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Sustainability through Process Automation

Greater efficiency and sustainability through automation, digitalization and modularization in the process industry!

Electro and Digital Industry Association

Foreword

Per aspera ad astra (Seneca): The path to climate neutrality

Russia's terrible war in Ukraine has put Germany's secure energy supply on hold. This represents a major setback for the planned energy transition. Does this also mean that the vision of the All-Electric Society has failed?

There is no doubt that the current war-related energy crisis marks a major turning point, especially as gas was intended as a bridging technology for the manufacturing industry and electricity generation. This is now no longer the case. Instead, we need to expand renewable energies and their base load capacity much more strongly and faster than before, here on site. This cannot mean that we become too dependent on renewable energy sources outside Europe. In addition, because gas is no longer an intermediate variable, we need to electrify areas for which a changeover was not planned until much later, for example, when CO_2 capture, and storage (CCS) processes have become economical.

Once again, we are faced with a series of unforeseen problems and massive delays. This is a clear wake-up call to act quickly! I see three areas:

- The fact is that we still need significantly more renewable electrical energy in order to move away from fossil fuels. We cannot rely solely on imports but must build as many wind and solar power plants as possible in Germany and Europe.
- We need to get away from gas as quickly as possible. Where possible, we should use electricity for heating, driving, steel production and chemical reactions, because electrification alone will bring enormous efficiency gains and thus reduce consumption.
- We must exploit all opportunities to increase energy efficiency. Rising energy prices are making measures that were previously not worthwhile economically viable. This includes all sectors. As one of the major energy consumers, the process industry must take decisive action here. Process automation can make major contributions to this, as this brochure shows.

How can we get out of this dilemma? By rethinking and cutting red tape! We need a new hydrogen distribution network, smart grids, charging infrastructures, LNG terminals, energy-efficient building refurbishment and power lines that bring green energy, perhaps generated offshore, to the consumer. We urgently need unbureaucratic, fast planning and approval procedures. To achieve greater energy efficiency, we need to make much greater use of "enabling technologies," in particular electrification, automation, digitalization and modularization. And we need all of this now!

Achieving lofty goals has demanded a great deal from all of us since time immemorial, as the ancient Romans already knew. Let us take encouragement from Seneca. Even if the road is hard: let's tackle it! This brochure is intended to encourage and support you.

Dr. Gunther Kegel, President of the ZVEI

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The Goal of This Brochure

The countries of the world, the EU, the German government and the business community all agree that in order to stop global warming as quickly as possible, we must achieve climate neutrality by 2050 at the latest. The process industry, one of the biggest consumers of energy, also wants to take this route as quickly as possible. Process automation is an important enabler for this. Automation forms the eyes and brains of the systems, so to speak, and supports the operating personnel in optimal operation.

The ZVEI working group “Process Automation for Sustainability,” headed by Ralf Haut (KROHNE), has been working for years on the topic of how process automation can make an important contribution to sustainability in the process industry. In 2012, NAMUR produced a NAMUR worksheet NA 140 on the contribution of automation technology to increasing energy efficiency. This document was created in collaboration between the two associations.

Without claiming to be exhaustive, this brochure summarizes concrete contributions of process automation to increasing sustainability. This includes:
- Innovative sensors and actuators (chapter 2),
- Energy-optimized processes, electricity instead of gas and hydrogen production (chapter 3),
- Modular, flexible systems (chapter 4),
- Energy management systems for sustainable system operation (chapter 5),
- Digital twins of the systems for simulation and optimization (chapter 6),
- Connectivity for fast data transmission (chapter 7) and
- IT tools for data use and analysis (chapter 8).

Chapter 9 presents prospects on the framework conditions.

At least half, if not more, of the energy efficiency gains necessary can be achieved through comprehensive electrification, automation, digitalization and modularization alone. And, of course, we also need to invest in the construction of new process plants to replace fossil fuels and promote the production and use of green hydrogen.

We have currently set around 10 percent of the energy efficiency levers in motion. This is not enough in the long term, but we are well on the way to achieving a further 40 percent - and the products, solutions and projects mentioned in this brochure are some of the promising tools we have at our disposal.

We hope that this brochure will reach as many decision-makers as possible at all levels and that the many opportunities will be implemented effectively.

Felix Seibl, ZVEI

Christine Oro-Saavedra, NAMUR

1 Sustainability in the Process Industry

This chapter introduces the subject of this brochure. Based on the global and German need for climate neutrality (section 1.1), sustainability is placed in relation to other requirements for the process industry in section 1.2.
Section 1.3 shows how the sustainability requirements for chemical processes have changed over the years.

1.1 On the road to climate neutrality

Back in 2015, the global community committed to 17 global goals for a better and sustainable future under the umbrella of the United Nations. Four of the 17 goals alone are related to the topic of "sustainability":

- Affordable and clean energy (Goal 7),
- Industry, innovation and infrastructure (Goal 9),
- Sustainable consumption and production (Goal 12) and
- Climate protection measures (Goal 13).

As an important building block for implementation, the German government has stipulated that Germany needs to be "greenhouse gas neutral" by 2045, i.e. a balance between greenhouse gas emissions and reductions has to be achieved. Emissions are to be reduced by 65% by 2030 compared to 1990 levels, and by 88% by 2040. This is the target set by the German government in the amended Climate Protection Act. This target covers all sectors: the energy sector, industry, transport, buildings and agriculture.

Industry is responsible for 22 percent of Germany's greenhouse gas emissions1. These emissions are made up of

- direct energy-related emissions from the use of fossil fuels to provide energy,
- indirect energy-related emissions generated by the electricity used, and
- process-related emissions caused by the use of fossil fuels and raw materials directly in the production process.

Chemical processes are very energy-intensive and rely on many raw materials.
In 2021, for example, they consumed 14% of all natural gas used in Germany. The German Chemical Industry Association presented a plan in 2019 on how the industry can become climate-neutral by 2050.

According to ZVEI estimates, at least half, if not more, of the energy efficiency gains necessary can be achieved through comprehensive electrification, automation, digitalization and modularization alone. Of course, investments in process plant engineering are also necessary in order to replace fossil fuels or promote the production and use of green hydrogen.

After all, around 10 percent of the energy efficiency levers have already been set in motion. This may not be enough in the long term, but we are well on the way to achieving an additional 40 percent in Germany and Europe. To achieve this, we have the promising

[1] https://www.klimaschutz-industrie.de/themen/klimaschutz-in-der-industrie/

solutions and projects mentioned in the following sections, among other assets, available.

1.2 Objectives of the process industry

Sustainability cannot be seen as a detached sub-task or made absolute. The basic prerequisite is that competitiveness must be maintained. This is the only way to maintain and further develop Germany as an industrial location from the perspective of the process industry. From an ecological point of view as well, nothing is gained if chemical plants in Germany that already meet high standards are closed and plants are relocated to other countries with lower environmental requirements instead. This is discussed in the "Messaging House" (Figure 1). Even though sustainable production is the focus of this brochure, it must be seen in the context of other challenges such as the shortage of skilled workers and supply chain resilience. The enablers of automation, digitalization and modularization are ideally suited to address all three dimensions. Automation allows systems to run at optimal levels, while digitalization creates an interesting, attractive working environment for skilled workers and modularization enables more flexible, cost-efficient production on site. The following use cases show how measurement technology and process automation products and solutions such as control systems, process analysis technology (PAT) devices, various sensors and actuators as well as the associated digitalization and modularization concepts act as enablers of sustainable production and also have a positive effect on the other challenges that need to be mastered.
(Source: ZVEI)

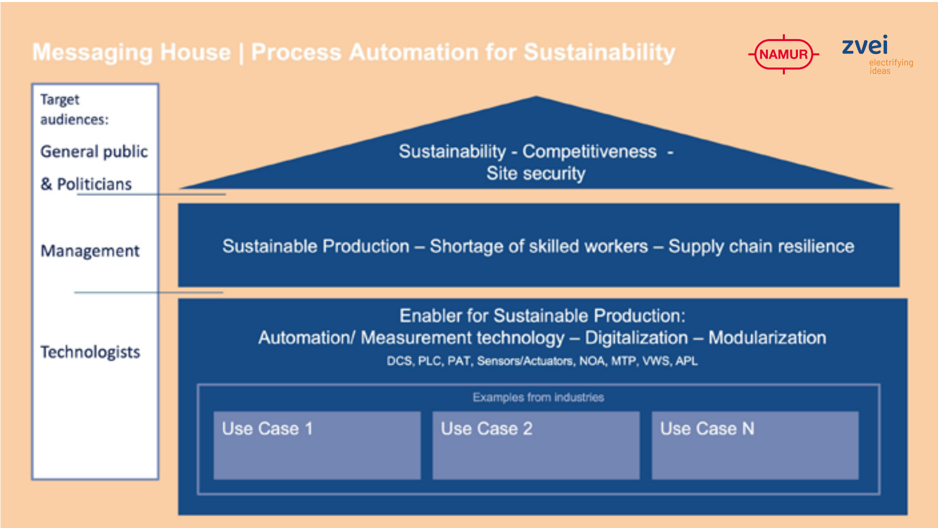

Figure 1:
Messaging House, Challenges in the process industry
(Source: ZVEI, NAMUR)

https://www.klimaschutz-industrie.de/themen/klimaschutz-in-der-industrie/

1.3 Starting position of the process industry

Saving energy has always been important for the process industry because energy costs represent a large share of the production costs. But the economical use of resources and the avoidance of emissions were also important drivers back in the 1960s and 1970s.

Of course, economic efficiency also plays an important role here. For this reason, preference has been given to measures that made economic sense or were at least justifiable. Examples of such "low hanging fruits" are shown in Figure 2. Examples include heat recovery from waste heat flows at high temperatures or improvements to the way that systems are operated on a daily basis.

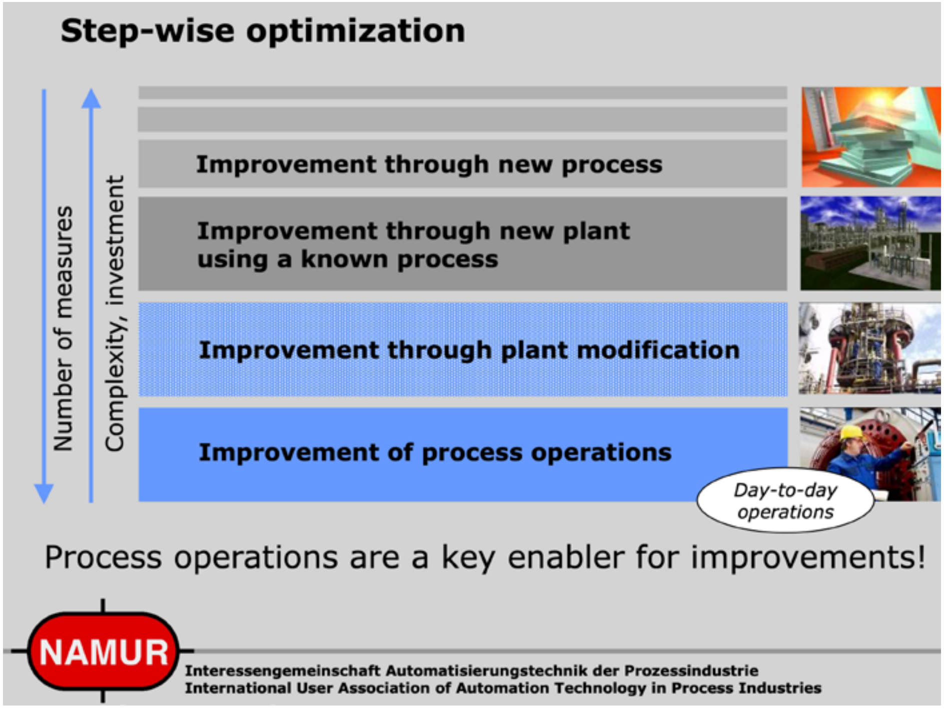

Figure 2: Step-by-step optimization of the sustainability of process plants. (Source: 1)

System modifications, new plant construction or even the development of even more sustainable processes require high investments. They are also labor-intensive and demand highly qualified specialists. The high complexity of automation tasks has also prevented good approaches.

- But now, on the one hand, the “pressure to suffer” has increased: High energy costs, binding sustainability targets and political and social expectations are forcing us to make better use of the opportunities and technologies we have available. A “disinterest in waste heat,” for example, is simply no longer an option.
- On the other hand, new technologies are creating new and more cost-effective possibilities: Better sensor technology, standardized interfaces, IT tools and more. These are all described in this brochure. These technologies are now ready for practical use and can be rolled out.

Source 1: K. Schächtele, S. Krämer: Energy optimization in the chemical industry. atp edition 1-2/2012, p.34-43

These modified or new systems must be operated effectively, of course. This includes not only the system and the operating personnel, but also the automation of the systems and the use of energy management systems. This is why NAMUR - the automation technology interest group for the process industry - set up the working group AK 4.17 "Energy efficiency" back in 2008.
The NAMUR worksheet NA 140 "Procedure for increasing energy efficiency in chemical plants – the contribution of automation technology" was published on June 1, 2012, and supports plant operators in energy efficiency projects.

2 Innovative Actuators and Sensors

Sensors are used to measure process variables and serve as the eyes on the process, so to speak. Actuators enable interventions in the process and correspond to the hands. There are currently many new developments and new applications in the field of actuators and sensors.

- New types of sensors have been developed, such as acoustic sensors or process analysis devices, for instance.
- The integration of additional sensors has become easier, whether through wireless solutions or standardized information models. This enables the implementation of online monitoring and online optimization.
- Sensors have more computing power and can therefore perform calculations independently, to compensate for temperature and pressure or to independently determine parameters, for example.
- Innovative actuators such as a valve with integrated sensors or a valve control system with many intelligent apps enable decentralized optimizations.
- Control Performance Monitoring software enables the continuous assessment and optimization of the behavior of control loops.

The examples in the following sections show how innovative actuator and sensor technology can be used to save energy and raw materials and improve quality. The increasing transparency of systems enables continuous optimization in the process industry.

2.1 Monitoring of steam traps

The generation of steam is responsible for around 50% of total energy costs in the process industry. The condensate that accumulates in steam pipes must be drained so that it does not impede the flow of steam. This task is performed by steam traps in a purely mechanical way, i.e. without an electrical connection, see Figure 3. Unfortunately, statistically 12.5 to 25% of steam traps fail. Cold, i.e. closed steam traps can lead to pressure surges, ruptures and products that do not conform to specifications, resulting in high levels of damage. Open blocked steam traps can lead to wasted energy costs of several thousand euros per trap because steam is constantly escaping. It is estimated that 20% of the steam escaping from a steam boiler and 5-10% of the energy costs are wasted in this way.

A wireless acoustic transmitter can be mounted on the discharge pipes from the outside during operation. It detects and transmits acoustic structure-borne sound and temperature data as well as device data, event status and leakages. Transmission takes place via the self-organizing WirelessHART network (IEC 62591). An accompanying steam trap monitoring software provides important real-time information about the condition of the steam trap: inactive, breached, clogged or flooded. A dashboard provides immediate insight into the condition, steam loss and energy loss of the steam traps. The algorithm provides detailed defect analysis and high stability for easy decision making, leading to fast response and business impact notifications. They also eliminate the need for manual inspections and can proactively prioritize maintenance to save time and costs.

Figure 3:
This is not how it should be. Steam escaping from a steam trap
(Source: Emerson Automation Solutions)
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Thanks to the battery power supply and the wireless protocol, no wiring of the devices is necessary. Retrofitting is therefore possible without any problems. Implementation is quite easy thanks to the use of the NOA concept (see section 7.1).
The chemical company DSM implemented online monitoring and tracked the results of the acoustic monitoring for a year. It was then decided to extend the solution to six plants worldwide. The expected savings for six plants equipped with 3800 WirelessHART transmitters amount to several thousand tons of CO_2. The payback period is less than two years. Part of this project, 30%, was subsidized by BAFA Module 3.
(Source: Emerson Automation Solutions)

2.2 Monitoring compressed air networks

Almost every production plant has a compressed air network, however these networks are rarely adapted to the actual consumption volumes. A key aspect of reducing costs and consumption in the long term is monitoring the compressed air consumption of the individual systems. The superordinated goal is to increase “sustainability.” An important parameter for the efficiency of compressed air systems is the amount of fresh air that is drawn in by the compressor at the inlet. This air delivery volume is usually referred to as FAD (Free Air Delivery).

The following example comes from a beverage manufacturer that decided to improve the monitoring of its compressed air network in view of rising energy and production costs. In addition to measuring FAD, inefficient air distribution and air pressure losses due to leaks were to be made visible. The company uses vortex frequency flow meters to achieve these measurement objectives. These devices have integrated pressure and temperature compensation as well as an energy calculator, including FAD functionality.

The measuring devices are used in the supply lines of individual systems, such as beverage bottling, to monitor consumption. In addition, the air delivery rate and the FAD value are measured directly downstream of the compressor to monitor the efficiency of the compressor. The volume flow, the operating temperature and the operating pressure on the compressor outlet side are needed to determine the FAD value. This is recorded directly by the vortex frequency flow meter. In addition, the measuring device requires externally determined values for the ambient temperature and the pressure on the compressor intake side, the current engine speed and the relative humidity on the intake and outlet sides. If the FAD value drops, this indicates that the energy efficiency of the compressor is decreasing, e.g. due to a dirty oil or air filter.

The solution that employs vortex frequency flowmeters has several advantages for the beverage manufacturer. It helps the user to create consumption profiles for the individual systems. Necessary maintenance work on the compressor can be planned as required and even be carried out preventively by determining the FAD value. The vortex frequency flow meters also enable effective leakage detection in the compressed air network. By eliminating all leaks, the beverage manufacturer can reduce the working time of the compressor and the auxiliary compressor needs to be used only rarely or not at all. The beverage manufacturer can now also quickly identify unfavorable distribution of the compressed air. By optimizing the air distribution, the problem is often solved quickly and without replacing the compressor; in the best case, the pressure at the compressor can even be reduced. Overall, the beverage manufacturer achieved an improvement in its sustainability of around 10 percent, with comparatively little effort and investment.
(Source: KROHNE)

2.3 Monitoring steam and gas networks

In supply and energy management systems, e.g. for steam, compressed air and natural gas, changing process parameters such as pressure and temperature require the use of separate sensors, including energy calculators to enable pressure and temperature-compensated flow measurement. When recording energy consumption, this leads to many different measuring points as well as increased procurement and installation costs – an expense that is often avoided.

For such applications, vortex frequency flowmeters with integrated pressure and temperature compensation and an integrated energy calculator offer a complete solution in a single measuring device. Additional cabling of pressure and temperature sensors via cable trays to the energy calculator is then no longer necessary. By integrating the individual sensors into the flowmeter itself, significantly higher overall accuracy is achieved, which creates a high level of transparency in supply networks. This enables the targeted control of maintenance measures in the energy system as well as system optimization in accordance with energy management as per ISO 50001. The precise measurement supports optimal operation, for example from steam generation through distribution to the consumer. The current energy consumption can be put in relation to the production quantities and support energy-optimized control of the systems.
(Source: KROHNE)

2.4 Monitoring the efficiency of steam boilers

The transition from natural gas to electricity as a heat source in industrial processes is a key component of the energy transition. It is possible to heat directly using electrical energy at the points of consumption, however, in many cases it is more economical to generate steam centrally and to heat with steam at the points of consumption.

This is particularly efficient at high temperatures, provides a high degree of flexibility for the individual consumption points and enables heat consumption and boiler heating to be somewhat decoupled in terms of time and thus to take advantage of fluctuating energy prices. Electric boilers are expected to play an important role in reducing carbon emissions and improving energy efficiency by 2040 rather than using gas-fired boilers.

Electric boilers can convert almost all electrical energy into heat, making them highly efficient, and produce no emissions at the point of use.

Smart sensors are crucial for monitoring the performance of electric boilers by measuring various parameters such as temperature, pressure and flow rate. In addition, smart sensors can use data to predict when maintenance is necessary. They thus help prevent unexpected breakdowns and ensure that the boiler is always operating at maximum efficiency. By externally monitoring the values measured, such as feed water and steam, operators can accurately calculate boiler efficiency. This enables the timely detection of problems, which is crucial for maintaining operational continuity and optimizing energy efficiency. In addition, operators can use vortex flowmeters to directly measure the mass and energy content of the feed water. Elecgtro-magnetic flowmeters improve this even further by monitoring the quality of the feed water through an integrated calibrated conductivity measurement. A combined approach maximizes the efficient and safe operation of the boiler, as the quality of the feed water has a direct influence on the performance of the boiler.

Modern vortex flow meters use the integrated compensation of pressure and temperature to enable simple compensation of mass and energy during steam measurement.
In addition, the measurement and compensation of the steam dry content enables operators to determine the actual energy content of the steam and monitor its moisture content, which is crucial for energy efficiency.
(Source: Endress+Hauser)

2.5 Online monitoring of safety valves

Pressure-retaining systems are protected by pressure relief devices such as safety valves or rupture disks so that excess pressure can be discharged in a targeted manner. These devices function purely mechanically so that no signal is triggered when they open or in the event of a leak. Monitoring is rarely carried out or only by performing pressure measurements, which are too inaccurate to detect the triggering of a safety valve and are also unable to detect leaks. It is therefore often the case that exhaust gas flares or exhaust gas burns are triggered and only then is the gas causing them searched for. This is why this gas is often referred to as “ghost gas,” as it often takes hours to locate the source. The triggering time of safety valves must also be verified from an official point of view. Leaks caused by defective safety valves or rupture disks can result in the waste of large quantities of valuable products and the energy required to manufacture these products. Even a small leak (0.1% of the flow rate of the pressure relief valve) can result in material losses amounting to tens of thousands of euros per year. Therefore, online monitoring of the pressure relief devices would make ecological and economic sense.

As a solution, the Marathon Petroleum Company implemented the non-intrusive wire-less solution with acoustic transducers. They were strapped to the safety valve from the outside during operation, see Figure 4, and record the noise levels of the safety valve and the temperature. The correlation of the acoustic values and the temperature ensures immediate detection of the triggering of safety valves and any leaks are also reported. This means that the status information from the pressure relief devices is available online. This makes it possible to quickly identify which safety valve or rupture disk in the flare system has triggered or is leaking, for example. The system provides the information that needs to be determined for official regulations. In one refinery, 69

wireless acoustic transmitters were installed on safety valves. Within 15 months, over 200 triggers of the 69 safety valves were detected. Of these, three safety valves were open, twelve were leaking and five were blocked by dirt so that they would not have opened fully in an emergency. In addition to the increased safety, there is also a financial return on investment, which was calculated at a few months.
(Source: Emerson Automation Solutions)

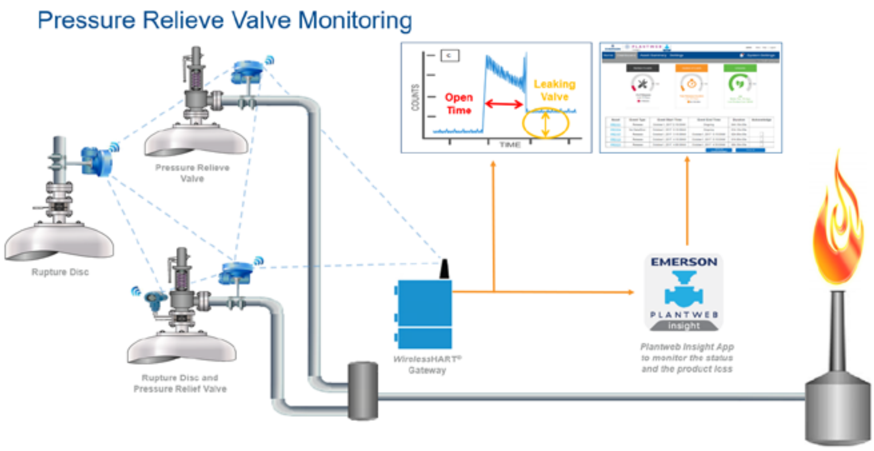

Figure 4:
Monitoring of safety valves on a flare system
(Source: Emerson Automation Solutions)
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2.6 Predictive maintenance for heat pumps

As the world moves towards a more sustainable future, the strategic potential of heat pumps in target industries is becoming increasingly clear. They are highly efficient and provide heat at low to medium temperatures, making them well suited for a wide range of industries, including the food and beverage and biotech industries. Heat pumps can achieve efficiencies of over 300%. They can utilize waste heat and ambient heat and thus reduce the overall energy requirement. However, they are only suited for high-temperature processes to a limited extent and require a higher initial investment compared to electric boilers.

Intelligent sensors play an important role in exploiting the full potential of heat pumps. They can monitor the performance of heat pumps in real time and provide valuable data that can be used to optimize operations according to changing supply and demand patterns and to plan maintenance. Typically, these sensors monitor parameters such as temperature, pressure and flow rate. This data can in turn be used to detect deviations from optimal performance.

In addition, smart sensors can use machine learning algorithms to predict when maintenance is necessary. For example, if the sensors detect a gradual decrease in the efficiency of the heat pump, this could indicate that the refrigerant level is low and needs to be topped up.
By predicting maintenance needs, smart sensors can help prevent unexpected equipment failures and ensure that heat pumps are operating at maximum efficiency and thus further increasing their energy-saving potential.

Flow measurement is a pivotal point in quantifying the recovered heat. Using sensors such as clamp-on or in-line ultrasonic sensors, operators can accurately measure the flow rate of the heat transfer medium. This data is key to calculating the amount of heat recovered and ensuring that the system is operating at peak efficiency. By creating heat balances and detecting changes in specific waste heat recovery, operators can quickly identify problems such as deposits on heat exchanger surfaces that affect efficiency. This proactive approach is crucial to maintaining optimal energy utilization.

The detection of corrosion risks is just as important. By monitoring parameters such as the dissolved oxygen content and pH value, intelligent sensors enable the timely detection of conditions that increase the risk of corrosion. This is crucial for operational continuity, as uncontrolled corrosion can lead to system failures and unplanned downtime.

Together, these advantages form the cornerstone of an energy-efficient and continuously operating heat recovery system, whereby intelligent sensors are the prerequisite for predictive maintenance and optimal energy recovery.
(Source: Endress+Hauser)

2.7 Monitoring heat exchangers

Heat exchangers are used to bring material flows to the desired temperatures with the help of a heating or cooling medium. The heat transfer between the process medium and the heating/cooling medium is ideal if the heat exchangers are not clogged up. Clogging reduces the heat transfer so that more energy is required to pump the process medium and/or a higher pressure loss of the heating/cooling medium occurs, which must be compensated for by increasing the pumping capacity. Even contamination of 2% can cause an energy loss of 10% and a capacity loss of 0.7%. Online monitoring of heat exchangers would therefore save energy, increase the system capacity and save costs.

The condition of heat exchangers can be monitored by measuring the temperature upstream and downstream of the heat exchanger. In most cases, however, only a temperature measurement is available, which is sufficient for regulating production, but not for detecting contamination. A wireless temperature transmitter and, if required, a wireless flow meter can be retrofitted without the need for cabling. A pre-configured application on the automation provider’s website continuously analyzes the process and

system status data and determines an assessment of the system status as a precise percentage. This can be used to derive information on necessary cleaning, costs of lost energy, fouling factors and rates as well as working fields of the heat exchanger and be used for a fact-based decision on measures to be taken. Data transmission via WirelessHART makes subsequent installation cost-effective. The preconfigured app solution calculates the data and, if desired, forwards it to the responsible employees or to higher-level systems, see Figure 5. The solution was installed at the chemical company BASF and had a return time of only a few months.
(Source: Emerson Automation Solutions)

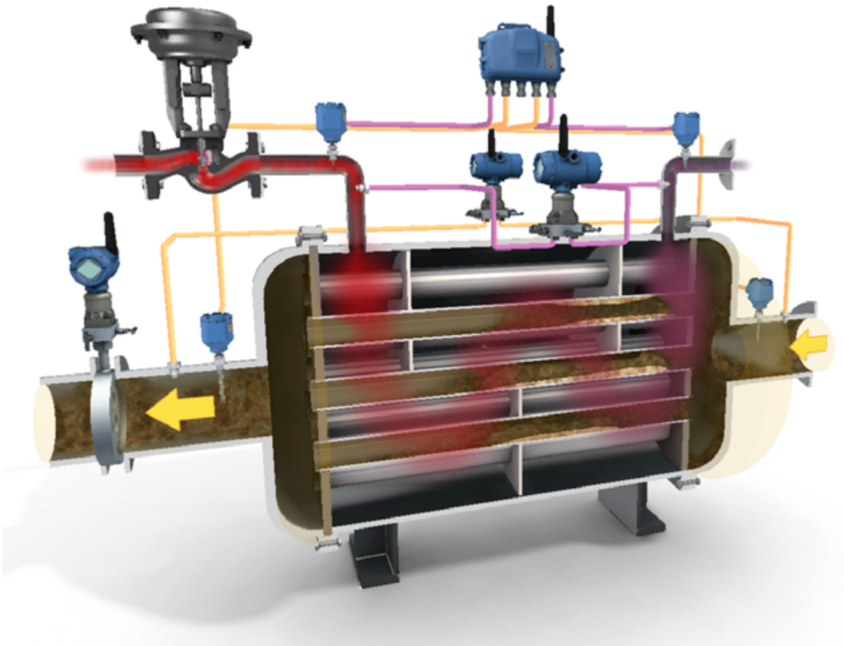

Figure 5:
Heat exchanger with associated PLT facilities
(Source: Emerson Automation Solutions)
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2.8 Online monitoring in a dairy

Dairies receive fresh raw milk every day, which is cooled and temporarily stored in tanks before being processed. The milk is usually delivered around the clock, seven days a week. In this example, the daily delivery volume of raw milk to the dairy is 750,000-800,000 liters. However, before the raw milk can be pumped from the tanker into the storage tanks, its quality must be checked using the pH value. The optimal and quality standard here is a pH value of between 6.5 and 6.7. Lower pH values indicate acidic raw milk in the transport vehicles. If even some of the acidic raw milk is pumped into the storage containers, the entire raw milk stock is contaminated. Further processing is then no longer possible. Consequently, the entire stock would have to be disposed of and all pipes, valves and tanks would have to be laboriously cleaned with chemicals.

On its way from the tanker to the storage tanks, the raw milk passes through a fully automatic pH measuring device installed in the pipeline, see Figure 6. This measures the pH value of the raw milk fully automatically and controls a downstream valve, which directs the raw milk into the storage tanks or stops the pumping. The fully automatic pH measurement not only monitors the pH value of the raw milk, but also analyzes its own performance so that the system is available around the clock. A redundant design of the measurement also allows fully automatic cleaning and calibration of a pH measuring point, while the measurement is taken over by the redundant measuring system. (Source: Knick)

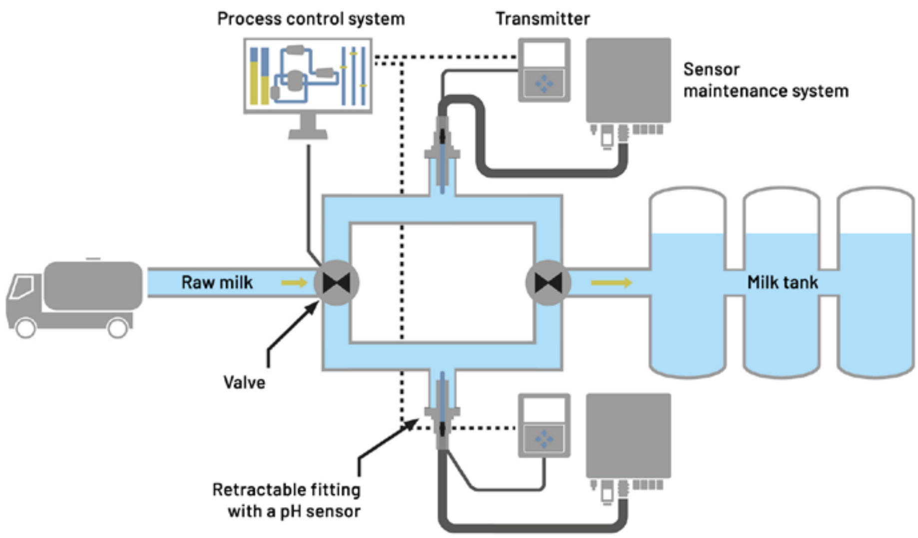

Figure 6:
Schematic representation of fully automatic pH measurement in redundant branches during raw milk delivery
(Source: Knick)

2.9 Corrosion monitoring

Early detection of corrosion and erosion events prevents leaks and ensures process safety and environmental protection. The option of automatic online data retrieval eliminates the need to send personnel to hazardous areas.

Corrosion and erosion monitoring enable proper decision-making in real time, allowing you to maximize the use of your system and achieve maximum profitability. Ageing systems, higher corrosiveness of the process media, stricter health and safety regulations, tighter CAPEX/OPEX budgets and the cost of leakage are common and well-known challenges in the industry

Such a corrosion monitoring system has already been implemented in most refineries in Germany. If cheaper heavy oil with a higher sulfur content is processed there, which entails an increased risk of corrosion, online corrosion monitoring is necessary. The measuring points are often difficult to reach for manual measurements. For this purpose, online monitoring of the pipe wall thickness was installed in the refineries using 270 impact ultrasonic sensors with wireless HART communication. The pipe wall thickness is evaluated via a web server including a prediction of the remaining service life of the pipes. The pipe walls are monitored in real time. A return on investment (ROI) of less than three months was calculated for the projects. (Source: Emerson Process Solutions)

2.10 Recording greenhouse gas emissions

In the EU, but also in other countries, there are now far-reaching regulations for recording greenhouse gas (GHG) emissions. For example, the Implementing Regulation (EU) 2018/20661 stipulates that greenhouse gas emissions from certain installations must be recorded and reported (Articles 1 and 2). This affects installations in accordance with EU Directive 2003/87/EC, Annex I2. These include emission-intensive installations such as refineries, glassworks and large installations for the production of aluminum, steel or cement clinker. An exception is made for plants that are fired with biomass. Various monitoring methods are available for recording, based either on calculation or measurement (Article 21).
The preferred method is a calculation based on material flows, e.g. gas consumption. If the analysis is extended to Scope 2, electricity consumption can also be taken into account. These methods are easy to use because they can utilize the existing data infrastructures of the control system. Their disadvantage is that they are partly based on assumptions. For example, an estimate of CO_2 emissions in cement production is primarily based on the quantity-based emissions from the sintering process in clinker production (i.e. the conversion of limestone to lime). However, dust losses (cement kiln dust - CKD), for example, are neglected. A measurement can correct or even replace the estimated values.

A measurement-based methodology continuously records the concentration of greenhouse gases in the flue gas flow and in any transfer lines between systems. Various technologies are available for performing CO_2 measurement. Non-dispersive infrared sensors in gas analyzers determine the CO_2 content by analyzing the absorption of certain wavelengths of an infrared light source. Chemical sensors are less well suited for industrial Environments, however, due to their short service life. One disadvantage

of sensors is the cost of hardware and regular calibrations. Their advantage is a credible value that has been measured.
(Source: ABB)

2.11 Process analysis technology for recycling

Bayer has set itself the goal of being climate-neutral by 2030 and significantly reducing greenhouse gas emissions in agriculture. At the site in Dormagen, a production plant for the fungicide prothioconazole was expanded with an iron-(III)-chloride recycling plant, see Figure 7. This reduces waste during production and is part of a comprehensive investment of 180 million euros in environmental protection, production expansions, safety and recycling.

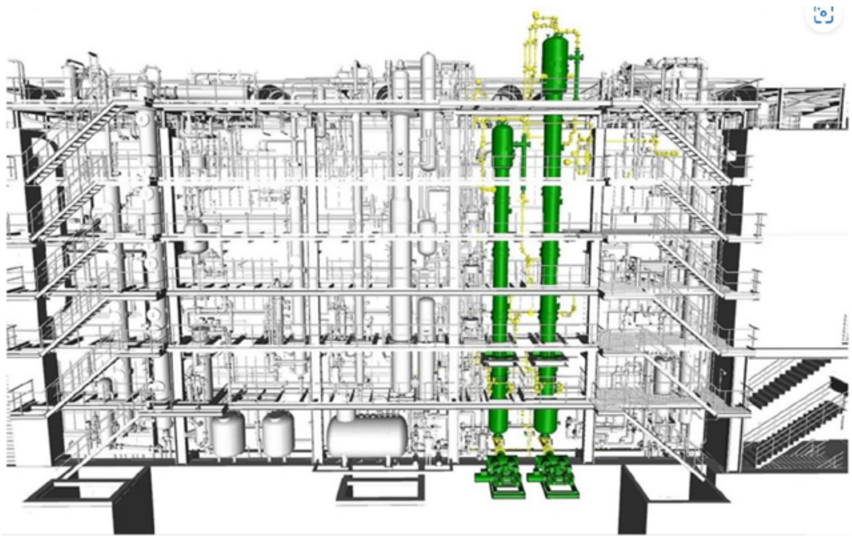

Figure 7:
Production plant for a fungicide with the new iron-(III)-chloride recycling plant (green)
(Source: Bayer)

Due to the complexity of the recycling process, such a recycling plant cannot be operated using only the classic physical sensors (temperature, pressure, liquid level). Rather, the process automation requires a large number of different PAT sensors for both the function and the safety of the recycling process - process analytical technology is an enabler for this recycling plant. Among other things, sensors for pH and redox value and several UV measurements (FeCl2/FeCl3) were used. A titrator for FeCl3 measurement allows near-real-time quality measurement, ensuring operation close to the optimum.

Thanks to recycling, 95% of the iron is recycled and wastewater treatment is also eliminated. This saves 22,000 tons of caustic soda, which was previously needed to neutralize the wastewater, and reduces the use of raw materials and additives. Around 9,000 tons of CO_2 emissions can be saved each year. (Source: Bayer)

2.12 Intelligent control valve with built-in sensors

Control valves are used to control the flow of media: A flow sensor measures the flow rate, a setpoint for the valve's positioner is generated in the process controller and the positioner then applies the appropiate amount of instrument air to the actuator to achieve the desired valve position. An innovative sensor valve integrates ultrasonic flow measurement into the valve body (see Figure 8) and has high-performance electronics that directly control a desired flow rate using a fast control loop. In addition, integrated temperature and pressure sensors provide their measured values, enabling the control valve to monitor itself.

The integration of flow rate, pressure and temperature measurement into a single control valve and a very powerful digital controller results in increased control quality. This improves the material and energy efficiency in a process. In addition, the control valve needs less energy and has a lower pressure loss. The sensor valve has the classic face-to-face dimensions of a valve and does not require straight inlet and outlet sections. This means that systems can be built smaller, lighter and with less material. It is also possible to regulate the flow rate to a specific set point and adjust another physical variable such as the temperature, level or medium composition derived from the flow rate directly by wiring from the external sensor to the control valve instead of using an extra controller.

Thanks to the increased information density and direct processing on site, it is now possible to implement predictive maintenance and even fault-tolerant operation. Another resource-friendly feature is that additional measurement equipment is made redundant in some cases (no additional energy consumption, no further investment in devices and systems, less space required) because additional process variables can be measured using the existing sensors and made available to the asset administration shell. (Source: FOCUS-ON VoF A SAMSON & KROHNE COMPANY)

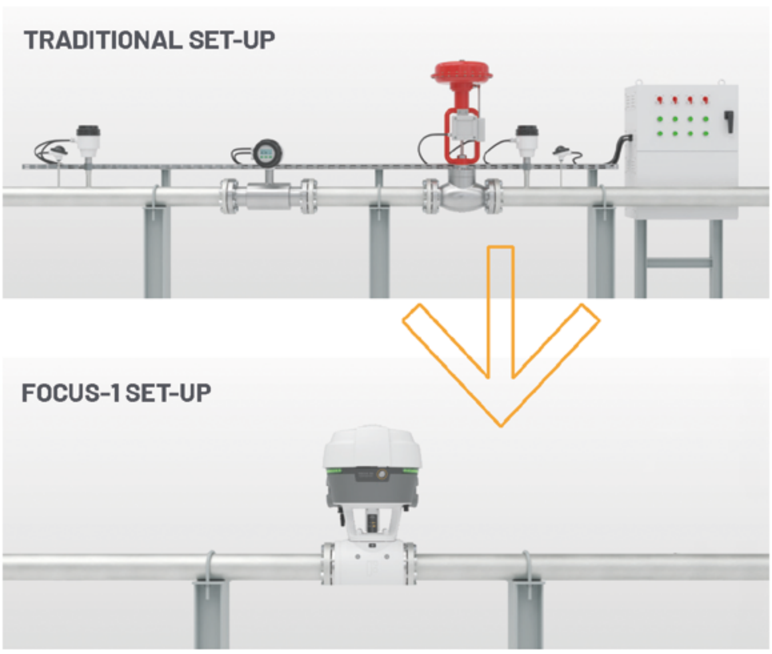

Figure 8:
Intelligent sensor valve compared to conventional instrumentation and control setup with temperature measurement, pressure measurement, flow measurement, a control valve, pressure measurement, temperature measurement and control cabinet (from left to right) (Source: FOCUS-ON VoF A SAMSON & KROHNE COMPANY)

2.13 Saving compressed air through intelligent valve control

Figure 9:
Motion terminal VTEM
(Source: Festo)

Pneumatically actuated valves are often controlled via valve terminals. These control the supply air to pneumatic actuators in order to achieve the desired movements with the help of the respective valve. An innovative motion terminal, see Figure 9, offers intelligent options on the way to "digitized pneumatics." The basic equipment offers the usual range of functions of valve terminals. Piezo valves can be controlled as required and enable precise flow control.

In addition, more than ten additional apps can be activated on the identical hardware via software, enabling high savings, e.g.:

- With an app, the travel times for retraction and extension are specified. The actual travel time is determined automatically, and the exhaust air throttling is adjusted, until the specified travel time is reached. Permanent monitoring and adjustment ensure that the dwell time is kept constant for life.
- In another app, only the pressure required for the respective load is applied. At the end of the work cycle, only the required working pressure is built up. This allows compressed air consumption to be reduced by up to 70%.
- To diagnose leaks, an app determines the pressure drop in the end position. The values are compared with reference values and differences above adjustable limit values are reported. The leakage test is not carried out during operation, but rather in separate test cycles.

The concept of the motion terminal that features standardized hardware and individually compiled apps has many advantages. Engineering and procurement are simple because the apps do not have to be defined from the outset. Spare parts inventory is reduced, and the required apps can be easily reloaded during the production phase and in the event of system modifications.
(Source: Festo)

2.14 Control Performance Monitoring

The complexity of industrial process applications is growing. At the same time, the demands on production targets are also increasing in terms of process reliability, flexibility, product quality and sustainability. In the process industry, control quality is vital to achieving these goals. However, studies show that half of all control loops are not operated satisfactorily. Furthermore, identifying potential for improvement and optimizing control loops is not a one-time task; by changes in production processes and wear this challenge remains ongoing.

Control performance monitoring software records and analyzes information at the system level using specific KPIs (Figure 10) and enables the automatic calculation of new parameter sets to optimize control loops without affecting system operation. At the same time, significant savings are made on the manual work steps required.

Besides increased product quality due to fewer fluctuations in the process variables, an increase in throughput due to more stable setpoint values that are closer to the limit values and improved process reliability due to fewer manual interventions required, the sustainability of production is also optimized. Longer actuator running times due to reduced variability, early detection of defective components and resource savings thanks to improved setpoint tracking enable the system's resource and energy efficiency to be increased.

By using the control performance monitoring software, the company Hamburger Rieger, an operating company, was not only able to reduce manual intervention and increase production stability, but also reduce the consumption of raw materials.
(Source: Siemens)

Figure 10:
Control Performance Monitoring in a chemical plant
(Source: Siemens)

3 Processes and Systems for Sustainability

Section 1.3 explained that climate neutrality can be achieved not only by making minor improvements in process operations, but also requires system modifications or new processes and systems. This chapter contains three examples:

- Clever utilization of waste heat, for example by using heat pumps, leads to significantly improved energy use, but also to more complex control tasks (section 3.1)
- Heating processes previously operated with gas must be converted to processes using electricity, either directly in the process or for steam production (section 3.2).
- The ubiquitous use of hydrogen requires easily controllable production plants (electrolyzers) and applications on an industrial scale (section 3.3).

3.1 Clever utilization of waste heat

The best possible use of waste heat, which is typically available in production processes but has often gone unused up to now, will be a core objective of the sustainable and efficient operation of production facilities in the future. To achieve this, it is first necessary to identify the waste heat potential from cooling requirements in the production process at high temperatures. This includes condensates in steam networks. This waste heat potential should be collected at central points in the plant and at the highest possible temperature for profitable re-use, for example for heating processes or for heating buildings (see Figure 11). Currently used high-value energy such as fresh steam can be replaced or at least reduced through this concept. In the long run, this also helps electrify the heat supply with high-temperature heat pumps, because while direct live steam generation with heat pumps is not efficient due to the high temperature range, heat pumps providing heat to hot water distribution networks is a conceivable option.

While this improved utilization of waste heat is a challenge for process engineering, it also places additional demands on automation. The additional energy flows between the individual heat providers and consumers lead to a meshing of different systems in terms of control technology. This must not lead to fluctuations in the quality and yield of the processes. As a result, more measurement technology and more complex control technology methods such as multi-variable control must be used in the long run. (Source: Bayer)

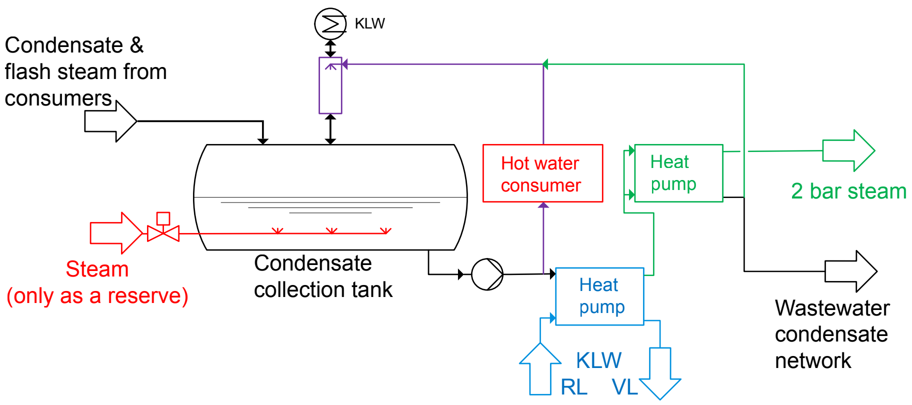

Figure 11:
Example of efficient use of waste heat
(Source: Bayer)

3.2 Electrification of fossil processes

When it comes to the electrification of fossil processes, a distinction can be made between a direct and an indirect approach. In direct electrification, electrical energy is used directly in production facilities to replace fossil energy for heating ("Power-2-Heat") or in chemical reactions ("Power-2-Chemicals"). In the case of indirect electrification, the electrification takes place outside the actual production facilities, e.g., for the production of raw materials ("Power-2-Chemicals") for in-house production by third parties, or for the production of energy sources ("Power-2-Gas," "Power-2-Hydrogen," "Power-2-Fuel"). Climate-neutral production is theoretically possible if electricity comes from renewable sources. To allow for the continuous use of electricity in an energy market with a limited and fluctuating supply of green electricity (e.g. weather-dependent solar and wind power) storage technologies are required.

Heating energy is currently mostly provided by fossil fuels such as natural gas, which is used in steam boilers to generate steam that is used to heat reactors, distillation columns, evaporators, dryers, etc. The use of alternative technologies for heating will therefore have to make an important contribution to climate-neutral production. Such alternative technologies are already known, but their implementation is often delayed for technical or economic reasons, as they can sometimes only be implemented in production plants at considerable expense.

One example of direct electrification of processes is mechanical vapor compression in distillation and evaporation processes (use of the product vapor after it has been compressed to heat the distillation sump). Multi-effect distillation (coupling of condensation and evaporation between different columns in a distillation sequence) can also make a promising contribution to saving energy and thus reducing heating requirements. Heat pumps can also be used to operate distillation plants or drying processes. Replacing steam heating with electric heating or improving operation with electrically powered functionality can also lead to increased process efficiency; examples of this include heating by microwave or infrared heaters and dryers, induction furnaces, ultrasound-assisted extraction or electromembranes. Sometimes it is also possible to replace thermal processes with less energy-intensive techniques, e.g. distillation with a membrane process. Some of these proposals increase the complexity of the processes. This leads to additional challenges in the field of measurement technology, automation, and control as well as the optimization of process operations that need to be addressed.

Whenever direct electrification within the process is not feasible or economical, it is worth considering the infrastructure that supplies the process with energy. Direct electrification of the supply system for (process) heat is possible with two main options, direct electric heating or heat pumps. Electric heaters are available in various sizes and can generate both steam (electric resistance or electrode boilers) and liquid heating media (electric resistance heating). Despite the high efficiency of electric heating systems, economic efficiency must always be taken into account due to the typically higher specific costs of electricity compared to alternative fuels; hybrid boilers, which combine electric heating with fuel heating or electric heating with heat storage to bridge times when green electricity is scarce and expensive, represent a sensible variant. Heat pumps that extract waste heat from a process or from the environment at a low temperature and raise it to the required temperature level represent a more efficient option for generating heat. This requires electrical energy, but typically much less than direct electrical heating. (Source: Bayer)

3.3 Production of "green hydrogen"

Hydrogen is already indispensable for many industrial processes. 80% of hydrogen is used for applications in refineries, ammonia production and the steel industry.

Green hydrogen is hydrogen that is produced with the help of an electrolyzer, whereby the energy required for electrolysis comes from renewable energies. Even if the overall efficiency in the production and use of hydrogen is still poor, there is no way around the use of hydrogen if Europe wants to become climate neutral. The reasons for this are the good storability of hydrogen (in contrast to electricity), its transportability and its high energy density. Hydrogen is a versatile energy carrier that can also be used to decarbonize a variety of sectors – either through direct use or by converting it into renewable downstream products such as e-methanol, e-ammonia or other alternative fuels. In order to contribute to global decarbonization, it is clear that the use of green hydrogen must increase significantly in the years to come.

Hydrogen can also be traded flexibly worldwide by ship, e.g. from countries with high levels of solar radiation or areas with low population density for wind power plants. However, regardless of imports, it is the declared goal of the EU, but also of Germany, to produce hydrogen in Germany with a large capacity. In July 2023, the National Hydrogen Strategy was updated by the Federal Cabinet. The target for domestic electrolysis capacity in 2030 was increased from 5 GW to 10 GW, with the remaining demand to be covered by imports. A hydrogen grid with a length of 1800 km is to be built by 2027/28, and by 2032 all major production, import and storage centers are to be connected to the relevant consumers. The development of technologies for large electrolysis plants is being promoted, with the aim of reducing capital costs by a third in relation to capacity. Electrolyzers require sensors for measuring temperature, pressures, liquid levels, flow rates and analyzers for determining the purity of the gases hydrogen and oxygen.

Traditionally, electrolyzers have been operated in the nominal load range. However, as the electrical energy available from renewable energy sources such as wind turbines and photovoltaics fluctuates, the electrolysis system must guarantee a high level of efficiency over a wide load range, between 25 and 100%, for example. It must also be possible to start up and shut down in a very short time. This can be achieved by selecting the appropriate control valves with a high control ratio and high speed actuation, particularly for hydrogen (and oxygen) outlet pressure control, combined with a high-performance control system. This results in an increase in efficiency, particularly in partial-load operation, which is only possible in this way. (Source: Siemens, SAMSON)

4 Modular Plants

Assembling a machine or system from modules instead of planning it individually from scratch saves time and money. This is obvious and is also used in many industries. In the process industry, the idea of a "modular plant" is only a good ten years old, however. Of course, a modular approach is not suited for large-scale plants, if only because the modules would be too large and too difficult to transport. However, modular plants are a very attractive option for laboratory, pilot plant and medium-scale production plants (e.g. in specialty chemicals or pharmaceuticals). It is not just about saving time and money, but also about flexibility in the event of fluctuating requirements and process improvements: If necessary, bottlenecks can be avoided by "numbering up," i.e. by adding additional modules or by "scaling up," i.e. replacing them with larger modules. Improved processes can often be achieved by quickly replacing modules in the sense of "trial and error" (iteration), see Figure 12

If process engineering modules can be replaced within a few days or hours, or even within minutes in the case of clogged systems, it must also be possible to integrate the software within this time. This is made even more difficult if the modules come with their own control systems, often even from different manufacturers. The concept of the "Module Type Package" (MTP) was developed to enable "plug and play" integration of the modules into operational automation. The various "services" of the modules, their operating screens, their alarms and their status messages are transferred to higher-level automation systems using a standardized file, the MTP file. The system can then be orchestrated there1. The MTP concept is now not only used in the process industry, but also in logistics, laboratories, shipbuilding and the manufacturing industry.
Four applications of the MTP are presented in this chapter:

- Better processes through modular process development and production (section 4.1)
- Application of MTP technology for package units (section 4.2)
- MTP for modular electrolyzers (section 4.3)
- MTP for the smart integration of electric trace heating systems (section 4.4)

Source 1: Thomas Tauchnitz (ed.): MTP Automation of Modular Plants. Essen, Vulkan-Verlag, 2022

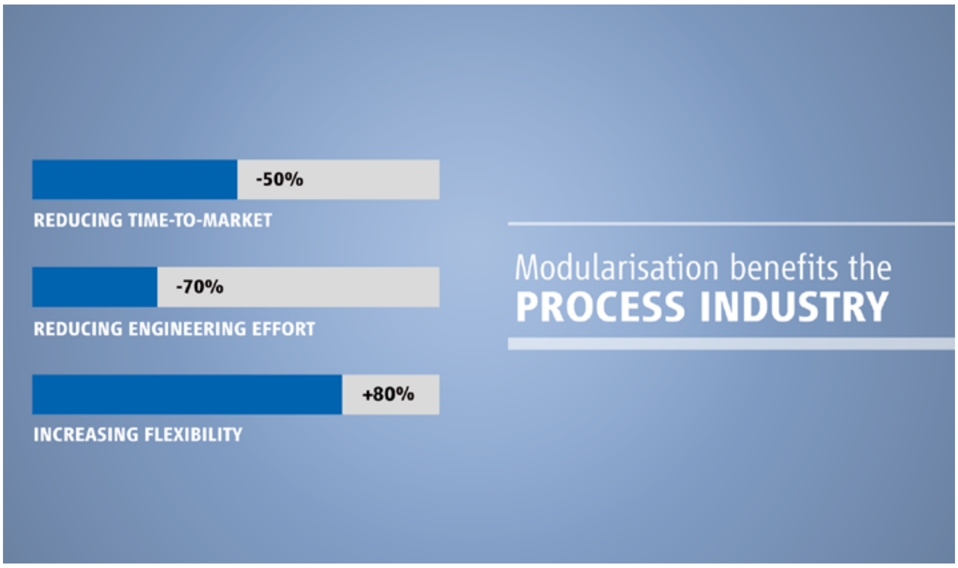

Figure 12:
Modular production is of great benefit to process plant operators worldwide. The MTP concept should therefore be standardized internationally.
(Source: NAMUR; ProcessNet, VDMA, ZVEI)

4.1 Better processes through modular process development

At the Tutzing Symposium in 2009, over 100 experts and decision-makers from industry and science discussed how to cut the time needed to plan and construct process plants in half. It was recognized as an important contribution to this to assemble plants from modules that are as standardized as possible: Not every reactor should be individually planned, simulated and manufactured, but rather by using already defined reactors to drastically reduce delivery and installation times. The repetitive use of the same modules could possibly save time and engineering effort even with the first repetition, but with further repetitions the process definitely pays off anyway. In order to speed up the installation of the system, slightly poorer system performance was considered acceptable.

Dr. Andreas Bamberg, Head of Process & Project Engineering at Merck Electronics KGaA, proved that modularity can lead to better rather than worse processes. The basic idea was to combine modularity with process intensification as early as the process development stage: By working with easily interchangeable modules in the laboratory, different approaches to process optimization can be tested within days. This enables the development and design of robust processes right from the start. The second step, namely moving from the laboratory to the pilot plant or straight into production, is drastically simplified if the processes developed in the laboratory can be transferred to production on a one-to-one basis. This presupposes that the corresponding modules are available in all three scales, i.e. laboratory, pilot plant and production. Modules that are perhaps poorly designed can also be easily replaced in the pilot plant and production, thereby avoiding bottlenecks. All of this contributes to efficient and robust modular systems.

The type of modular process development described here of course also works without the MTP interface of the modules. But if the interfaces for each new combination of modules have to be created with a great deal of engineering effort, the costs increase, time is lost and the willingness to try out better processes by quickly changing modules is drastically reduced. In this respect, the MTP makes an important contribution to the rapid development of perfect processes.
(Source: Merck; an interview with Dr. Andreas Bamberg appeared in atp-magazin 10-2022, p.24ff)

4.2 Integrating package units with MTP

The Module Type Package (MTP) was originally developed for modular process engineering systems. But does it also make sense for "conventional" process engineering systems planned as one-time processes? The answer to this is clearly "yes!" Because conventional plants also use a large number of package units: centrifuges, dryers, filters, presses, packaging machines, blowers and many more. These package units are normally supplied with their own controls and operating screens. This is sufficient if they are only operated on site and no central data storage is required. Sooner or later, there is usually a desire to be able to monitor and operate them from the control room and store the process data in a central historian system. There is also often a desire to integrate the machines into the DCS-supported automation of the process plant so that they can be controlled by the central automation system.

To do this, an interface between the machine control system and the higher-level control system must be configured individually for each package unit: What data must be transferred from the machine and displayed in the DCS? Which functions should be accessible from the DCS? Which warnings, alarms or shutdowns need to be configured? The costs for defining, programming and testing each individual type of machine and control system can be estimated at between €25,000 and €50,000. This money can be saved by using the digital description of the machines by MTPs. If a large plant uses even just ten different machines, the savings from the MTP can amount to up to half a million euros.

In addition to these one-time savings, the use of MTPs for package units has further advantages that also have an impact on the sustainability of systems:

- Package Units can be easily replaced thanks to the standardized interface. If more energy-efficient machines have been developed or the old machines generate too high losses or are outdated, the "old treasures" can easily be replaced with modern machines.
- The MTP interface allows flexible machine utilization. Instead of using oversized machines for possible future or past performance peaks, smaller machines can be used at the optimum operating point and, thanks to "numbering up" or "down" can be adapted to current requirements.
- Modern business models such as "pay per use" or "machine as a service" enable flexible and cost-effective systems.

(Source: Heubach)

4.3 Modular electrolyzers

Electrolysis for hydrogen production is a promising process, but it is known to have high energy requirements. This document examines the energy-intensive nature of electrolysis and shows how energy-saving potential can be exploited through the modular design of the system and the use of the Module Type Package (MTP).

Electrolysis is a process in which water is split into hydrogen and oxygen. The splitting of water requires considerable amounts of electrical energy and the gas treatment to purify the hydrogen produced from impurities is also energy intensive.

The modular design of the electrolysis plant and the use of the MTP as a manufacturer-neutral interface between the automation systems offer solutions to these challenges. Thanks to the MTP, it is not only possible to flexibly assemble the modular system on a physical level, see Figure 13, but also to seamlessly integrate it into the automation technology. Regardless of the automation solution used for each individual module, the MTP provides the required driver. This enables plug & play of the electrolysis plants in the control systems, saves time and prevents errors during integration. From the presentation “QT 5.3 eModule, Modular concepts for operation and automation of electrolysis plants” of the H2Giga consortium for the Status Conference 2023 shows that the integration of a single signal from the electrolyzer requires 1 working hour. Each device is expected to have 300-400 signals. Thanks to the MTP, this effort is eliminated completely. By using the MTP and its modular design, several advantages can be used to reduce energy consumption and increase energy efficiency. Firstly, the modular design allows the system to be scaled quickly and easily. Depending on requirements, the system can be expanded or reduced in size to ensure optimal use of the available energy. This means that energy consumption can be better regulated and adapted to current requirements.

Secondly, the modular design enables more efficient use of the heat energy that is generated as a by-product of electrolysis. With a modular system, this excess heat can be recovered and used for other purposes, such as heating the water supplied to the system or industrial processes. This improves the overall energy efficiency of the system.

The use of the MTP gives plant manufacturers greater freedom in the selection of components, as they are freed from the vendor lock. This allows them to focus on the availability and efficiency of the components in order to optimize the design of the system.

Overall, the modular design of the electrolysis plant in combination with the use of the Module Type Package offers a wide range of options for reducing energy consumption and increasing energy efficiency. These advanced approaches help to further promote electrolysis as a sustainable and future-proof technology for water production.
(Source: Semodia)

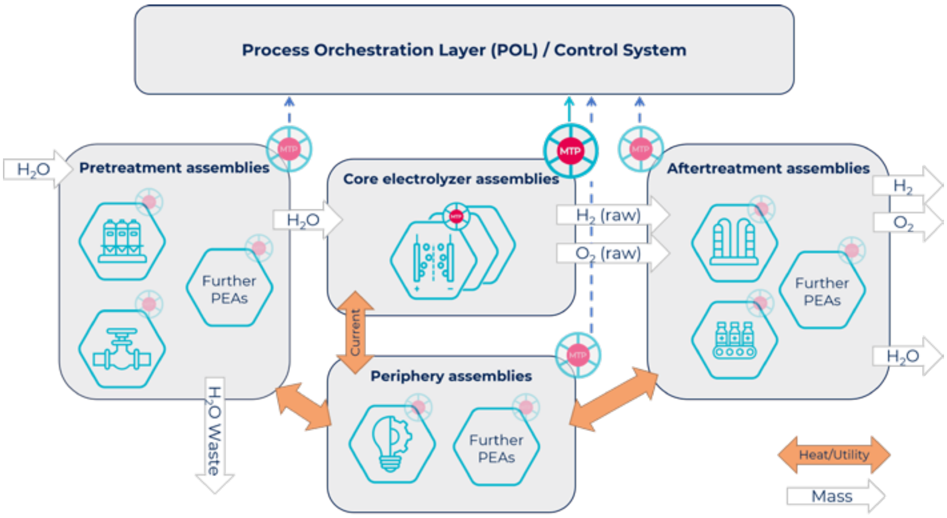

Figure 13:
Highly scalable hydrogen electrolysis processes using MTP technology from L. Bittorf et al, "Upcoming domains for the MTP and an evaluation of its usability for electrolysis," 2022 IEEE 27th International Conference on Emerging Technologies and Factory Automation (ETFA), Stuttgart, Germany, 2022, pp. 1-4, doi: 10.1109/ETFA52439.2022.9921280.

4.4 Smart integration of electric trace heating

In the process industry, pipes often need to be tempered so that the medium they contain has a defined temperature. This prevents the product from freezing in winter or crystallizing, for example. For this purpose, they are fitted with an electric heating tape. The automation of such pipe trace heating systems is not trivial, as it is not only a matter of fast and precise temperature control, but for safety reasons it is also necessary to prevent the pipes from overheating and thus creating a risk of explosion or damaging the product. And the pipe trace heaters must be integrated into the automation of the system, as different temperatures may be required depending on the product or process step.

An international company that offers components and systems in the field of electrical engineering, electronics and automation has developed a reliable and intelligent connection, see Figure 14. Safe disconnection is guaranteed by a safety-oriented control system. Integration into higher-level automation systems takes place with the help of the Module Type Package. The MTP file describes the functions offered, such as temperature control to constant or variable setpoints, defines a user interface, describes the continuously transmitted measured values and lists possible alarms. The temperature is controlled by means of pulse width modulation, enabling high control quality and avoiding energy losses due to large temperature fluctuations. Thanks to the MTP file, the pipe trace heating system can be integrated into the higher-level process automation system in the same way as process engineering modules by means of "plug and play." The control system can therefore be easily adapted to changed processes without having to change the pipe trace heating software.

MTP-compliant process modules such as the temperature control module described here in the form of a heat-tracing box can benefit from the fact that the MTP concept is compatible with the so-called NOA concept (see section 7.1) for monitoring and optimizing systems and devices. The holistic approach opens up new possibilities for monitoring and diagnosing modules and helps increase availability. The NAMUR recommendation NE 184 "Diagnostics and maintenance functions for modular process units" describes suitable diagnostic concepts that can also be used with the trace heating box.

Based on the information about a sensor failure, a heating tape defect or a cable break, the system operator is informed about it being "out of service." Or the maintenance technician is informed that he must include the trace heating box in his maintenance plan. (Source: Phoenix Contact)

Figure 14:
Electric trace heating with control, described in an MTP (source: Phoenix Contact)

5 Innovative Energy Management

You can only control what you can measure. Without transparency, it is impossible to determine the current status, set targets or make plans for improvement. For this reason, many companies are introducing energy management systems in accordance with the ISO 50001 standard. Although this is not mandatory, in Germany it is a prerequisite for important tax breaks such as peak equalization or the limitation of the EEG levy. But regardless of these regulatory requirements, energy management systems help to operate systems economically. This chapter presents useful applications.

- Section 5.1 presents the energy efficiency management system that a leading plastics manufacturer has been using for more than 10 years.
- Energy management systems should not only record how much energy has been consumed, but also help to identify potential savings in ongoing processes (section 5.2)
- Energy monitoring gains in value if it records consumption not only for complex system components, but also down to aggregate level (section 5.3).
- Energy management systems should not only monitor, but also control operation in such a way that as little energy as possible is consumed (section 5.4).
- Determining the increasingly required CO_2 footprint of products ("How much CO_2 is generated during the production of 1 kg of color pigment?") can only be done in an economically viable way with electronic support (section 5.5)
- Section 5.6 shows what an energy management system can contribute to a climate-neutral production site for a company in the electrical industry.
- Complex product and energy flows exist in interconnected sites. Joint optimization requires data exchange via a neutral platform (section 5.7)
- The example of a software suite for the water industry shows considerable savings potential (section 5.8).
- It is important to consider the expected energy consumption when selecting appliances and design must be taken into account. The tool on the vendor's homepage assists the customer with this (section 5.9).

5.1 Energy efficiency management in production

Covestro, a leading manufacturer of high-tech polymers, established an energy management methodology back in 2010 and has continuously developed it further.
It consists of three steps:

- Energy efficiency check
  The processes are analyzed in detail here. Projects aimed at improving energy efficiency are identified, categorized and prioritized based on this information. Action plans are drawn up for the selected projects and their implementation is monitored. The "Plan-Do-Check-Act cycle," which is also required by ISO 50001, is implemented here, forcing continual improvement and documenting it.

- Online energy monitoring
  To actively save energy, system managers need online data on the current energy consumption of their system. The current specific consumption is compared with the best possible practice (Best Demonstrated Practice) and displayed on the operating screens. The employees in the control rooms thus develop a constant awareness of energy consumption.

- Energy loss cascade
  Even if the system is operated with the "best possible practice," this does not mean that the theoretical minimum energy consumption is achieved. To identify and evaluate the various energy losses, four "energy performance indicators" were defined, each related to the production volume.
  (see Figure 15)

  - TEO: The theoretical energy optimum ("ideal process") is the energy consumption of the best known process in the best conceivable infrastructure. According to current knowledge, less energy consumption is not possible.
  - PEO: The plant energy optimum ("ideally rebuilt") is the lowest energy consumption of the chemical process used that could be achieved in a new building, in an environment that is also ideally constructed.
  - OEO: The operational energy optimum ("ideally operated") is the energy consumption achievable in the real system if there were no losses due to product changes, partial load operation, shutdowns or planned deviations from ideal operation.
  - CEC: The current energy consumption ("Measured Consumption").

Thanks to this well thought-out and transparent cascade, all levels of responsibility know what realistic targets they can set themselves for plant operation, plant modifications and new builds and for process development. The normalized energy indicators can be derived from the energy cascades as a requirement of ISO 50001:2018 via the quantified external influences such as temperature influence or partial load.
(Source: Covestro)

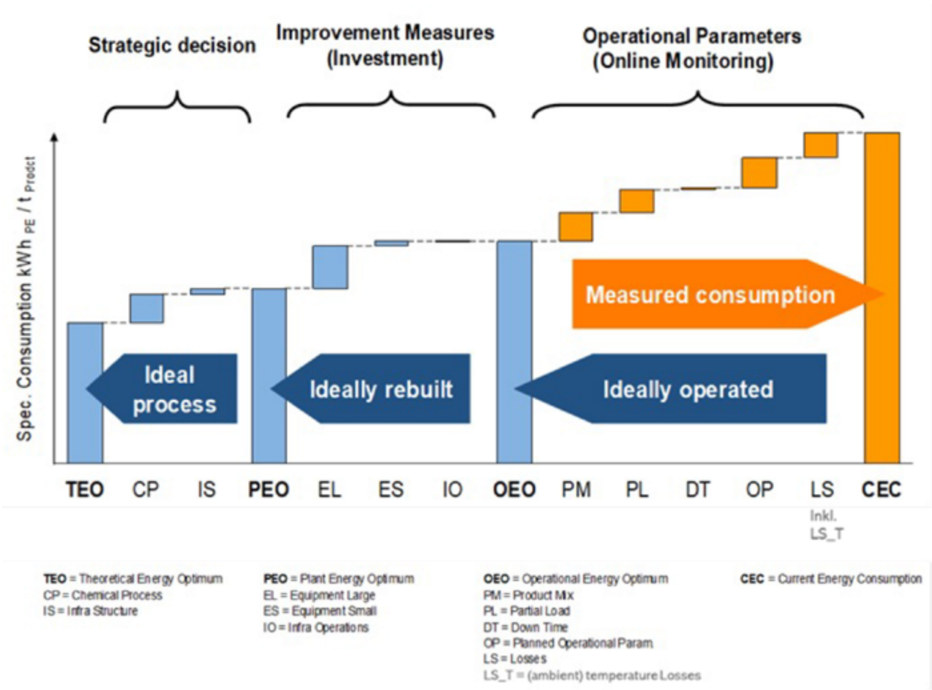

Figure 15:
Energy loss cascade
for production plants
(source: Covestro)

5.2 Exploiting sustainability potential in system operations

A key issue for all sustainability initiatives is recognizing potential and proving that the implementation of measures has been successful. At the same time, it is important to be able to prioritize measures that often require investment. While it is easy in some cases, e.g., if a plant is shut down without replacement or CO_2 is captured with the help of green electricity and fed into a material recycling process, most systems are largely connected and are therefore complex. For example, process engineering production cannot only be characterized by the direct emission of CO_2 but must also take the emissions generated during the production of the raw materials and by the energy used into account. If this consideration is extended to include material recycling and the circular economy, the considerations become more complex, but no less important.

There is extensive material on this topic, in which the structure of key performance indicator systems is proposed: These can be developed very locally for individual devices or plant components as well as covering entire plants or sites. The strong interconnectedness of consumers often results in apparent contradictions that can only be resolved by a consistently aggregated and model-based system of key figures. The results of the EU project MORE, summarized in the NAMUR recommendation NE162 and the book [Krämer, S.; Engell, S. (eds.): Resource Efficiency of Processing Plants. Wiley-VCH, 2017, Figure 16] show how such a KPI system can be set up. Successful industrial implementations from the process industry show that this can make sustainability effects transparent and thus save resources.

If potential for improvement is identified, there are several levels of optimization available. The simplest approach, which can often be implemented quickly, is an improvement through changes in process operations. Typically, energy savings of 3 to 10% can be achieved in an operation that has not yet been fully optimized. More substantial improvements often require larger investments. However, it is important to consistently

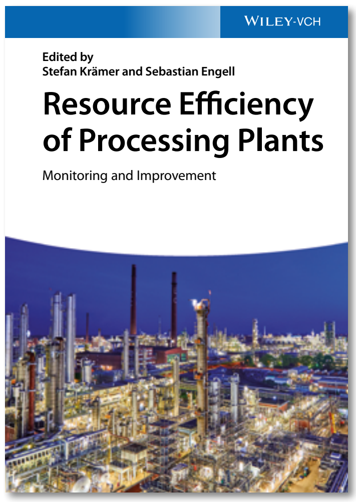

Figure 16:
Book title "Resource Efficiency of Processing Plants"
(Source: Wiley-VCH)
Stefan Krämer and Sebastian Engell (editors): Resource Efficiency of Processing Plants: Monitoring and Improvement, Cover, 2018, Copyright Wiley-VCH GmbH. Reproduced with permission.

maintain the improved operating mode, as we often tend to fall back into old patterns of behavior. To do this, one needs the key figures live during operation.

The Operation Improvement Potential (OIP) is therefore an important measure in the KPI system and the visualization. It displays, for example, the optimal operating status of the system in current operation, which cannot be influenced by the operators, the "Best Demonstrated Practice" (BDP), at the current outside temperature. This is compared with the actual operating mode and the potential for improvement is displayed in real time (see also [NE162]). A comprehensive, coherent system of key figures, supported by simple models, can even reveal possible causes for the suboptimal operating status.

However, the combination of different key figures can also lead to contradictions. For example, it could make sense economically to emit CO_2 even though this contradicts the long-term objectives. There are two approaches to solving this problem with multiple criteria: The metrics are combined in a weighted manner using "resource currencies" or the trade-off is presented on a Pareto front, which supports the decision.

In many large, continuous plants such as refineries, steam crackers or power plants, the Operation Improvement Potential can be increased automatically through optimization and advanced process control by minimizing a cost function. It may even be possible to identify a better operating mode than the previously known optimal operating mode.

Classic indicators that can be used for the OIP include overall resource efficiency, overall material efficiency or overall energy efficiency. Because waste can also be a cost factor and can become a recyclable material flow in the age of the circular economy, the relative waste generation is also very interesting, as it is linked to the necessary raw material input in circular processes. The carbon footprint is also relevant and can also be displayed live. A consistent indicator must be defined here, such as the simple indicator CO_2 emissions per ton of product. This is given to the customer at the time of purchase to determine the CO_2 emissions along the value chain. These factors are particularly important in the circular economy, as material efficiency does not always have to coincide with CO_2 efficiency.

Chemical production processes are typically strongly coupled and production resources are organized hierarchically (plant, system, sub-system, ...). The statement of an efficiency indicator related to only one individual resource can be misleading, as improvement effects in one resource can simultaneously mean deterioration effects in a linked resource. The net effect of a measure, e.g., a change in operating mode, must therefore always be considered in the overall context of a production site or even across sites, without losing the possibility of targeted impact analyses down to the level of individual aggregates.

In addition to the OIP method, the aggregation principle is another important basic principle of the recommendation for calculating efficiency indicators described in the NE162. Based on a known hierarchical plant topology and the description of the energy and material flows between the plants and sub-plants at the site, plant operators and production managers can be provided with an automatic overview of the energy and material flows via dashboards. The resulting cause-and-effect analysis can subsequently be made available. The prerequisite for this is that all relevant energy and material flows can be modeled in the direction in and out of the balancing volumes and that the associated measuring points and calculation-relevant characteristics of the individual flows (such as enthalpy parameters) can be assigned to the structural models.

INEOS operates one of the largest petrochemical sites in Europe in Cologne. INEOS has been using the benchmark and aggregation method in accordance with NE162 since 2018 to calculate key figures both retrospectively as part of ISO 50001 reporting and operationally to evaluate and visualize current energy efficiency for the purpose of economically and ecologically optimized plant operation. At INEOS in Cologne, dashboards are made available in the control rooms to transparently display the current potential energy savings that can be influenced by plant operators (Figure 17). For this purpose, the hourly averaged operation improvement potential figures (OIP) are visualized in the form of color-coded tiles and displayed with detailed information on the trends of individual energy figures compared to the benchmark values applicable in comparable operating situations. By describing the energy and material flows of the entire site in a hierarchical structural model, a top-down analysis can be used to identify the systems or sub-systems causing significant improvements or deterioration and to initiate countermeasures.

Figure 17:
Dashboard for visualizing currently usable energy efficiency potential (source: INEOS)

The goal of the following example is to understand the energy consumption of a Bayer batch process per batch or per day and to identify influencing factors. The Energy Performance Indicator uses existing (live) measurement data to correlate consumption and product quantity. Multivariate data analysis is used to correlate these indicators with the outside temperature, for example. The results can be seen in Figure 18: Short process durations and large approaches are more efficient at higher temperatures. (Source: INEOS, Bayer, LeiKon. First publication: [Source 1])

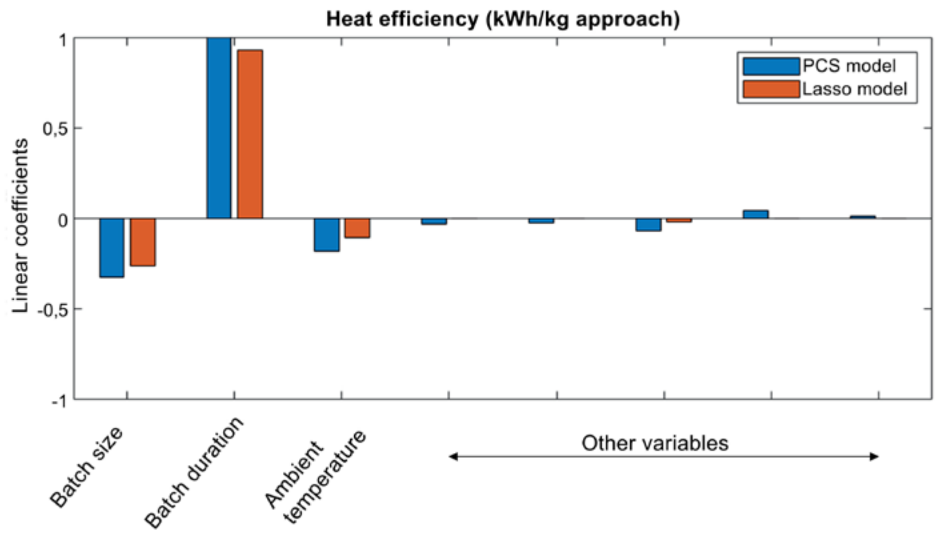

Figure 18:
Linear coefficients of a multivariate data analysis using PLS and lasso regression for the heating efficiency of a batch apparatus (source [1]) [source 1: Buss, F., Kalliski, M.; Kochenburger, T.; Förtsch, D.; Krämer, S.: CO_2-Neutralität und Energieeffizienz. atp magazin 2022-03, p.58-67]

5.3 Energy and CO_2 monitoring down to the aggregate level

To enable smart energy management for maximum sustainability, the first step is to record consumption on the basis of machine status and production meters and prepare it transparently for comprehensive analysis using meaningful KPIs. The resulting optimization measures are the basis for a sustainable transformation.

A resource forecast at plant level based on previous data allows production to be planned more efficiently and consumption and the resulting CO_2 footprint to be verified. Additional flexible resource management that can quickly adapt to changing customer and environmental requirements, peak and base load management and the flexible integration of renewable energy sources help to accelerate the increase in efficiency of the plant and meet international standards and norms.

Saving energy in complex processes such as those in the process industry requires a good understanding of the details of the production process. For example, it is not always clear why similar lines or successive batches consume different amounts of energy. It is also important for standards such as ISO 50001 to identify systems and components with high energy consumption and thus understand specific potential savings. This potential can then be realized as part of an ongoing improvement process. In addition to savings, ISO 50001 certification can also mean savings on levies and taxes (e.g. in connection with the EEG).

Monitoring energy consumption and process data is one approach to implementing CO_2 monitoring (see section 5.5) For example, the Corporate Sustainability Reporting Directive emphasizes the importance of reduced energy consumption and higher energy efficiency and identifies energy indicators as an essential component of sustainability reporting [source 1, p. 16]. Appropriate data analysis tools can intelligently record and provide the data for this.

From a technical point of view, monitoring down to the aggregate level is possible with a known system structure and existing measurement technology. Many energy management systems are certified in accordance with ISO 50001 and can monitor energy flows and consumption values of processes and assign them to the respective consumers or cost centers. Typically, this is also possible across locations in order to realize improvements at the company level. These systems work with dashboards and key energy figures and can interact with other components via technologies such as OPC UA.

As a concrete example, thanks to the implementation of an energy management system, a company in the glass industry achieves savings in the double-digit million range per year through peak equalization and the EEG levy. The optimization of production, the possibility of weighing up investments based on energy consumption and automatic and convenient reporting are further benefits for the customer. Savings in the tens of millions of euros per year can be expected.
(Source: ABB, Siemens)
[Source 1: Directive (EU) 2022/2464]

5.4 Active energy management system

The energy supply of the future can be made sustainable, environmentally friendly, safe and economical by employing flexible and intelligent energy management. A high degree of flexibility is crucial in order to implement efficient processes regardless of location and size – whether for industrial and commercial customers, energy producers, virtual power plants or in the intelligent power supply of charging stations.

A comprehensive energy management system must be at the heart of energy-efficient site optimization. With such smart technology, all energy flows can be automatically measured, monitored and controlled in real time to conserve resources. Excess energy produced is stored or fed into the public grid. This saves CO_2 and at the same time is aimed at achieving maximum energy self-sufficiency.

Energy efficiency is thus becoming an alternative and attractive resource. This new data and information transparency is rapidly gaining in importance for more and more companies as part of the required sustainability reporting.

One solution for industry follows a multi-stage optimization approach that enables industrial plants to significantly reduce CO_2 emissions, save energy costs and increase the degree of self-sufficiency from the grid without affecting operations.
From the second step onwards, it is no longer just a question of monitoring, but of active suggestions and interventions in the systems in order to achieve direct energy savings.

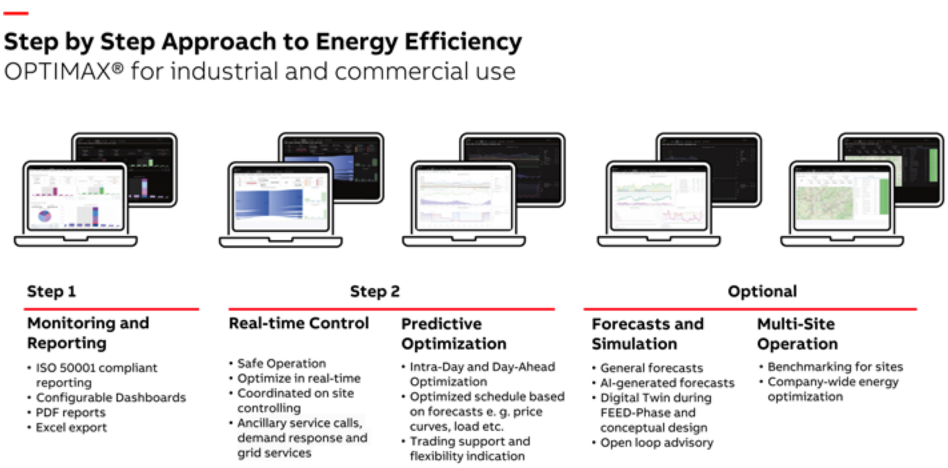

Figure 19:
Multi-stage optimization approach for CO_2 emissions from industrial plants
(Source: ABB)

Due to the many interfaces, optimization software can be linked to current systems and is manufacturer- and system-independent. The flexibility of the solution enables nearly unlimited integration and expansion. Whether electricity, heat, steam or hydrogen: the learning system knows the individual energy sources and consumption, takes weather forecasts and daily energy prices on the market into account.

An energy management system offers day-ahead optimization based on weather and load forecasts. Based on the data obtained, the intelligent system can automatically control flexible loads, generation units and storage systems. The energy available is distributed optimally and cost-efficiently so that all production processes run smoothly despite the savings. Energy resources are then coordinated in real time to balance supply and demand through dynamic load shedding. By optimizing supply and demand, industrial sites can easily add low-cost, renewable energy without compromising grid reliability or stability. Ideally, under favorable price/production conditions, even surplus energy production and spare capacity can be sold and fed into the grid.

The energy management system is an investment that pays off quickly for industrial plants. It collects and reports consumption information and thus reduces the time required for regulatory reporting – as required by ISO 50001, for example - by up to 50 percent. It also has visualization tools and dashboards that can be used to identify a site's hidden energy-saving potential. Further savings are achieved through the continuous optimization of various energy resource options, load and market dynamics, as well as volatile systems such as solar PV, EV charging stations or large storage hardware - for the economic benefit of the company and to protect the environment.
(Source: ABB)

5.5 Creating a CO_2 footprint in the value chain

Due to increasing customer requirements, the special attention of investors and ever stricter regulatory provisions, industrial companies are faced with the major challenge of seamlessly recording the entire CO_2 footprint of their products, known as the product carbon footprint (PCF). The major challenge here is that emissions occur at all stages of the supply chain and therefore not only have to be recorded locally, but also exchanged between companies and added up. In most cases, average values are currently used to calculate emissions, but these only provide static information. However, in order to actually be able to make data-based decisions for effective reduction measures, a dynamic PCF is required that reflects the real, current CO_2 values on site and is aggregated along the supply chain.

A software package enables the cross-company and secure exchange of dynamic, constantly updatable data along the entire value chain. The data sovereignty of all parties involved is paramount and sensitive information remains protected. The option of voluntarily verifying emission values at every stage of the value chain creates additional trust. The scalability of the PCF data exchange in the entire chemical industry is currently being tested in a pilot project. This would be a decisive step towards decarbonizing the sector.
(Source: Siemens)

5.6 Climate-neutral production site as a goal for companies

With a virtually climate-neutral production site, a company in the electrical industry shows how the energy transition can succeed without sacrificing profitability (Figure 20). Smart energy management and cross-sector networking make this possible. In practice, it shows how the idea for a self-sufficient energy supply of the future, which is independent of industry and company size, works.
The unclear development of energy prices and the decarbonization of companies and industries are leading many companies to rethink their approach. To save costs and become less dependent on volatile energy markets, more and more companies are simply generating the energy they need themselves. In terms of sustainability, renewable energies are becoming increasingly important.

Innovative technology solutions make it possible to reduce emissions and develop new economic energy models. This requires holistic solutions that consider all aspects of energy generation, storage and consumption in the plant or company - across all sectors. In the production site of the future, all components are digitally networked with one other through the energy system and can be controlled and optimized. This intelligent networking and control turn energy efficiency into an alternative resource.

The resulting benefits are demonstrated by the current earnings data from a nearly CO_2 -neutral and energy self-sufficient production site in Germany:

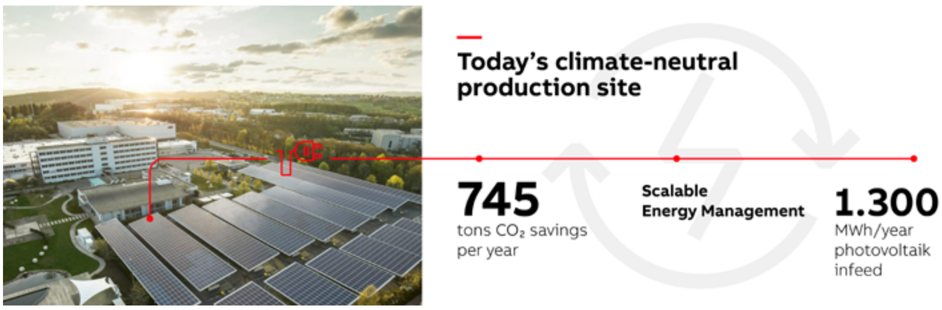

Figure 20: Climate-neutral production site (source: ABB)

A comprehensive site management system is used at a production site. Thanks to this smart technology, all energy flows can be measured, monitored and controlled automatically in real time to conserve resources. Any surplus energy produced is then fed into the public grid. The results speak for themselves: the CO_2 savings are above the target expectation. In 2022, between 1,100 MWh and 1,300 MWh of the planned 1,100 MWh were produced. The ROI has been significantly reduced from 8 years to 6 years.

5.7 Energy management in the chemical park network

The various plants of several companies in a chemical park are often combined into a network via various product flows. They are supplied with several forms of energy by the chemical park operator, electricity, gas, steam, pressure or cooling water, for example. The chemical park operator either generates these energies himself or purchases them from public suppliers. This close material-based connection is contrasted by data silos. Each plant operator uses his own system for production planning and energy management. Information exchange between plant and chemical park operators usually takes place via paper or e-mail.

Energy optimization can only be achieved by taking the plant operator's production planning into account. For example, typical steam generators need twenty to thirty minutes to reach a different operating point. If no forecast data is available, the chemical park operator must keep the steam available for possible changes in the plant operators' requirements. Electronic information exchange is particularly necessary for the expected dynamic sales prices for individual energies. A chemical park-wide data space is therefore necessary for sustainable chemical production with the lowest possible energy requirements and strong resilience.

NAMUR Open Architecture (NOA) is ideal for connecting production planning and energy management systems to a data space. NOA was originally developed as an extension of the automation pyramid for secure networking between OT and IT networks. The same principle can also be used to protect the networks of the individual operators against unauthorized access from the chemical park's data space.
(Source: ABB, Yncoris)

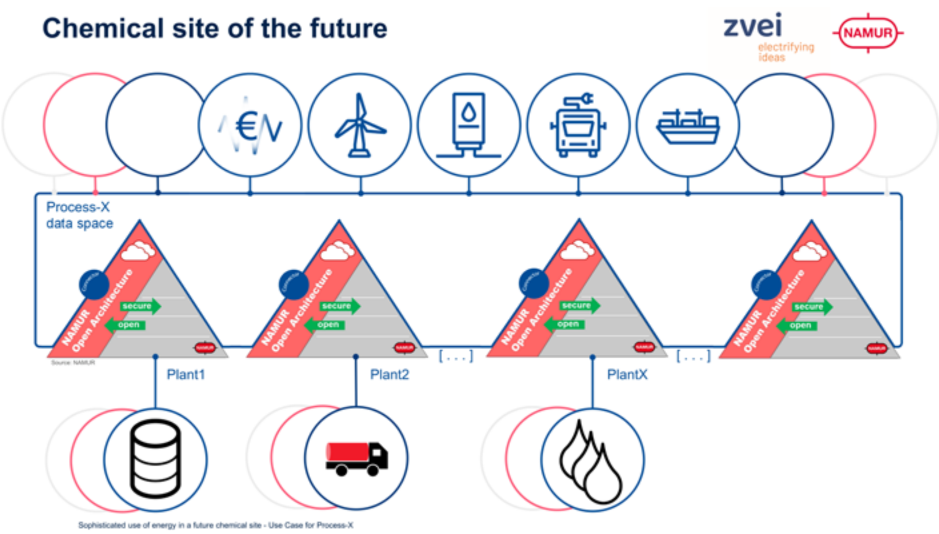

Figure 21:
Energy in the chemical park network - use case for Manufacturing-X
(Source: ABB, Yncoris)

5.8 Application for the water industry

An optimization suite has been developed specifically for the water and wastewater industry to optimize operations based on real-time data. This enables water supply companies to increase energy efficiency, minimize water losses, reduce pollution, and improve predictive maintenance. The suite not only helps to conserve water resources, but also to save energy and CO_2. Two applications in the suite use artificial intelligence methods and are described briefly below:

- **Optimization**
  This app helps water supply companies to fully automatically optimize pump schedules in a supply network, taking volatile electricity tariffs, varying costs and the availability of water supply sources into account. In addition, it enables the optimization of individual pumps or groups of pumps, taking mechanical and hydraulic parameters into account. Optimized pump operation can reduce energy costs by 5% - that doesn't sound like much, but the water industry is one of the largest consumers of energy in the world, consuming 14%.

- **Leakage detection and localization**
  The AI-based application is used to detect and localize leaks in drinking water networks based on real-time monitoring. As a result, water supply companies can not only reduce water loss, but also save energy and ensure water quality. For example, a Swedish water supplier with a water loss of more than five million cubic meters per year can save energy and resources with the help of this app, in particular by detecting and localizing small leaks, which are responsible for the lion's share. (Source: Siemens)

5.9 Sustainable design of pneumatic equipment

The CO_2 footprint of a component is made up of three components.
- The CO_2 footprint in the direct production of the component,
- The CO_2 footprint "upstream," i.e. at the suppliers of the materials used in the components.
- The CO_2 footprint "downstream", i.e. at the plant operator.

Of course, the component manufacturer can only provide the first two values. The system operator is responsible for determining the component utilization.

If a buyer only compares the CO_2 footprints of the production and the upstream determined by the component manufacturer to select a device, they clearly fall short. This is because if the component is used for many years, the energy requirement in the life cycle can cause much more CO_2 than the production. This must be examined in each individual case. However, the calculation is complicated because the energy requirement depends very much on the design of the application and the operating mode of the component, and the CO_2 footprint of the energy used by the operator.

A leading supplier of pneumatic and electrical components offers a Solution Finder for its devices that determines the CO_2 footprint and energy consumption per year for the respective task for various solution variants (electrical/pneumatic in addition to the individual customer price. CO_2 emissions and energy consumption depend, among other information, on the working stroke, maximum payload, required pressing force in the end position and the number of cycles. The Solution Finder makes it possible to compare the electric vs. pneumatic drive technology options. However, the respective operator must still evaluate CO_2 emissions and energy consumption with their respective costs in order to calculate the "Total Cost of Ownership." Other dependencies, such as supply pressure, torque reserve or oversizing, must also be taken into account.

On the one hand, this example shows the complexity of evaluating sustainability, but on the other hand it also illustrates the importance of good support for the decision by the manufacturer.
(Source: Festo)

(Note: More information on this topic can be found in Jikadra, K.; Ortwein, A.; Roos, E.: Der Weg zur klimaneutralen Produktion. Atp magazine 2023-03, p.52-59)

6 Digital Twin

The implementation of Industry 4.0 is inconceivable without the concept of the digital twin. The digital twin is the “digital representation,” the replica of a real object.
It comprises all the digital data available about the object. For a long time, this was a rather theoretical concept, and there were different ideas about what a digital twin should contain or be able to do. Now, however, after intensive detailed work, there is a standardized data model that can be used to digitally map all aspects of a real component, the Asset Administration Shell (AAS). An international standard for the AAS is currently being developed (IEC 63278-1).

The data model is implemented in sub-models that are intended to successively cover all facets of a component, such as identification, documentation, approvals or certificates. However, it should also be possible to document the use of a device and maintenance measures. Care is always taken to ensure that public standards are created or integrated, such as the digital nameplate and identification link (IEC61406) or the documentation standard according to VDI 2770. In this way, the Asset Administration Shell is suited as a universal data exchange format across manufacturer and operator boundaries and makes it possible to achieve the digital twin of entire systems.

An information and status image of the system is an important enabler for increasing sustainability, as will be shown in the application examples.

In this chapter, applications of the digital twin in the process industry are mentioned that serve to save energy and increase efficiency:
- A training simulator for the system and process control system shortens commissioning and enables process improvements to be tested using the simulation (section 6.1)
- The digital twin of a pipeline enables the detection and location of leaks and energy-optimized operation (section 6.2)
- The CO_2 footprint of complex components can be determined and communicated automatically thanks to standardized sub-models (section 6.3)
- The pump control in a re-cooling plant can be optimized using a digital twin (section 6.4).
- The NOA concept (see section 7.1) makes it possible to automatically transfer data from field devices to engineering systems. This eliminates outdated documentation with its risks to safety and availability (section 6.5)
(source: Knick)

6.1 Training simulator as a digital twin

When a system is set up or operated, all the data on the process, the system and its automation is known. If this knowledge is available in digital form, this is the digital twin. This enables a simulation of the plant, not only of the process, but also of the plant automated by a control system. A training simulator represents a very useful application of this simulation option.
This consists of the dynamic model of the process, a simulated (emulated) process control system as a place for the training participant and a workstation for the trainer where he can specify the training tasks.

Many companies in the chemical industry use training simulators for all major projects. They have great advantages for new plants, but also for existing plants:

- In the case of new systems, they enable the system operators to be trained during the project period. Employees can practice regular operation, start-up and shutdown as well as load changes at an early stage. Process automation can test the software for controls and processes on the simulation and even optimize the settings of the controllers and alarm limits. Production can use the simulator to gain an understanding of the dynamic behavior of the system and therefore create the necessary operating instructions in a practical manner.
- A training simulator enables new employees to be well trained during system operation. Experienced plant operators can also be trained in infrequent start-up and shutdown procedures and, above all, on how to act in the event of malfunctions, just as is customary and prescribed in aviation. Process automation can test changes and optimizations to software and parameterization without disrupting the running system. An important and sustainable example is that simulation helps with the implementation of modern controls, such as model predictive controls, by testing them before go-live and building confidence in the operations team. Production can carry out case studies and evaluate process improvements or expansions. And all this while production is running normally and independently of the production plan.

Users of training simulators report very successful commissioning: a large-scale plant is often commissioned in 4-6 weeks; all controls function as expected and regular operation can be started early. The significant shortening of the commissioning phase has great economic advantages, enables early market supply with advanced products and avoids the energy and raw material consumption and emissions of a long commissioning phase. Even during plant operation, the constantly well-trained operating team contributes to the availability, flexibility and safety of the plant and changes and optimizations are only carried out after performing realistic tests. This is why a training simulator is an important companion in the sustainable life cycle of a chemical plant.
(Source: Covestro)

6.2 Digital twins for pipeline monitoring

Digital twins can be used not only in engineering and for system simulation, but also for other tasks. For example, a manufacturer of industrial sensors uses them for various pipeline monitoring applications (Figure 22). One of these applications is leak detection using the E-RTTM- Technology. E-RTTM stands for Extended-Real Time Transient Model, which extends a feature generation module with a signature analysis with leak pattern detection. An E-RTTM leak detection system creates a digital twin of a pipe based on the data measured and pipe and fluid properties. The technology uses the values of flow, temperature and pressure meters measured to calculate flow, pressure, temperature and density at each point along the virtual pipeline. The model then compares the flow values calculated with the actual values from the flow meters. If the model detects a flow discrepancy, the leak signature analysis module determines whether this was caused by an instrument error, a creeping leak or a spontaneous leak.

Besides detecting and locating leaks in order to reduce losses in pipelines to a minimum, systems based on a pipeline model provide additional information about the operation and behavior of the pipeline. This includes information for the predictive maintenance of pipeline segments, survival time analyses of gas pipelines and batch tracking calculations to reduce product rejects, for example.

The manufacturer of industrial sensors has also introduced an innovative solution for efficient transportation planning and training in control rooms. This cutting-edge technology not only enables pipeline operators to simulate planned operating scenarios and accurately assess their safety and efficiency using digital twins of their pipelines. It also provides real-time forecasts of pipeline behavior, 48 hours in advance, for example, and gives early warning of impending challenges. This includes the detection of potential problems such as over- or underpressure, supply bottlenecks or deviations from contractual requirements. In addition, the technology enables the optimization of pipeline efficiency and minimizes the risks associated with incorrectly planned maintenance measures. With the help of digital twins, pipeline operators gain better insight into operations to make sound decisions and ensure the smooth and safe operation of their pipelines.
(Source: KROHNE)

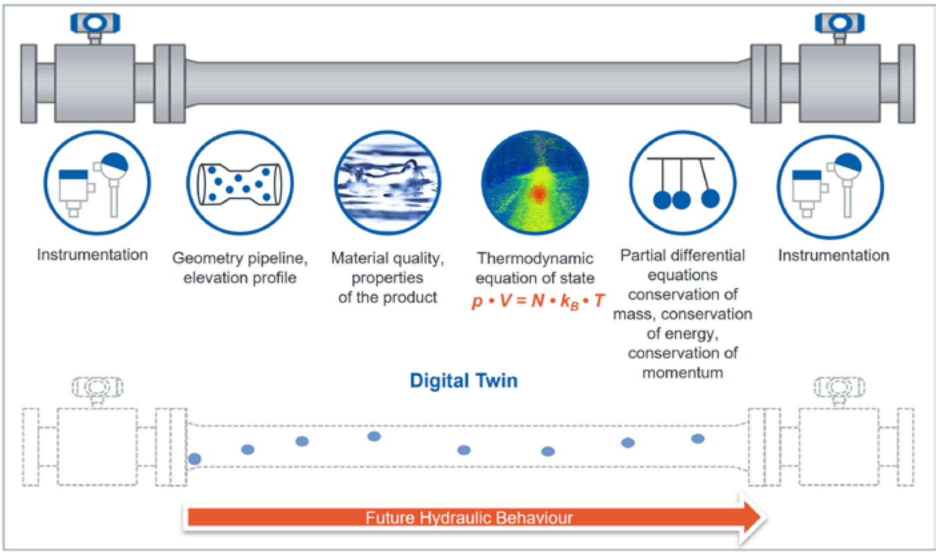

Figure 22:
Applications of the digital twin for monitoring a pipeline
(Source: KROHNE)

6.3 CO_2 footprint of an electrical enclosure

The CO_2 footprint (Product Carbon Footprint, PCF) plays an important role in assessing the sustainability of a system (e.g. a machine). However, if a system is assembled from many supplied components, each of which has its own CO_2 footprint, determining the overall PCF of the machine is very time-consuming and requires an automated solution. The digital twin provides the basis for this as it contains all the data on these components in electronic form.

With the "PCF@Control Cabinet" showcase, the ZVEI has demonstrated how the asset administration shell can help here. A control cabinet consisting of many components such as the housing, the control gear, the switches and protective devices serves as an example. All components are identified via the identification link in form of a QR code in accordance with IEC 61406. The "Digital Nameplate for Industrial Equipment" sub-models with the nameplate data and "Carbon Footprint" with the CO_2 footprint of the component are contained in the asset administration shells of the respective components. The PCF of the enclosure is then determined using the identification links of the components during planning or at the latest when the enclosure is assembled, e.g. by scanning the QR codes. This is then used to provide the nameplate data and the PCF of the finished enclosure to the operator.

The ZVEI showcase "PCF@Control Cabinet" was presented at the Digital Summit in December 2022. Among the participants were Federal Chancellor Olaf Scholz and Minister of the Interior Nancy Faeser, see Figure 23.
(Source: ZVEI)

Figure 23:
Prof. Dr.-Ing. Dieter Wegener, Spokesman for the ZVEI Industry Management Committee 4.0 presents the PCF@Control Cabinet at the Digital Summit in December 2022. Participants: Federal Chancellor Olaf Scholz, Transport Minister Volker Wissing, Minister of the Interior Nancy Faeser and Anna Christmann, BMWK Commissioner for the Digital Economy
(Source: ZVEI)

Note: the white paper "ZVEI-Show-Case PCF@Control Cabinet" (in English) can be downloaded from the ZVEI website (https://www.zvei.org/presse-medien/publi- cations/zvei-show-case-pcfcontrolcabinet-whitepaper)

6.4 Digital twin for a recooling plant

Figure 24:
Digital twin for a recooling plant.
(Source: Infraserv Höchst)

Successful pilot project: a digital twin saves 411 megawatt hours at this recooling plant.
© Infraserv GmbH & Co, Höchst KG, 2023

The energy-optimized control of a recooling plant in an industrial park (Figure 24) with the support of a digital twin of the pump control is yet another successful example.

"With the help of Artificial Intelligence and machine learning, we can find hidden patterns in data that help to optimize plant operation and availability," explains a data science expert at the industrial park site operator. Statistical methods and mathematical algorithms are used to exploit the full potential of the data obtained. The team analyzed and interpreted fine-grained data from the pumps used in the recooling plant over the course of an entire year. This revealed that the pump control could not yet be geared towards energy-optimized operation. Energy savings potential results when the demand for water can be met with a lower output. Wear and energy consumption can be reduced significantly if the speed of the flexible pump with frequency converter is favorable, and the pump is switched over in good time. For the energy-optimized control of the recooling plant, the system was recreated as a digital twin - i.e. as a virtual representation of the system. The mathematical algorithm now shows the optimal pump combination for the respective demand in order to operate as energy-efficiently and pump-friendly as possible. Components such as built-in dampers or pressure restrictions are also taken into account, depending on the requirements. The virtual simulation of the recooling plant can be compared to a mathematical modular system and can therefore also be transferred to other systems. The methodology developed is currently being rolled out to other recooling plants.

"Basically, the process control systems used so far have only been designed to ensure operation. Despite years of experience, our colleagues on site had no chance of identifying the potential for optimization," the site operator explains. "By using data science, we can now take much bigger steps and work in a much more targeted way," said the refrigeration/cooling/water operations assistant involved in the project. "The program serves as a support tool and is an effective method of using energy efficiency in routine operations to save time."

Extrapolated to one year, the savings achieved correspond to 411 MWh. Expressed in CO_2: 173 tons per year. Savings of 2.6% to 5.6% of emissions – depending on the annual requirements. A considerable figure that could be achieved without any technical investment.
(Source: Infraserv Höchst)

6.5 Digital twin always up to date “as built”

Currently, the internal data from field device information, which enables statements to be made about the status of the device (so-called vital data), represents a largely unused but very important resource for reliable and efficient operation. Currently, in most cases only the primary measured values of the sensor, which usually describe the process data, are used. Use of the device information elsewhere was never intended and is not possible with the 4-20 mA current signal.

During ever deeper networking, it has now been recognized that the wealth of information within a typical sensor or actuator can also be extremely useful in other places, outside of direct process control. An “Automated as built” use case was defined, which uses precisely this live information to create a digital twin of each field device in the operator’s engineering tool. The basic problem from the past, that the field device data could not be tapped past the process control system, is now solved by using the NOA concept (see section 7.1), because the Namur Open Architecture (NOA) provides open, secure and non-reactive access from the core automation to the previously unused information in the field device and now makes it available outside the actual process control system.

In the "Automated as built" use case, see Figure 25, the NOA information is made available to an engineering system, e.g. of the plant operator. This means that the engineering department now knows the current status of the field instrumentation at all times. If, for example, a faulty field device is replaced, the replacement device is automatically updated with the new type, serial number and other device parameters in the NOA server and therefore also in the planning system. The employee responsible can then apply this change with a single click and the entire system documentation is up to date. This eliminates outdated and incorrect documentation and the associated risks to safety and availability.

However, up-to-date system documentation is only the first step: if a device has been replaced in the field in the example above and the replacement device has been updated in the engineering system, further steps are usually required, such as a new proof of intrinsic safety. To do this, the operator’s engineering system uses the updated device information (type, serial number) to retrieve the new intrinsic safety parameters from the device manufacturer’s AAS server for the exact replacement device in a fully automated process via an administration shell (AAS) and the planned Process-X data room. In this way, the proof of intrinsic safety can also be automatically updated for the measuring point.

In the future, field device information will be available via NOA and the asset administration shell in an open, manufacturer-independent, standardized and data protection-compliant manner. In addition to the “Automated as built” use case, there are of course many other conceivable everyday use cases that can be automated smartly and efficiently with the information that is now available.
(Source: Bilfinger, Phoenix Contact)

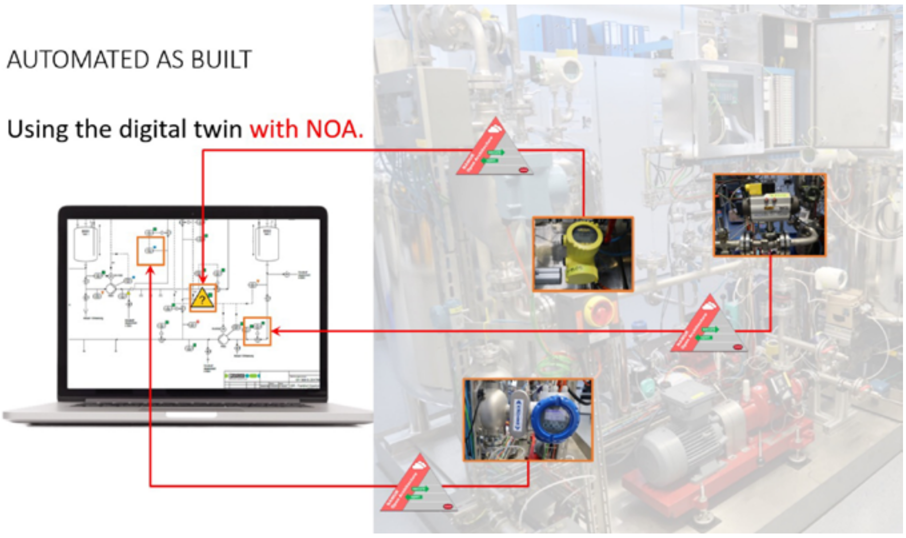

Figure 25:
Automated as Built" use case
(source: Bilfinger, Phoenix Contact)

7 Connectivity in the Process Industry

Innovations often fail due to a lack of data from the process or system. To be more precise: because data is available in electronic form on site in the field device, but it is too time-consuming to transfer this data to the IT systems. This may be due to unsuitable protocols (a 4-20 mA current signal only transmits a single measured value), missing electrical cables or excessive programming effort (because each device interface has to be programmed manually).

Connectivity is the underlying technical term. This brochure cannot cover the full complexity of the topic, but three new technologies are presented. These make it possible to use available data from field devices easily and cost-effectively. Scalable connectivity solutions are a prerequisite for data-based contributions to climate neutrality.

- The existing signal transmission via 4-20 mA or fieldbuses is replaced by Ethernet-APL. APL stands for Advanced Physical Layer and meets the requirements of the process industry, such as intrinsic safety in hazardous areas and two-wire connections (section 7.1).
- As an alternative to signal transmission using electrical cables, there are various radio technologies that have special advantages for retrofitting and widely distributed and mobile systems (section 7.2).
- Every device manufacturer and every device supply different data and uses different designations for it. The standardized NOA information model PA-DIM represents a uniform "language" for the data and makes integration into the information budget easier and cheaper (section 7.3).

7.1 NOA – Access to process and device data

The NAMUR Open Architecture (NOA) concept is the most sensible way to optimize existing, often quite old systems as well as new systems. A detailed description of the NOA concept has been published[1].

In the NAMUR Open Architecture recommendation, the structure of the automation pyramid (ISA-95), as it has been developed for decades, is maintained with Level 0 to Level 4 with all the safety and protection functions. Additional useful optimization of the production process to avoid unplanned downtimes or reductions, to optimize energy consumption and to further increase safety can be implemented with the NAMUR NOA concept, the parallel system to the automation pyramid. By implementing the NOA concept, a return on investment (ROI) of only a few months has been successfully demonstrated in many projects over the years (Figure 26). It is important to start with small projects, demonstrate success and then scale up the project. With proof of success, simple and risk-free implementation and an ROI of a few months, management is also in favor of expanding digital transformation projects.

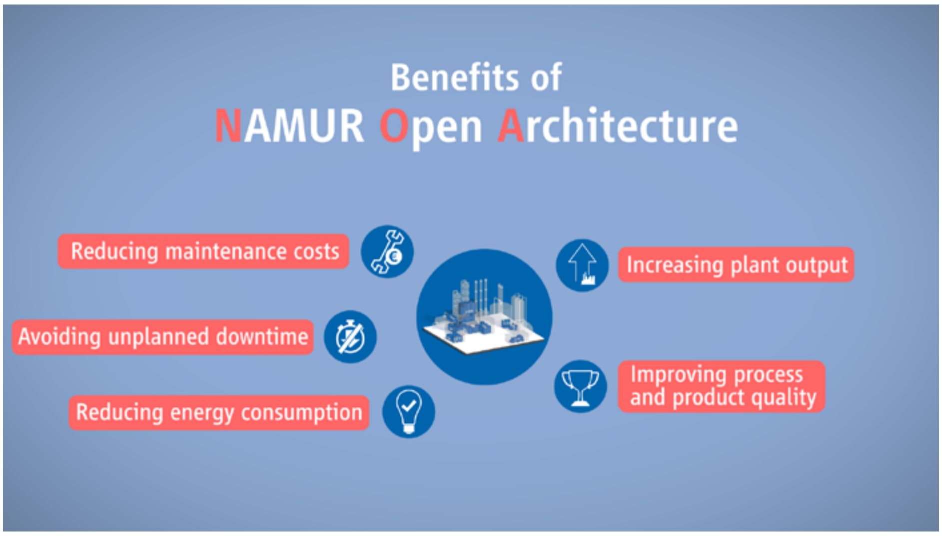

Figure 26:
The process industry expects NOA and the data it makes available from the plant to offer a wide range of benefits that will lead to greater overall plant efficiency.
(Source: NAMUR, ZVEI)

It is important to note that NOA was developed specifically for brownfield systems. It is suited for retrofitting existing systems because it makes data available in sensors and actuators that was previously inaccessible in a standardized form (PA-DIM information model). Additional sensors, so-called Monitoring+Optimization sensors (M+O), can also be easily integrated. This eliminates the high configuration effort previously required for the respective devices. The examples of retrofitted sensors shown in sections 2.1, 5.2, 2.7 and 2.9 are successful projects that utilize the great advantage of the NAMUR NOA strategy. In conjunction with the rapid implementation of wireless M+O sensors (without wiring effort) to gain more insight into the production process, as well as the provision of clear instructions on the smartphone of the employees responsible for the plant part/asset.
(Source: Emerson Process Solutions)

Source 1: Source: Thomas Tauchnitz (ed.): NAMUR Open Architecture (NOA). Essen, Vulkan-Verlag, 2021

7.2 APL - Field communication with Ethernet speed

80 percent of all new field devices in the process industry are still supplied with a current interface (4-20 mA). The current signal only supplies the measured value of the process variable, pressure or temperature, for example. The smart capabilities contained in modern field devices, which enable self-diagnostics and additional information, for example, cannot be used in this way. Additional communication paths such as a HART signal superimposed on the current signal or fieldbuses are slow and cumbersome.

A solution has now been developed for the requirements of the process industry, such as explosion protection and two-wire technology: Ethernet-APL stands for Advanced Physical Layer. This standardized communication technology finally allows "Ethernet speed" (10 Mbit/s) right to the field Additional features relevant for process industry include: intrinsic safety, two-wire connection, power supply to the devices via these two wires and sufficient permissible cable lengths. It is expected that Ethernet-APL will quickly gain acceptance due to its great advantages and replace the previous 4-20mA, HART and fieldbus solutions. Then there will finally be "Ethernet to the field device."
In terms of sustainability and the energy transition, this digital technology has several advantages:

- The accuracy of the values measured increases because there are no signal conversion losses. Processes can therefore be controlled more precisely, and permissible limits can be used more effectively.
- The intelligence of the devices can be used decentrally. Complex calculations can be carried out and implemented decentrally in the devices so that measurements and controls are accelerated.
- The self-diagnosis of the devices means that impending failures can be detected and prevented, either by maintaining the devices or by adapting the operating mode. This leads to higher system availability.
- The devices were previously delivered, installed and forgotten. Ethernet-APL provides the basis for software improvements and necessary IT security patches for the devices during their life cycle and can therefore increase the service life of the devices.
- Thanks to the faster and digital connection, additional sensor signals from existing (brownfield) or already planned (greenfield) devices can be used. This can mean that no additional, dedicated sensors need to be planned, procured and installed.
(Source: BASF)

7.3 Wireless technologies

Production plants in the process industry are closed systems: energy consumption can only be optimized where additional insight into the process is possible. This insight can be gained by linking existing measurements or using additional field device parameters, although there are limits here. Further optimization is made possible by additional measurement technology, the Monitoring + Optimization (M+O) sensors. These are either expensively wired or inexpensively implemented using wireless sensors such as WirelessHART, LoRa or NB-IotT. In the meantime, wireless technology has gained worldwide acceptance through tens of thousands of networks.

The wireless technology has proven that data reliability is just as high as with wired systems. Thanks to wireless technology, potential problem areas can be monitored flexibly, cheaply and quickly and be eliminated in good time, such as energy consumption measurements, corrosion of pipes, triggering and leakage of safety valves, condition monitoring of pumps, fouling of heat exchangers, cooling towers, detection of defective steam traps, etc.

Another option is the use of clip-on wireless sensors, which can be retrofitted during operation of the process system in order to diagnose failures in good time. With this technology, the process does not have to be interrupted and there is no need for additional cabling. The engineering effort for additional measuring points is also significantly reduced with wireless technology, as there is no longer any need to document a wired loop with cable diagrams. The wireless devices are powered by batteries, which is why long battery life is important to keep the cost of replacing batteries to a minimum. With data transmission of the measured values per minute, battery lifetimes of more than 10 years are common today. This means that the maintenance costs for wireless transmitters are lower than for wired transmitters, which must be tested every five years in accordance with the Atex directive.

A second application is the use of the second channel. Until now, diagnostic options via HART have often already been integrated into the sensors and actuators, but these diagnostics are usually not used. A simple and quick to install solution is to read out the data in parallel to the 4-20 mA system via a WirelessHART THUM adapter in order to use the full diagnostics of the field devices online. M+O sensors are characterized by the fact that they can be installed quickly and cost-effectively in addition to the existing M+C sensors (Measurement + Control), preferably during operation.
(Source: Emerson Process Solutions)

8 IT Tools

Outside the industry, information and data technology is innovating at an enormous pace. Just think of smartphones, cloud computing and Artificial Intelligence; we use them every day. Application in industry and especially in the process industry is lagging far behind. The reasons for this are manifold and not be discussed here. Instead, we present four areas of IT that can contribute to the sustainability and profitability of the process industry:

- IT solutions can be implemented decentrally in production companies or in the cloud. Flexible, cost-effective and energy-saving solutions can be created by combining both technologies well (section 8.1).
- Artificial Intelligence is the umbrella term for methods of making computers "intelligent" so that they can absorb and process information and use this knowledge to solve problems. Section 8.2. summarizes applications of AI with regard to the sustainability of the process industry.
- Technical devices and systems become obsolete. This limits their lifespan and capabilities and ultimately leads to more waste and high costs for new solutions. Obsolescence management attempts to stop this obsolescence and support migration to new solutions (section 8.3).

8.1 Edge/cloud computing

The advantages of cloud computing are well known: Anyone who wants to operate IT solutions can rent computing and storage capacity on cloud systems. This saves investment costs, can be scaled flexibly and saves IT administration costs. Data backup, high availability through redundancy and good IT security concepts can be added. In the mid-2010s, there was a strong tendency to go directly "from the field device to the cloud."

In the meantime, the disadvantages and risks of cloud solutions have also been discussed: Many operators do not want their data on globally accessible systems - despite all the contractual safeguards. The dependence on a constantly available Internet connection i s viewed critically. The fulfillment of real-time network requirements cannot be guaranteed – in fact, there have already been spectacular failures. And finally, a constant high data rate via globally distributed networks increases power consumption. The alternative is a local "on-premises" solution, i.e. at the operator's location. This does not have to and should not be in the basement of the respective company, but rather implemented on site in suitable premises. This means that the aforementioned advantages of the cloud solution are lost, but availability and real-time capability are in the hands of the operator.

System operators must weigh up the pros and cons and should have the freedom to decide. Combinations are also conceivable, the productive machine on-premises and redundancy in the cloud, for example. However, the freedom to decide presupposes that the providers of systems and services support both options. Diagnostic software should therefore be offered both in the cloud (or by the software provider) and on-premises. This requirement contradicts the current desire of providers to collect all customer data on their own premises.

8.2 Artificial Intelligence (AI) based on big data

Artificial Intelligence, especially in its current incarnation as deep learning, has enormous potential to revolutionize large areas of our lives. AI offers a number of solutions in connection with the sustainability of process industries. However, it is still in its infancy in some cases. AI complements and interacts with neighboring fields such as simulation and mathematical optimization.
AI is very diverse, but a possible classification of modern models can be based on their capabilities (see Figure 27).

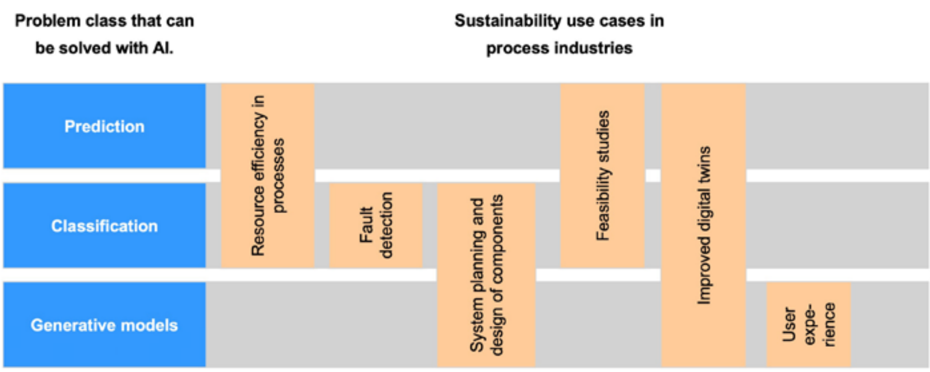

Figure 27:
Solution classes and applications of AI
ABB

At its core, a neural network is nothing more than a mathematical function that converts input variables into output variables and whose parameters have been statistically learned. This means that current and historical values can be used as input variables for a prediction of one or more values (prediction). A possible simple prediction is the temperature in a tank in 2 hours. Solutions from the field of classification take input data and decide to which group (i.e. class) this data belongs. Anomaly detection is an important sub-concept of classification. For example, a simple classification decides whether there is a fault in a component based on measured variables. Finally, generative models that create an output (e.g. an image) from an input (e.g. text) are currently very present in the media. All of these models can support the sustainability efforts in process industry.

Resource-efficient processes

Classification and prediction can be used to optimize processes and minimize energy consumption and emissions in the process[1]. Such optimizations are also possible without AI (see section 2) but can be further improved or implemented more cost-effectively using the new technology. High efficiency is essential, especially in the field of green hydrogen production through electrolysis. In addition to technical data, economic data beyond the system boundaries can also be taken into account, e.g. spot market forecasts or H2 storage capacities[5].

Detection of defects

As already mentioned several times in this document, non-critical technical defects are often drivers of inefficiencies in the process. AI-supported anomaly detection can be carried out with the help of sensor data. Technologies such as autoencoders learn relevant normal states of the system and calculate an anomaly value for each new situation. High anomaly values can be indicators of irregularities that need to be rectified. For example, leaking valves or pipes that lead to material or energy losses can be detected[2]. Similarly, poor electrical contacts that lose energy as heat are visible to intelligent image recognition algorithms in the infrared range[3].

System planning and component design

One example use case that AI can be used for is the design of plants for hydrogen electrolysis or wind farms that can be optimally conceptualized based on historical data. AI can identify data-driven best practices in this context. Complex simulation models can be replaced or supplemented, thereby reducing planning costs.

Feasibility studies

For many projects, the early analysis of profitability is essential. By predicting yields for various historical scenarios, it is possible to quickly assess feasibility. Various vectors such as models for renewable energies, weather forecasts, electricity market prices, electrolyzer models, plant balances and hydrogen derivatives, are included in this process[5].

Improving digital twins

AI improves digital twins by providing insights that go beyond the capabilities of physical sensors. Data-driven predictions of future values can provide previously unavailable insights. Algorithms can also detect abnormal sensor data (see above). This improved situational awareness of cause and effect supports more agile and sustainable decision-making[5]. An example of the combination of a digital twin and AI has already been described in section 6.4.

User experience

Handling industrial information is not always easy, even for experts. Generative AI can ensure that data is presented in a way that is easier to understand and that research into problematic cases is simplified through easier interaction, e.g. via natural language questions.
(Source: ABB, Schneider Electric)

Source 1: Reduce Carbon and Costs with the Power of AI | BCG
Source 2: A novel pipeline leak detection approach independent of prior failure information - ScienceDirect
Source 3: Sensors | Free Full-Text | Integration of Novel Sensors and Machine Learning for Predictive Maintenance in Medium Voltage Switchgear to Enable the Energy and Mobility Revolutions (mdpi.com)
Source 4: AI-Generated Product Design: Tools and Examples - Board of Innovation
Source 5: ABB, Schneider Electric - How AI can accelerate the transition to green hydrogen (se.com)

8.3 Avoiding obsolescence

That products become obsolete is a trivial observation. This is due to the limited durability of technical components, but also to technical progress. Obsolescence jeopardizes the quality of production and sooner or later leads to the replacement of components and thus to electronic waste and the consumption of resources for new components.

Obsolescence is the technical term used for this. In practice, targeted maintenance is carried out in an attempt to keep the service life of devices as long as possible. Otherwise, there are only two radical solutions: Deliberately continuing to operate systems with outdated devices for as long as possible or replacing them with new devices. However, replacing individual devices with modern components is often difficult because they are usually equipped with new technologies and require a more modern environment, e.g. digital communication. And in general, replacing appliances should also be viewed critically from a sustainability perspective: It generates waste, requires new raw materials and leads to inefficient plant downtimes and faulty production.

The European Union is imposing additional requirements on manufacturers and operators. On December 15, 2022, the Commission presented a draft of a new "Cyber Resilience Act," which is aimed at protecting consumers and industry from products with unsuitable IT security features. It obliges manufacturers of digital products to systematically take security issues into account during development and offer security support and software updates to eliminate identified vulnerabilities. Users must be informed about remedied vulnerabilities. This applies to the entire product life cycle, but for at least five years. The regulations affect all companies that manufacture or trade in products with digital elements. There is still no requirement for operators to read the manufacturer's instructions or eliminate vulnerabilities. However, it is realistic to expect that such requirements will come for operators of critical infrastructure or hazardous systems. It will soon no longer be possible to operate outdated digital products with a naive eye. But there are also opportunities: if devices must be updated anyway, they can also be functionally improved in the process. This can prevent obsolescence, at least with regard to the software.

For the specific area of automation systems, NAMUR recommendation NE 121 "Quality assurance of I&C systems" deals with sustainability and obsolescence management. System providers should offer concepts and products, e.g. service products, and anchor them in their development processes so that the systems can be maintained in the long term and migration to successor systems is possible without any problems. Renewal can also take place in stages, e.g. by replacing the computers and servers, but continuing to operate the field-related components - provided the vendors support this. Buyers, e.g. system operators, should define their obsolescence management requirements from the outset and take them into account when evaluating the offer.

9 Prospects

As we have seen in this brochure, there are a variety of technical solutions for improved sustainability in the process industry. Some are brand new, others have been available for years.

Many of the technical solutions shown here focus on energy efficiency and the reduction of greenhouse gas emissions. The industry is thus addressing crucial aspects for sustainable development. Reducing greenhouse gases is a huge social challenge for future decades. The EU Commission has paved the way with the EU Green Deal: greenhouse gas emissions are to be reduced by 55% by 2030. The goal is to achieve climate neutrality by 2050. This can only be achieved through far-reaching transformations of the economy and society and massive investments, including in industrial processes.

Sustainability naturally encompasses many other aspects. The process industry is already addressing these too. Here are just a few examples:

Circular economy: In addition to the energy transition, a resource transition is also needed. The linear model, whereby raw materials are extracted, used and then disposed of, is no longer viable. Appliances and systems consist of valuable raw materials that can be returned to the cycle. In addition to the ecological benefits, there is also potential for reduced dependence on raw material imports. It is important that the circular concept be considered from the outset. Appliances and systems are increasingly being designed to be resource-saving, durable and repairable. Old appliances are recycled. Recycled raw materials can be used in new appliances - where available and justifiable in consideration of other product properties.
Here it is important that standards, for example, ensure that recycled materials have clear quality criteria. Reliable availability is also important for their use.

Use of materials: Products in the process industry and process automation are high-tech applications. The requirements for the materials used are correspondingly demanding. Specialty chemicals are often required to ensure that devices and systems are durable, safe and perform well. The process industry and process automation are aware of the associated responsibility. Comprehensive chemicals legislation also ensures that substances are evaluated and, where necessary, restricted in their use. Proposals to restrict entire groups of substances such as PFAS are currently causing unrest in the industry. For many applications, including those that are essential for the energy transition, there are currently no alternatives to PFAS. It is therefore important that a risk-based approach be chosen and that there is no restriction of entire groups of substances.

Responsible supply chains: Supply chains are often international and highly complex. Violations of human rights or environmental regulations outside the EU cannot always be ruled out. Laws at the national or European level that are intended to regulate responsibility in the supply chain are already in force or in preparation. The process industry and process automation take these aspects very seriously. It is important that the requirements can be implemented, especially for SMEs. Requirements must apply equally to domestic and foreign market players, be verifiable and harmonize with existing regulations. In addition to such product and process-related measures, there are a number of other challenges that need to be overcome when using new technologies in process automation on a large scale:

Education: In the collective consciousness of our society, process automation plays a rather subordinate role. The potential of these technologies for reducing greenhouse gas emissions must therefore be explained in a comprehensible way. A solution-oriented, positive narrative motivates people to make an active contribution to implementing the theoretical possibilities.

Training: The implementation of solutions requires specialists, who are already becoming increasingly scarce. The shortage of engineers is now in the hundreds of thousands. However, measurement technology and process automation are the key to implementing energy- and resource-efficient technology. Computer science and Artificial Intelligence are also playing an increasing role in this context. Promoting STEM education plays a crucial role in achieving climate targets.

Research: The state of the art in the field of sustainable process industries must also be advanced through public and commercial research. Unbureaucratic research funding with corresponding thematic focus programs enables continuous improvements in energy and resource efficiency and thus a reduced ecological footprint.

Favorable environment: A society that wants sustainability and has the necessary technologies and experts at its disposal should make collective decisions to pave the way for their use. This includes a reliable and modern digital infrastructure as well as legislation that simplifies the use of technology. For example, super write-offs for climate-friendly technologies could further encourage corresponding investments.

Sustainability through long-term thinking: Companies should also broaden their time horizons, especially in connection with cutbacks. Many climate-friendly measures are essentially investments that pay for themselves through increased efficiency. Instead of discarding measures due to longer amortization periods, life cycle costs should be considered more closely. Energy audits and the resulting savings plans, which are monitored via energy management systems, should be actively practiced within the company.

LIST OF ABBREVIATIONS

List of abbreviations

AAS	Asset Administration Shell
APL	Advanced Physical Layer
BAFA	Federal Office of Economics and Export Control
CAPEX	Capital expenditures, investment costs
EMS	Energy Management System
FAD	Free Air Delivery
HART	Highway Addressable Remote Transducer
IT	Information Technology
KPI	Key Performance Indicator
MTP	Module Type Package (see VDI/VDE/NAMUR Guideline 2658)
NAMUR	User Association of Automation Technology in Process Industries
NOA	NAMUR Open Architecture
OPEX	Operational expenditures, operating costs
PAT	Process analytics measurement technology
PCF	Product Carbon Footprint (CO_2 footprint)
PLS	Process control system
VWS	Administration shell
ZVEI	Electro and Digital Industry Association

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