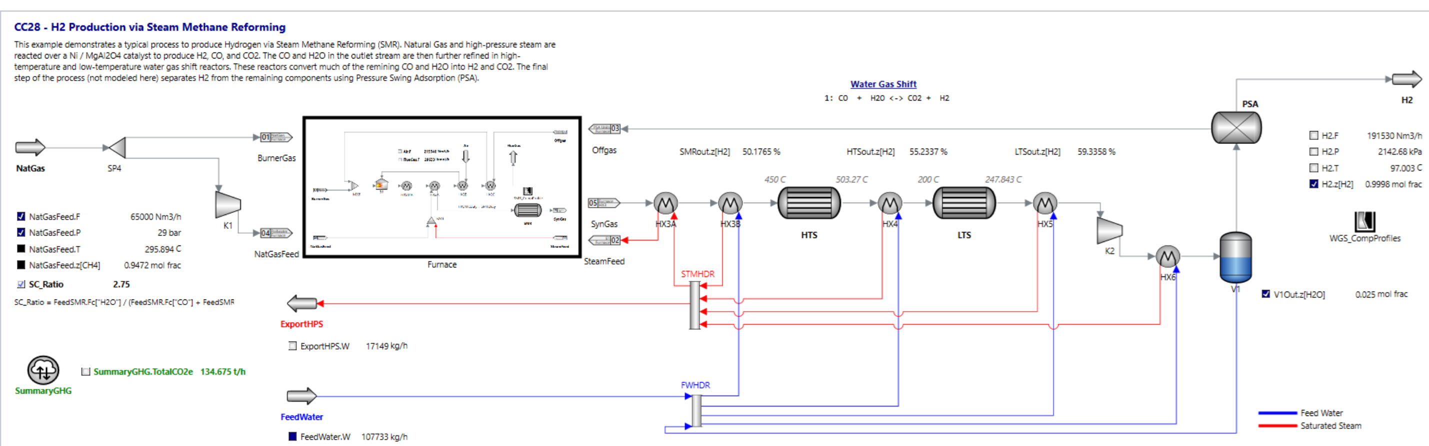


Figure 1: SMR flowsheet in AVEVA Process Simulation demonstrating hydrogen production

The SMR process may be a mature technology, but there is still much to be gained from brownfield plants. Most plants were not originally designed to minimize carbon emissions. Greenhouse gas (GHG) emissions can be calculated, tracked, and minimized through advanced optimization and dynamic analysis of startup and shutdown. Brownfield plants also have an opportunity to reduce carbon intensity through combined heat and power simulations to investigate fuel switching, blending, and balancing.

Blue hydrogen

Blue hydrogen projects face all the same challenges as SMR with the addition of carbon capture and storage (CCS) processes. CCS is a difficult process to model and optimize on its own. Carbon capture in absorbers is not an equilibrium process but a mass transfer limited process.

AVEVA Process Simulation includes a rate-based distillation column accurately modeling diffusion fluxes, diffusivity in the vapor, and mass transfer calculations through the film between the vapor and liquid phases. Hydrogen engineers will need to analyze SMR and CCS concurrently to understand the effect on blue plant KPIs. The plant may face different market demand models depending on carbon capture efficiency.

Green hydrogen

Most proposed green hydrogen assets are pure greenfield projects. While this grants a certain freedom, project engineers must start from a blank page. Engineers need to answer an array of interdependent design questions such as:

- Which electrolyzer technology to build around?
- How to balance the dynamic nature of solar and wind energy supply?
- How to optimize clean water production and wastewater treatment?
- What hydrogen storage and transport options are available and preferred?

The answers to these questions may change during design and over the life of the plant. It is critical to have a simulation platform that allows for extensive what-if analysis for different scenarios.

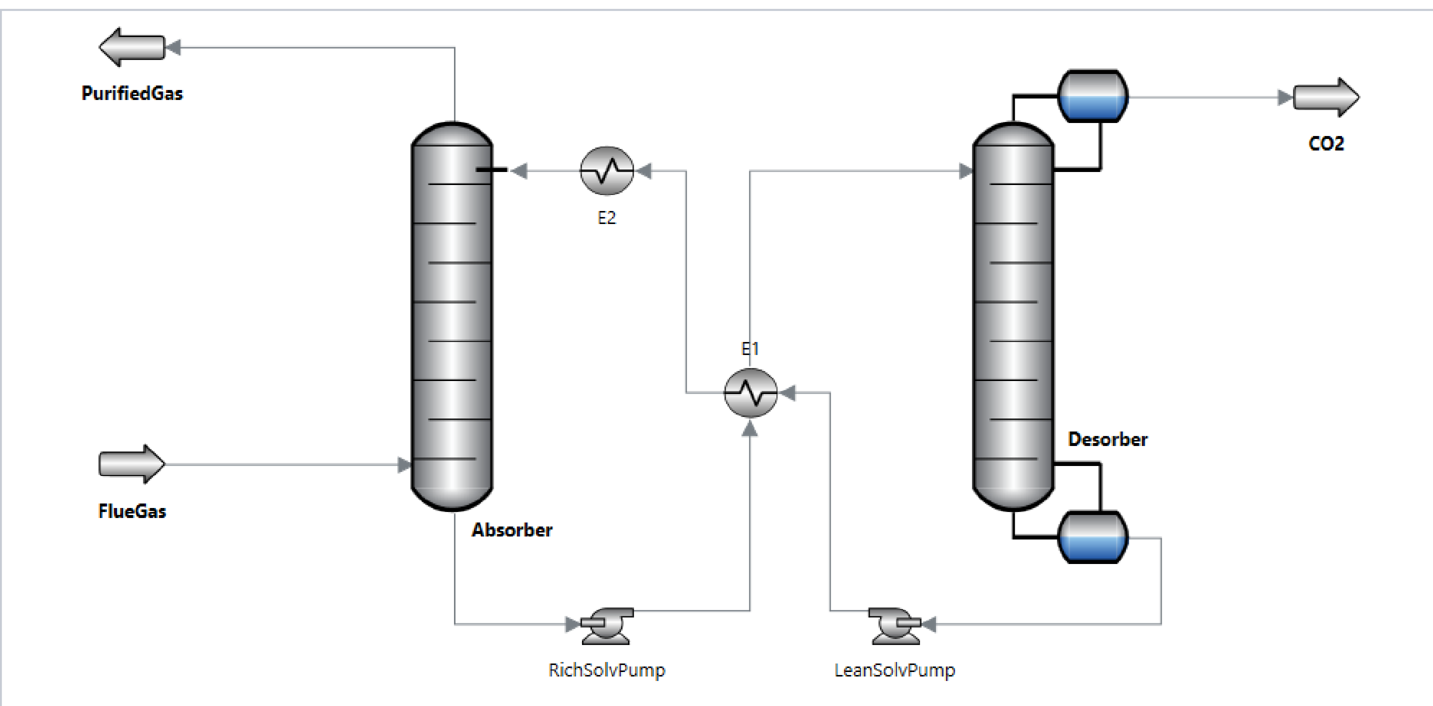


Figure 2: Blue hydrogen adds a carbon capture process to the optimization challenge

This simulation flowsheet (see fig. 3) demonstrates a small renewable energy grid including two wind farms and three solar farms. The model also includes both the process elements (pumps, heat exchangers, electrolyzers), the electrical elements (transformers, power lines), and a hydrogen liquefaction facility. The simulation runs at steady state to calculate average power output. The same simulation also runs dynamically to predict the variability of power produced during the day as wind conditions change and the sun rises and sets. The model also looks at electricity supply and demand considering importing or exporting to the grid, spot prices, and hydrogen requirements.

Innovative hydrogen technologies

As the hydrogen transition continues, technology will change rapidly. Relatively few hydrogen technologies have been deployed beyond the pilot scale when compared to refining or chemical processes. Universities and research institutes are piloting many different ideas. New adsorbents could significantly improve the efficiency of CCS processes.

Different electrolyzer technologies are being optimized for different applications. As the industry develops, companies must remain agile to benefit from innovation.

AVEVA Process Simulation accelerates the engineering cycle to enable agile process design. Engineers can explore more alternative designs and evaluate them against the project's operational and economic goals. When the project moves from conceptual design to FEED, mistakes have already been caught. Designs are already mature.

The Construction Industry Institute reports that projects with a high FEED maturity and accuracy outperformed projects with a low FEED maturity and accuracy by 24 percent in terms of cost growth, and 12 percent in terms of change order performance.[6] Process simulation is a key enabler to achieving a highly mature FEED. It uses the insight and knowledge from the simulation model to eliminate design errors before capital is committed and when the cost to correct a mistake is the lowest.

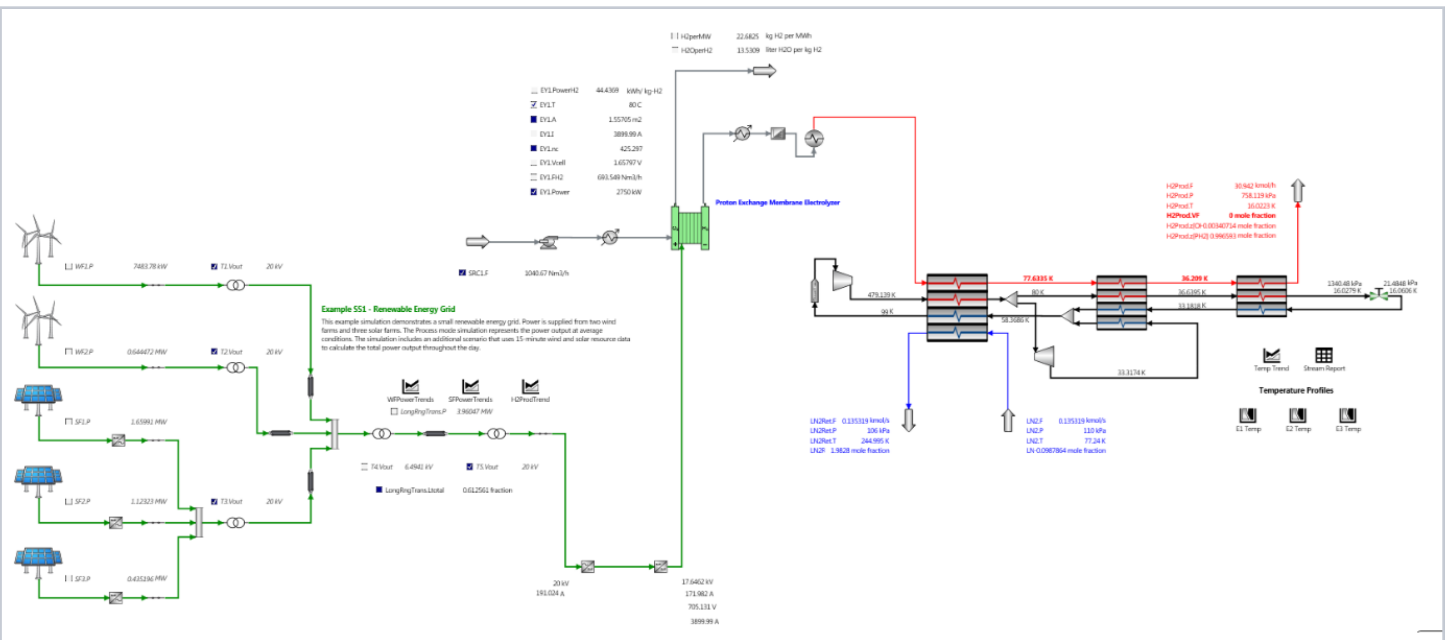


Figure 3: A green hydrogen flowsheet in AVEVA Process Simulation with a small renewable energy grid including two wind farms and three solar farms

From FEED to startup

The digital twin, first born in conceptual design, lives on as the hydrogen project shifts into real-world equipment, concrete, and steel.

Data-centric engineering enables agility and collaboration

As a project moves toward detailed design, some of the equipment in the FEED phase will change. It is important to keep the simulation in lockstep with design changes to ensure that as the physical asset takes shape, the digital twin remains a mirror image. The simulation can be used continually to ensure that the latest detailed design changes do not negatively impact the controllability and operability of the asset.[7]

With AVEVA™ Unified Engineering, simulation data created in conceptual design and FEED is readily available for use in detailed design and is checked and validated in real time to break down data silos and increase engineering and design efficiency.

Real-time data sharing enables instantaneous visibility across all project partners and reduces handover burden.By executing conceptual, FEED, and detailed engineering design from one single data-centric hub, multi-discipline teams, and external suppliers can collaborate in real time.

A single source of truth enables automated workflows across process and engineering data for overall reduced capital project time, cost, and risk.

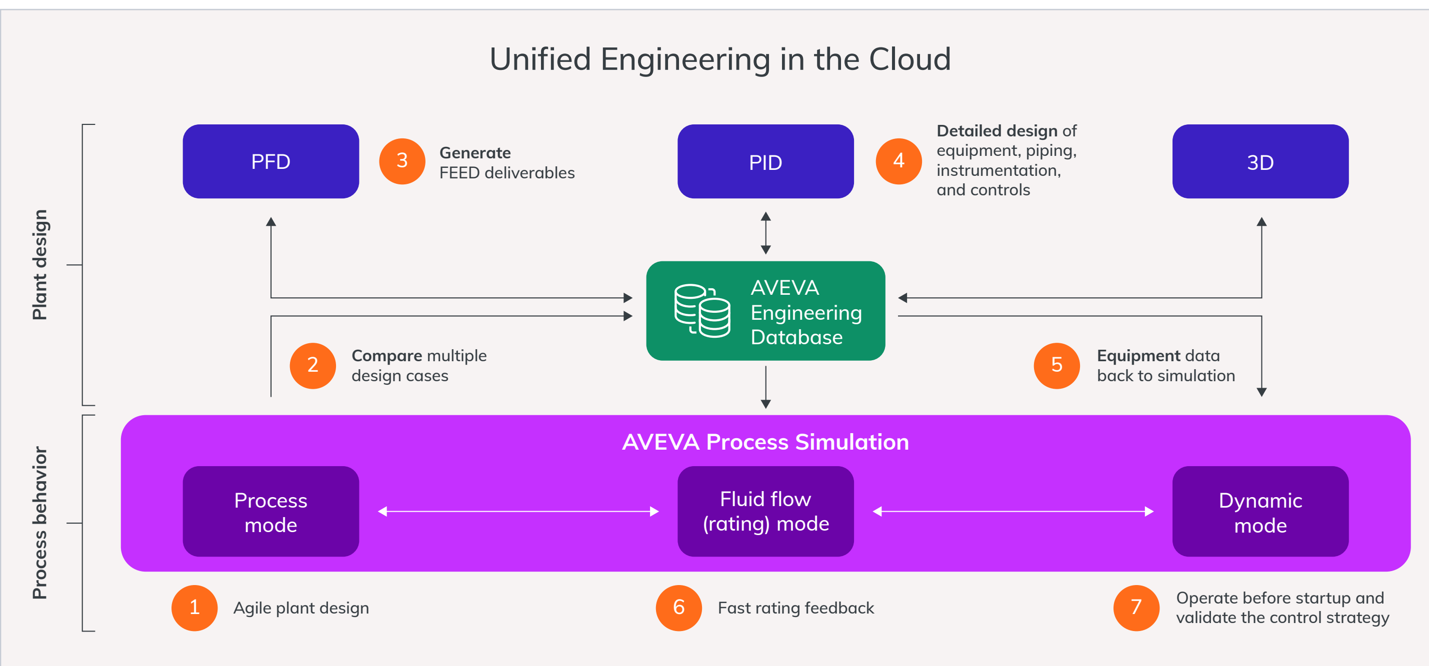


Figure 4: AVEVA Unified Engineering offers insights throughout the lifecycle

Aker Carbon Capture - success story

Aker Carbon Capture's (Aker CC) longstanding goal is to help companies mitigate their CO_2 emissions via the use of carbon capture and storage (CCS) technologies. Working hand-in-hand with high-emitting process industries like cement, steel, and oil and gas, Aker CC relies on AVEVA's data-centric engineering solutions to efficiently engineer easy-to-replicate carbon capture units. With AVEVA's help, Aker CC has been able to reduce the cost of medium-sized offerings by over 90%.

Read the success story

Change is inevitable, but risk is optional

Accurate risk evaluation and quantification is an important step to delivering a successful major CAPEX project. A data-centric, unified approach allows project teams to truly understand what they know and don't know about a project and determine how much risk they are carrying from a cost perspective. Additionally, the ability to demonstrate a bulletproof risk-mitigation plan to the financial backers of a project sets the groundwork for successful funding and, ultimately, project success.

Experienced from day one

A well-designed, well-executed hydrogen plant needs only one more thing to succeed – people. However, in most locations, there is no experienced hydrogen workforce to recruit.

Companies will need to start up new plants with new personnel. Armed with a highly responsive digital twin, the EPC, and the Owner-Operator can ensure teams have the right skills. Training operations staff using the digital twin allows them to practice startup repeatedly and even fail repeatedly in a completely safe environment.

Practice makes perfect, and the operations staff, in a condensed timeframe, develop the required skills and competency to ensure a smooth and error-free startup. Operators gain the experience and awareness needed to make complex technoeconomic decisions that will determine the operational success of a hydrogen plant.

Beyond startup to operations

The value of a digital twin does not end with startup. After handover, digital twins built with AVEVA solutions continue to grow to support ongoing operations and drive efficiencies throughout the life of the asset. When connected to plant data through AVEVA™ PI System™, the simulation model can provide inferential measurements to support decision-making for operational excellence. Models can be used to troubleshoot the causes of abnormal operations. The digital twin also forms the backbone of a plant's workforce competency development program through immersive training environments.

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Turn promises made into promises kept

The nascent hydrogen economy stands to disrupt multiple industries. Engineers must design and build blue and green hydrogen plants in an environment of tremendous uncertainty. AVEVA's solutions for process simulation and engineering spark ingenuity so that engineers can keep the promise of a net-zero hydrogen economy.

About the author

Dr. Ian Willetts is Vice President of simulation and learning at AVEVA, responsible for the global management of the process design, simulation and training business.

Ian has thirty years of experience applying process simulation and optimization solutions in the process industries. Ian graduated from Oxford University in the United Kingdom with a PhD in Engineering Science and recently completed his MBA at the Said Business School in Oxford.