10 Challenges Semiconductor Fabs Can Transform into Business Opportunities

A Schneider Electric Reference Guide

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Abstract

Driven primarily by rapid industry growth worldwide, the semiconductor fabrication industry faces a broad range of significant business challenges. The challenges include the need to achieve sustainability goals, improve power reliability, enhance cybersecurity, accelerate time to market, mitigate supply chain issues, reduce energy costs, improve operational efficiency, optimize equipment maintenance, attract/retain a high-quality workforce, and empower the workforce.

This reference guide explains how fabs can overcome these ten challenges and transform them into business opportunities, as well as demonstrates via specific use cases how leading practices enable semiconductor fabs to enhance global competitiveness. The guide describes each of the ten use cases in terms of its drivers or key challenge areas, leading practices to turn the challenge into an opportunity, and a sample case study.

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Introduction

Purposes of this Guide

The purposes of this guide are:

- To explain how semiconductor fab companies can overcome a broad range of business challenges and transform them into business opportunities.
- To demonstrate via specific uses cases how leading practices enable semiconductor fabs to enhance global competitiveness.
- To provide a comprehensive reference source for Schneider Electric customers and prospects seeking to achieve sustainability goals, improve production reliability, reduce costs, accelerate time to market, mitigate supply chain issues, empower their workforce, and meet other challenges.

The Use Cases

In this guide, challenges become opportunities.

This guide addresses ten significant “use cases” in the semiconductor fabrication industry. Each of these use cases can be viewed as a daunting challenge that companies face today. Many of these are driven by the rapid growth the industry is experiencing. Yet, each of these use cases can also be viewed as an opportunity. Leading companies that effectively address them can increase global competitiveness. Following are the ten use cases (see Figure 1):

- Achieve sustainability goals
- Improve power reliability, quality, and resilience
- Enhance cybersecurity
- Accelerate time to market
- Mitigate supply chain challenges
- Reduce energy costs
- Improve operational efficiency
- Optimize equipment maintenance
- Attract/retain a high-quality workforce
- Empower the workforce

This guide describes each use case in terms of its drivers or key challenge areas, leading practices to turn the challenge into an opportunity, and a sample case study.

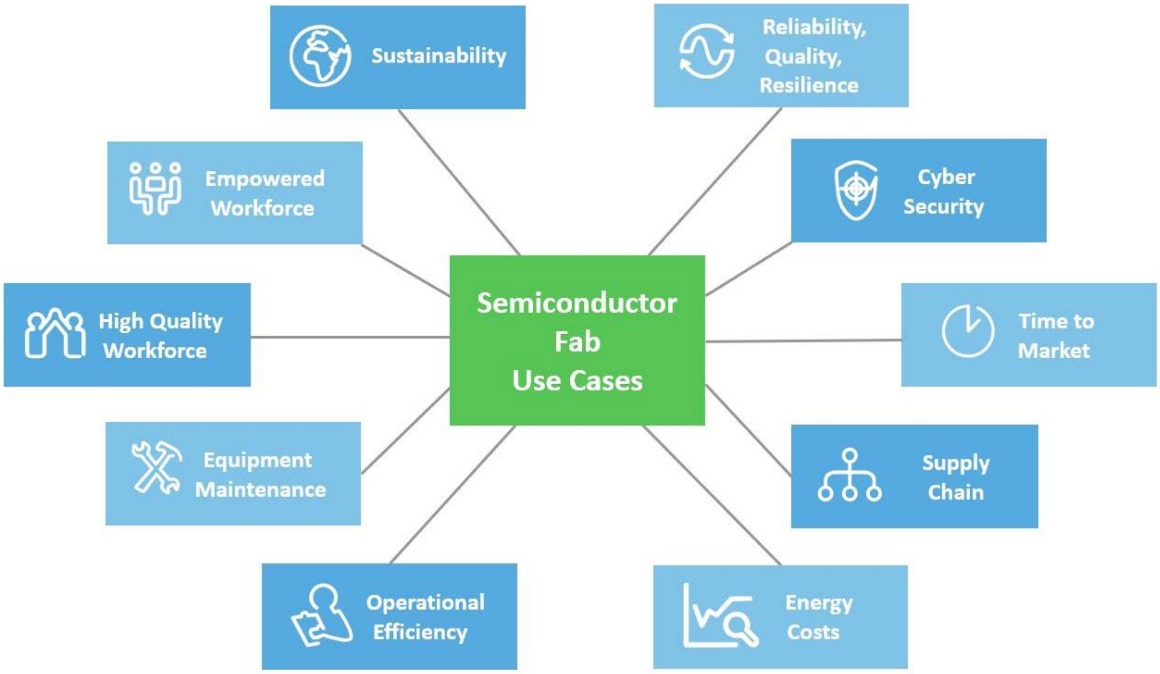

Figure 1. This guide examines ten semiconductor fab use cases

A Lifecycle Approach to Increase Competitiveness

A lifecycle approach can be used to increase global competitiveness in the semiconductor industry.

Several of these use cases are relevant to effectively managing the use, cost, quality, reliability, resilience, and sustainability of energy. A lifecycle approach can be used to increase global competitiveness in the semiconductor industry:

- In the **project phase** (the design and construction of fabs), the focus is reducing total cost of ownership, improving time to market, and cost-effectively responding to worldwide market demand.
- In the **operation phase** (the operation and maintenance of fabs), the focus is improving resilience to safeguard 24/7 operation, ensuring asset return on investment, maintaining high product quality and on-time delivery, extending equipment life, protecting brand reputation, and empowering the workforce—thus reducing OpEx and increasing competitiveness.

Throughout this guide, including in the crucial area of sustainability, there are two common themes:

- The increasing importance of transitioning to a smart facility through acceleration of a digital transformation aligned with industry 4.0
- The increasing emphasis on operational efficiency and energy efficiency throughout the facility

Working with a company with comprehensive experience on the facility side of the fab—including expertise in energy management, industrial automation, digital transformation, and sustainability—can provide the most effective services and solutions.

The Definition of Efficiency

This guide defines efficiency as whatever the semiconductor fab seeks to improve, and thereby increase profitability, using KPIs or metrics that are quantifiable.

In this guide, “efficiency” is defined in a customer-specific manner, so that it covers areas in which the semiconductor fab seeks to improve and become more efficient. This can include energy efficiency, operational efficiency, production efficiency, maintenance efficiency, personnel training efficiency, or others.

Each of these forms of efficiency can be measured using key performance indicators (KPIs) or metrics *that the fab is currently using* (e.g., energy consumed per unit of the solution), not metrics that the outside company suggests. The existing customer metrics can apply to an existing standalone solution for a single business unit, a new solution that is serviced across business units, or an innovative new solution that requires collaboration and partnering with companies with a proven track record.

In some cases, the “efficiency” solution that the fab needs require an outside company to partner with other entities. This, in turn, promotes the business benefits of co-innovation with the fab. This customer-driven process includes asking for and applying company goals, solution needs, constraints, KPIs, etc., and then using these as the starting point for improvement. This approach applies equally well to both the facilities side and the manufacturing side of the fab.

Moving toward Digital Transformation

The best way to explore digital transformation at a semiconductor fab is step out of the day-to-day operational world and define aspirations for 3-5 years hence. Digital transformation solutions help the fab achieve those aspirations.

To help achieve this, a consultative approach enables fab decision makers to temporarily detach their thinking from the constraints of the current physical world (i.e., the fab, the assets, and the equipment in the fab). Instead, these leaders can consider a virtual world, which is not necessarily constrained by the limitations of the physical world. This involves temporarily stepping away from day-to-day operational challenges. It enables the definition and capture of fab personnel’s aspirations for a future world (e.g., 3-5 years hence), where some or all of these limitations are removed. This approach can be applied to the functions of operations, planning, maintenance, training, etc.

Once these aspirations are defined, a roadmap of steps that are necessary to achieve these aspirations can be defined. This roadmap bridges the gap between the fab of today, and the fab in 3-5 years. It identifies how to move along a path from “A” (today) to “B” (the future). This process can be conducted in a design thinking workshop, which attempts to build a future vision and infuse familiarity with digital transformation, co-innovation, workforce transformation, and other advances *in the context of realizing these aspirations.*

Consultative Approach

Digital transformation is *not* adopting technology for technology's sake; it is adopting technology and processes to meet specific business needs that people define and implement.

An "Ask Why" Consultative Approach

The traditional approach of providing solutions is to suggest that fab leaders adopt certain technologies, or to ask the fab what technologies they want, and then delivering those. However, an alternative "consultative" approach asks the fab personnel "why?" Why do you want this technology? Extending this inquiry into more detail, with more instances of asking "why?" leads the company leaders to consider the rationale for their requests of specific solutions. The process asks the company to defend the perceived business value of the requested solutions. This mindset resists the temptation to propose products and solutions upfront, but instead delves into the business needs, constraints, and goals.

Start with Current Organizational Approaches

This "ask why" consultative process starts with the approaches that the organization currently uses, and tailor approaches based on that starting point, rather than strongly recommending approaches that force the organization to change. This approach applies to questions regarding data gathering, cybersecurity, confidentiality, privacy, use of cloud computing, co-monitoring, and potentially other related practices. This recommended practice involves asking the organization what approaches they seek and what approaches they currently allow. This approach can be game changing in interactions between organizations and outside companies.

The key questions that the solution provider asks the organization in this process are:

- Do you need this service?
- What are your business pain points?
- What are the strategies you have today?
- How are you making decisions on those strategies?
- Could information, with a delivery method that enables you to take action, be of interest to you?

When the organization says yes to this question, then the recommended practice is to point out that this service will require the outside company and the fab to access and view certain information together. Then the recommended question is: Who in your organization, and what department, handles permission for this access? Once a discussion is initiated with this authorizing person, during which the outside company explains the need for a service, the recommended question is: What approaches do you use today and/or how do you want to do this? This then establishes a starting point for how to best move forward.

Rather than the common approach of the outside company leading with a product offering to the organization, the approach described above leads with a service that defines business goals, defines what information is needed to address these goals, gathers that data using collaboratively-defined processes, takes action, and then verifies the results of the action. The commonly-used alternative of initially simply implementing a product that outputs information is problematic because the result is information for information's sake. What is missing is the *meaning* of this information—how it helps meet goals, and what recommended actions result from the information.

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Achieve Sustainability Goals

Sustainability and decarbonization has become a primary requirement in the semiconductor fabrication industry.

Drivers

Sustainability has many faces. It poses challenges. It forces a hard look at the direct and indirect impacts of corporate actions. But in such assessment, it also uncovers opportunities for change that can help address several other corporate challenges. In this way, sustainability challenges can be viewed as an *enabler of positive change, with cross-cutting benefits.*

Following are reasons why these challenges related to sustainability have become more urgent and comprehensive in the semiconductor fabrication industry.

- **Industry rapid growth.** A global chip shortage and exploding demand is spurring high growth rates in the industry. This growth is and will continue to proportionately (or even more rapidly) increase greenhouse gas (GHG) emissions, energy consumption (which can impact emissions), and water consumption—unless measures are implemented to curb these increases. The industry's carbon emissions are overtaking those of the auto industry—traditionally viewed as a high carbon emitting industry.[1] The industry also emits high global warming potential (GWP) fluorinated compound chemical gases used in the production process, which are further discussed below.
- **Intensifying scrutiny.** In the face of a global shift to a low-carbon economy, semiconductor companies are increasingly pushed to reveal and reduce their carbon footprint. The stakeholders demanding this visibility include the companies' customers, employees, local regulators, and financial investors. With an increasing focus on environment, social, and governance (ESG), both local and foreign government entities and regulatory jurisdictions are ramping up their sustainability scrutiny of the industry.
- **Nature of the industry.** The semiconductor industry is inherently energy-intensive and water-intensive in its 24/7 operation, compared to other industries.
  - The energy dependence is increasing and is expected to further intensify as advanced technologies are deployed (e.g., extreme ultraviolet lithography, EUV).
  - Industry water usage is increasing (20-30%) due to a manufacturing boon in the last few years. At the same time, tighter discharge regulations and zero liquid discharge and recovery rates for water are being linked to sustainability targets.

Responding to these drivers, 65 entities are founding members of SEMI's Semiconductor Climate Consortium.[2]

[1] *Hotcars,* Peter Els, "The Truth about the Carbon Footprint of a New Car that No One's Talking About," November 9, 2021, https://www.hotcars.com/the-truth-about-the-carbon-footprint-of-a-new-car-that-no-ones-talking-about/.

Increasing Facility-side Focus

A semiconductor fab can be considered to consist of two key areas:

- The **manufacturing process** is dependent on highly-automated semiconductor manufacturing equipment (SME).
- The **facility side** consists of support and infrastructure equipment, including utilities such as electrical distribution, water, chilled water, natural gas, and chemicals, as well as data management (e.g., data centers). These utilities are critically important because they directly and indirectly impact SME functions and performance.

Throughout this guide, and particularly in the area of sustainability, a common theme is the increasing emphasis from semiconductor companies to accelerate digitalization on the facility side. This increased facility scrutiny is due to several factors, including but not limited to the following:

- Fab energy consumption is increasing (up to 30% of fab OpEx, and expected to increase further) due to technological evolution, energy costs are rising.
- Water consumption is increasing due to the more complex manufacturing process. Daily water use at a large fab can reach 10 million gallons, which is equivalent to water use of about 300,000 households.[3] The industry currently uses about 264 billion gallons per year, primarily for process water.[4]
- The increasing need for more optimized energy use and resilient electrical distribution can account for up to $40 million in losses from a single 30-minute power outage.[5]

The less scrutinized and less optimized facility side offers "low hanging fruit": business areas where significant improvements are evident and can be leveraged—with the right business partner.

Leading Practices

Decarbonization and Adaptation

An effective climate strategy embeds into business strategy a combination of decarbonization and adaptation approaches.

Decarbonization addresses the levels of heat-trapping greenhouse gases in the atmosphere by reducing the *sources* of these gases and enhancing the reservoirs (*"sinks"*) that accumulate and store them. This can be approached in the following manner:

- Define success by aligning on your corporation's vision and strategy
- Establish targets to identify the appropriate goals and prioritize action
- Deploy a program to implement a decarbonization plan and drive performance
- Innovate, measure results, and iterate to sustain results and meet goals

[2] SEMI, "Semiconductor Climate Consortium," https://www.semi.org/en/industry-groups/semiconductor-climate-consortium.
[3] Gradiant, "Water Scarcity Concerns Drive Semiconductor Industry to Adopt New Technologies *(IEEE Spectrum)*," January 26, 2022, https://www.gradiant.com/news/water-scarcity-concerns-drive-semiconductor-industry-to-adopt-new-technologies-ieee-spectrum/#:~:text=Chip%20fabs%20around%20the%20world,consumption%20of%20roughly%20300%2C000%20households.
[4] C. Jones, *Semiconductor Digest*, "Water Supply Challenges for the Semiconductor Industry," October 24, 2022, https://www.semiconductor-digest.com/water-supply-challenges-for-the-semiconductor-industry/#:~:text=They%20expect%20water%20demand%20to,with%20desalination%20and%20recycled%20NEWater.
[5] *TechPowerUp*, "Minute-long Power Outage at Samsung Plant Damages Millions Worth DRAM and NAND," January 1, 2020, https://www.techpowerup.com/262566/minute-long-power-outage-at-samsung-plant-damages-millions-worth-dram-and-nand.

Adaptation minimizes the vulnerability to negative impacts, and minimizes the impacts themselves, of climate change that are already occurring, and takes advantage of beneficial opportunities that arise. This is sometimes called “resilience.” Adaptation can be approached in the following five ways:

- Adopt a forward-looking lens to scan and identify risks and opportunities
- Assess exposure, vulnerabilities, and potential impacts of these risks
- Seek, pivot, and adapt new processes, practices, and business models that enable a smooth transition to a low-carbon world and better absorb climate-related shocks
- Strengthen resilience planning by performing regular scenario-mapping and stress tests
- Drive and sustain momentum and system changes through active engagement and partnership with stakeholders in the broader ecosystem (e.g., local communities)

Decarbonization Levers

When hiring a sustainability partner, investigate how well they practice sustainability. Do they practice what they preach?

Schneider Electric recommends a decarbonization strategy that addresses all three types of carbon emissions:

- **Scope 1** emissions are direct GHG emissions from sources that an organization controls or owns (e.g., emissions associated with direct on-site fuel combustion in boilers, furnaces, and company-owned fleets or vehicles).

  In addition, as part of the intricate iterations and processes of etching and plasma cleaning in chemical vapor deposition (CVD) tool chambers, a variety of high-GWP fluorinated compound process gases are emitted. These include perfluorocarbons (e.g., CF_4, C_2F_6, C_3F_8, and c-C_4F_8), hydrofluorocarbons (e.g., CHF_3), nitrogen trifluoride (NF_3), and sulfur hexafluoride (SF_6). These gases contribute significantly to semiconductor fabs’ scope 1 emissions. The GWPs of these gases are thousands or tens of thousands of times higher than that of CO_2.[6]
- **Scope 2** emissions are indirect GHG emissions associated with the purchase of electricity, steam, heat, or cooling. The organization calculates the emissions from its local power grid using a “location-based method,” and explores engaging in contracts with its electric utility in a “market-based method.” The location-based method reveals what the organization is physically emitting, and the market-based method reveals emissions for which the organization is responsible through its purchasing decisions.
- **Scope 3** emissions are the result of activities from assets that the reporting organization does not own or control, but that the organization indirectly impacts in its value chain.

While semiconductor manufacturing contributes to curbing emissions from the “demand” side, the industry is also helping to reduce emissions from the “supply” side. It accomplishes the latter by enabling higher efficiency of power conversion in electrical appliances and renewable energy generation, while supporting applications in electric transportation.

[6] UN Climate Technology Centre & Network (CTCN), “PFC, HFC, and SF6 Emissions from Semiconductor Manufacturing,” January 1, 2000, https://www.ctc-n.org/resources/pfc-hfc-and-sf6-emissions-semiconductor-manufacturing.

Encompassing these three emission scopes, Schneider Electric recommends a three-step approach to decarbonization across the entire plant lifecycle (see Figure 2):

- **Step 1. The strategize phase** focuses on accelerating the sustainability journey. It includes establishing carbon goals (e.g., Science Based Targets, SBT, 1.5°C-aligned net zero, carbon neutrality that allows for offsets or climate positive)[7] measuring the enterprise's baseline, creating a decarbonization roadmap, structuring a decarbonization program and governance, and communicating a commitment to the program across the enterprise and external stakeholders.
- **Step 2. The digitize phase** enables clear visibility with actionable insights. It includes monitoring resource usage and emissions, identifying opportunities to reduce resource usage, and reporting and benchmarking progress.
- **Step 3. The decarbonization phase** aims for net zero and 100% renewable energy to reduce and save on energy consumption, as well as optimize water resource usage. This phase includes the following four decarbonization levers: Electrify operations, reduce energy use, replace energy sources, and engage the enterprise's value chain.

Careful attention to **cybersecurity** cuts across all three of these phases.

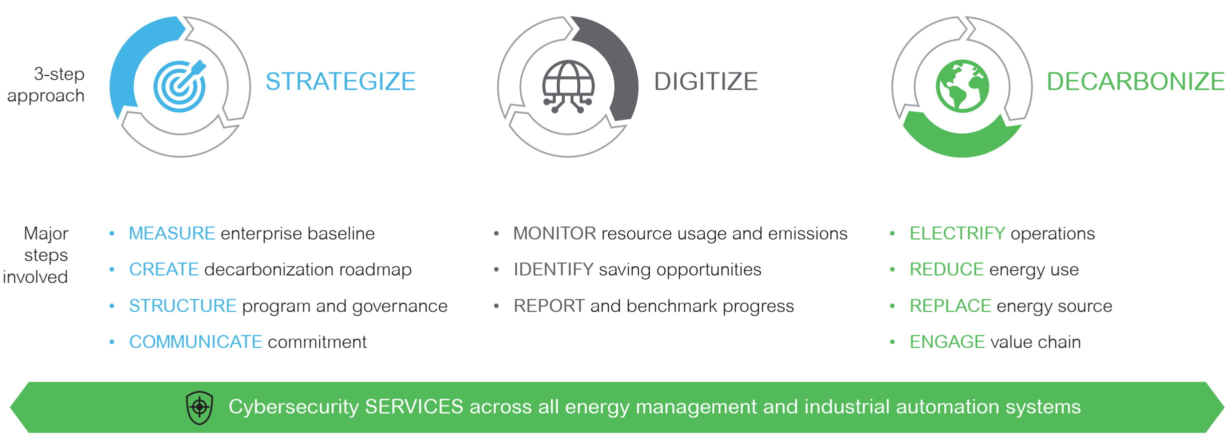

Figure 2. The recommended three-step approach to sustainability

[7] The SBT initiative (SBTi) is a global body that enables businesses to set emissions reduction targets in line with climate science (e.g., keeping global temperature increases below 1.5°C or 2.0°C, compared to pre-industrial temperatures). *Climate* positive and *carbon* negative are synonymous and mean further reductions beyond carbon neutral. "Carbon positive" is a confusing term, and hence not recommended. Carbon neutral and net zero are similar, but net zero goes beyond only carbon and typically covers a larger scale (e.g., net zero includes all GHG, not only CO_2)
[8] The Green Premium is the additional cost of choosing a clean technology over one that emits more GHGs.
[9] In a circular economy, products are manufactured in a way that enables them to be disassembled and materials within them to be broken down by nature or returned to production. Essentially, the product is created with its end-of-life taken into account; it is reinserted into the supply chain instead of landfilled.

A closer look at the decarbonization phase reveals the range of recommended action areas (see Figure 3), which enable semiconductor fabs—today and in the future—to better manage the energy equation, while simultaneously enhancing plant performance:

- The "**reduce energy use**" area includes digitalization to optimize energy use for significant energy use (SEU) utilities on the facility side, including chillers, compressors, air handling units, fan coil units, and exhaust fans.
- The "**replace energy sources**" area includes implementing strategic integrated sourcing to switch from carbon-intensive energy to low-carbon sources in consideration of the Green Premium,[8] entering into renewable energy power purchase agreements (PPAs), and engaging in markets to purchase and sell carbon credits (to address emissions that cannot otherwise be reduced).
- The "**engage value chain**" are includes decarbonization of the supplier chain, engaging suppliers in decarbonization efforts, addressing circularity,[9] and designing and building for sustainability.
- The "**electrify business operations**" area includes optimizing mobility (e.g., electric vehicle, EV) solutions, industrial and building processes, and microgrid solutions.

Note that the top portions of Figure 3 primarily address scope 1 and 2 emissions, while the bottom part of the diagram primarily addressed scope 3 emissions.

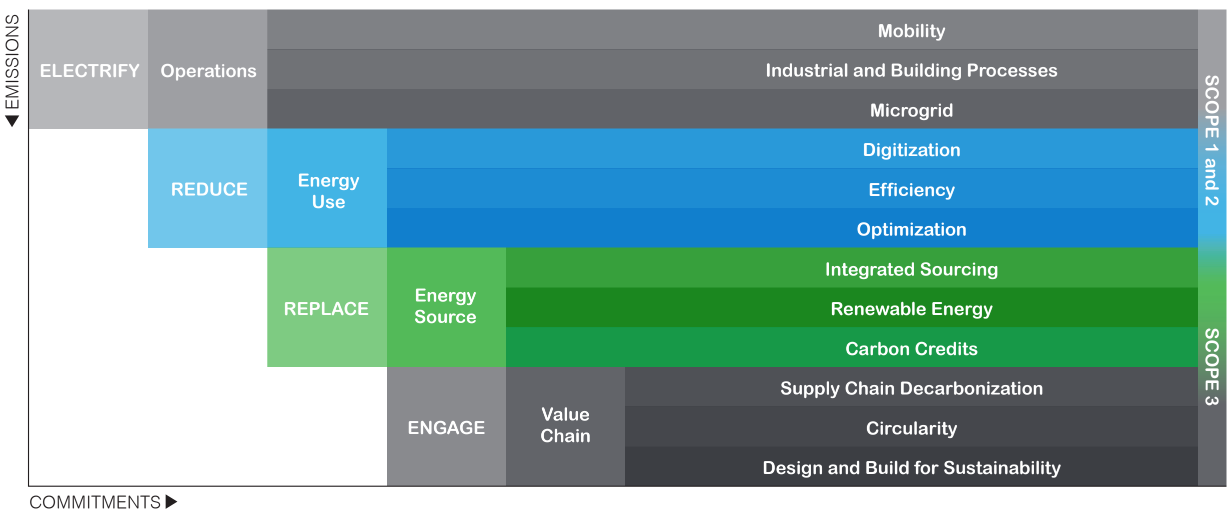

Figure 3. Take action on a decarbonization strategy through practical decarbonization levers

[8] The Green Premium is the additional cost of choosing a clean technology over one that emits more GHGs.
[9] In a circular economy, products are manufactured in a way that enables them to be disassembled and materials within them to be broken down by nature or returned to production. Essentially, the product is created with its end-of-life taken into account; it is reinserted into the supply chain instead of landfilled.

Water Resource Management

At a semiconductor fab, water resource management (water supply and wastewater treatment) is an integral and crucial part of production (see Figure 4).

- Water supply consists of production of ultrapure water/deionized water (UPW/DIW) and recirculation. This represents about 70% of water use in the semiconductor fab (which is primarily used in the front-end fab)
- Wastewater treatment includes basic water treatment, nitrous/alkaline, and acidic water treatment.

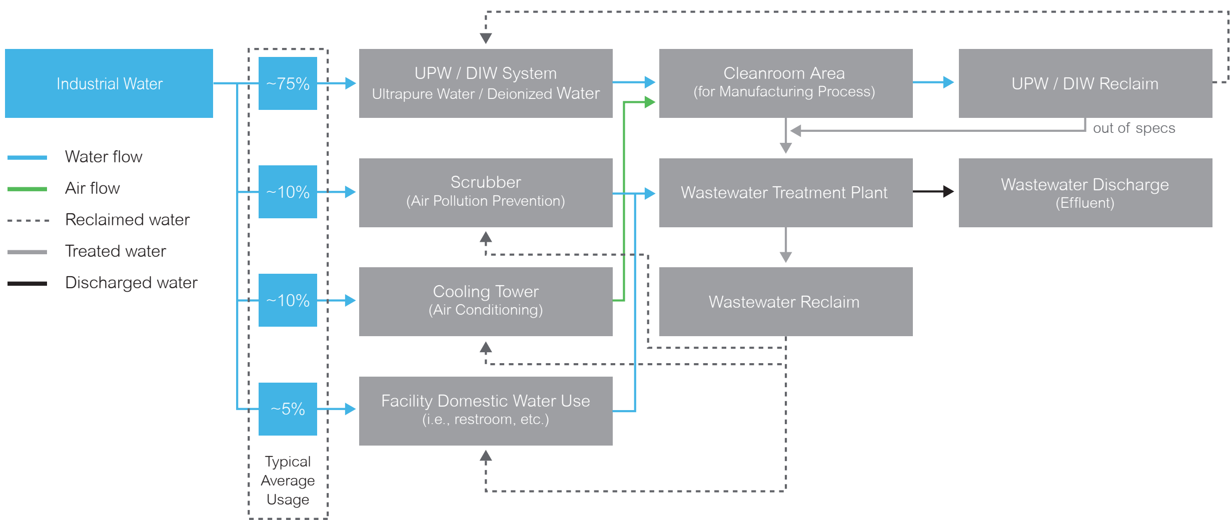

Figure 4. High-level process overview of water supply and wastewater steams in a semiconductor fab plant

Efficient use of water resources and wastewater treatment is an important component of sustainability and minimized environmental impact at semiconductor fab. By leveraging artificial intelligence and machine learning, fabs can better manage water circularity.

Democratization of Data

As Schneider Electric describes in its *Guide to Value-Driven Grid Data Management*,[10] data management is a complex, multi-faceted, and crucial part of most utility functions today. With regard to sustainability, one important dimension of data management is the "democratization" of data. Due to the diverse range of stakeholders in the semiconductor organization—and in the broader ecosystem—effective communication of sustainability challenges, risks, opportunities, solutions, and benefits is a difficult undertaking. As data is gathered from large troves and diverse sources in various forms, it needs to be synthesized, shared, and assessed across the organization. This involves building an organizational culture of data openness, visibility, and collaboration, where input from all relevant parties is considered. This process builds a culture of equitable joint ownership and responsibility for insights gained and actions implemented. As a result, a broad range of managers, analysts, engineers, and other personnel have a voice in—and become part of—the changes that are needed. This extends beyond the internal organization to suppliers, contractors, local utilities, and third-party energy service providers.

A Shift in Metrics

Another aspect of data democratization is development and implementation of sustainability and decarbonization key performance indicators (KPIs) or metrics that a broad range of stakeholders in the organization can understand and use to improve decision making. The lifecycle approach

[10] Schneider Electric, "Guide to Value-Driven Grid Data Management," https://www.se.com/ww/en/work/campaign/grid-digital-twins-guide/.

described earlier shifts fabs' emphasis from simple "product performance metrics" to "lifecycle assessment metrics." From the C-suite through middle level management to implementers of action, everyone needs to understand the metrics. They need to be crafted to address the challenges faced and the solutions implemented in a way that enables ongoing measurement, assessment of progress, and feedback to improve further actions.

Microgrid

Purchase of energy from a local microgrid can support fab sustainability efforts through the potential of the microgrid to integrate (today or in the future) distributed energy resources, such as solar, wind, energy storage, and fuel cells. The fab can evaluate the ability of this power purchase to support its sustainability goals, relative to the microgrid's power reliability and quality. When in "islanded" mode, microgrids may experience power quality degradation, so fabs should consider this potential limitation. Few microgrids are larger than 10 MW and fab peak demand can be several times larger than this. As a result, a microgrid can only complement other local and on-site power sources. Hence, a local microgrid is an additional option in the fab's portfolio of energy options. Evaluation of this option requires careful consideration of the energy cost, reliability, and quality—which is best conducted by a resource with deep microgrid experience.

Sustainability Synergism with Other Challenges

Sustainability touches almost every other business challenge that semiconductor companies face. Hence, effectively addressing these challenges has a benefit multiplier effect.

Following are sample influences and impacts of sustainability on other business challenges (see Figure 5):

- **Time to Market.** Off-site prefabrication (e.g., data centers) methods that accelerate time to market can also enable use of sustainable practices, such as eliminating use of materials such as concrete, which generates CO_2, using less steel, and employing re-usable materials. Standard designs of new fabs, which can also accelerate time to market, can be optimized for sustainability and other business goals.
- **Supply Chain.** By its nature, the supply chain challenge is closely tied to scope 3 emissions. Hence, as part of scope 3 sustainability, fabs can re-examine their relationships and practices with suppliers, as well as long-term procurement strategy, as part of climate risk scenario mapping.
- **Cost of Energy Use.** The drive to reduce energy costs via improved energy efficiency of operations supports sustainability goals; reduced energy use can translate into reduced emissions.
- **Power Quality and Reliability.** Ensuring reliable and high power quality can help safeguard the lengthy manufacturing process and avoid production wastage that can translate into unnecessary carbon emissions.
- **Workforce Transformation.** To support sustainability, fabs can better engage, imbue, and devise incentives that mobilize personnel to participate in and contribute to the company's climate actions.
- **Equipment maintenance.** Fabs can extend equipment life and plan to replace obsolete equipment with more sustainable components that avoid unplanned downtime.

Figure 5. Sustainability influences other business challenges

Customer Case Study

A large semiconductor company had established aggressive goals for near-term carbon neutrality, and long-term compatibility with SBTi 1.5°C and 100% renewable energy. Armed with a CEO commitment, Schneider Electric implemented a four-step holistic approach to the company's climate journey:

- Conducted energy audits at multiple sites, across several countries
- Defined the program execution governance
- Shared renewable energy and carbon offsetting market intelligence and built a strategy in clean mobility for company cars
- Co-created an efficient and realistic carbon roadmap, and prepared implementation

The project team then supported program execution management over multiple years. The Schneider team adopted the approach of defining success, setting targets, deploying the program, and sustaining results. Schneider delivered a robust carbon neutral roadmap that is ready for deployment in the areas of energy efficiency, on-site photovoltaics (PV), power purchase agreements, energy attribute certificates, and carbon offsetting.

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Reduce Energy Costs

Reducing the single largest variable cost at fabs means increasing energy efficiency, which also helps meet aggressive corporate goals for sustainability.

Drivers

- Energy is one of the largest variable costs for semiconductor fabs (up to 30% of total cost).
- Most fabs can set a reasonable goal of reducing energy spend, via increased energy efficiency, by 10-15%.
- Reducing energy use is a primary means of decarbonizing, as less energy consumed usually means less CO_2 is emitted, from whatever source is generating the power—to the extent that the energy source is fossil fuel-based (i.e., not nuclear or renewables).

Leading Practices

Semiconductor fabs have the opportunity to reduce energy usage and corresponding energy costs, via improved energy efficiency. To reduce energy spend, Schneider Electric recommends that semiconductor fabs implement an effective, robust energy management system. This system can simultaneously improve operational efficiency and support sustainability via reduced direct and in direct carbon emissions.

Schneider Electric also recommends implementation of technologies that provide energy managers, facility management, and operations teams visibility into how energy is used throughout the fab, as well as an energy performance tracking platform, to work together to accomplish energy reduction goals.

Another recommended practice is implementing shadow billing to identify utility billing errors. Digitally store utility shadow bills for future reference and create “proof of error” for use in billing disputes.

These recommendations can be implemented in four ways.

Perform energy usage audits and analyses. Continuously collect energy usage data from power meters and other equipment and use software to:

- Reveal energy usage patterns across all processes and equipment types (see Figure 6)
- Identify the factors that contribute to energy usage
- Detect abnormal energy consumption
- Identify the best opportunities for energy savings

Conduct energy performance analyses. Measure energy usage in the context of production and track normalized energy KPIs (e.g., kWh/wafer) to:

- Manage energy as a real-time operational variable
- Track true energy performance
- Quantify energy reduction and savings accurately
- Operate in accordance with energy management best practices and ISO 50001[11]

[11] International Organization for Standardization (ISO), “ISO 50001, Energy Management,” https://www.iso.org/iso-50001-energy-management.html.

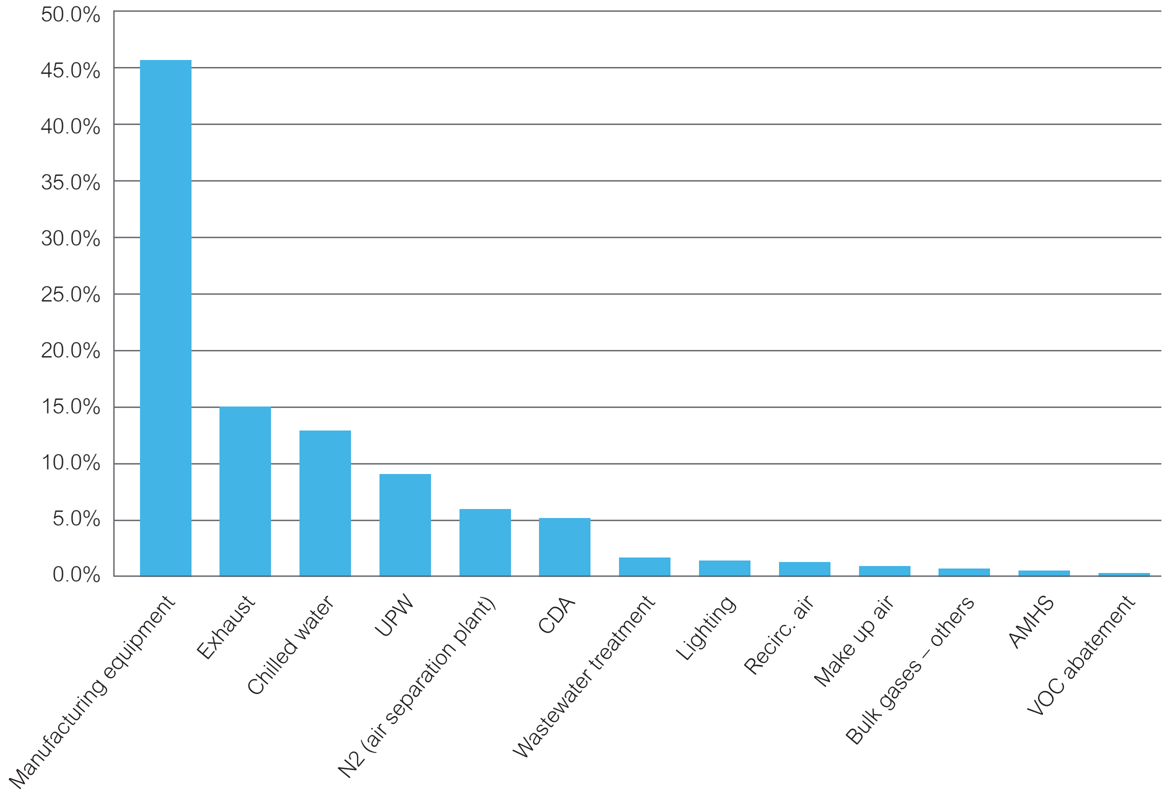

Figure 6. Continuously collect energy usage data to reveal energy usage patterns across processes and equipment types

Verify utility bills. Install a "shadow meter" and use software for validating that the bill is free from errors each month to:

- Proactively identify billing mistakes
- Avoid overpaying for energy
- Improve service levels from the utility company

Implement power factor correction. Install power factor correction equipment to maintain power factor to:

- Reduce monthly electricity bills
- Increase power system capacity
- Improve power efficiency and equipment performance

Install high efficiency equipment. Install uninterruptible power supplies, variable-frequency drives, and other high efficiency equipment.

04 |

Accelerate Time to Market

Drivers

No business challenge in this guide better captures the impacts—and opportunities—of a high-growth scenario than the need to accelerate time to market. This challenge is the intersection of four factors:

- **Technological advancement,** including the drive to win the miniaturization battle—the race to 3 nm (and smaller) process technology.
- **Competitive economic pressures,** including the need to reduce total cost of ownership (TCO)
- **Exploding chip demand** and a chip shortage (expected to continue for some time), which requires rapidly expanded capacity, in the face of supply chain issues, to take advantage of business opportunities
- **Evolving customer needs** worldwide, which need to be met rapidly and cost-effectively

Leading Practices

Design versus Reality

Eliminating existing silos between the electric power design team, construction team, and operational team open compelling opportunities for beneficial collaboration.

After a new plant is designed, the realities of construction (e.g., supply chain issues), with its rigid schedule, preclude obtaining some parts or materials, necessitating construction team deviations from the design specification with parts or materials that meet the requirements. Once the plant is built, which is different from its initial design specification, and it is effectively handed off to the operation team, it may need to be operated in different ways than were originally envisioned. Hence, the performance of the plant's electrical equipment may be different than anticipated.

Effective communication between these three teams throughout plant design, construction, and operation enables operational feedback to the design team, for example. In this way, designs can be enhanced in the future, potentially accelerating time to market, a feedback loop across the lifecycle (see Figure 7). The opportunity for this feedback becomes amplified in the high growth scenario in which the semiconductor industry is immersed.

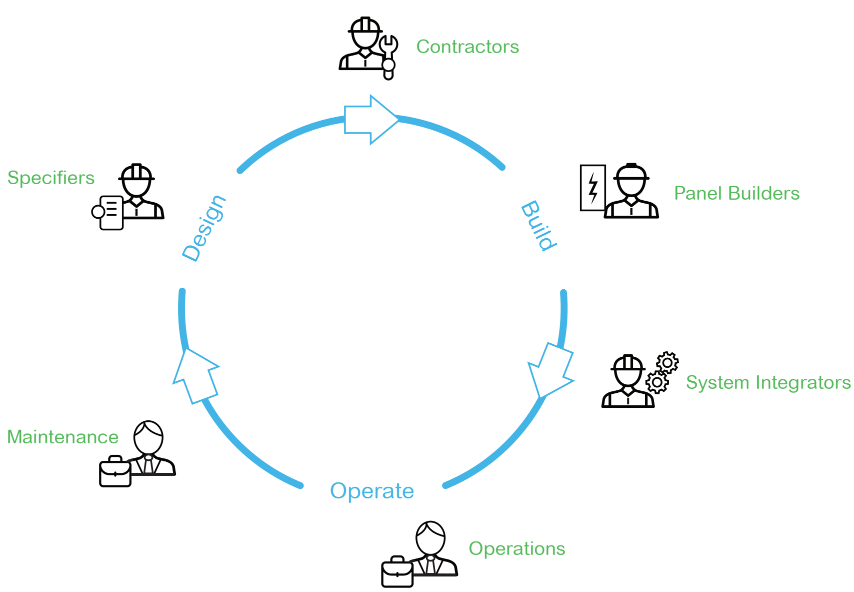

Figure 7. Effective communication between teams throughout plant design, construction, and operation enables a feedback loop of enhancement

Prefabrication

The data center—essential to a fab—provides a prime opportunity to illustrate the business value of prefabrication.

Semiconductor fabs cannot operate without a reliable on-site micro data center. Business and operational functions require a higher level of computational analysis, and requires core servers, networking, and connectivity. Hence, the fab's data center plays a critical role.

Using prefabrication approaches offers various benefits compared to a stick-built data center, including scalability that closely matches demand, rapid deployment and hence reduced time to market, and minimized capital expenditure by reducing oversized infrastructure.

Challenges to Managing Data Center Growth

Facility and data center managers are expected to never run out of capacity and keep the data center operational 24/7. To help ensure this and given uncertain business forecasts, traditional construction lead times require build-out of extra capacity (see Figure 8). The best-case result is an over-built infrastructure that mitigates risk and anticipates potential business growth. On the other hand, the worst-case result is that if the business forecast is overly optimistic, the capital investment is too large, in light of reduced demand. In either scenario, traditional construction is filled with delays, cost overruns, and human errors.

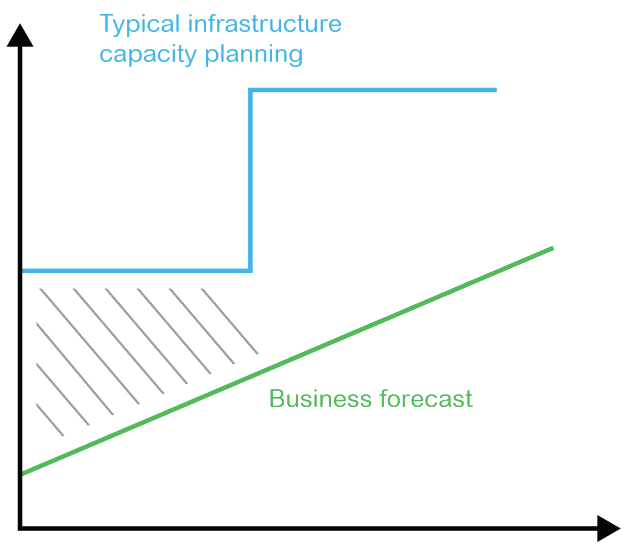

Figure 8. Traditional infrastructure capacity planning builds out extra capacity

Recommended Practice: Prefab Approach

Prefabrication is more than simply off-site integration. It is a process that includes designing in advance, building off-site, using modular parts that are easy to repair, testing more rapidly off-site, using common practices to minimize supply chain complexities, and delivering. It covers the design, build, *and operate and maintain* portions of the lifecycle. Prefabrication is inherently scalable and quicker to deploy, using a building-block approach (see Figure 9). It is designed to allow facility and data center managers to plan and grow the infrastructure on timelines that more closely meet demand.

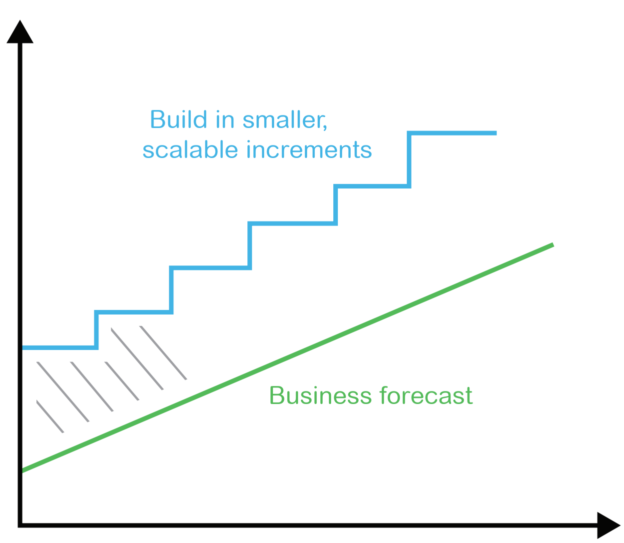

Figure 9. Prefabrication enables modular capacity planning to reduce financial risk

This results in minimized capital spending by reducing oversized infrastructure; and reduced financial risk and managed capacity demands (up or down). Building and testing the components in a factory-controlled environment accelerates construction and reduces time to market. This approach also simplifies on-site construction and reduces delays and cost overruns. Prefabrication can also save space by enabling higher density in a smaller footprint. A building information modeling (BIM) methodology can also be leveraged in this approach.

Another recommended prefabrication approach is to specify that a large percentage of the components in the data center modules be manufactured by the same provider. This provides the benefits of economy of scale, reduces supply chain problems, and enables the provider to understand maintenance and repair needs.

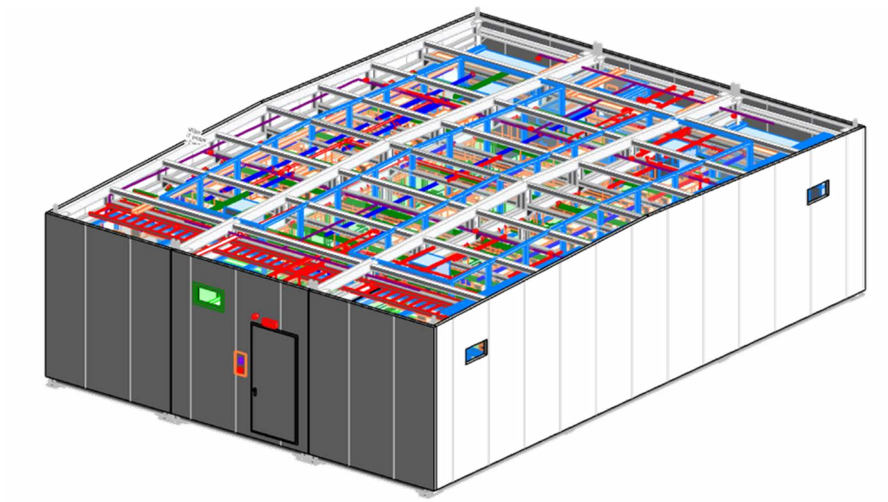

Figure 10. Semiconductor fab companies can benefit most from “regional data centers” in “modular data halls” that include power modules

Semiconductor fab companies can benefit most from “regional data centers” in “modular data halls” that include power modules (see Figure 10). In this arrangement, multiple modules form a single space. The facility can be completely prefabricated, or a hybrid is feasible using assemble-on-site construction. This arrangement reduces complexity and deployment time for a large data center build-out and reduces risk and construction delays. It enables design of the infrastructure and building to work as a system, and offers scalable, repeatable solutions that are available globally. This arrangement also enables use of sustainable practices, such as eliminating use of concrete, which generates CO_2, using less steel, and employing re-usable materials. Both indoor deployment or outdoor deployment are possible (see Figure 11).

Indoor Deployment

- Utilize a simple building shell to build-out data halls to take advantage of low-cost real estate
- Indoor power skids maximize benefit of space, density, and easy deployment of prefabricated power infrastructure

Outdoor Deployment

- Minimize CapEX by installing data halls outside with a simple connection to a building at the entry way
- Power modules can be located in generator yard

Figure 11. The pros and cons of indoor deployment and outdoor deployment of prefab data centers

Following is a summary of the reasons why organizations are deploying prefabricated modular data centers:

- Challenges in allocating or justifying space to build or expand
- Capacity or business drivers that require new capacity fast
- Variances in labor quality in different regions
- Reduced complexity and construction costs from changes and delays
- A standardized build process that ensures predictable cost and performance

Customer Case Study

A large semiconductor company sought to significantly expand its laboratory space via new construction. The space available was limited, and the timeline from construction to production was tight.

To address these challenges, Schneider Electric constructed a prefabricated modular building with busbars, switchboards, racks, rack power distribution units, chillers, an uninterruptible power supply (UPS), and liquid cooling. This prefabricated approach reduced the timeline for construction, compared to traditional construction approaches.

To achieve this, Schneider Electric used a consultative approach with the organization. The team addressed the unique challenges and specific requirements of the building's fire systems, liquid cooling, and electrical system. The team was able to effectively compress the original design using fewer buildings to meet the site space constraints.

05 |

Mitigate Supply Chain Challenges

Supply chain and time-to-market challenges are linked, Schneider Electric recommends a holistic approach to mitigating both.

Drivers

Like in any manufacturing industry, reliable electric power is critical to plant operation. Supply chain issues related to electrical distribution components are evident due to high demand for the equipment and microprocessor chip shortages. In response, owner/operators of semiconductor fabs have consistently expressed concerns about these supply chain challenges. These challenges become more difficult as these companies grow rapidly. Supply chain issues are closely related to, and impact, time to market, because delayed delivery of critical electrical equipment can have a cascading effect on planned production.

Leading Practices

Following are leading practices that can be applied to help mitigate supply chain challenges related to fabs' electrical distribution systems.

Standardized Design

One leading practice is to standardize an optimal design, or reference architecture, for electric power systems and components. The design is "optimized" in terms of sustainability, operational efficiency, energy efficiency, reliability/resilience (including cyber security) and power quality, and maintenance practices.

Employing this standardized design decreases the amount of engineering needed for each project, decreasing the lead time for engineering. This, in turn, enables these critical components to be ordered earlier, decreasing lead time. These critical parts can potentially be ordered from multiple sources to further reduce risk. This approach is particularly relevant for initial engagements with new customers.

Standardized design offers other business benefits. For example, implementing a standardized design at multiple facilities enables more centralized, unified technical support of operational and maintenance activities. A global support team can move from site to site as needed, rather than maintaining site-specific support teams for each site.

In the past, plants were typically over-designed and over-engineered to err on the side of ensuring 24/7 reliable operation. Today, a reference architecture for a new plant, as well as upgrades and enhancements to existing plants, can be more precisely designed using digital tools. This can provide the dual benefit of reducing upfront cost by avoiding over-designing (CapEx) and reducing ongoing operation and maintenance (O&M) costs via pre-construction simulation using these digital tools (OpEx).

For a semiconductor company with facilities in multiple countries, a standardized fab design worldwide for its facilities would multiply the benefits of standardization. An outside company is more likely to be able to provide effective guidance on standardization. A key attribute of this company should be a *global* perspective and experience, combined with strong *local* experience and resources.

A company with a global perspective, combined with local resources, is best able to advise the fab on standardized fab design and multiply the benefits of standardization.

Project Forecasting

The first step in a series of supply chain mitigation actions is to conduct an accurate project forecast. To do this, the company and supplier discuss constraints and risks, and establish an agreement to manufacture and deliver defined equipment, in order to limit risk exposure. The supplier needs to be flexible enough to manufacture the needed equipment at the suitable time, to minimize the risk of supply chain disruption. Standardized design of the equipment, and pre-defined information and financial flows, facilitate effective planned procurement.

Synchronized Procurement

For existing customers, with which the provider (SE) has a trusted partnership arrangement, another leading practice is to initiate a purchase order for critical components earlier in the process than placing the purchase order for a broader set of components. This synchronized procurement approach is particularly useful when a standardized design is implemented and/or when a second or later phase of a project is similar to the first phase. This involves an evolution from a customer/supplier relationship to a partner relationship. With this approach, the customer and supplier can work together to identify critical components, pre-order them in advance, and stock them in their inventory, or book manufacturing capacity and secure a delivery lead time.

Transparency and Open Communication

Following are recommendations for addressing supply chain challenges:

- **Communicate** constraints, delays, and steps being taken to mitigate issues in an open manner.
- **Define a single point contact** for each customer in a portion of a regionally-dedicated organization.
- **Define effective escalation processes.** Establish an effective process to internally quickly and efficiently escalate supply chain issues and performance. This involves defining an internal process that engages the right person at the right time to expedite each inquiry. In all cases, the defined process is respected. This is an agile process that smooths the process for preferred customers via visibility into the most efficient way to escalate, the right person to address the issues, across each region.
- **Select a provider with a “customer first” initiative** as a corporate guiding principle that formalizes a service and support arrangement, which can include round-the-clock problem solving, no unanswered questions, etc.

Customer Case Study

Faced with global supply chain limitations, a large semiconductor company sought to construct a new building on a tight timeline. The company needed overall system design and support (e.g., layout planning and system study, including the protection scheme and future 66-kV conversion). The company also needed installation coordination for its raised floor structure.

To meet these needs, Schneider Electric delivered several key components faster than the project timeline using advanced ordering, substitution of effective components to speed delivery, and line-of-business support. Schneider established relationships with the company from high-level engagement to design and technical support, as well as commercial negotiation.

06 |

Improve Power Reliability, Quality, and Resilience

Drivers

For semiconductor fabs, local utility power is a primary dependency and threat, in the form of degraded power reliability, quality, and resilience.

Degraded power reliability, quality, and resilience can reduce operational efficiency and productivity, increase operating and maintenance costs, damage devices and equipment, and result in costly unplanned downtime.

Electric power distribution grids, as well as the electrical systems within plants, are becoming more complex. In the semiconductor fab, these complexities include more types of equipment, more digitalization, convergence of information technology (IT) and operational technology (OT) networks, use of the internet of things (IoT), as well as other touchpoints. Yet, all of these systems need reliable, resilient electric power.

Amidst this backdrop, power quality issues (e.g., voltage disturbances and fluctuations) are occurring more often:

- Power quality problems cost the European economy about €150 billion ($163 billion) per year.[12]
- Voltage sags and power outage incidents cost semiconductor fabs about €10 000–€50 000 ($11,000-$54,000) per event.[13]
- Power quality issues cause 30-40% of downtime events.
- More than 15% of facilities operate with problematic power quality conditions.

Semiconductor plants are highly sensitive to these fluctuations, and hence the risk to these fabs is increasing. This calls for resilience to not only extremely short power quality fluctuations, but also longer outages.

Leading Practices

To reduce the semiconductor fab's risk exposure, the challenge is to reduce its dependence on the local electric power distribution grid.

Reducing Grid Dependence

The recommendation is to take charge. This can be achieved using the proper electric system design, the proper power conditioning equipment, use of internal or third-party power sources, and use of an internal power management system to maintain power even if the grid ceases to provide it.

For a fab plant, a fundamental building block is the design and implementation of an optimal power system that manages the risk, including the risk of reduced reliability, power quality, and resilience. However, whenever complexity is introduced in a design for mission-critical equipment, the possibility of increased risk exists. Over-engineering such a system with excessive complexity may introduce failure points and actually introduce more risk. A balance is needed where a reliable design provides more independence without introducing additional unknowns. This is also called "full power orchestration," which addresses the fab's orchestration of its power sources. In addition to the local utility grid, these sources can include alternative energy sources, whether owned by the fab or a third party.

[12] J. Manson, R. Targosz, "Pan European Power Quality Survey Report," Leonardo Power Quality Initiative (LPQI), 2007, https://www.semanticscholar.org/paper/PAN-EUROPEAN-LPQI-POWER-QUALITY-SURVEY-Targosz-Manson/9c8b59b90b1371f0b2fa703841d6d6663cda3ada.
[13] Electric Power Research Institute (EPRI), "Power Quality Applications Guide for Architects and Engineers," report TR-113874, Palo Alto, CA 1999, https://www.epri.com/research/products/TR-113874.

Power Architecture

Today, power architecture includes backup power design with power correction equipment, UPSs, battery energy storage systems, etc. Mitigation of power quality fluctuations via electronic active correction is commercially mature. These power electronics devices actively, precisely, and reliably counteract the fluctuations in real time at the level of a fraction of a cycle.

The current approach is a three-level approach:

- Level 1 correct or “cleans” the power entering the facility.
- Level 2 uses UPSs downstream to ensure smooth ride-through of momentary interruptions during brownouts and outages.
- Level 3 engages backup power systems to sustain ongoing power (e.g., minutes, hours, or even days) to critical loads.

Today, the functions of maintaining high power quality and reliability are handled with separate equipment. This is a hybrid or multi-pronged approach. In the future, a single set of power conditioning equipment will ensure resilience to all sorts of disturbances—from interruptions of less than a cycle, to a few seconds, and continuing to minutes, hours, and days. Technological advances in this area will maintain stable, clean power within the fab, even when impacted by voltage fluctuations from the grid. These designs will mitigate both short-term and long-term outages, as well as power quality issues in real time.

Digitalization of Electrical Distribution

Power mitigation devices perform their function the vast majority of the time automatically. However, how can a semiconductor fab know the risk it faces across two time scales: 1) in real time, and 2) over time? A digital layer in the form of digital tools is needed that gathers measured power quality-specific data across both of these time scales, as well as applies artificial intelligence (AI)-based probable-cause, root-cause analytics of electrical system events on premises.

- **Real-time monitoring.** This provides the ability to confirm continued low risk (by examining trends using metrics) in real time. Power-related events can be acute and sudden, occurring quickly and potentially catastrophically. Real-time monitoring to gather information on these events aids rapid diagnosis, effective emergency response, and rapid recovery from events. Reducing recovery time is critical for semiconductor fabs, where lost production time is lost revenue.
- **Electrical asset lifecycle management.** This is important to monitor as the power-related devices and systems age over time. Power-related problems can be caused by evolving chronic changes that occur slowly, gradually degrading resilience. This enables a view of change over time (by examining trends using metrics) to validate ongoing resilience. This provides information that aids maintenance activities, decisions on expansion, etc.

Electrical Digital Twin

Another effective way to mitigate the challenges of enhancing reliability, resilience, and power quality is to develop and leverage an electrical digital twin.

A digital twin is a general term for any software or model that emulates a real-world system’s as-built or as-operated state. The purpose of a digital twin is to optimize the organization’s operation, planning, personnel training, and other functions via improved decision-making (i.e., better informed, faster decisions). This is accomplished using powerful simulators and/or analytics in a virtualized, software-defined environment.

For semiconductor fabs, a digital twin of the electrical distribution system ("electrical digital twin") merits special attention because it can address reliability, resilience, and power quality challenges across the entire fab lifecycle (design, build, operate, maintain), as well as support other business challenges including:

- Increasing the effectiveness of workforce training via simulation capabilities
- Supporting maintenance planning and execution via access to a single digital source of truth, and faster root-cause analysis
- Accelerating time to market via simulation of new electrical distribution equipment design
- Empowering operators to take necessary actions via simulation of "what-if" analyses based on real-time plant loading

Schneider Electric recommends the following three-step process to develop and implement an electrical digital twin for a semiconductor fab (see Figure 12).

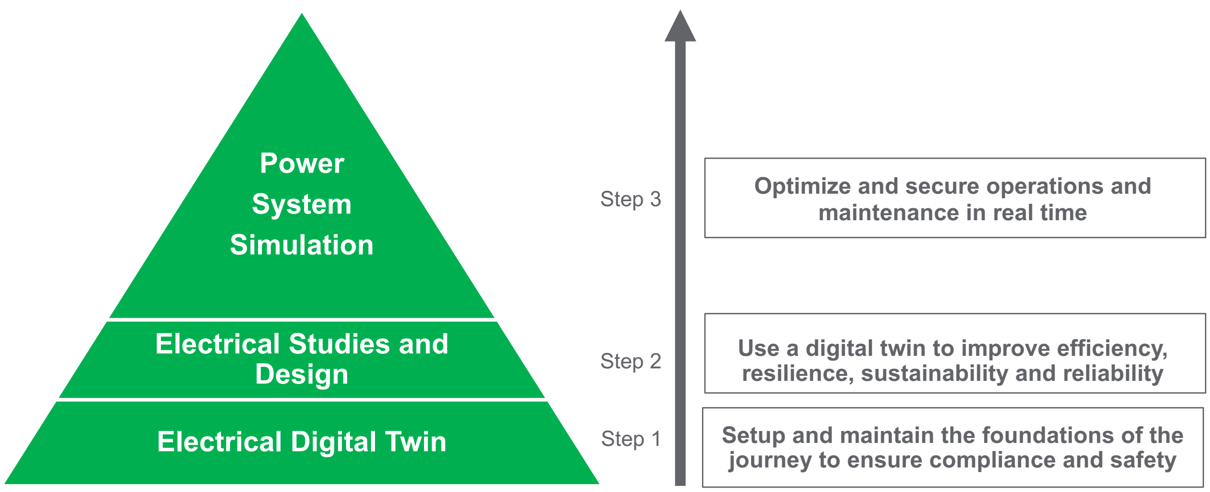

Figure 12. The recommended three-step process to develop and implement a digital twin for the fab's electrical distribution system

Step 1: Develop a digital twin of the plant electrical system: Setup and maintain the foundations of the journey to ensure compliance and safety.

- This step involves developing a digital file of the plant's electrical network. This is a transition from the existing hard copy and AutoCAD (computer-aided design) format (that is a partial, static, and probably out-of-date view of the electrical network) to an electrical digital twin of the complete power system network.
- This digital twin becomes a single source of truth for the electrical design across the plant lifecycle. Enterprise managers, design engineers, operators, planning engineers, field engineers, maintenance crews, automation engineers, controls and approvals personnel, and analysis engineers can all access this model of the electrical design. Figure 13 shows the capabilities this provides.

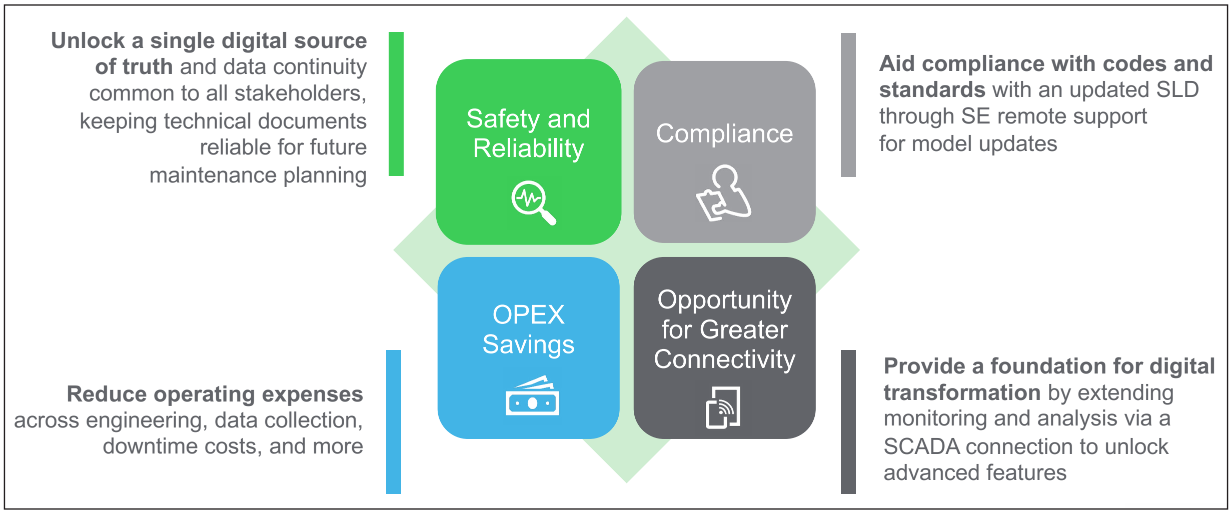

Figure 13. Electrical digital twin capabilities for the fab's electrical distribution system

Step 2: Conduct electrical studies and design: Leverage the digital twin to improve efficiency, resilience, sustainability, and reliability. Figure 14 illustrates the sort of analyses that this facilitates.

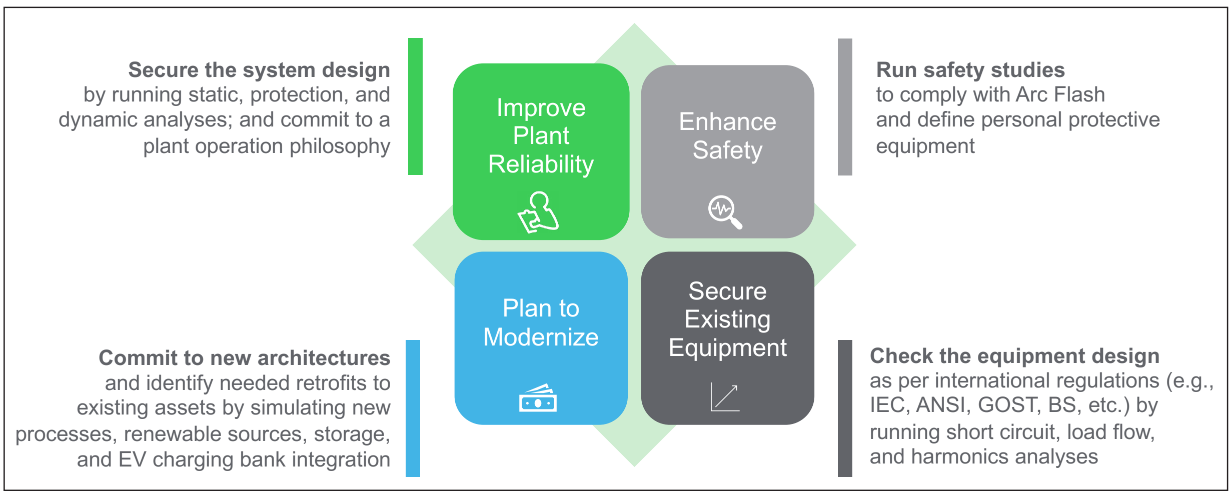

Figure 14. Analyses that an electrical system digital twin facilitates for the fab's electrical distribution system

Step 3: Conduct power system simulation: Optimize and secure operations and maintenance in real time. This step involves connecting the digital twin to real-time measurements and topology to evaluate actual system response to operator actions. This can facilitate predictive simulations ("what-if" scenarios), operator training simulation, and "validate-before-operate" capabilities. Figure 15 provide more ways that this capability can be used.

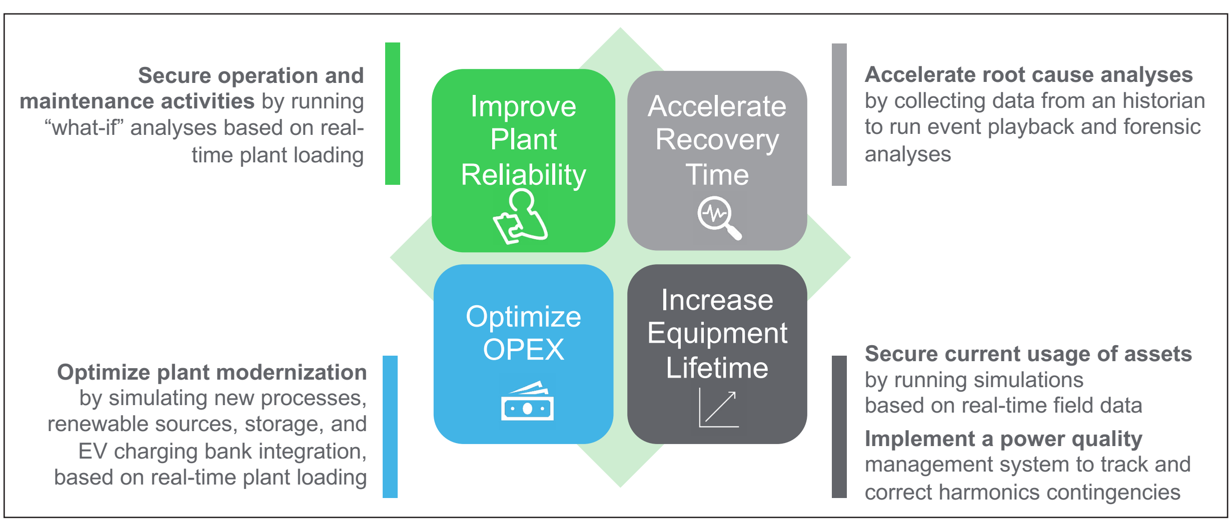

Figure 15. Real-time capabilities of connecting an electrical system digital twin to real-time data for the fab's electrical distribution system

Customer Case Study

A major semiconductor chip manufacturer currently operated a 24/7 high-purity cleanroom with a large number of original equipment manufacturer (OEM) process tools. The company sought to ensure electric power system availability and reliability, as well as to lower the impact of grid excursions as much as possible.

Schneider Electric met these challenges by implementing specific metering solutions, secure power with a UPS, edge control with a monitoring tool, and various advisory services. These tools:

- Provided detailed analysis reporting for improved plant power quality
- Quickly identified abnormalities and alerted designated personnel via email
- Exported energy billing data to accounting or financial systems
- Helped to ensure power quality compliance
- Helped to improve the safety, reliability, and efficiency of the electric power system

07 |

Improve Operational Efficiency

Drivers

The need for semiconductor fabs to improve operational efficiency stems from three drivers—each of which are tied to rapid growth in the industry:

- **Supply Chain.** As a result of the global supply chain disruption and chip shortage, semiconductor fabs seek to become more limber, as they expand capacity of existing fabs and build new ones.
- **Regionalization.** An emerging trend among semiconductor fabs is localizing manufacturing in each region, mitigating geopolitical influences and taking advantage of government incentives.
- **Workforce Transformation.** A global shortage of experienced, knowledgeable personnel—a competency gap—in the semiconductor industry requires new ways to attract, retain, and train personnel in a wide range of skillsets. This workforce transformation goes hand-in-hand with operational efficiency; implementation, monitoring, and enhancing practices for operational efficiency require a talented workforce.

Leading Practices

Integrated, Unified Operations

What does "digital transformation" mean for the facility side of the semiconductor manufacturer? One manifestation of the digital transformation is the rise in embedded intelligence (smart chips) with increased processing power and capabilities in an ever-increasing number of consumer and business-to-business products. This raises complexities for fabs. These challenges require semiconductor fabs to think holistically about digital transformation.

This evolution also means that only optimizing individual components of the fab separately is not sufficient. In addition to this "siloed" optimization, a common digital thread across the entire plant is needed to link all of these individual optimizations. Schneider Electric recommends that semiconductor fabs embark on a connected, integrated operational scheme. This practice of unified operations—a single version of the truth—will provide leading semiconductor fabs the next type of competitive advantage. This requires cooperation between the fab facility team, construction team, and operation team.

Common Practices across Fab Facilities

Utilities that a fab needs for operation include systems for electrical distribution, chilled water, space heating and cooling, water supply, natural gas, chemicals, etc. At the fab, a centralized facility management team typically consists of an electrical team and an instrumentation and control (I&C) team. The cross-cutting practices and technologies needed for day-to-day O&M of these systems require communication across the facility management team. One important tool in this area is a top-level layer of software—the "glue" that coordinates these teams.

Remote Expert Support for Operational Staff

Remote expert support can aid management of real-time alerts. This need is particularly acute when a new fab plant is commissioned and provisioned, and the operational team takes "ownership" of the plant. Early in plant operation, generation of a large number of alerts, including many nuisance alarms, is common, and acting on these is not straightforward since the operation team is new at operating the plant. The plant's training module may deviate from actual plant operation due to changes in operation necessitated during the construction process. Working through the intermediary (the prime contractor who installed the plant) to OEMs may be a complex process. Adding to the difficulty, design deviations implemented in construction may not have been fed back through the contractor to the OEMs, to the operational team, or to the personnel supporting it.

A leading practice is to engage a remote expert support team that is specifically tasked with supporting operational personnel immediately after a new site is commissioned (e.g., for the first 90 days). This team can help the plant operational team by co-managing alarms and through an inevitable learning curve via transfer of knowledge. Without such a team, the company may need sufficiently more operating personnel at the beginning of the plant life. This team can offset that need, reducing first-year OpEx. An important additional practice in this area is to document and cross-communicate lessons learned in this process.

Remote expert support can also be useful in brownfield (existing) plants. When unanticipated or emergency issues arise (e.g., Covid impacts on staffing access restrictions), the off-site support can obviate the need to quickly ramp up staffing, which can be challenging.

A third scenario in which this support is beneficial is when new employees are hired, in response perhaps to high turnover, or employees with different backgrounds than the personnel they replace. Despite these employees' lack of training, the remote support practice should provide live chat and other forms of communication to remotely guide these new employees through processes. In essence, this is training while doing.

Customer Case Study

A leading semiconductor company with several fabs sought a means to support its operators in the field with their day-to-day tasks. The company's expectation was to increase operator autonomy levels and skills by bringing the data to the right place in the right context.

To meet these needs, Schneider Electric implemented an augmented reality platform—first on a pilot basis, and then a few months later, in an extended project. This platform included a three-dimensional (3D) digital twin of specific power equipment and other assets such as pumps and field equipment. This tool:

- Enabled field operators to make appropriate decisions more rapidly by easily accessing up-to-date contextual information, including real-time process data, equipment documentation, and identified specific points of interest
- Helped improve the safety of the work environment by eliminating direct contact with equipment
- Helped avoid human errors via use of step-by-step guidance on digitized operation and maintenance procedures
- Laid the groundwork for remote expertise support using the platform, potentially improving response time

08 |

Optimize Equipment Maintenance

Remote expert support, predictive analytics, and related approaches for O&M data interpretation reduce maintenance costs, extend equipment life, minimize downtime, and enable extension of leading practices to multiple fab sites worldwide.

Drivers

Drivers in this area include the urgent need to:

- Maintain high reliability in the plant
- Anticipate electrical equipment failures before they occur, to minimize downtime
- Avoid failure of large, long-lead time electrical items, such as power transformers
- Minimize fire risks from electrical equipment, to maximize personnel safety, as well as protection of the entire plant

Leading Practices

Reduce Electrical Maintenance Costs

The semiconductor industry is highly competitive—pressure to reduce operational and maintenance costs is very high. Traditional time-based maintenance methods are not efficient and a reactive approach to maintenance is too risky. Digitization and cloud-based analytics have transformed how electrical maintenance is conducted. Semiconductor companies can significantly reduce maintenance costs and the amount of disruption it causes by moving to a modern, proactive, condition-based maintenance approach. This can be accomplished in two ways:

Electrical Asset Performance Monitoring

Schneider Electric recommends digitizing the electrical infrastructure with sensors and smart devices that incorporate onboard diagnostics, connect to power management software, and leverage digital services to:

- Move from reactive to condition-based maintenance strategies for critical assets like transformers, breakers, gensets, automatic transfer switches, UPSs, and capacitor banks
- Monitor asset attributes and performance over time and be notified of any abnormalities or potential failures
- Enhance the maintenance strategy with expertise through digital services to conduct more precise maintenance only when needed at the optimal time

Electrical Asset Lifecycle Management

Schneider Electric recommends connecting to specialized software that can:

- Easily access asset information to build a maintenance plan
- Receive scheduled maintenance notification to better plan and avoid unexpected failures
- Capture and share tasks with instructions to the assigned service engineer

- Generate event logs and reports on asset maintenance automatically
- Update the digital twin to keep up-to-date and continuously manage asset management

Predictive Analytics

Semiconductor fabs need to be able to detect the potential for electrical equipment failure, to gain the advantage of time, especially in light of ongoing supply chain issues. Predictive analytics can provide this advance warning, which can enable proper planning for maintenance activities. This involves anticipating needs, and identifying the right people, the right parts, and the right competencies (expertise), including remote access for support.

Operation and Maintenance (O&M) Data Interpretation

In the data management area, interpretation of the O&M data that is gathered on plant electrical equipment could be one of the key challenges for semiconductor fabs. Schneider Electric recommends using a consultative approach to jointly interpret the data to improve understanding of what the data means, how to act on the data correctly, and how to verify the effectiveness and outcomes of the actions. Support for this data interpretation can be structured into three tiers:

- **Tactical, operational support,** in which an alert is generated, and the outside company representative contacts the site, discusses potential reasons for the alert, determines if the company has on-site personnel who can verify and address the problem. This support should also include discussion of whether an on-site or off-site team needs to be proactively deployed (and when), parts need to be ordered, or continued monitoring is needed without immediate action.
- **Country-level support,** in which tactical support is provided across multiple sites in the country, common issues can be identified and relayed across the sites to management personnel, and new recommendations and best practices can be disseminated.
- **Global-level support,** in which full oversight is provided for all company sites worldwide, which reports to a person in the company with global responsibility. Here, worldwide recommendations and best practices can be discussed. Best practices identified at some sites can be fed back to designs at other sites, on a global level.

The Cloud, Cybersecurity, and Internal Department Silos

A common perception among many semiconductor fabs is that storing data, including O&M data on electrical equipment, in a shared or public cloud is a cybersecurity vulnerability. While such storage provides clear operational benefits, the perceived risk of doing so is predominant in some organizations. (This is not uncommon in other industries, and is usually the initial primary objection to storing data in a shared or public cloud.) Hence, there is a need to improve awareness and better communicate the value proposition of cloud computing and the robustness of cybersecurity measures in various types of clouds.

One impediment to moving forward in this area is that the ownership of the cloud connection (IT) practices is different than the ownership of the facility and operational (OT) management. Hence, cooperation between these two groups (IT and OT) is necessary. In its client engagements in this space, Schneider Electric has learned that these interdepartmental silos are a pressing strategic challenge that C-suite personnel in semiconductor companies face today.

Remote Expert Support for O&M Staff

Whenever possible, the fab also seeks to eliminate interference with the critical electrical equipment of the plant, which means limiting the amount of access to the site for outside personnel. This access poses complexity due to the high security nature of the facility, and hence, the difficulty scheduling time for outside personnel, as well as personnel safety (e.g., exposure to high-voltage or medium-voltage equipment, and the potential for an arc flash incident, for example). Hence, the fab seeks to gain insight and visibility inside the examined component, without the need for human intervention at the affected equipment.

Remote expert support provides a range of benefits, including reduced interference with plant equipment and improved personnel safety. In this arrangement, the outside company and fab personnel both monitor O&M data on electrical equipment in real time. This *co-monitoring* function is one way, and hence, is distinct from *co-managing*. In co-monitoring, no two-way communication exists, and there is no command and control. The nuances of this arrangement are best performed in joint consultation between the outside company and fab personnel, to ensure fab comfort with the setup. In most cases, the data monitored is a copy of the information and is not in real-time (e.g., data collected every 15 minutes or every hour). Concerns over the confidentiality and privacy of operating and maintenance data are typically company specific and can be addressed by tailoring practices to what the fab allows. This can be mutually achieved in various ways (e.g., anonymizing data, processes for vetting personnel, addressing the locations of monitoring personnel).

Customer Case Study

Schneider Electric provided large-scale condition monitoring solutions for two facilities of a major semiconductor company. The company had encountered two specific equipment failures: a switchboard fire incident, and corrosion and high humidity in an unmonitored switchgear compartment. The company was concerned about unexpected equipment failures and potential operational disturbances with high business costs.

To address these concerns, Schneider Electric installed a comprehensive sensor monitoring system, on-site monitoring, including power monitoring, and continuous monitoring. The company benefitted from 24/7 continuous thermal and humidity monitoring, mitigation of electrical failure risk, prevention of interruption to production lines, and more rapid anticipation of critical issues via smart alarming.

09 |

Enhance Cybersecurity

In today's connected industrial world, cybersecurity underpins business resilience, including most semiconductor fab activities.

Drivers

Following are the primary drivers for a resilient, comprehensive cybersecurity program in the semiconductor fab industry:

- **Avoid operational disruption.** Lost production from a cybersecurity attack means lost revenue. If the OT environment is breached, power monitoring and the control system can be disrupted, and the production floor can be brought to a halt.
- **Protect the expanded attack surface.** Increased connectivity and growth in digital devices, including Industrial Internet of Things (IIoT) increased the risk exposure to cyber-attacks.
- **Reduce the impact of breaches.** In addition to the above, cyber breaches entail tangible and intangible loss of revenue, reputation, market confidence, and intellectual property. The impact is not just at a single point in time, but typically includes a long tail effect that trails the breaches.
- **Regulatory compliance and ESG.** The World Economic Forum (WEF) cited cybersecurity as an environmental, social, and governance (ESG) issue; and characterized cyber risk as the most immediate and financially material sustainability risk that organizations face today.[14] Regulatory agencies, customers, shareholders, investors, suppliers, and other stakeholders are increasingly seeking assurance via visibility into, and verification of, a resilient framework to manage cybersecurity risk.

Leading Practices

Integrate People, Process, and Technology. Schneider Electric recommends establishing a cybersecurity strategy for operational technology and operationalizable policies to manage cybersecurity risk holistically and systematically using a risk-based approach, which should integrate people, process, and technology (see Figure 16):

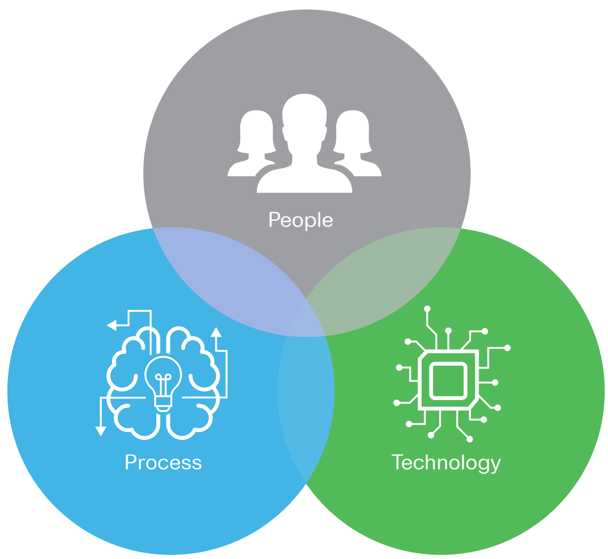

Figure 16. Leading practices across the entire line of cybersecurity defense integrate people, process, and technology

- **People.** A vigilant workforce with knowledge of evolving cyber tactics used by attackers is a strong deterrent against cyber threats. In many cases, people are the first and last line of defense. A crucial element of this area is to cultivate a cyber safety culture organization-wide, constant communications, and ongoing awareness training. This includes the supply chain network.
- **Process.** To identify and manage cyber risks, semiconductor companies need to establish and maintain a robust and operationalizable process governance framework. Companies can begin with risk and threat assessments and gap analyses—with references to leading standards and industrial best practices—and apply them contextually.

[14] A. Sarnek, World Economic Forum (WEF), "Cybersecurity is an environmental, social, and governance issue. Here's why," Mar 1, 2022, https://www.weforum.org/agenda/2022/03/three-reasons-why-cybersecurity-is-a-critical-component-of-esg/.

- **Technology.** Employ purpose-built technology to gain visibility into the digital and physical environment. Organizations can harness effectively managed technology to protect the semiconductor plant, its equipment, systems, and digital intellectual property, as well as the technology and information related to its suppliers and vendors.

Implement Defense-in-Depth. Schneider Electric recommends a defense-in-depth approach for semiconductor companies. While some companies assume that the systems they implement already incorporate leading practices to mitigate cybersecurity risks. The systems alone are only a starting point. The way the systems are implemented and integrated into the company's environment is equally important. The processes for implementation and integration of systems should protect the integrity of the company environment. Once the systems are operational, many other security aspects should be considered as part of the overall operation, depending on the risk assessment. These range from access control to network segregation and cyber testing. In addition, dedicated services are needed that provide an objective perspective and broader experience in reviewing or developing a solution design, training the company's team, and providing ongoing managed security services.

Use Global Cybersecurity Standards. Schneider Electric recommends applying global standards and industrial best practices such as the ISA/IEC 62443 Standard and NIST Cybersecurity Framework.

The ISA/IEC 62443 Standard is the world's only consensus-based cybersecurity standard for automation and control system applications. It has the following features:[15]

- A flexible framework to address and mitigate current and future security vulnerabilities
- It defines requirements and procedures for implementing secure systems
- It leverages a holistic approach that bridges the gap between OT and IT, as well as between safety and cybersecurity.

The NIST Cybersecurity Framework is based on existing standards, guidelines, and practices for organizations to better manage and reduce cybersecurity risk. It was designed to foster risk and cybersecurity management communications among both internal and external organizational stakeholders.[16]

Cybersecurity for the Operational Lifecycle. Schneider Electric recommends cybersecurity elements across the semiconductor fab operational lifecycle:

- **Initial Assessment.** The first step is to assess and review systems to detect gaps and risks, as well as to uncover any security malpractices, assess personnel security competencies, provide emergency response services, etc.
- **Design and Implementation.** With an understanding of the company's unique needs and requirements, as well as knowledge of best practices and industry standards, the next step is to design, develop, and implement an effective and defensible security architecture. Critical infrastructure needs to be protected through a defense-in-depth-based security approach can be customized to meet the company's needs.
- **Monitoring.** The cybersecurity solutions should then be monitored to detect threats, apply patches, and ensure the smooth functioning of devices and the system as a whole.
- **Maintenance**. Continual review and updating of cybersecurity protection is important. This ensures that systems and skills are up-to-date and tested regularly to maximize security and peace of mind.
- **Training.** People are the most important element in ongoing, effective cybersecurity protection. Designing and delivering effective training for various roles in the organization is beneficial. From basic awareness to expert-level skills, the company needs to establish a cybersecurity culture goes beyond education and training.

[15] International Society of Automation, https://www.isa.org/standards-and-publications/isa-standards/isa-iec-62443-series-of-standards.
[16] NIST, "Cybersecurity Framework," https://www.nist.gov/cyberframework.

Figure 17 provides a list of recommended elements for the semiconductor fab operational lifecycle.

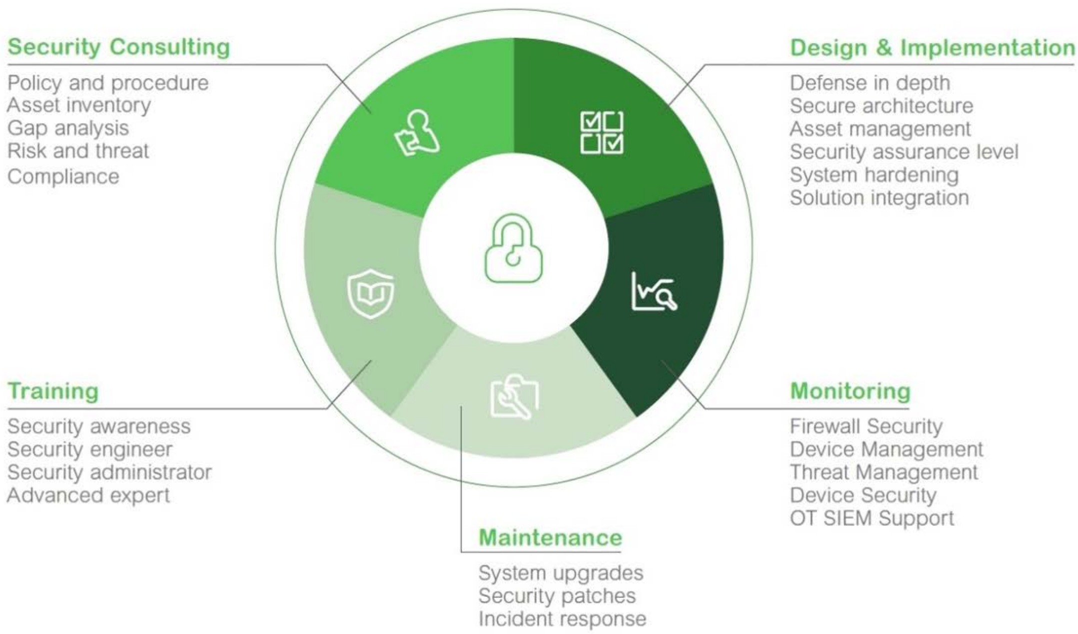

Figure 17. Key elements of the operational lifecycle for semiconductor fabs

Implement Cybersecurity Solutions. Schneider Electric recommends that cybersecurity solutions identified for implementation cover the following categories (see Figure 18):

- **Permit** – Manage access to operations systems and information through network and physical controls.
- **Protect** – Implement specific controls as part of the operations systems for ongoing protection.
- **Detect** – Monitor the operating environment to detect and communicate threats.
- **Respond** – Develop procedures and systems to support rapid response to cyber incidents to contain and mitigate attacks.

Permit	Protect	Detect	Respond
• Authentication, Authorization, Accounting • Multi-Factor Authentication • Network Segmentation • Secure Remote Access • Physical Security	• Endpoint Protection, Anti-malware, • DLP, HIPS, Whitelisting • Removeable Media Control • Patch Management	• Security Information & Event Management (SIEM) • Network Performance Monitoring • Asset Identification • Anomaly Detection • Intrusion Detection	• Backup / Disaster Recovery • Forensics • Incident Response

Figure 18. Cybersecurity solutions by categories

Digitization has accelerated IT/OT convergence. This enables companies to make improved, real-time business and operating decisions to react more quickly to changing market dynamics and the competitive landscape. To take advantage of this convergence, the company needs to think differently about cybersecurity. Leveraging real-time operating data to tobatin better-informed/data-driven SC decisions. OT and production systems can no longer be obscured by proprietary standards and hard-wired connectivity. At the same time, the proliferation of sensors, intelligent devices, and other at-risk digital endpoints has broadened the attack surface for cyber criminals. Protecting this surface requires a sound strategy and holistic approach.

Managing cyber risk requires competency at every level from the Board room and the top floor to the shop floor. Exploit technology effectively by employing trained people to manage and act, with robust processes and policies to govern and operationalize in order to deliver value. Technology alone is not effective. Optimal integration of people, processes, and technology is essential. Activities can be outsourced, but not the risk.

10 |

Attract/Retain a High Quality Workforce

Workforce transformation goes hand-in-hand with operational efficiency. Improving operational efficiency require a talented workforce. Attracting and retaining that future-ready workforce requires fabs to compete with other industries.

Drivers

- Attracting talented personnel to the industry may be challenging.
- Retaining this talent poses similar challenges.
- A different mix of skillsets (e.g., greater emphasis on software skills) is needed.
- More fabs are considering localization as a key strategy.

Leading Practices

Future-Ready Workforce

The digital transformation to integrated operations and planning, digital tools that break down functional silos, O&M data interpretation, and other capabilities requires a future-ready workforce. “Sunrise” is a term mostly attributed to IT, software, and e-commerce industries, which leverage high growth areas such as artificial intelligence and machine learning, internet of things, edge computing, robotics, smart sensors, and others. Conversely, manufacturing industries tend to be called “sunset” industries. However, this new way of operating and planning at fabs is likely to attract (and retain) talented personnel to this industry, who are more likely to view it as a “sunrise” industry. Hence, an additional benefit of the digital transformation is the ability to attract and retain a high quality workforce via a people-centric transformation.

Workforce perception of corporate culture and values, diversity and inclusion, and work-life balance, for example, are three factors that are important to employees. According to the results of a recently-published McKinsey analysis in the semiconductor industry, semiconductor companies trail both tech companies and auto companies in average employee satisfaction in all three of these areas.[17] Talented personnel are likely to be attracted to an industry that:

- Is adopting exciting advanced technologies that other industries are adopting
- Allows them to quickly learn what they need to learn, in interesting ways
- Establishes a policy of work-life balance
- Enables them to work on meaningful, interesting tasks early in their careers (rather than “paying their dues” for years)
- Adopts a hybrid work model (e.g., as a result of the pandemic) with innovative ways to foster collaboration between manufacturing, technical, and research and development teams

[17] McKinsey & Company, “How semiconductor makers can turn a talent challenge into a competitive advantage,” September 7, 2022, https://www.mckinsey.com/industries/semiconductors/our-insights/how-semiconductor-makers-can-turn-a-talent-challenge-into-a-competitive-advantage.

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Empower the Workforce

Cutting-edge workforce training has arrived, and leading semiconductor fabs recognize its value in today's rapid growth scenario.

Drivers

While electrical distribution systems have become more complex, seasoned electrical professionals are retiring, and operational budgets are tightening. This leaves facility management teams with fewer, less-experienced people to maintain critical assets and respond to any threats to electrical continuity while frequently working on unfamiliar equipment under stressful conditions. Rapid growth in the semiconductor industry compounds this challenge due to added pressure to minimize downtime, adopt new unfamiliar technology and quickly learn how to operate and maintain it, and avoid the increased potential for operational errors that often accompany growth.

Leading Practices

Extended Reality

Extended reality (XR) technology—including virtual reality (VR), augmented reality (AR), and mixed reality (MR)—is already well-established in applications like healthcare, manufacturing, and industrial training. Emerging XR tools are also well suited to electrical distribution, specifically for O&M. These tools can help semiconductor fabs accelerate training, empower the facility workforce to improve safety and efficiency, and save time isolating risks and restoring power.

VR, AR, and MR. VR is a fully immersive experience of computer-generated imagery and sounds. AR overlays computer-generated information on the real-world. MR enables users to interact and manipulate real physical items as well as virtual ones. XR encompasses all three of these technologies (see Figure 19). "A recent survey of manufacturers shows that 56% of those polled said they have implemented some form of AR/VR technology into their organization over the last 12 months. 29% said they are realizing more than a 25% increase in productivity efficiency [while] 61% said they are realizing as much as a 20% savings in costs."[18]

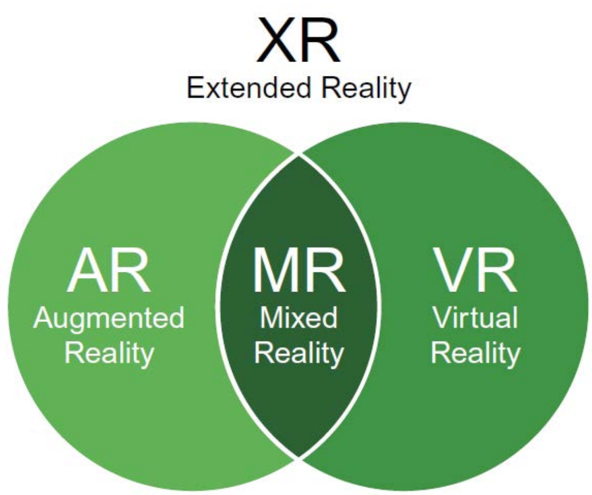

Figure 19. Extended reality is the complete scope of augmented reality and virtual reality technologies, and their combined use as mixed reality

[18] Rob Spiegel, "Manufacturers Are Turning to AR/VR to Reduce Production Costs," Design News, June 25, 2020, https://www.designnews.com/automation-motion-control/manufacturers-are-turning-arvr-reduce-production-costs.

An XR system organizes relevant data (e.g., on electrical equipment, procedures, electrical network status, etc.) and enables field data access via mobile tablets, smartphones, digital glasses, or XR headgear.

- When using AR, the real device or object, such as an electrical cabinet, can be superimposed with a schematic diagram or step-by-step procedures (see Figure 20). It can also be overlaid with live data, showing selected readings from each device or sensor in the cabinet.
- In the case of VR, a virtual environment is created that represents, for example, a functional piece of equipment or a complete electrical room with all associated equipment. There are no "real" objects with VR, but the virtually-modeled objects can appear three-dimensional and very realistic.
- In the case of MR, a VR modeled image can be presented to the technician while they are using AR to view information about the real equipment in front of them.

Figure 20. An AR system can quickly find and reveal other required documentation or information, such as a virtual schematic that can be correlated with switchgear operation

Akin to Digital Twins. In this respect, both AR and VR are essentially "digital twins" of the actual functioning electrical equipment. For AR and VR used in electrical O&M, real-time data is accessible from the database of an energy and power management system. It integrates with a graphical digital twin of the electrical switchgear, sometimes including equipment from multiple vendors. Further layers of information can also be accessed, such as electrical diagrams, images, or videos. AR provides a capability akin to "x-ray vision," virtually revealing the internal components of an actual cabinet, machine, or device (see Figure 21). To enhance safety in a real operating environment, varying levels of XR access can be granted, depending on user roles and responsibilities.

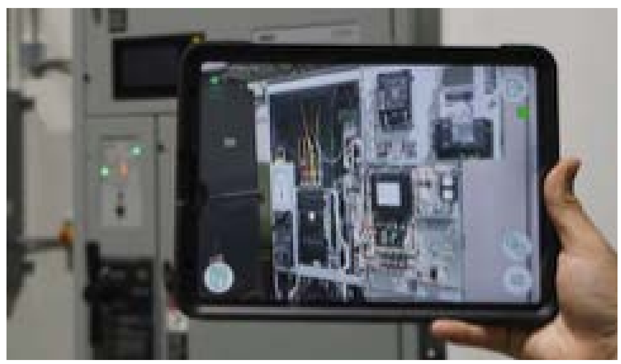

Figure 21. XR enables a technician to see behind the door of an electrical cabinet with "x-ray vision" for increased safety

Delivering Electrical System XR Solutions. Creation of customized AR/VR solutions typically requires many hours of 3D developer labor—at a high cost. However, the newest XR solutions for electrical O&M are game changers. They offer a more affordable approach that uses a plug-and-play architecture comprised of default AR and VR components representing common electrical equipment. When supported by vendor services, a ready-to-use XR application can be provided to a facility team, complete with all digital equipment models and functionality. This results in a solution that is many times faster to implement than traditional methods.

One of the challenges of using AR or VR for O&M is ensuring data accuracy, which requires recurring updates. Achieving this using traditional XR solutions is costly and time consuming. In contrast, new authoring platforms function as three-dimensional presentation software, facilitating these updates. Fabs can use these platforms in full-service supported mode or self-service mode performed by the fab's in-house maintenance team.

Business Benefits. Electrical system XR is enabling a wide range of powerful benefits for facility management teams:

- **Enhanced safety.** XR alerts technicians when nearing or crossing safe boundaries, describes personal protective equipment (PPE) requirements, and visually delivers clear guidance and procedures to help reduce human error and unsafe practices.
- **Improved cost efficiency.** XR prepares technicians before they arrive on-site, saves time in performing procedures, and enables faster access to information that helps avoid the need for return trips.
- **Enhanced resilience and reliability.** XR helps engineers and technicians closely collaborate and work with greater confidence to address risks and restore service faster.
- **Training efficiency.** The combined AR and VR experience helps improve skills transfer by providing trainees context and cases closer to reality, with the ability to repeat exercises anywhere, at any time.

Customer Case Study

A leading semiconductor company faced the challenge of siloed data in a computer-assisted maintenance management system, supervisory control and data acquisition (SCADA) system, maintenance guide, and other locations. The company sought to gather, centralize, and display data in the plant to support operators' daily challenges.

To address this need, Schneider Electric provided an XR solution to the company. After only a two-month limited trial, the company perceived the following benefits:

- **Display of the right information, at the right place, in the right context.** This involved providing data on site in a meaningful context even for some equipment that does not have a human-machine interface.
- **Increase operator autonomy, skills, and versatility.** This helps operators perform tasks when they are a newcomer, when they are on-duty alone at night, or when they are not familiar with certain equipment (due to the large site, with a large variety of equipment).
- **Support maintenance activities.** This provides maintenance personnel step-by-step guidance for pre-established maintenance trouble scenarios, in a manner similar to a smartphone voice-controlled digital assistant.

The company subsequently ordered a second project to install the XR solution in its process cooling water room.

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About Schneider Electric

Schneider's purpose is to **empower all to make the most of our energy and resources, bridging progress and sustainability** for all. We call this **Life Is On**.

Our mission is to be your digital partner for Sustainability and Efficiency.

We drive digital transformation by integrating world-leading process and energy technologies, endpoint to cloud connecting products, controls, software and services, across the entire lifecycle, enabling integrated company management, for homes, buildings, data centers, infrastructure and industries.

We are the **most local of global companies**. We are advocates of open standards and partnership ecosystems that are passionate about our shared **Meaningful Purpose, Inclusive and Empowered** values.

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Acronyms

Acronyms

AI	artificial intelligence
AR	augmented reality
BIM	building information model
CAD	computer-aided design
CapEx	capital expenditure
CO_2	carbon dioxide
DIW	deionized water
DLP	data loss prevention
EaaS	energy-as-a-service
EMS	energy management system
EPRI	Electric Power Research Institute
EU	European Union
EUV	extreme ultraviolet lithography
ER	extended reality
ESG	environment, social, and governance
EV	electric vehicle
GHG	greenhouse gas
HIPS	host intrusion prevention system
HMI	human-machine interface
HV	high voltage
HVAC	heating, ventilating and air conditioning
IEC	International Electrotechnical Committee
IIoT	industrial internet of things
IoT	internet of things
ISO	International Organization for Standardization
IT	information technology
KPI	key performance indicator
ML	machine learning
MR	mixed reality
MV	medium voltage
NIST	National Institute of Standards and Testing
O&M	operations and maintenance
OEM	original equipment manufacturer
OpEx	operating expenditure
OT	operations technology
PPA	power purchase agreements
PPE	personal protective equipment
PV	photovoltaics
RTU	remote terminal unit
SBT	Science Based Targets
SBTi	Science Based Targets initiative
SCADA	supervisory control and data acquisition
SF_6	sulfur hexafluoride
SIEM	security information and event management
SLD	service level definition
TCO	total cost of ownership
UP	ultra-pure
UPS	uninterruptible power supply
UPW	ultrapure water
VR	virtual reality

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