DECARBON TECHNOLOGIES

Uhde

Digital Products

Enhancing Plant Capabilities

engineering.tomorrow.together.

thyssenkrupp

Decarbon Technologies

Key Technologies for the Green Transformation

thyssenkrupp Uhde is part of the Decarbon Technologies segment of thyssenkrupp. We are an enabler of the green transformation by providing key technologies for significant CO_2 reduction. Due to their direct impact on intelligent and resource-efficient plant operation, our digital products and solutions leverage our purpose of the dual green and digital transition.

Content

Tomorrow's Digital Products at your Hands

With the development of computer hardware and artificial intelligence (AI), digital products have really taken off in recent years. For plant operators, there is no better way to optimize plant performance than plant digitalization

At thyssenkrupp Uhde, we offer a wide range of plant digitalization solutions to help our customers maximize production, reduce feedstock and energy consumption and effectively reduce emissions. Digitalization can also significantly improve plant availability and safety.

1. Data Analytics and Consultancy

This includes service products such as remote plant condition monitoring, regular reporting and expert advice as well as root cause analysis of issues.

2. Digitalized Maintenance

This includes methods for detecting wear as well as predicting failure and the remaining lifetime.

3. Predictive Operation

Our predictive analytics combine data-based empirical machine-learning models with process-based know-how. The goal is to predict operating and process behavior as well as quality issues and describe future process inefficiencies.

4. Performance Optimization

This may be through an improvement in energy consumption, product quality or production rate of the plant. Another goal is to extend equipment lifetime.

Our digital products portfolio can be divided into four categories

Digital Twin

Predictive operation and performance optimization often use so-called digital twins, a virtual representation of the real plant. Both predictive operation and performance optimization are used to compare the performance of the real plant with the simulation to perform what-if analyses, detect abnormal process behavior, optimize plant performance, etc.

Leveraging the Capabilities in a Fertilizer Complex

01

Plant Digitalization at El-Nasr Company for Intermediate Chemicals (NCIC)

As part of the digital services and operation & maintenance project at our customer's nitrogen fertilizer complex in Egypt, thyssenkrupp Uhde installed tools and solutions that further increase plant efficiency and transparency.

An established digital infrastructure provides the basis for remote performance monitoring including real-time dashboards and regular provision of performance reports. Implemented digital twins predict process behavior and plant performance by combining real-time plant data with process models that incorporate the latest machine learning algorithms.

Another tool provided in parallel is the Uhde® Ammonia Operator Training Simulator Centre which enables current & future operators to train on an ammonia plant in a simulator environment (normal operation, startup, shutdown) whereby the operator is trained to deal with various situations in a simulator environment before operating the real plant.

Approximate timeline of full digital implementation

9 months

Phase 1 Operation Support

- Set up of digital infrastructure and cloud connection
- Preparation of Standard Operating Procedures
- Operator Training Simulator

6 months

Phase 2 Data Driven Support

- Remote Performance Monitoring incl. Dashboards
- Supply of White Box Digital Twins

6 months

Phase 3 Performance Plus

- Supply of Black Box Digital Twins

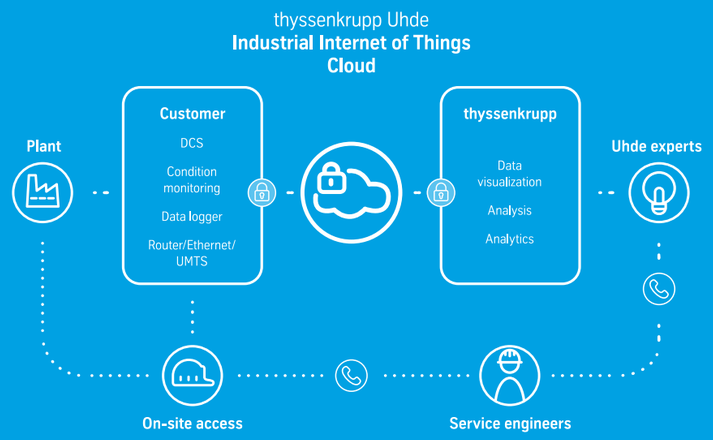
Service Phase

- Commenting of standardized reports by process technology specialists

Data Analytics & Consultancy

02

Digital Infrastructure



All data-driven services and products offered by thyssenkrupp Uhde are based on the digital infrastructure. It consists of two main components:

- thyssenkrupp data logger
- thyssenkrupp Industrial Internet of Things (IIoT) cloud

The data logger is connected to the DCS of the plant via a standard interface, preferably OPC UA. Its purpose is to collect and store operating data in the field. The customer has easy access to this data. The data logger can also transfer data to the thyssenkrupp cloud via a secure internet connection.

Of course, our system uses the latest security standards as described on the following page.

Data Security

- Multi-Factor Authentication
- Encrypted data storage
- Protected data transmission
- Subject to European Data Protection Law
- All servers located in the EU
- Logical separation of customer data
- Regular security checks

Our digital services are based on the trust that you place in us. Therefore, the protection of your data is of utmost importance to us. In order to ensure the highest possible security anywhere and at any time, we apply state-of-the-art security technologies:

Access to the web applications for users and admins is secured by **Multi-Factor Authentication (MFA).** Passwords are securely stored as salted hash.

- All data on our servers are protected by the **latest encryption technology.**
- Data in transit between backend or frontend components is **protected by TLS.** Edge Device communication is **protected by SSH2.**
- As a German company we are **subject to the law of the European Union,** incl. one of the **strictest data protection laws** in the world.
- Our **platform is located in the European Union.**
- We pursue the strategy of a **strict logical separation.** Customer data stored and processed is strictly separated, e.g. role and authorization concept.
- Our **data security standards and roadmap** are regularly **checked by internal auditors** (CERT, ISO Team) and by **external parties** (KPMG, Mogwai Labs), incl. ISO 27001 reviews, penetration tests, Red Teaming Measures.

Remote Expert Support (on demand)

The transfer of data to the thyssenkrupp IIoT cloud enables thyssenkrupp Uhde's data scientists and technology experts to analyze the data and gain valuable insights into the operation and status quo of the plant.

thyssenkrupp Uhde's specialists can then provide the customer with any necessary recommendations for operation and maintenance while monitoring the live data. Communication between thyssenkrupp Uhde's specialists and the customer is established using appropriate software, such as MS Teams, and mobile devices.

The benefits: The customer can contact thyssenkrupp Uhde's specialists directly on demand in the event of critical conditions to receive recommendations for corrective action based on an analysis of the root causes by our specialists.

Remote Performance Monitoring (continuous)

This service is also based on the operating and analytical data transferred to the thyssenkrupp IIoT cloud via a secure internet connection.

The data is regularly analyzed by our process experts and data scientists to identify the key parameters and root causes for any anomalies. The plant status is shown on a customized dashboard. Regular reports including recommendations for operation and maintenance are provided to the customer. The contents of these reports are explained to the customer in regular meetings or telephone calls.

The benefits: The customer receives a user-friendly process overview with important key performance indicators through remote monitoring and analysis of performance and operation by our data scientists and technology experts. Deep process insights are provided by pinpointing influential processes and uncovering potentially inefficient process areas that would otherwise remain hidden.

Digitalized Maintenance

03

General Aspects

Professional maintenance is key to achieving high plant availability, which is one of the most important factors in plant profitability.

Over the years, maintenance has evolved from purely corrective maintenance through preventive maintenance to predictive maintenance. However, it is still a challenge for any operating company to find the ideal balance between these three methods in order to minimize maintenance costs (see Figure 1), as there is no one-size-fits-all approach.

Corrective maintenance may never be entirely avoidable, and too much preventive maintenance will increase overall maintenance costs. Predictive maintenance is, of course, ideal, but it may not be suitable for all assets in a plant.

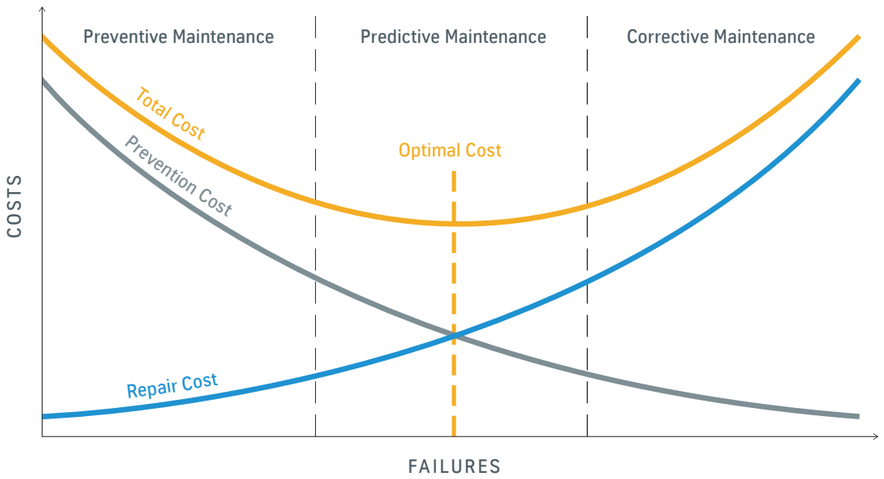
thyssenkrupp Uhde can set up a maintenance system for its customers comprising several steps such including criticality analysis etc.

Computerized Maintenance Management System (CMMS)

The maintenance steps can be implemented using a computerized maintenance management system (CMMS), which provides functions such as:

- Master Equipment Hierarchy
- Maintenance Plans
- Work Order Management
- Management around Spare Parts
- Analytical Reports

Most of the above functions can also be implemented on a standalone basis, without an overarching CMMS.



Maintenance optimization

(Spare) Parts Management

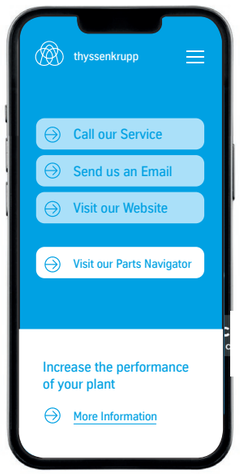
In order to ensure quick and hassle-free identification and ordering of a spare part or piece of equipment in an operating plant (e.g. when a part needs be replaced), thyssenkrupp Uhde offers a state-of-the-art solution package that comprises two components. These deliver the greatest value as a combined solution, but can also be ordered as a single solution:

Digital Service Stickers

Industry-suitable stickers/badges (designed for a chemical plant environment) are affixed to every relevant piece of equipment and/or spare part. These stickers have a QR code that provides additional information when scanned using an ordinary device such as a smartphone or tablet with an internet connection. The information displayed ranges from material-numbers/TON and specific contact details for further support from thyssenkrupp Uhde to detailed drawings and instructions.

In combination with thyssenkrupp Uhde's PSPN (see explanation on the right), the digital service sticker means that thyssenkrupp Uhde's customers can identify all required information about a specific part at the click of a button and no longer need to waste copious time rifling through the documentation. This is essential for placing enquiries quickly and easily, and for initiating further technical analyses.

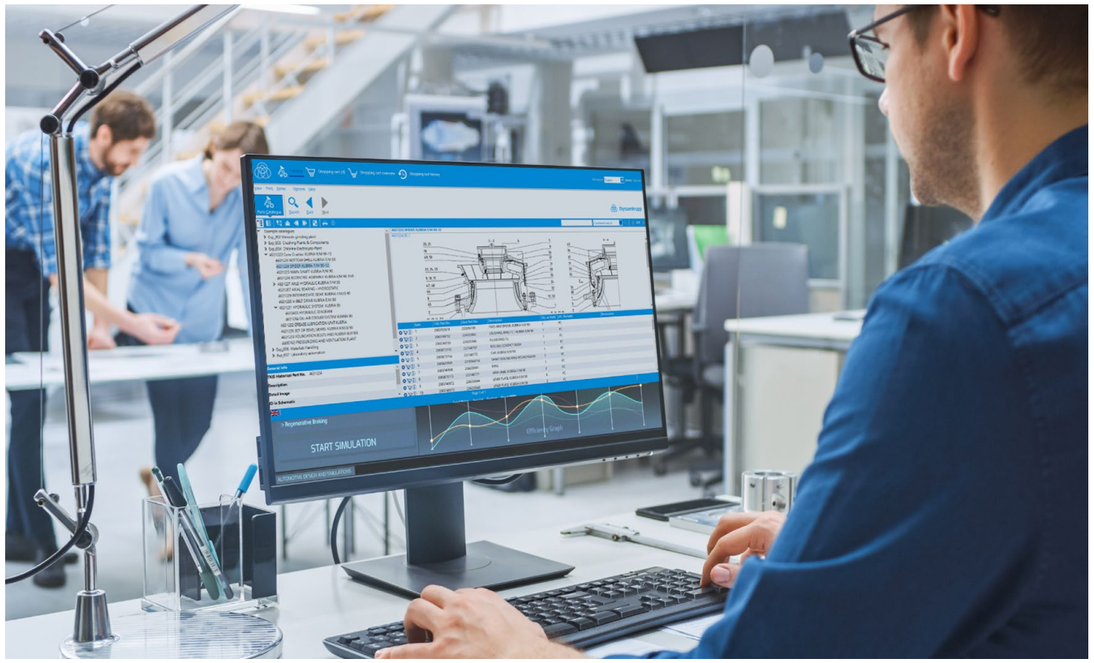
The benefits: Making data to identify the equipment quickly available



Professional Spare Parts Navigator (PSPN)

thyssenkrupp Uhde's PSPN is a software solution tailored to the customer's plant. It enables quick and easy access to the required information on any part installed in the plant by simply browsing through a digital system.

In addition to finding drawings and further specifications, it is also possible to order selected parts from us. If no framework agreement is in place, the system can generate a draft for the customer's procurement department at the click of a button, so that the normal procurement process can be initiated within their organization. This drastically reduces the need for internal discussion and coordination among the operating and maintenance personnel and the procurement department regarding specific parts specifications.



The digital service stickers (see above) are linked to the PSPN, meaning that each scan takes the user directly to the PSPN, where the respective item can be identified for further action, such as triggering an order process for the item.

An advanced level of configuration is also possible, where thyssenkrupp Uhde links its SPN with the customer's ERP system and synchronizes the two systems. Although this requires an additional implementation project, the result brings a huge benefit in that parts can be ordered at the click of a button in accordance with company guidelines and requirements without the need to do anything more. This automated, fully digital ordering process saves a lot of money while increasing the desired availability of all relevant spare parts.

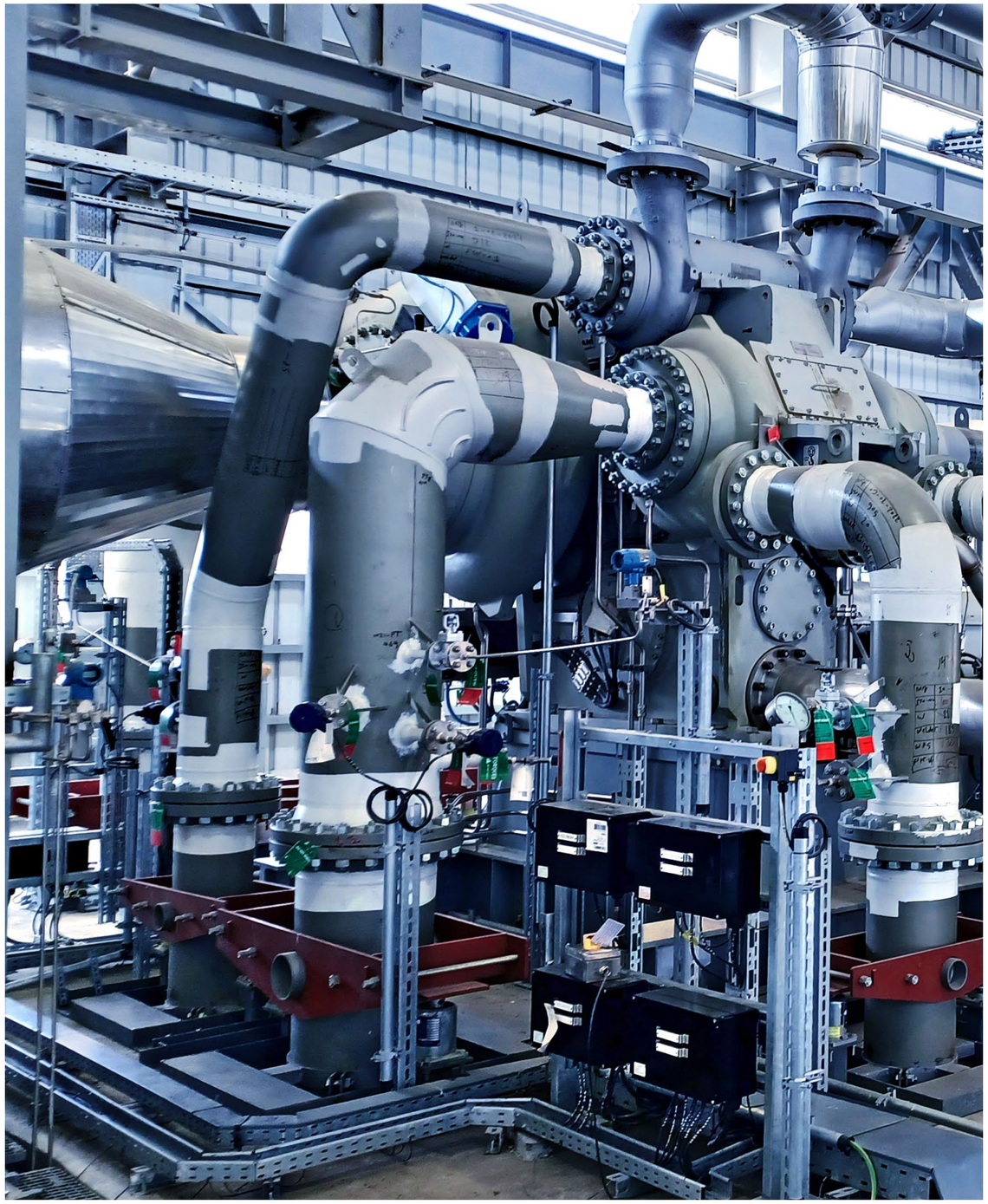
The benefits: The customer can identify the correct spare parts quickly and accurately, thus speeding up order and delivery processes.

Automated Machine Monitoring

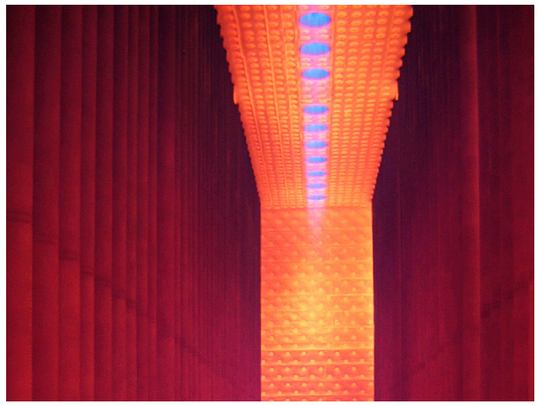
Our automated machine monitoring system continuously monitors and analyzes turbomachinery relevant data using special algorithms, e. g. dynamic limit monitoring of operating parameters using advanced analytic algorithms.

The results are then evaluated by our turbomachinery specialists. This ensures that anomalies are detected at an early stage so that measures can be taken to avoid any negative impact on machine performance. The customer can also access visualized data. Overall, thorough machine monitoring significantly reduces expenditure on spare parts, maintenance personnel, downtime and repairs.

The benefits: Real-time transparency of turbomachinery operating data improves reliability and availability/uptime to enable maximum output and efficiency. Component life and the entire machine life is extended, as are the overhaul intervals. This reduces machine-related costs over a plant's lifetime.



Advanced analysis of turbomachinery data



View into a reformer

Lifetime Assessment of Reformer Tubes

Many of thyssenkrupp Uhde's process technologies are based on steam-reformer-type reactors

Although the lifetime of such reactors is very long, a further increase in plant availability can be achieved by monitoring the reformer tubes. Lifetime Assessment of Reformer Tubes is an online system for monitoring the condition of the reactor. Relevant parameters such as temperature and pressure are continuously measured and tracked over time, thus preventing overheating of the reformer tubes. By applying empirical values and known causalities, the remaining lifetime of the tubes can also be predicted.

The benefits: The customer gains an insight into the condition of their reformer tubes and a prediction of the tubes' remaining lifetime. This prevents unexpected plant shutdowns as well as the premature replacement of tubes that may still be serviceable for several years.

3D Scan and Application of Drones

Whether you are planning a plant expansion/revamp or want to learn more about the current condition of your plant and buildings, our (laser) scanner services are just what you need.

We offer drone flights to assess your plant from every angle, carried out by our experienced experts who know the plant inside out. Alongside purely visual inspections, we also offer scans of the plant, such as infrared or laser scans, to assess various plant conditions (for example thermodynamic). The latter is particularly useful for creating 3D models for a variety of purposes (e. g. revamp planning – “will there be installation problems due to surrounding components?”).

The benefits: This can be used in general as a tool to support a variety of maintenance tasks and it offers fast and efficient detection of, for example, leaks at heights that are difficult to access.

Remote Inspection

With our advanced remote support tools, you can contact our experts via smartphone, tablet or data glasses from any job site.

Our experts can provide real-time, on-site assistance via PC, tablet or smartphone for immediate trouble shooting and regular maintenance. During the live support, you can make videos and take screenshots, as well as set markers in the live image - all of which can be available as documentation after the remote service. If required, our experts can provide you with various documents such as data sheets, technical diagrams, checklists, etc.

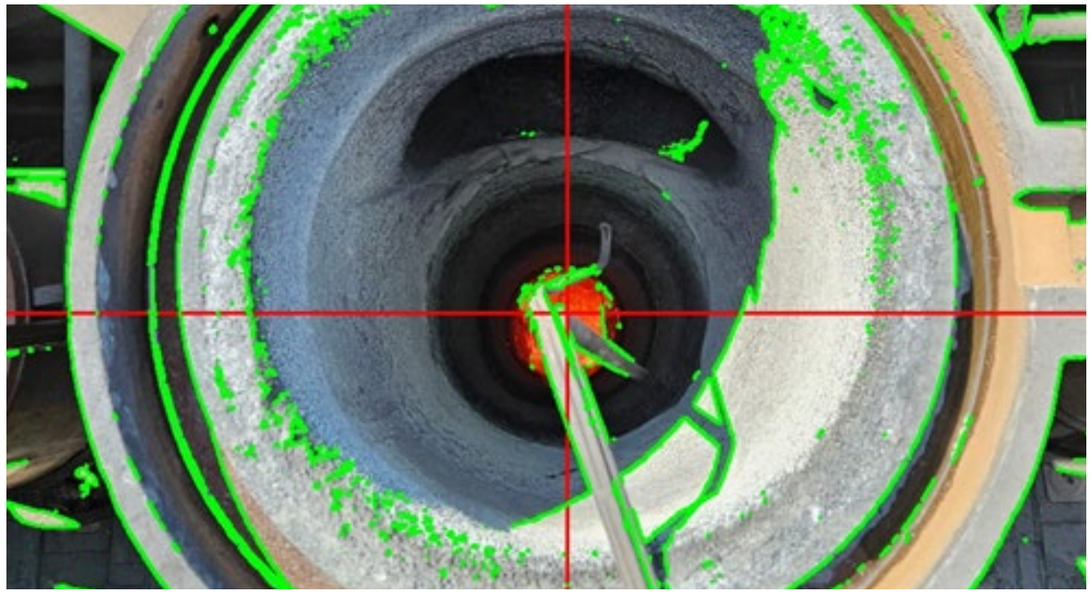
The benefits: e.g. quick and hazzle-free support when facing unplanned challenges.

Computer Vision

Fast and reliable analysis of images is one of the benefits of AI. It can also be applied in the inspection of chemical plants.

This effectively reduces the time required for manual inspection by the maintenance team (for example inspection of coke oven batteries). The detection of potential defects follows a data-driven AI approach based on an AI model that is first trained to identify patterns from a set of pre-processed images.

The benefits: Systematic image capture and anomaly classification significantly reduce manual inspection time.



Detection of relevant deviations inside a rising pipe

Digital Twin

04

Digital Twin

A digital twin is a virtual representation of a plant or process unit and forms the technical basis for most of the “Predictive Operation” and “Performance Optimization” product clusters. It can be enhanced with other components, such as 3D models and computerized maintenance management systems (CMMS).

Advanced methods of process control include, for example, multivariable model predictive control (MPC) and feed-forward control. The above methods typically require in-depth process knowledge and usually work without the application of machine learning and deep learning.

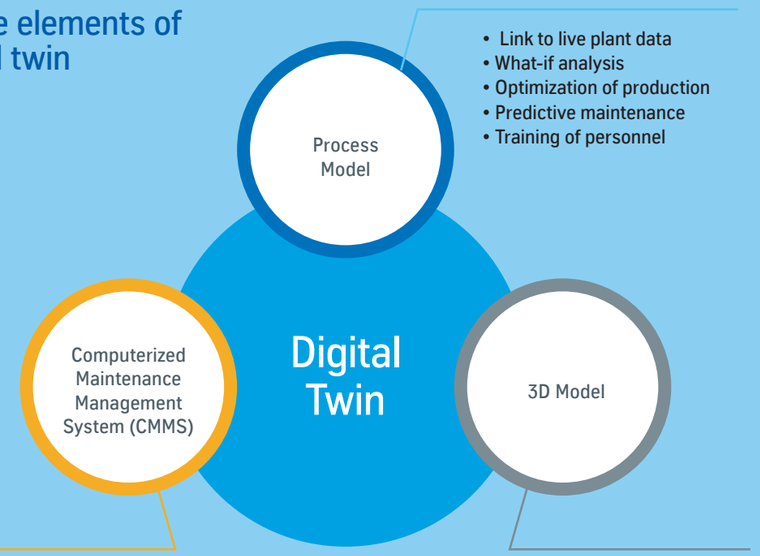
There are three different models for digital twins:

1. White-box model: Based on a process simulation containing typical building blocks such as reactors, distillation columns, heat exchangers, pumps, etc. It applies thermodynamic models, chemical models, and techno-economic models.
2. Black-box model: A purely statistical model that describes the relationship between input and output parameters of a chemical plant. These AI models are often based on neural networks that need to be trained with operating data from a plant.
3. Hybrid models: A combination of the above models.

The extent to which a digital twin is implemented for each plant or process unit typically depends on the importance and complexity of each control task. The twin is continuously (24 hours/day, 365 days/year) fed with measured data from the real plant, and processes this data in near real-time. Running in parallel with the real plant, it provides virtual monitoring, prediction and optimization functions. This allows operators to be alerted to abnormal plant behaviour and to make data-based decisions, backed up by calculated process parameters that cannot be measured directly.

The benefits: Better plant transparency, less unwanted fluctuation, increased process stability and flexibility, plus enhanced dynamic adaptive operation. Accurate and timely information on actual plant performance is provided in near real-time, at any time. The exact response time of each element of the digital twin depends on its complexity. Digital twins help operators to identify different operating conditions, even in the case of multi-dimensional interdependencies. Digital twins can also provide virtual sensors and improve the preparation of future revamp studies.

Possible elements of a digital twin



Depending on the chosen model(s), the following modules can be included in a digital twin:

(Advanced) Condition Monitoring
Monitors anomalous operating patterns of critical assets over time to predict wear, failure and remaining time to failure. Recommends optimum maintenance schedule and operating range to extend a campaign run or minimize wear.

Anomaly Detection
Detects, at an early stage, anomalous machine behavior and patterns that may lead to malfunction or wear through continuous analysis of process data.

AI Soft Sensors
AI soft sensors, i.e. non-physical and purely data-based sensors, employ AI models during plant operation to provide a continuous, real-time stream of predicted values for key performance indicators such as product quality or purity, which could otherwise only be determined by offline, delayed or costly measurements.

Process Forecast
Predicts operating and process behavior, process inefficiencies and quality issues in advance using real-time plant-data-based empirical machine-learning models.

What-if Analyses
Simulate and predict process adjustments or changing conditions (such as fluctuating feedstocks or prices) and their impact on plant KPIs using digital twin models.

Wear & Lifetime Prognosis
Monitors anomalous operating patterns of critical assets over time to predict wear, failure and remaining time to failure. Recommends an optimum maintenance schedule and operating range to extend a campaign run or minimize wear.

Continuous Leaning
Self-learning AI models continuously learn from new operating data and improve control strategies, automatically adapting to any variations or disturbances in the process or operating environment.

Predictive Operation

05

Operator Training Simulator

An operator training simulator (OTS) is a virtual learning platform for operators to familiarize themselves with plant elements and their behaviour, based on a customized dynamic process simulation of a real plant.

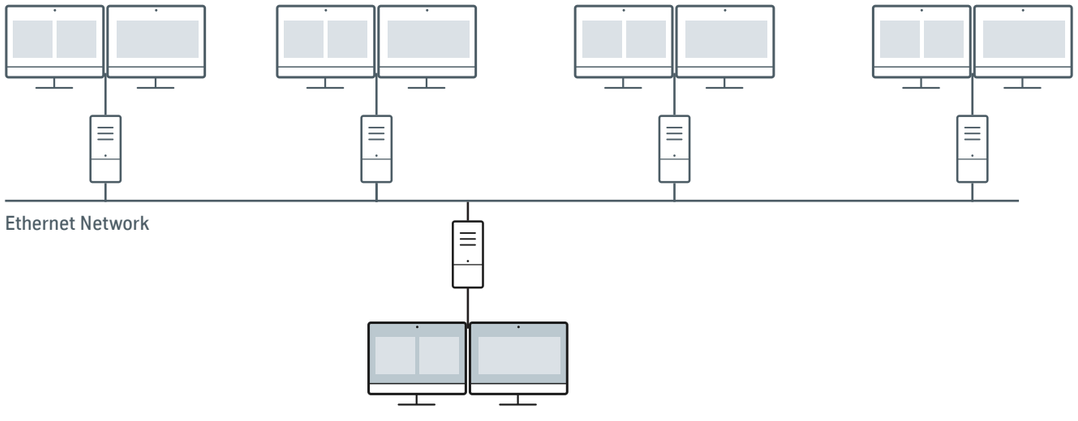
Like an aircraft flight simulator, it creates the technical and graphical environment required to train personnel. Plant operators feel like they are in a real control room, sitting in front of monitors, watching DCS screens, controlling the process, generating trends, fine tuning control parameters, etc.

The main benefit of an OTS is that, in addition to normal day-to-day operating tasks, it provides hands-on training for scenarios which occur less frequently, such as start-up, shutdown, malfunctions and safety-critical/emergency situations. This prepares operators to cope so that they can maximise uptime and safely operate the plant at its highest efficiency and productivity.

Ideally, the OTS should be developed at the same time as the real plant, as it can then be used for training to prepare the operators for their work prior to commissioning and operation. In addition, it can be used to support commissioning by testing the control system upfront, tuning control parameters, etc.

The benefits: Qualify perfectly trained personnel without risking a negative impact on the plant operation due to unexperienced staff.

A typical training environment :



AI Assistant (open-loop)

A key objective of digitalization is to continuously improve plant performance, which is typically measured by the following key performance indicators (KPIs):

- Production rate
- Plant availability
- Energy efficiency
- Product quality
- Catalyst condition
- Critical equipment condition
- Effluents and emissions

In today's world, many plants are still operated with fixed setpoints for control parameters, which has proven relatively effective and is a compromise based on trial and error in the past. To avoid the risk of lower production, these setpoints often remain unchanged for several years as the approach taken is never to change a running system. Operation under these conditions is stable, but not usually optimal, and may well impact plant profitability.

By using a digital twin running in parallel with the real plant, it is possible to optimize plant operation and maintenance without risking trips or temporary losses in performance.

The open-loop AI assistant suggests new setpoints for the various plant parameters, which the operators can then enter into the plant's control system, i.e. the plant operators are guided by the digital twin, but remain in full control of the plant and make the final decision on whether or not to implement the suggested changes.

The benefits: The AI assistant helps to optimize plant performance while respecting all process and equipment constraints. It also reduces the number of process alarms as the assistant predicts future constraint violations and suggests appropriate measures for alarm avoidance.

Performance Optimization

06

General Aspects

Where conventional process control exhausts its possibilities, our performance optimization solutions can handle even the most complex control tasks.

The following solutions are typically used in specific sections of a plant that are difficult to control. However, there is a trend towards using these systems in complete process units or even plants.

Advanced Process Control (APC)

Where system behaviour is known or can be predicted, control of such systems can be handled by APC. The development of APC is typically a task performed by a joint team of process and instrumentation specialists.

Advanced methods of process control include, for example, multivariable model predictive control (MPC) and feed-forward control.

The above methods typically require in-depth process knowledge and usually work without the application of machine learning and deep learning.

The benefits: A further automated and more precise operation

AI Controller (closed-loop)

Based on a digital twin, the AI controller goes one step further than the AI assistant described in the previous chapter by closing the loop, i.e. the AI controller automatically optimizes plant performance by continuously manipulating the setpoints of process parameters in the plant's control system.

Operators do not need to implement the suggested changes themselves.

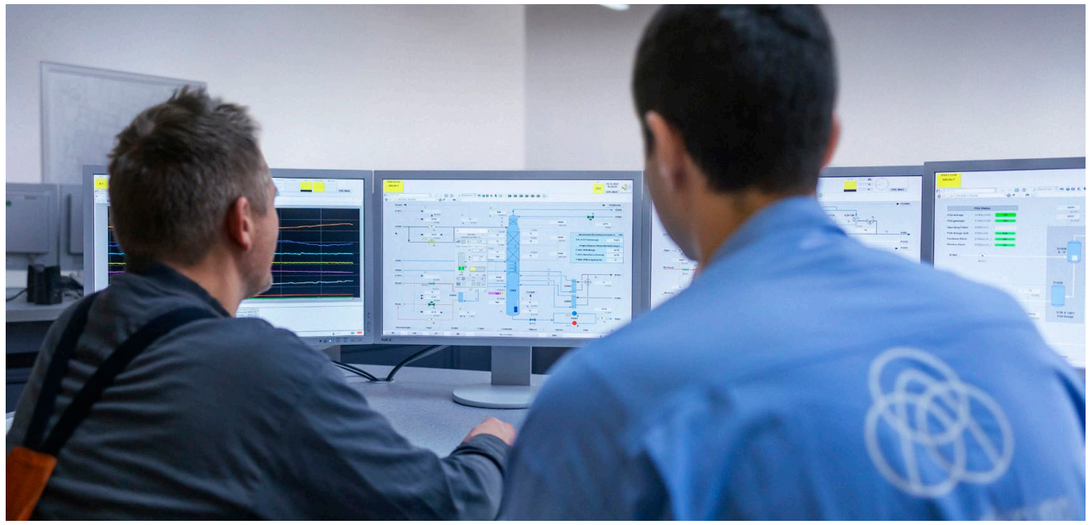
Proactive and predictive control based on AI models predicts future plant response and determines an improved control strategy in advance, enabling fast corrective action even under dynamic operating conditions.

The benefits: The AI controller can find the right control setpoints to achieve multiple objectives simultaneously. Models can be set up to continuously learn from new data and automatically take account of changes in the process or operating environment. This enables fast corrective action even under dynamic operating conditions.

Development of an AI Controller at HOLBORN

07

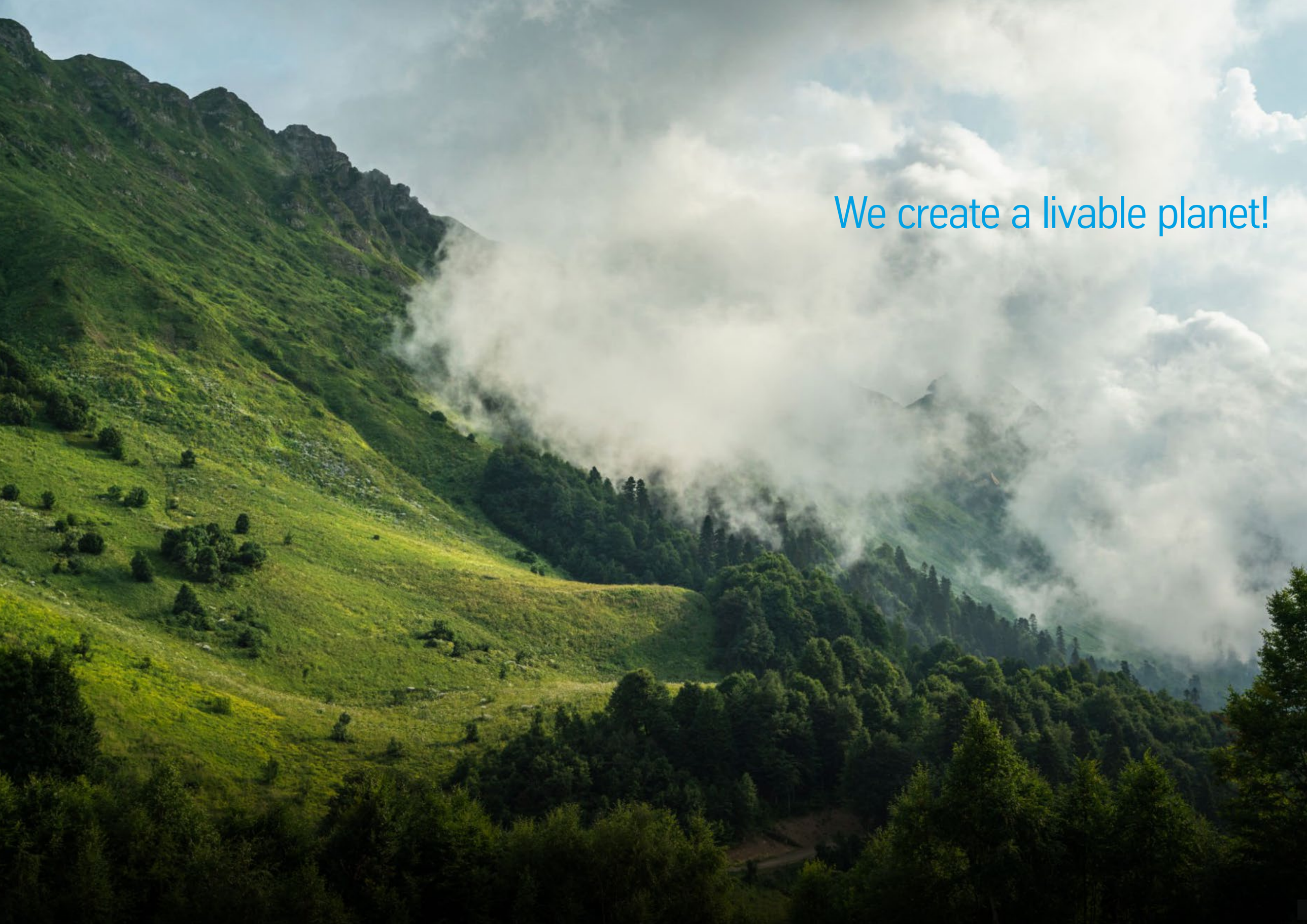
Applying AI in the Field in a Joint R&D Project



Within the framework of a cooperation with our client HOLBORN Europa Raffinerie GmbH, our domain experts and data scientists have been developing digital solutions in the field of predictive process and performance control using data analytics and artificial intelligence.

As part of the R&D program, process performance optimization targets are aimed to be realized by means of developed open or closed loop solutions: In the former case an AI model assists operators by providing predictions of a controlled variable and set-point advices whereby the operator can implement the recommended control actions manually. Closed loop operation on the other hand not only provides optimal set-point recommendations but automatically implements the control actions without the need of operator's intervention.

By employing AI-based process performance optimization tools, optimal operation set-points are maintained to achieve multiple objectives such as maximizing product yield, quality and throughput as well as minimizing energy consumption.


We create a livable planet!

Decarbon Technologies
Uhde

thyssenkrupp Uhde GmbH
Friedrich-Uhde-Straße 15
44141 Dortmund, Germany

www.thyssenkrupp-uhde.com