FITZEMEYER & TOCCI ASSOCIATES, INC.

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SEMICONDUCTOR & MICROCHIP RESEARCH & MANUFACTURING FACILITIES

DESIGNING FACILITIES TO HELP SUPPORT GROWTH AND INNOVATION

FITZEMEYER & TOCCI ASSOCIATES, INC.

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About the Guide

The recent focus and enthusiasm for American-led semiconductor, microchip (and other supporting sub-industries) has led to advancements in research and manufacturing facilities. Moreover, post-pandemic related supply chain issues have exacerbated the need for more companies and institutes in the US to help lead the way. Between venture capital and federal funding (CHIPS Act, National Science Foundation, etc.) there is an enormous amount of capital flooding the market for advancements in research, production, and other supporting markets. To support these advancements, facilities industry professionals need to be ready to design these spaces appropriately. Whether it be a private company or a public university, there will continue to be immense pressure to have facilities that are able to support these exciting advancements.

This guide will review challenges and roadblocks; while also providing insights and strategies of how-to best plan, design and build these facilities.

Learning Outcomes

This guide will discuss:

Outcome 1

Identify current challenges facing the advancement of the semiconductor industry, as it relates to construction, installation and maintenance of the facilities.

Outcome 2

Identify corresponding/applicable codes and standards for reference when designing, constructing and/or maintaining a semiconductor facility.

Outcome 3

Identify major design factors to consider when designing a semiconductor facility.

Outcome 4

Discuss long-term strategies for facility success and longevity.

Over the past few decades, major growth in advanced technology devices have created an enormous demand for microchips. Everything from computers, phones, tablets, automobiles, and other basic appliances now have microchips. The demand is only expected to grow, as more international populations expect to have these devices as part of day-to-day living; in addition to more devices becoming technologically advanced. Furthermore, there have been multiple supply disruption events; along with geopolitical issues that may have further ramifications.

Domestically, there has been a flood of capital to the microchip production market to help push the United States as a leader; whereas microchip production is currently, highly dependent on other international companies particularly as it relates to advanced chip production. In addition to private, venture capital; there was a recent, largely bipartisan, CHIPS and Science Act passed by congress to help surge the production of American-made semiconductors and address supply chain vulnerabilities.

"This legislation represents months of bipartisan and bicameral negotiations," said Science, Space, and Technology Committee Chairwoman Eddie Bernice Johnson. "The majority of this bill is made up of bipartisan provisions that started in the House Committee on Science, Space, and Technology—which I am privileged to lead. They were built with rigorous input from the scientific community, industry, academia, and other stakeholders on what they need most to succeed in the 21st century. In this bill we are putting forth strong initiatives at NSF, NIST, NOAA, DOE, and NASA. We're building a diverse STEM workforce ready to tackle the challenges we face, we're strengthening our manufacturing capabilities, we're revitalizing American science and innovation, we're fighting the climate crisis, and so much more. And we're doing it all with the needs of each and every American in mind. "

Given all these factors, there has been (and will continue to be) a massive increase in microchip research, development, and manufacturing facilities throughout the United States. This continued growth will put pressure on designers, contractors, and facility managers alike (both public and private); to ensure the facilities are being designed, constructed, and maintained safely, efficiently and with longevity.

All figures, codes, facts and numbers mentioned in this guide refer to the US market.

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THE CHALLENGES

Skilled Labor Shortfalls

The design and construction of microchip R&D and manufacturing facilities is incredibly complex. To successfully achieve project completion, the project team needs to have in-depth knowledge, experience, manpower and capability. All of these are challenges in the current design and construction labor markets.

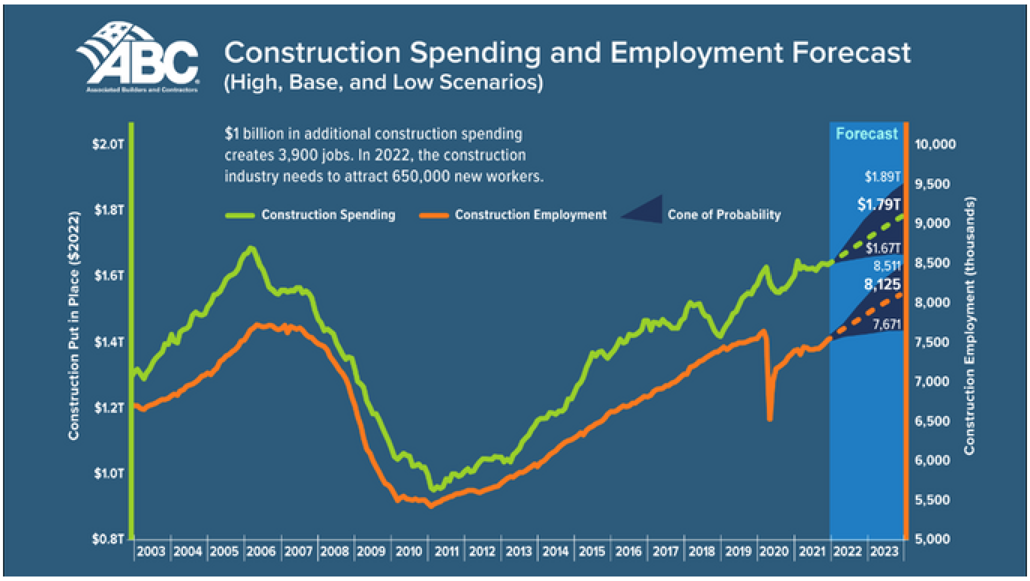

Figure 1 - Construction Spending & Employment Forecast (credit: Associated Builders and Contractors (ABC))

Labor shortages, particularly with experienced design and construction and maintenance workers capable of designing and building these advanced technology facilities, are apparent. The construction industry will need to attract nearly 650,000 additional workers on top of the normal pace of hiring in 2022 to meet the demand for labor, according to a model developed by the Associated Builders and Contractors (ABC).

Additionally, an added concern is the decline in the number of construction workers ages 25-54, which fell 8% over the past decade, per ABC Chief Economist Anirban Basu. Additionally, older workers are exiting the workforce (the industry's average age of retirement is 61 years old), and more than 1 in 5 construction workers are currently older than 55.

Due to the complexity of a microchip manufacturing facility, contractors need to be trained and experienced in this market. The skilled laborers who do have experience and knowledge to build these facilities are quickly leaving the workforce and there are simply not enough younger laborers to teach, train and educate to fill the gap. Once the facilities are designed/built, it takes a very specialized skillset to maintain the spaces properly and safely.

Existing core skills and experiences are rare on US territory today and can be mainly found abroad. The US needs to be able to attract those competencies and make sure the know-how is transferred.

To accomplish fast track, speed-to-market buildings and maintain longevity, it will be essential for microchip facility designers, builders, suppliers and maintenance professionals to address these issues head on. Schools (Tech and Higher Education) will need to develop strategies for engaging prospective students/teachers. Employers will need to be appealing to skilled laborers who may be viable for this market. And most importantly, there will need to be an enhanced focus on training younger engineers, designers, and construction workers to get the knowledge and experience from the older generation that is at or nearing retirement. Knowledge transfer will be essential to sustained success.

DID YOU KNOW?

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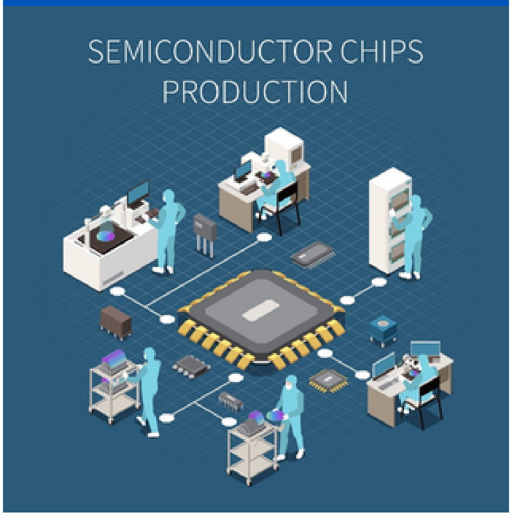


REFERENCE CODES & STANDARDS

References

As with any type of facility or space, it is critical to understand the applicable codes and standards for designing and constructing it.The design team shall work with the Owner, code official(s) and any Authority Having Jurisdiction (AHJ) to identify, adopt and integrate all necessary codes, standards and good practices when designing and constructing a facility.
Below is a list of codes, standards and other references that may serve as a starting point for microchip manufacturing facility design. The list below is not the only codes, standards; and the design team and Owner should work together to identify any other federal/state/local ordinances and/or codes that need to be adhered to.

NFPA 318: Standard for the Protection of Semiconductor Fabrication Facilities

The semiconductor industry continues to advance, requiring new safeguards to address evolving hazards. Reorganized and with major revisions to the requirements for both gas-detection systems as well as smoke detection systems, NFPA 318: Standard for the Protection of Semiconductor Fabrication Facilities applies to semiconductor fabrication facilities and comparable R&D areas in which hazardous chemicals are used, stored, and handled -- containing a cleanroom or clean zone or both. Chapters address every aspect of safety, from general safety precautions and fire protection to construction, chemical storage and handling, hazardous gas cylinder storage and distribution, bulk silane systems, production and support equipment, emergency control station, and means of egress. The 2018 edition of NFPA 318 assists all stakeholders involved in fire protection: engineers, AHJs, facility personnel, and contractors. Requirements for gas-detection systems as well as smoke detection systems are technically modified and also revised for clarity. Gas detection criteria are revised to clarify when detection is needed and where it is required to be physically provided. Requirements for detection are revised to include not just minimum capabilities of detectors but also coverage areas, alert and alarm sensitivities, and maximum transport times taken from NFPA 76: Standard for the Fire Protection of Telecommunications Facilities, which were based on research conducted by the Fire Protection Research Foundation.

International Building Code (IBC)

The International Building Code (IBC) establishes minimum requirements for building systems using prescriptive and performance-related provisions. It is founded on the broad-based principles that make possible the use of new materials and new building designs. The IBC is fully compatible with the International Codes (I-Codes) including the International Energy Conservation Code (IECC), International Mechanical Code (IMC), International Plumbing Code (IPC), International Fire Code (IFC), International Fuel Gas Code (IFGC), and others.

NFPA 70: National Electrical Code

Adopted in all 50 states, NFPA 70, National Electrical Code (NEC) is the benchmark for safe electrical design, installation, and inspection to protect people and property from electrical hazards.

ISO 14644-1 Cleanrooms and Associated Controlled Environments

Cleanrooms and associated controlled environments provide for the control of contamination of air and, if appropriate, surfaces, to levels appropriate for accomplishing contamination-sensitive activities. Contamination control can be beneficial for protection of product or process integrity in applications in industries such as aerospace, microelectronics, pharmaceuticals, medical devices, healthcare and food. This part of ISO 14644 specifies classes of air cleanliness in terms of the number of particles expressed as a concentration in air volume. It also specifies the standard method of testing to determine cleanliness class, including selection of sampling locations.

Underwriters Laboratories (UL)

Underwriters Laboratories Inc. is chartered to establish, maintain, and operate laboratories for the examination and testing of devices, systems and materials to determine their relation to hazards to life and property, and to ascertain, define and publish standards, classifications and specification for materials, devices, products, equipment, constructions, methods, and systems affecting such hazards.

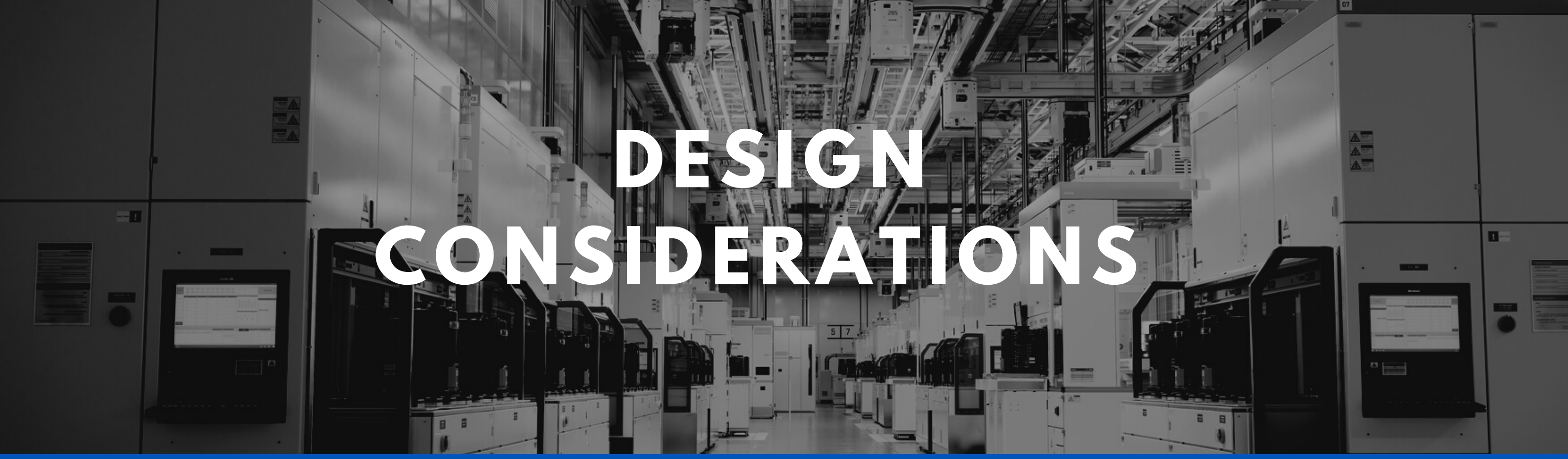
SEMI Standards

SEMI Standards are voluntary technical agreements for the semiconductor, flat panel display, micro-electromechanical systems, photovoltaic, and high-brightness LED industries. SEMI Standards are written documents and can take the form of specifications, guides, test methods, terminology, or best practices.

FM Global Standards

FM Approvals is an international third-party research and certification organization, which specializes in loss prevention, engineering, and research. FM Approvals has focus on objectively testing property loss prevention products and services and certifying those that meet rigorous loss prevention standards; and encouraging the development and use of FM Approved products and services that improve and advance property loss prevention practices.

To reiterate, the list above is simply a starting point, whereas an in-depth code analysis shall be done on a project-by-project and building-by-building basis.



DESIGN CONSIDERATIONS

There is a myriad of considerations when designing a semiconductor manufacturing space. Below are a few of the major items to consider and review during the design phase of a project.

Microchip Manufacturing Clean Rooms & Environmental Requirements

Semiconductor manufacturing and some of the R&D operations are required to be done within a cleanroom. Furthermore, semiconductor manufacturing typically takes place is ISO 14644-1 Class 5 (or better/'cleaner'), which has very stringent requirements. An ISO Class 5 stipulates Maximum Allowable of Concentration (particles per cubic meter by micrometer size) as follows:

CLASS	Number of Particles per Cubic Meter by Micrometer Size					
	0.1 micron	0.2 micron	0.3 micron	0.5 micron	1 micron	5 microns
ISO1	10	2				
ISO2	100	24	10	4		
ISO3	1,000	237	102	35	8	
ISO4	10,000	2,370	1,020	352	83	
ISO5	100,000	23,700	10,200	3,520	832	29
ISO6	1,000,000	237,000	102,000	35,200	8,320	293
ISO7				352,000	83,200	2,930
ISO8				3,520,000	832,000	29,300
ISO9				35,200,000	8,320,000	293,000

Figure 2 Number of Particles per Cubic Meter per ISO Class

Once the microchip has been manufactured, the assembly, packaging and QA/QC are typically performed in lesser standards (i.e. ISO Class 7 or ISO Class 8). ISO Class 5 Clean Spaces require a tremendous amount of amount of air changes per hour (ACH) to maintain the particle requirements, with ranges between 250 ACH – 350 ACH, typically. That many air changes within a space, results in ceiling having 50%+ of coverage allocated to HEPA filters alone. When combined with sprinkler, lighting and any other devices; and ISO Class 5 sometimes has up to 100% ceiling coverage to MEP/FP infrastructure (i.e. there are no 'blank' ceiling tiles). Low return and/or floor return (using elevated floors with return duct/capture below) allow for unidirectional airflow, further reducing the risk of contamination.

Temperature and humidity control requirements are equally critical for manufacturing spaces. Typically, a temperature of 65deg-70degF, with relative humidity maintained between 35%RH-50%RH are required. A minimum relative humidity is important in electronics manufacturing to ensure static charge can't be generated and harm the raw materials and/or devices. The temperature and humidity must also not have large deviation swings and are often expected to have tolerances <2degF and/or <2%RH.

Air and Water Permitting

As is the case with many laboratories and/or manufacturing applications, the design and construction team need to be aware of the necessary air and/or wastewater permitting that need to occur. With electronics, semiconductor, wafer, microchip manufacturing there are many processes and hazardous waste byproducts that need to be properly permitted.

For airside exhaust, it is necessary to design applicable scrubbers to ensure that all necessary local, state and federal guidelines are being met. The Environmental Protection Agency (EPA) has further detailed information in the Semiconductor Manufacturing: National Emission Standards for Hazardous Air Pollutants (NESHAP).

Proposals to design and building semiconductor manufacturing facilities are subject to lengthy environmental reviews, that may take over a year. With that in mind, along with CHIPS act and Bipartisan Infrastructure Law going into effect, the Biden administration has announced a Permitting Action Plan which expands the authority of the Federal Permitting Improvement Steering Council (FPISC) to identify conflicts and roadblocks. Additionally, the Bipartisan Infrastructure Law expands eligibility of 'FAST-41' status to projects of critical economic importance (of which semiconductor manufacturing facilities would be categorized).'FAST-41' status expedites the environmental permitting process of such facilities.

Necessary air, water and wastewater permitting need to be considered at the start of a project to ensure a streamlined and transparent project.

Unique Challenges

Facilities of this complexity require unique challenges not seen in any other buildings. Infrastructure support systems in typical buildings (HVAC, electrical, plumbing, etc) are just a portion of the overall systems to consider in semiconductor manufacturing and/or R&D facilities.

Process gas and liquid systems and associated distribution are a critical aspect of the tools and equipment that are fit-out in these buildings. Not only do these systems have unique design and installation challenges, but they also affect associated life safety systems. Systems like toxic gas monitoring are required to keep occupants able to work in a safe environment.

Semiconductor tools and equipment are also inherently sensitive to the environment in and around the facility. Design professionals need to understand exact requirements, in order to accommodate this expensive equipment. Such considerations include vibration/seismic isolation, acoustics and electromagnetic interference (EMI) that may be caused by sources external (and internal) to the building; which need to be considered and designed for.

Building Operations & Maintenance

Due to the complexity and logistical nature of semiconductor manufacturing facilities, building operations and maintenance (O&M's) are quite challenging. As with the design and construction of such facilities, the limited experience and knowledge amongst building operators and maintenance staff need to be considered during the design, construction, and commissioning of the facility.

The creation of building and equipment maintenance procedures, along with necessary staff training is critically important. Procedures need to be developed and necessary QA/QC processes need to occur. Trainings need to be documented, recorded, and scheduled to be reoccurring in perpetuity to ensure all staff is educated on these complex systems and equipment. This is not only important during Owner move-in or startup, but also during the whole life of the facility as there are constant equipment replacements, code updates and other ongoing changes to the building and/or systems.

Many building Owners also choose to retain design and/or construction staff after the building is constructed. This may be in the form of a consulting agreement, ongoing training program or service contract. It's critical that the building is not constructed then handed off to O&M staff with only closeout training. An overlap period helps O&M staff engage the professionals that designed and/or installed the building systems to understand design intent, O&M requirements, and any other questions or issues that may arise.

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LONG TERM SUCESS

As more capital flows into the semiconductor market, and more projects gain steam, it will be important for Owners, Designers and Contractors to have a long-term vision for success in mind. There is always an inherent instinct to make quick decisions to get things fast-tracked, and online immediately. Much consideration needs to take place for the long-term viability of the project/building, but also the surrounding community and businesses that will support these facilities.

In the Manufacturing Facility Team of Scientist Wearing Sterile Protective Coverall Set's up / Programs Modern Industrial 3D Printer, High Precision Manufacture of Semiconductors under Process.

A semiconductor research/development and/or manufacturing facility uses a tremendous number of resources (power, water, sanitary, and other utilities). Geographical location, access to necessary utilities and reliability/stability of the resources need to be considered. Renewables and overall energy efficiency are important to building payback and overall longevity.

The high density of energy consumption in these facilities provide short, attractive payback periods for an Owner. This justifies creative thinking during planning, design and the construction phases of a project in order to achieve long-term efficiency in the overall building.

Additionally, the manpower required to support these facilities is equally enormous. Depending on the size/scope of the facility and project, there may be need for hundreds or thousands of labor necessary to support the facility. If facility construction is occurring near an already populous area, then less consideration may occur. However, if the facility is constructed in less populous area, then indirect factors need to be considered; such as infrastructure, housing, education, and other worker needs.
The operation of such facilities cannot be run remotely: attract workers to jobs with high and constant presence requirements can also be an important challenge in the post-covid period.

SUMMARY

This guide illustrates the challenges facing the design and construction and operations of semiconductor research, development, and manufacturing facilities.Designers, Contractors, and Owners alike must consider all the necessary codes and standards when considering facility builds and/or renovations. Additionally, certain design parameters must be considered at the forefront of all projects.The continued growth of the semiconductor manufacturing space in the United States is incredibly challenging and exciting. The fast-track nature of these projects adds to the challenge, while a long-term vision must be considered to ensure viability, building efficiency and overall success.

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