Fab of the future:

Velocity with smart manufacturing

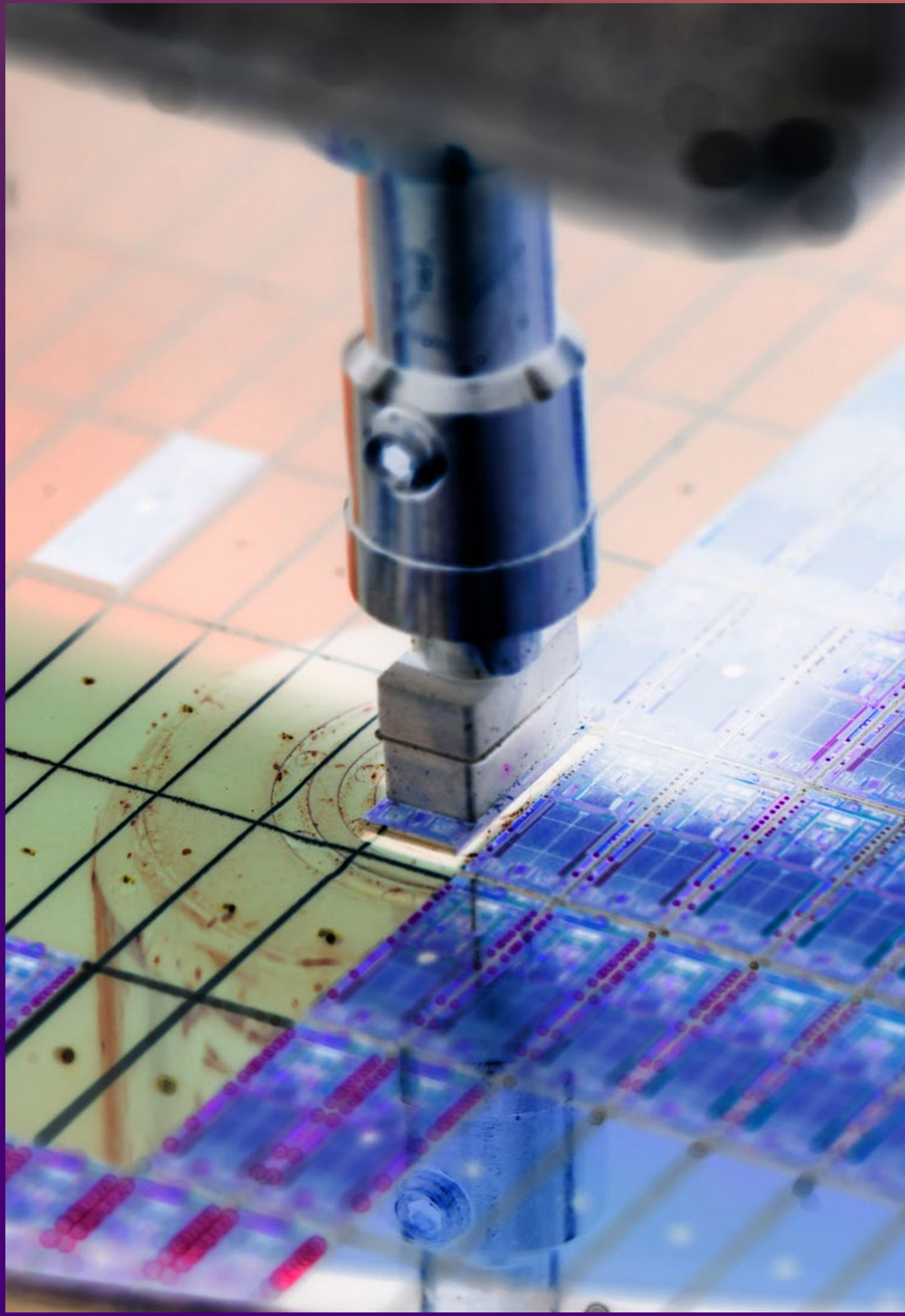
accenture

Overview

With the rapid pace of technology innovation, it's no surprise that today's fabs are continuously adapting, innovating, and transforming. They see huge opportunities to leverage and advance the latest emerging high-growth areas of Enhanced Reality, Internet of Things (IoT), Artificial Intelligence (AI), Automotive, and 5G. At the same time, they still need to keep pace with the conventional growth in demand as computing becomes pervasive in all aspects of day-to-day life.

However, fabs also face a sobering reality: Their complexity, scale, and variability make it a constant challenge for fabs to balance critical priorities: keeping manufacturing operating costs low, supply chains robust, processes integrated, throughput high, quality uncompromised, and cycle time minimized. Further, challenges including increased regulatory challenges, pressure to stay ahead of the curve in a highly competitive environment, and delivering on the promise of sustainability, require fabs to not simply adapt, but to do so quickly.

How can fabs achieve their priorities of providing cutting-edge innovations, optimizing operations, and creating sustainable values? The answer is to embrace digital technologies across the end-to-end supply chain to become a truly digitally connected and digital-led smart fab of the future.[1]



SEMICONDUCTOR INDUSTRY VALUE CHAIN

Chip design & development
- Concept definition
- Chip architecture and layout development
- Software and IP services

Fabrication, assembly, & test
- Material, chemicals, & mfg. equipment
- Fabrication and testing of chips on silicon wafers
- Packaging, bonding, and testing

Marketing & sales
- Product strategy
- Customer identification
- Demand creation

Distribution
- Distribution of components
- Value-added supply chain & design services

Electronics assembly
- Purchase of individual components and sub-assemblies
- Assembly and testing of electronic systems

Finished product integration
- Final system assembly and integration testing
- Retail distribution

Recycle, repair, remanufacture

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Reuse, recycle, repair, remanufacture

Recovery and reuse
(Semiconductor manufacturing circularity)

Key Challenges and Priorities

Fabs and the ecosystem must evolve from their conventional structure and leverage modern paradigms of technology and manufacturing to realize their full potential. Doing so means taking aim at several pivotal focus areas where the fab and its ecosystem face major challenges today:

PEOPLE AND SKILLS

A study by the Semiconductor Industry Association, in partnership with Oxford Economics, found that building new fabs can create nearly 200,000 jobs and adds $25 billion annually to the US economy.[2] Yet according to a recent survey from SEMI, 82% of executives reported a shortage of qualified technical candidates,[3] which adversely affects overall productivity. With growing demand for digitally skilled resources, fabs need to find the right people with right expertise, or equip existing talent with the skills to handle ever-changing digital technologies and their use in manufacturing, operations, and quality. A centrally managed and technologically enabled *collaborative learning and training digital center* to upskill and reskill workforces, at scale, has become a big priority.

DESIGN

With the development of advanced nodes, circuit designs are becoming more complicated, which in turn means more resources to simulate, optimize, and verify circuits are required. The industry faces numerous challenges, including higher design costs, slower maturity of silicon processes and design rules, and higher turnaround time from the fab to achieve quality and yield targets. Additionally, manual testing of physical designs leads to significantly greater cost and takes a lot of time. Fabs are also struggling to strike a balance between high R&D costs and ROI in designing advanced nodes for manufacturing. Automation of design processes leveraging generative design tools is desperately needed, along with exploring the potential of AI to boost design success rates, superior performance and shorter payback period.

PRODUCTION

Fab wafer manufacturing is very capital intensive, and the development of advanced nodes lower than 7nm will only increase the cost of manufacturing. However, developing new process technologies and deploying them to production phases takes considerable time. The disaggregated design strategy is already mired in challenges involving combining components with different yields, throughput times, and capacity constraints into a single package. Smaller and smaller chip sizes will compound these challenges in the future due to limitations in Moore's Law.

QUALITY

Production of a new advanced node chip requires more than 1,000 process steps. If something goes wrong at any process step from oxidation to metal deposition and etching, it can result into lower performance or even chip failure. At the same time, automotive, medtech, IoT, and other industrial applications require highly reliable chips over a long period of time. But traditional optical inspection tools are ineffective in detecting defects. The quality function is ripe for interconnected tools, equipment, and processes with advanced machine learning, analytics, and AI capabilities that can identify defects and process drift on a real-time basis.[4]

PLANNING

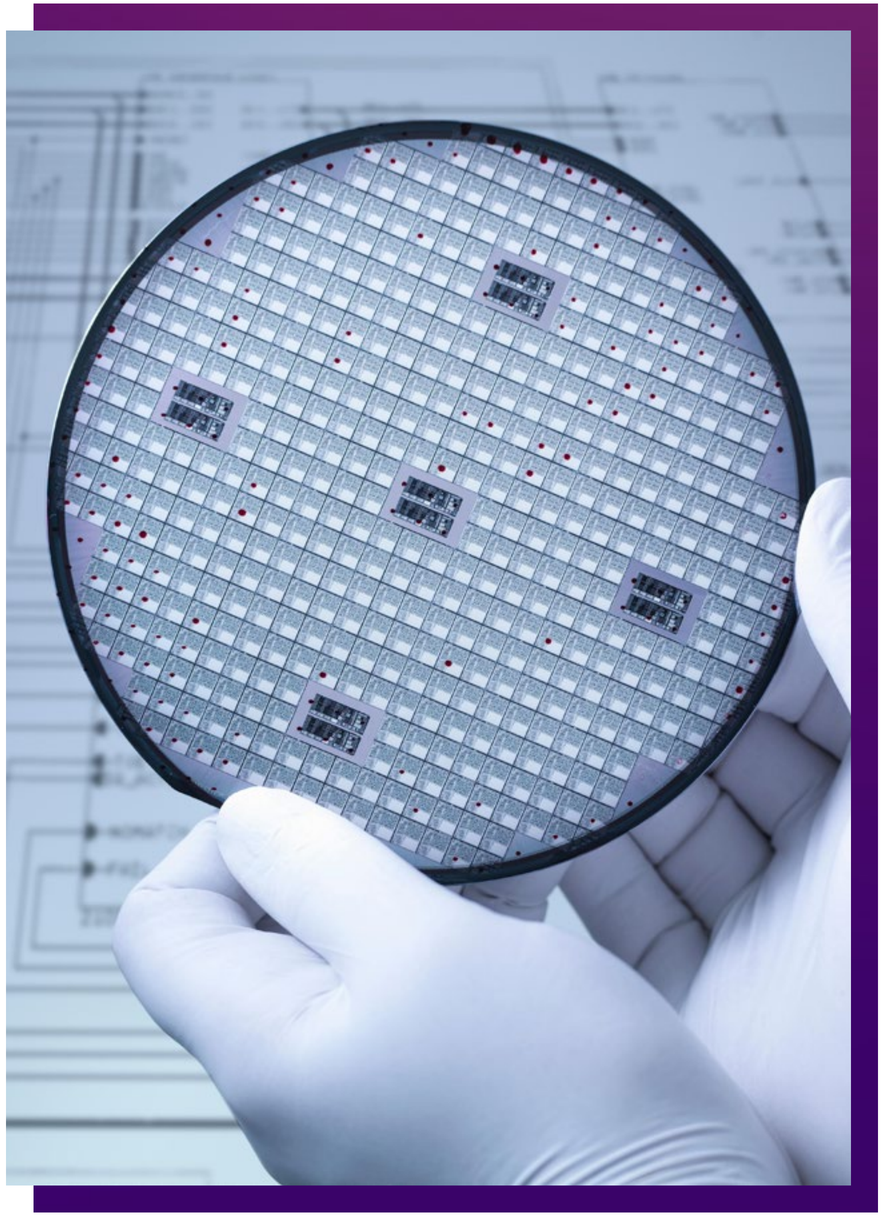
Covid-19 has led to a chip shortage, which has a cascading effect across industries, including semiconductor manufacturers. In fact, the shortage has extended lead times for many semiconductors out to more than a year. It's difficult to source multiple direct and indirect materials due to complex supplier networks spread across geographies, and it takes at least five years to fund and build a fab. As we have seen, these demand- and supply-side pressures, coupled with quality issues and price fluctuations, can disrupt the supply chain—making a flexible and agile supply chain an urgent priority for semiconductor manufacturing.[5]

PACKAGING

Packaging is becoming more complex as a result of innovations in semiconductor fabrication. Multiple integration technology platforms have emerged that provide cost, size, performance, and power optimizations to cater to different segments such as mobile computing, automotive, 5G, AI, AR/VR, and IoT. However, these packages pose a challenge for traditional package design tools and methodologies struggle to keep up with new packaging requirements, and design teams must verify and optimize the entire system in such cases. The industry as a whole needs to make far greater progress in 3D modelling, prototyping, and digital twins for advanced packaging solutions.[6]

SUSTAINABILITY

Information and computing technology is expected to account for as much as 20% of global energy demand by 2030, and chip manufacturing accounts for most of the carbon output. In fact, chip manufacturers have a larger carbon footprint than traditionally more polluting industries like automotive.[7] According to research at United Nations University, 50% of the energy consumed by a semiconductor chip over its useful life is attributable to the original manufacturer. Moreover, the semiconductor manufacturing process is responsible for significant water consumption as well as chemical emissions. Smart and connected plants will help the semiconductor companies to track and control the consumption of power, emissions and water usage.



Fab of the future – making Industry 4.0 live

The preceding challenges are, indeed, significant, but they're certainly not insurmountable. In fact, digital technologies are uniquely positioned to help fabs overcome these obstacles to innovation and growth.

Consider, for example, the digital framework we've developed that illustrates the fab of the future (Figure 1). This framework depicts a holistic approach to optimizing the end-to-end value chain across the build, operate, and maintain phases—with an overarching Manufacturing Collaboration Tower at the center—that can enable fabs to unlock genuine business value.

FIGURE 1: A FRAMEWORK FOR THE FAB OF THE FUTURE

Digital Engineering

Digital Twin & Digital Thread for realistic modelling, simulation and actionable insight for the fab plant built and commissioning

Modular Production Lines with flexible and optimized multi-directional layouts

Smart Factory

Cloud & Digital Twin Enabled for flexible production and operations

Connected Asset Performance

Analyze Big Data, apply AI to predictive model that can alert of equipment failures before they occur

Quality Management

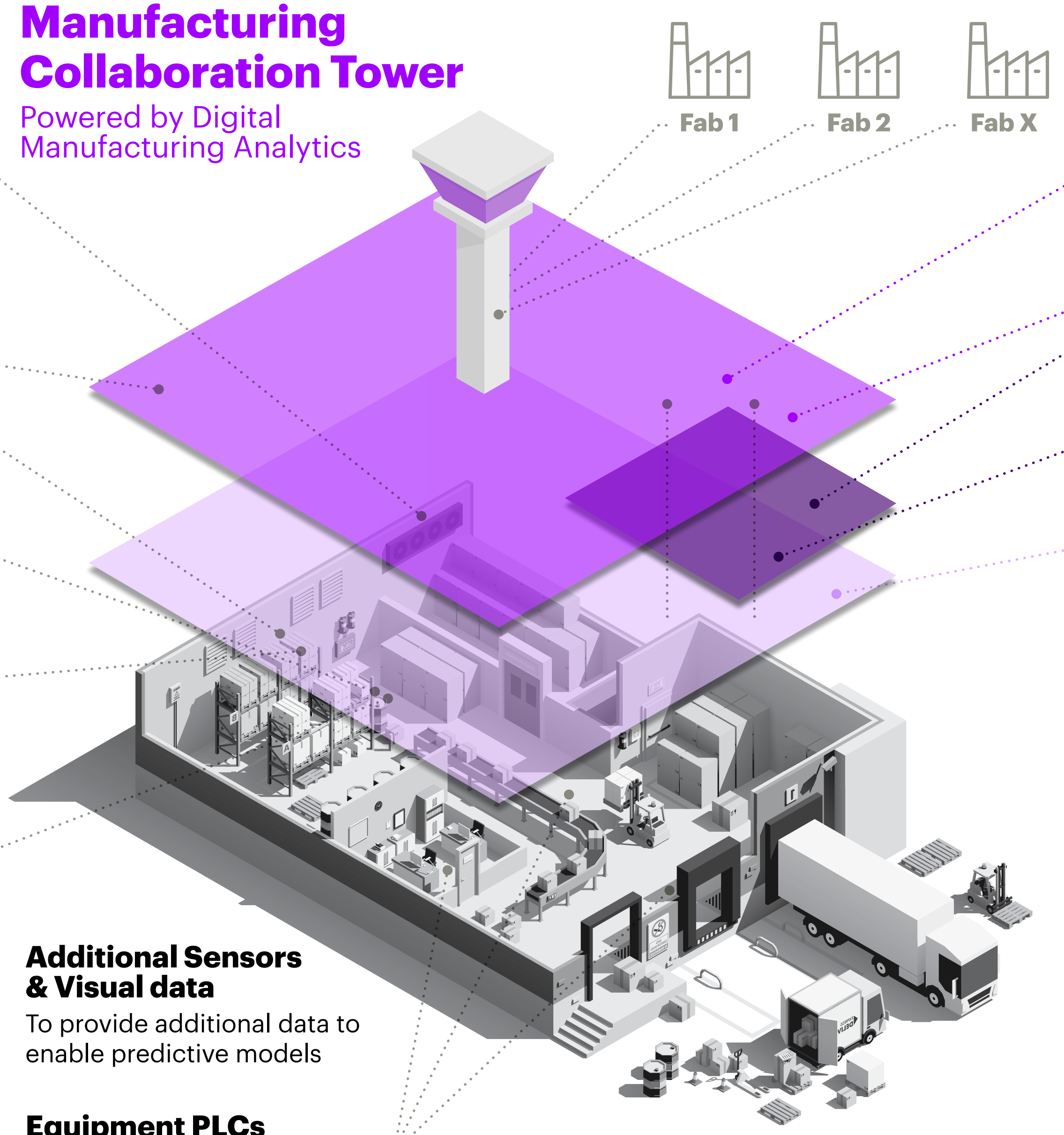
End-to End Quality Management using sensors and advanced analytics for automated detection of defects and improving quality

Integrated Processes

Data from ERP, MES and key systems, with seamless integration and advanced analytics and sensors to derive actionable insights in real-time

Manufacturing Collaboration Tower

Powered by Digital Manufacturing Analytics



Additional Sensors & Visual data

To provide additional data to enable predictive models

Equipment PLCs

Used for connected equipment for smarter control and automation

Central / Leveraged Platform

Cloud Platform
- Data Lake
- Multi-system integration

Supplier Ecosystem
Open Data
Partners Ecosystem

Edge Gateway
Wireless and wired network

Plant Platform
Edge Switches, VLAN, SCADA, Historian, MES

Integrated Supply Chain

Dynamic Production Planning/ Scheduling, Connected Suppliers/ Distribution Centers, Remote Operations approach to remotely monitor, assess, guide and resolve issues from a central location driving optimization

Sustainability

Use of technology as a catalyst to bring change in Environmental, Social and Governance ecosystem. Centralized Energy & GHC Emission Control Tower

SMART BUILD

Leveraging digital in a fab's "build" phase provides the most convenient way of embedding digital DNA in the plant through connected systems and processes, smart layout, efficient planning, and integrated insights at every link of the fabrication value chain. The most important digital solution from the perspective of fab in this phase is Digital Engineering – Digital Thread and Digital Twin.

Digital Engineering – Digital Twin and Digital Thread and their role in building the fab of the future

The right Digital Twin and Digital Thread strategy can open new and vast areas of opportunities for the fab plant. Digital Thread connects processes across a fab operation's value chain—from oxidation and coating to etching and metallization. This, in turn, creates the foundational layer for developing a Digital Twin of the fab.

Digital Twin can help virtually build and commission the fab processes and systems through digital modelling and simulation of the actual fab environment, with the learning from those exercises being transferred to the actual implementation. Additionally, virtual plant simulation and production planning can help improve material flow planning across the production facility, precisely detect manufacturing dynamic bottlenecks, increase throughput, and optimize energy consumption. Assembly operations simulations can help create and optimize robot paths and efficient placement of manufacturing equipment. Production processes, down to the layer of real controllers, can be modeled, simulated, and validated using Digital Twin to monitor, control, and optimize the relevant machines, production cells, and production lines interaction.

A Generative Design Studio, built on Digital Twin and machine learning, can help create and optimize fab design plans. The optimized design generator helps populate initial fab designs by leveraging data and learnings from past projects, customization needs, and cross-industry best practices, such as performance metrices, process requirements, locations, and budget.

Digital Engineering – Modular Production Lines with flexible and optimized multi-directional layouts

Advanced plant layout modelling solutions (2D/3D fab layouts), using a data-driven hybrid modelling and simulation approach built on a digital emulator, can help create flexible, optimized multidirectional fab plant layouts with a modular line setup, energy-efficient design, and sustainable production processes. Modularization of fab production lines using advanced modelling solutions helps integrate and validate processes prior to actual physical construction, thus equipping fabs with plant layouts that can rapidly adjust to frequent changes in semiconductor production requirements, minimize delay risks, and ensure optimum quality and operational efficiency.

INTELLIGENT OPERATE AND MAINTAIN

Empowering operations and maintenance with digital can unlock enormous benefits and help get the most out of a digital fab by unlocking a wide range of new opportunities. Some of the key digital solutions for smart operations and maintenance include the following:

Smart Factory enabled by Cloud and Digital Twin for flexible production and operations

Cloud technology is nothing new to the semiconductor industry;[8] in fact, this game-changing industry has helped other sectors become the major disruptors they are today. However, when it comes to actual cloud adoption in a fab, progress has been slow due to concerns over security or innovation capacity.

However, with an enterprise-level, secure, customized, and mature cloud solution now available for fabs, fabs need to embrace the cloud for flexible, location-agnostic, and smarter manufacturing. Cloud can create transparency in the value chain with increased visibility and service consumption metrics. Real-time data accessibility and analysis of key business metrics on the cloud can drive better resource efficiency and cost stewardship. Cloud-accelerated innovation for semiconductor capabilities can also provide the highest levels of reliability and fastest pace of innovation.

> Fabs need to embrace the cloud for flexible, location-agnostic, and smarter manufacturing.

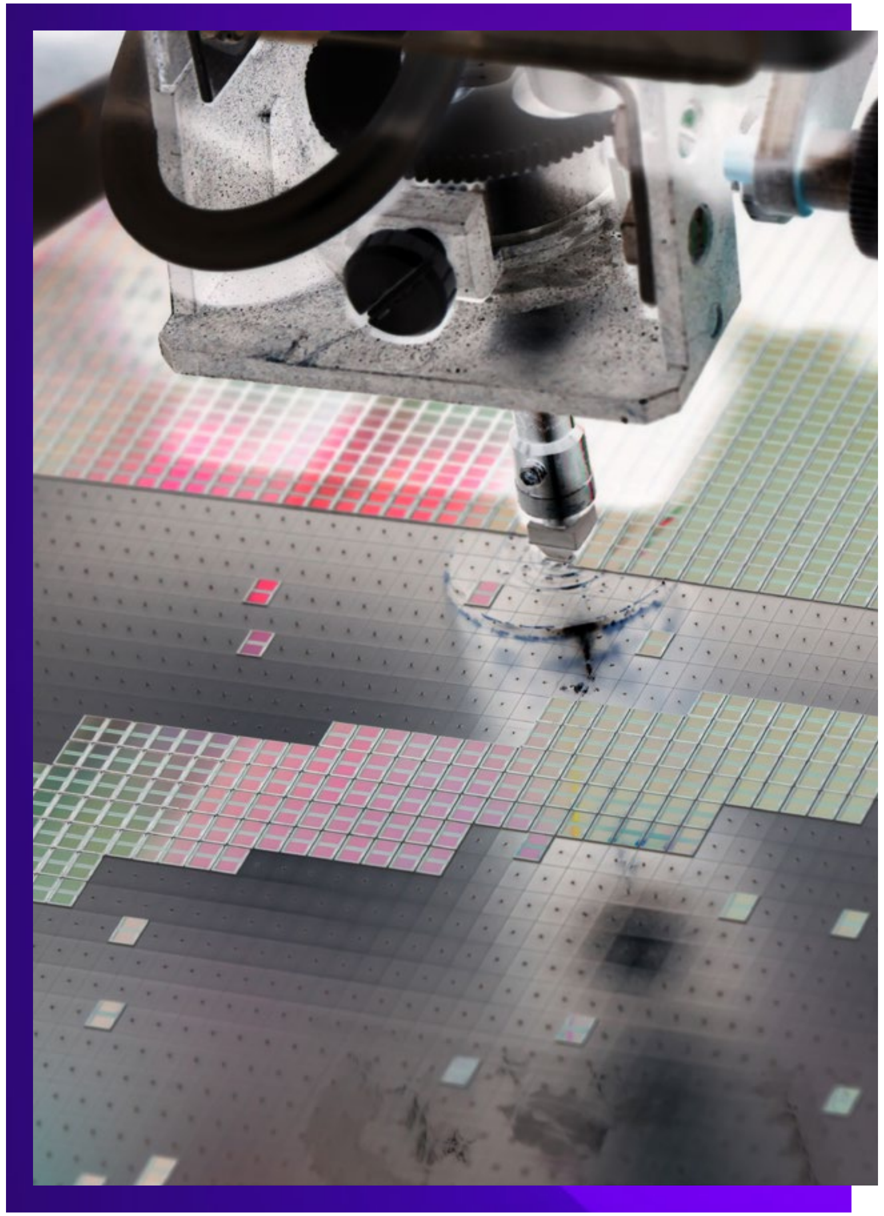
By providing a consolidated platform for management, a cloud-enabled smart factory can perform and accelerate decision making on processing time, staging, raw material management, and more—ultimately automating manufacturing including setup changeovers, lay-outing and routings, and maximizing throughput. Fabs can leverage the cloud to store and analyze data and make the information readily available to suppliers and vendors, and also standardize the business processes across disparate sites for more insightful production and performance analysis. Advanced analytics and AI allow interpreting and connecting manufacturing (fab) on the cloud to help deliver relevant product and engineering insights for improving product development and manufacturing quality.

> A virtual production model for fab operations and maintenance helps optimize throughput, yield, quality, and cost with faster turnaround time.

Forging Digital Twin in fabs' operations and maintenance is yet another vital enabler for the smart fabs of the future. Digital Twin-led[9] realistic simulations and tests in new product development can deliver useful information much earlier in the design phase, leading to optimization of semiconductor material behavior, integration, and advanced packaging. With real-time virtual modelling of products and the production process, Digital Twin also provides insights into the condition of highly expensive semiconductor equipment, products, and production environment. Virtual testing and simulation can improve overall equipment effectiveness (OEE), as well as enhance resource and maintenance management. Finally, a virtual production model for fab operations and maintenance helps optimize throughput, yield, quality, and cost with faster turnaround time.

End-to-End Quality Management for automated detection of defects and improving quality

With processes becoming more complex, rapid innovations compelling frequent changes, and supply chains becoming more geographically dispersed, end-to-end Quality Control and Quality Assurance has be an integral part of each process step in a fab. Real-time, AI-driven monitoring with integration of processes and built-in alarms helps provide automated early detection of quality deviations and faults. Sensor-based tracking, automated process steps validation, data visualization and analytics are also critical. Built across the end-to-end lifecycle of design service, mask making, wafer manufacturing, backend service and packaging, they enable proactive monitoring, faster potential failure mode identification and effect analysis, improved statistical process control, accurate measurement system analysis, and optimal continual improvement.[10] This, in turn, makes a semiconductor company "quality resilient"—a must for the fab of future to deliver the best services to the next generation of high-potential customers in highly regulated industries.



Predictive and Prescriptive Maintenance to enhance asset up-time and asset life cycle

An integrated solution with advanced analytics, AI, and ML helps monitor an asset's health in real time and alerts the operations team to take necessary proactive actions. An ideal solution employs a core analytics engine that uses all possible and available data, through seamless system integration, to:[11]

- **Predict Asset Failure:** Advanced analytics techniques and ML algorithms can model and predict failure events for critical or "bottleneck" equipment.
- **Automated Root Cause Analysis (RCA):** Analytics can identify the root cause that possibly led to a failure, with detailed components of the asset involved, along with failure reasons with probabilities, for better analysis and inspection.
- **Predictive and Prescriptive Maintenance:** Advanced simulation and analytics can help prescribe or even automate the remediation action with accuracy and reliability, matching that of humans, eliminating the chances of human error while enhancing asset up-time and asset life cycle.
- **Asset Performance Management:** Connected assets with sensors provide real-time data on asset performance, which helps in identifying bottlenecks and resolving issues quickly.

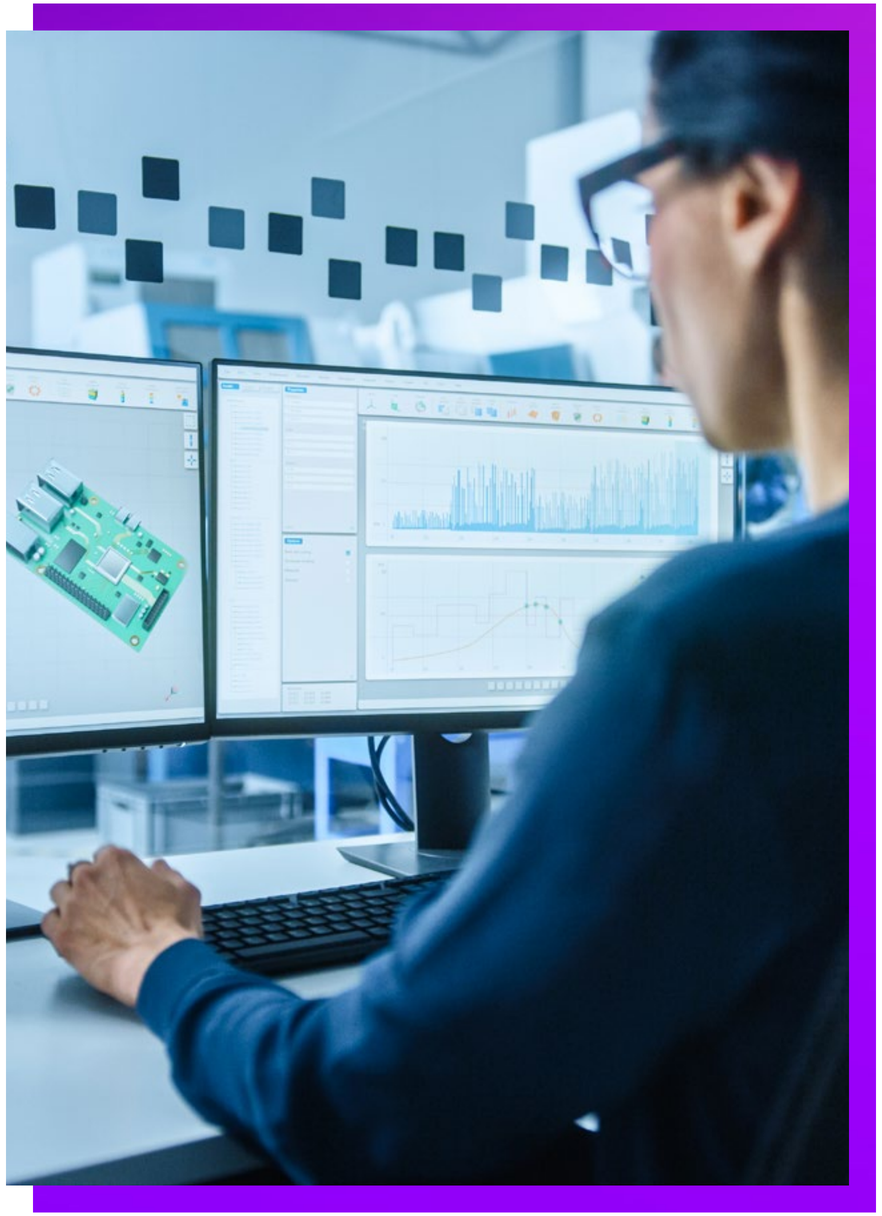
In addition, a AR/VR wearables solution can provide a step-by-step guide to identify affected equipment and maintain it with ease and accuracy.

Intelligent Insights from Integrated Processes using ERP, MES and other key systems

To achieve automation's full potential of in operations and planning, fabs need to redesign their legacy process flows with seamless cross-system and -application integration. Available data from Enterprise Resource Planning (ERP), Manufacturing Execution System (MES), and other key systems—coupled with seamless automated integration with advanced digital technologies such as smart sensors, AI, advanced analytics, and cloud—can generate key actionable, real-time, and intuitive insights. These insights help a fab define, monitor, control, execute, and document best-in-class manufacturing operations, planning, scheduling, packaging, and shipping from anywhere, anytime.[12] Seamless integration to remove siloed systems and processes is required to increase efficiency and throughput, reduce costs, make faster decisions, boost operations reliability, reduce lead time, minimize variability, and assure quality.

Integrated Supply Chain for end-to-end supply chain orchestration

Advanced analytics implemented across the entire value chain provides insights and visibility into areas such as sales and operations planning, raw material procurement, inventory management, supplier management, and logistics. Analytics also enables fabs to optimize their suppliers' network in logistics and implement remote operations via a shop floor control tower. Overall, applying analytics to the supply chain helps decrease time to market and increase demand and supply planning resiliency.



Sustainable Manufacturing for Net Zero outflows and Circular Economy

Manufacturing sustainability is of paramount importance across any phase of the fab operations, be it build, operate, or maintain. Sustainability goals for fabs include using technology as a catalyst to spur change in the Environmental, Social, and Governance (ESG) ecosystem. Digital technology with connected sensors, built-in KPIs, and live intuitive dashboards can serve as the foundation for innovation and collaboration in planning, execution, monitoring, analysis, and optimizing sustainability measures across the entire enterprise—from strategy to operations to the supply chain—to achieve end-to-end sustainable systems and processes that drive business values. Digital is the obvious enabler when it comes to monitoring, controlling, and automating processes that can help address environmental and climatic concerns, such as carbon-neutral computing, carbon footprint reduction, energy savings, water and wastewater management, industrial waste management, health and safety, and other natural resources conservation. Additionally, a centralized energy and GHG emission control tower can help fabs address their sustainability challenges—particularly those focused on energy, emissions, water and waste management—by providing accurate reporting, increased visibility, and actionable insights related to their sustainability initiatives and results.

> Digital is the obvious enabler when it comes to monitoring, controlling, and automating processes that can help address environmental and climatic concerns.

Cyber Resilience

The fab of the future must be laser-focused on building cyber-resilience across all phases of fab operations through proactive monitoring of cyber incidents and robust cybersecurity compliance management. With products, processes, and plants all connected, cybersecurity must be infused from the very start—in the build phase of the fab itself—and should extend its comprehensive, 24x7 coverage across all the value chain and life cycle stages of the fab plant. Smart access management, robust firewalls, secure remote access, IT security vulnerability management, and integrated threat monitoring—along with a holistic, proactive cyber resiliency continuity plan for recovery and remediation—is what makes the fab of the future secure and safe.

How to Become a Fab of the Future

In the face of not only the challenges they face, but also the significant growth opportunities before them, leading semiconductor companies have begun to recognize the importance of becoming a "connected fab of the future."

Even better, many have already made clear commitments to build and enable the smart fabs using the solutions available today, yet with a vision for the future. Along their journey, these companies will be driving toward eight key imperatives a "fab of the future" transformation requires, as illustrated in Figure 2. Two of these imperatives are especially critical and worth calling out here.

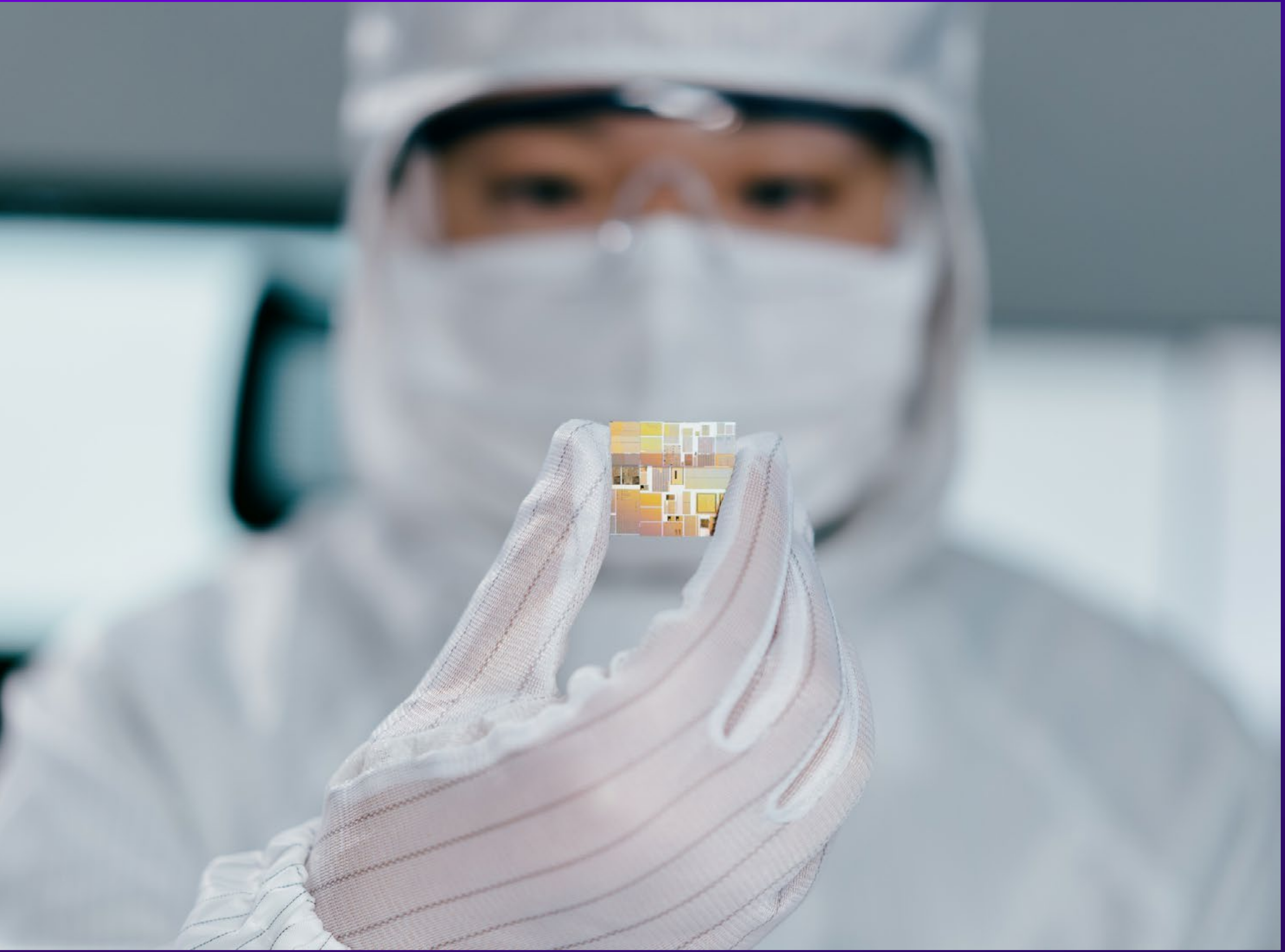
FIGURE 2: INDUSTRY 4.0 KEY IMPERATIVES FOR THE FAB OF THE FUTURE

- **Digital Engineering** (Digital Twin & Digital Thread, Modular Production Lines) and their role in Fab of the Future
- **Smart Factory** enabled by Cloud and Digital Twin for flexible production & operations
- **End-to-End Quality Management** for automated detection of defects and improving quality
- **Predictive and Prescriptive Maintenance** to enhance asset up-time and asset life cycle
- **Intelligent Insights from Integrated Processes** using ERP, MES and other key systems
- **Manufacturing Sustainability** to adhere to Environmental, Social and Governance ecosystem
- **Digital Manufacturing Analytics** for actionable insights on key semiconductor manufacturing value drivers
- **Manufacturing Collaboration Tower** for seamless visibility in end-to-end manufacturing and intelligent decision making

The possibilities are endless...

The first is **Digital Manufacturing Analytics,** which is needed to get the maximum outcome from the other seven imperatives. Digital Manufacturing Analytics needs to be built as an integral capability into all digital solutions to help drive actionable insights on key semiconductor manufacturing value drivers: machine performance (Overall Equipment Effectiveness (OEE), fault detection and classification data), manufacturing quality (metrology and defectivity), and yield (multivariate analysis and test time reduction).[13] Additional assets such as Bayesian modeling, AI algorithms, and semantic layers can help create digital solutions and infrastructure that drive lower wafer costs, reduce yield variation and ramp up time, optimize depreciation/capital investment, and increase overall machine utilization.

Importantly, Digital Manufacturing Analytics also serves as the pivotal enabler of the second vital imperative, a **Manufacturing Collaboration Tower**. Fabs must be able to proactively manage and control end-to-end internal manufacturing operations, as well as ensure reliable and efficient collaboration with the external interfaces of design, back-end services, and packaging. An overarching Manufacturing Collaboration Tower spanning the end-to-end build, operate, and maintain phases—and powered by the cloud, advanced analytics, AI, and proven simulation models—can provide a consolidated view and actionable insights for optimization across manufacturing operations. A Manufacturing Collaboration Tower helps achieve new efficiencies through the connected fab of the future and enables real-time visualization of machine performance indicators, automatic collection of production and quality data, KPI visualization, analytics for OEE improvement, predictive insights and proactive risk management. This holistic view can help the fab more effectively manage demand, supply, production, and maintenance, more efficiently use materials and assets, reduce costs, and minimize shop floor disruption.



With chips being the key enabler of the digital disruption that's sweeping the business world and the lives of everyday consumers, fabs enjoy tremendous growth opportunities—both existing as well as ones that are yet to emerge.

But to capitalize on these, fabs will need to address the myriad challenges across their business and ecosystem that constrain their ability to respond. Digital technologies are the path forward. They can help fabs transform design, production, quality, planning, and packaging—while becoming more sustainable—so they can become the fab of the future that's positioned to pursue the endless possibilities that technology makes possible.

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About the Authors

Syed Alam
Managing Director – Strategy & Consulting
Semiconductor Global Lead
syed.f.alam@accenture.com

Gopichand Gurada
Principal Director – Strategy & Consulting
Industry X
gopichand.gurada@accenture.com

Amit Kumar
Managing Director – Strategy & Consulting
Industry X
amit.l.kumar@accenture.com

Prasad Satyavolu
Managing Director
Industry X, North America
prasad.satyavolu@accenture.com

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