CHIPS for AMERICA

SUMMARY REPORT

CHIPS R&D Program Standards Summit

September 26–27, 2023

NIST NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

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EXECUTIVE SUMMARY

The CHIPS and Science Act appropriated $50 billion to the Department of Commerce's CHIPS for America program both to support semiconductor research and development (R&D) and to expand semiconductor manufacturing capacity in the United States. Within CHIPS for America, the mission of the National Institute of Standards and Technology's (NIST) CHIPS Research and Development Office (CHIPS R&D) is to accelerate the development and commercial deployment of foundational semiconductor technologies by establishing, connecting, and providing access to domestic research efforts, tools, resources, workers, and facilities. A key element in achieving these CHIPS R&D goals is to accelerate the private sector-led development and deployment by industry of effective technical standards.

CHIPS R&D has developed a comprehensive standards roadmap that responds to calls from the private sector for semiconductor standards efforts, the requirements of CHIPS legislation, and the provisions of the U.S. Government National Standards Strategy for Critical and Emerging Technology. The CHIPS R&D standards roadmap is centered on a vision for a vibrant microelectronics standards ecosystem that is smarter, faster, and more inclusive and agile in enabling innovation.

A Standards Summit event was organized as the first of the CHIPS R&D standards activities with the goal of bringing private sector thought leaders together to identify strategic standards priorities for the semiconductor sector.

The CHIPS R&D Standards Summit was a two-day hybrid event with over 220 in-person attendees and over 400 virtual participants. The four overall topic areas that served as the focus for the Summit and the topics that emerged from the ensuing discussions are summarized below.

1. **Identifying Strategic Standards Priorities**—This topic area focused on identifying strategic priorities for the semiconductor and microelectronics community, emphasizing standards that drive innovation and accelerate commercialization. The following five strategic standards priority areas emerged from discussions.
    - Chiplets
    - Data Interoperability
    - Digital Twins
    - Supply Chain Security and Resilience
    - Advanced Packaging and Heterogeneous Integration
2. **Enabling Innovation in Standards Development**—Sessions on innovation in standards development explored how new approaches and methods could be leveraged for accelerating standards development and making the process more inclusive and agile. The following four approaches emerged from discussions as key paths forward.
    - Standards Incubators and Accelerators
    - Collaboration among Standards Setting Organizations
    - Community-wide Coordination on Consensus Standards Goals
    - Navigating the Standards Landscape

3. **Promoting a Diverse, Standards-capable Workforce**—The plenary and subsequent breakout sessions on this topic focused on strategic initiatives to cultivate a diverse, standards-capable workforce. Four areas emerged as important opportunities for initiatives.

    - Collaboration between Industry and Academia
    - Certification and Credentialing Programs
    - Multidisciplinary and Interdisciplinary Education and Training
    - Community Colleges as Career Entry Points

4. **Linking Standards and Research**—This topic area focused on pre-standards research in new metrology for robust and effective standards. Four guiding principles emerged from the discussions as follows.

    - Meeting Industry Needs
    - Advancing Industrial Competitiveness
    - Keeping Pace with Innovation
    - Promoting International Collaboration on Consensus Standards

Overall, the insights gathered at the Summit covered strategic standards priorities, innovation in standards development, education and workforce needs, and linking standards and research. Next steps are to convene a series of expert workshops focused on the specific topics and approaches that emerged from the Summit. The goal in these workshops is to develop action plans suitable for implementation across the semiconductor sector, including options for CHIPS R&D support. Collectively, these action plans will provide the basis for working together to create a vibrant microelectronics standards ecosystem that is smarter, faster, and more inclusive and agile in enabling innovation.

INTRODUCTION

CHIPS FOR AMERICA

The CHIPS and Science Act[1] appropriated $50 billion to the Department of Commerce's CHIPS for America program both to support semiconductor research and development (R&D) and to expand semiconductor manufacturing capacity in the United States. This includes $39 billion for the Department of Commerce (the Department) to expand domestic semiconductor manufacturing capacity through an incentives program and $11 billion to advance U.S. leadership in semiconductor R&D. These R&D advances will be realized through four programs: the National Semiconductor Technology Center (NSTC), the National Advanced Packaging Manufacturing Program (NAPMP), the CHIPS Metrology Program, and a CHIPS Manufacturing USA institute. These investments, across both the R&D and incentives programs, seek to strengthen U.S. competitiveness, support domestic manufacturing and innovation, and create good jobs across the country.

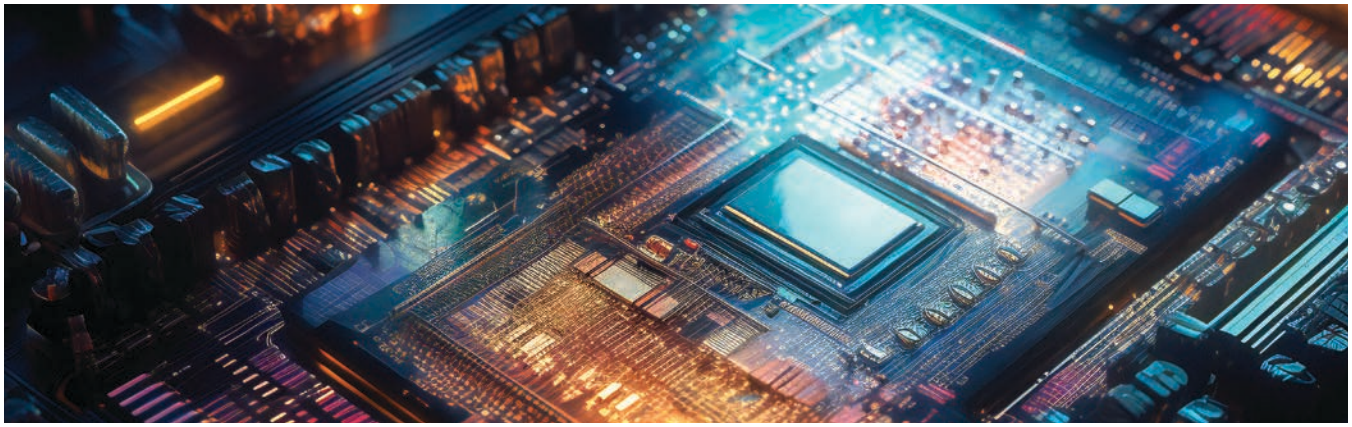
CHIPS R&D MISSION AND GOALS

Within CHIPS for America, the mission of the National Institute of Standards and Technology's (NIST) CHIPS Research and Development Office (CHIPS R&D) is to accelerate the development and commercial deployment of foundational semiconductor technologies by establishing, connecting, and providing access to domestic research efforts, tools, resources, workers, and facilities. CHIPS R&D aims to achieve the following goals by 2030.

- U.S. Technology Leadership: The United States establishes the capacity to invent, develop, prototype, manufacture, and deploy the foundational semiconductor technologies of the future.
- Accelerated Ideas to Market: The best ideas achieve commercial scale as quickly and cost effectively as possible.
- Robust Semiconductor Workforce: Inventors, designers, researchers, developers, engineers, technicians, and staff meet evolving domestic government and commercial sector needs.

A key element in achieving these CHIPS R&D goals is to accelerate the private sector-led development and deployment by industry of effective technical standards.

1 P.L. 117-167, CHIPS and Science Act of 2022 (Creating Helpful Incentives to Produce Semiconductors)



WHAT STANDARDS ARE AND WHY THEY MATTER[2]

From chips to connectors, packages, and circuit boards, the semiconductor industry relies on technology standards for everything from strategic planning to everyday operations and global marketing. In the broadest sense, standards are the common and repeated use of rules, conditions, guidelines, or characteristics for products or related processes, practices, and production methods.[3] They enable technology that is safe, universal, and interoperable. Standards define the requirements that make it possible for equipment developed by one company to be suitable for use by manufacturers worldwide, for testing and performance results to be used across a broad supply chain ecosystem, and for components to interoperate through standardized communications protocols. Standards also help manage risk, security, safety, privacy, and quality in the development of new innovations. In short, good standards are good for business, good for consumers, and good for society.

Standards Setting Organizations (SSOs), including standards-development organizations (SDOs), consortia, Special Interest Groups (SIGs), and other entities[4], consist of experts from industry, academia, civil society groups, and government, all of whom share a common goal of ensuring safety, interoperability, and competition in a particular technology or technology application. In well-functioning SDOs, ideas are selected not on the basis of the nationality, employer, or personality originating them, but instead on the basis of technical merit. Six principles govern the international standards development process: transparency, openness, impartiality and consensus, effectiveness and relevance, coherence, and a commitment to participation by low- and middle-income countries[5].

Today's semiconductor standards landscape is large, complex, robust, and active with coverage ranging from materials to chips, devices, packages, printed circuit boards, and manufacturing equipment and facilities. Examples illustrating this breadth of coverage include the following.

- ISO 29.045 Semiconductor materials
- ASTM D7980 Anions in Ultrapure Water for Manufacturing
- IEC 63068-4 Defect detection in silicon carbide wafers
- UCIe Universal Chiplet Interconnect Express
- iNEMI Package Warpage Prediction Simulation
- IEEE 1481-2019 Integrated Circuit Library Architecture
- UL 1557 Electrically Isolated Semiconductor Devices
- JESD243A (JEDEC) Counterfeit Electronic Parts
- SEMI E30 Communications and Control of Manufacturing Equipment
- IPC 2-17a Connected PCB Factory Exchange for Printed Circuit Boards
- NFPA 318-2022 Fab Facility Fire Protection

Achieving CHIPS R&D's goals will require cooperation and collaboration across this landscape of effective private sector standards setting organizations.

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2 United States Government National Standards Strategy for Critical and Emerging Technologies
3 https://www.whitehouse.gov/wp-content/uploads/2020/07/revised_circular_a-119_as_of_1_22.pdf
4 Patent Challenges for Standard-Setting in the Global Economy
5 World Trade Organization Principles for the Development of International Standards, Guides, and Recommendations

CHIPS R&D AND STANDARDS

Support for private-sector-led technical standards for the semiconductor industry is an integral part of the CHIPS R&D strategy and is in keeping with CHIPS Act provisions (15 USC §4656 (e)), which specify that:

> *" … the Director of the National Institute of Standards and Technology shall carry out a microelectronics research program to enable advances and breakthroughs in measurement science, **standards**, material characterization, instrumentation, testing, and manufacturing capabilities that will accelerate the underlying research and development for metrology of next generation microelectronics and ensure the competitiveness and leadership of the United States within this sector" (emphasis added).*

Standards were also identified by private sector stakeholders as a core competency for CHIPS R&D. Both the need for standards and ensuring that standards align across different stakeholders were highlighted in many of the responses to NIST's request for information to guide the design of CHIPS programs (see NIST Special Publication 1282).

GUIDING PRINCIPLES FOR CHIPS R&D STANDARDS EFFORTS

In developing its standards efforts, CHIPS R&D adopted principles expressed by Congress in the CHIPS and Science Act (42 USC §18951(a)), which provides that:

> *(1) openness, transparency, due process, balance of interests, appeals, and consensus in the development of international standards are critical;*
>
> *(2) voluntary consensus standards, developed through an industry-led process, serve as the cornerstone of the United States standardization system and have become the basis of a sound national economy and the key to global market access;*
>
> *(3) strengthening the unique United States public-private partnerships approach to standards development is critical to United States economic competitiveness; and*
>
> *(4) the United States Government should ensure cooperation and coordination across Federal agencies to partner with and support private sector stakeholders to continue to shape international dialogues in regard to standards development for emerging technologies.*

The design of CHIPS R&D standards efforts is fully aligned with the United States Government National Standards Strategy for Critical and Emerging Technologies (USG NSS CET). The four objectives and underlying action items of the standards for critical and emerging technologies strategy, which includes semiconductors and microelectronics, are as follows.

1. **Objective 1:** Investment
    a. Action: Increase R&D funding to ensure a strong foundation for future standards development.
    b. Action: Support the development of standards that address risk, security, and resilience.
2. **Objective 2:** Participation
    a. Action: Remove and prevent barriers to private sector participation in standards development.
    b. Action: Improve communications between public and private sectors on standards.
    c. Action: Enhance U.S. Government and like-minded nations' representation and influence in international standards governance and leadership.
3. **Objective 3:** Workforce
    a. Action: Educate and empower the new standards workforce.
4. **Objective 4:** Integrity and Inclusivity
    a. Action: Deepen standards cooperation with allies and partners to support a robust standards governance process.
    b. Action: Facilitate broad representation in standards development.

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CHIPS R&D Standards Roadmap

CHIPS R&D STANDARDS ROADMAP

CHIPS R&D has developed a comprehensive standards roadmap that responds to calls from the private sector for semiconductor standards efforts, the requirements of CHIPS legislation, and the provisions of the USG NSS CET.

VISION

The vision of the CHIPS R&D Standards Roadmap is for:

> *A vibrant microelectronics standards ecosystem that is smarter, faster, and more inclusive and agile in enabling innovation.*

This vision provides for working with the semiconductor standards sector in enhancing strategic focus, matching the pace of standards development to the pace of innovation in the semiconductor sector, expanding opportunities for participation in standards activities, and responding effectively to the needs of industry.

MISSION

The mission of the CHIPS R&D standards effort comprises six elements as follows.

1. Support private sector leadership.
2. Focus on strategic priorities.
3. Open and accelerate the standards innovation pipeline.
4. Support education, awareness, and workforce development.
5. Align government efforts.
6. Partner with allies.

OUTCOMES

Implementation of the CHIPS R&D Standards Roadmap is intended to achieve the following outcomes.

1. Standards at the speed of innovation;
2. A standards-enabled global market;
3. Standards as innovation platforms;
4. Inclusive standards leadership;
5. Education for career opportunities in standards development; and
6. A diverse standards-capable workforce.

In pursuing these outcomes, the CHIPS R&D standards effort is intended to:

- Enhance U.S. economic security through standards that support innovation, collaboration, and a vibrant domestic landscape of small, medium, and large corporations;
- Support national security through standards that underpin a domestic semiconductor industry that is resilient, reliable, secure, and a global leader in semiconductor technologies; and
- Enable future innovation through standards that provide for interoperability, define powerful measurement capabilities, and establish effective testing and assurance methods that spur adoption of new technologies.

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CHIPS R&D Standards Summit

CHIPS R&D STANDARDS SUMMIT

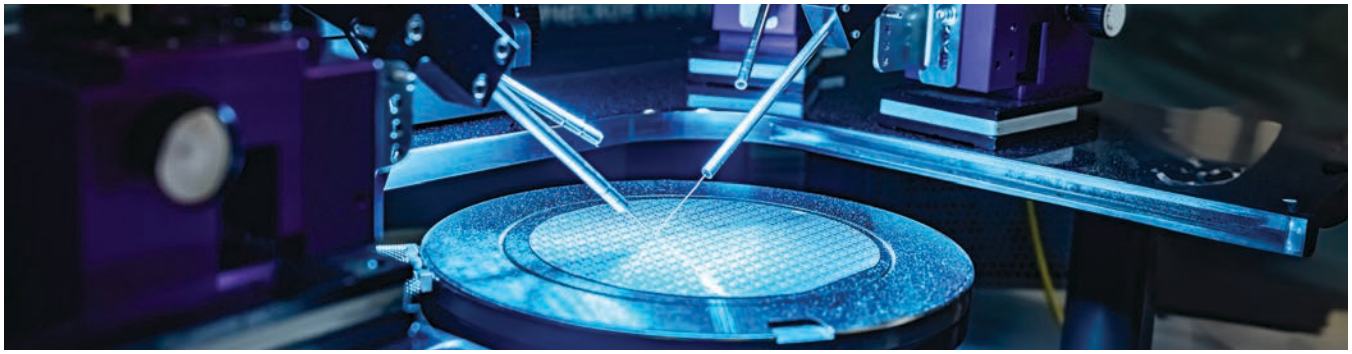
A Standards Summit was organized as the first of the CHIPS R&D standards activities with the goal of bringing private sector thought leaders together to identify strategic standards priorities for the semiconductor sector.

OVERVIEW

The CHIPS R&D Standards Summit was a two-day hybrid event with over 220 in-person attendees and over 400 virtual participants. Attendees represented over 300 companies, more than 40 universities, and over 50 consortia and non-profit organizations from across the United States and 28 countries worldwide. The approach used to capture input from participants to inform this report is described in Appendix A.

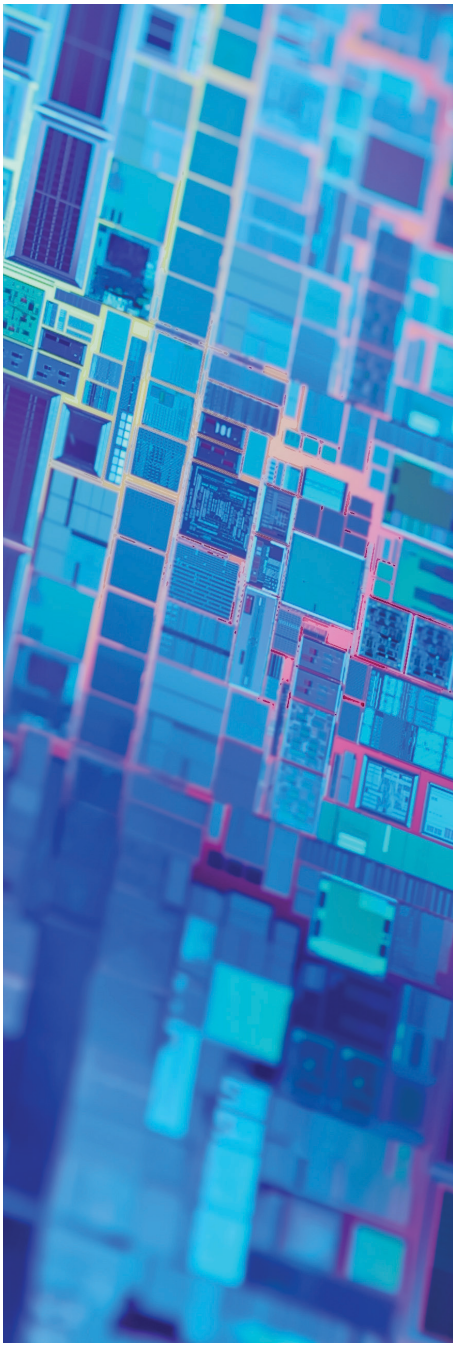
The event was planned by an organizing committee comprising leaders from SSOs, industry consortia, and government representatives (see Appendix B). The design of the Summit centered on four topic areas as described below.

1. **Strategic Standards Priorities**—One of the primary purposes of the summit was to identify strategic standards priorities that meet the needs of industry and can drive innovation and increase value and efficiency across the semiconductor and microelectronics sector. By identifying key priorities, stakeholders helped pave the way for a smoother, more efficient innovation pipeline.
2. **Innovation in Standards Development**—The second topic area centered on identifying opportunities for innovation in standards development, to keep up with the rapid pace of innovation in the industry. This included exploring the concept of incubators and accelerators that can expedite the standards-development process.
3. **Building a Diverse and Skilled Workforce**—The third topic area focused on approaches for a standards-capable workforce that is skilled and diverse, able to provide a broad range of perspectives and ideas. This included exploring the role of universities, community colleges and vocational schools, and other training and educational organizations.
4. **Linking Standards Efforts to Research**—The fourth topic area centered on strategic linking of research and standards efforts. The goal was two-fold. First, consider approaches to ensure that standards are based on leading-edge science, engineering, and metrology principles. Second, consider means for aligning research goals with the needs of industry, ensuring that the foundational science is in place when the time for standards development and adoption is ripe.



Day one of the Summit focused on plenary sessions designed to seed discussions in the corresponding breakout sessions on day two (see Appendix C for the agenda). Keynote speakers and panelists provided insights and identified key challenges in each of the four topic areas. Presentations were followed by question-and-answer sessions to further the exchange of ideas.

The breakout sessions on day two enabled summit participants to engage directly in discussions centered on identifying gaps and opportunities and highlighting critical challenges facing the U.S. semiconductor and microelectronics standards community. For each breakout session, both in-person and virtual participants were distributed into five breakout groups. Each breakout group had one moderator and two technical facilitators. The technical facilitators reviewed the breakout session's purpose, objectives, and instructions and facilitated conversations on the breakout session's topic. The moderator recorded the minutes of the group discussions, collected participant responses, and assisted the technical facilitators with monitoring the virtual meeting platform breakout room.



The sections below describe significant findings that emerged for each of the four topic areas.

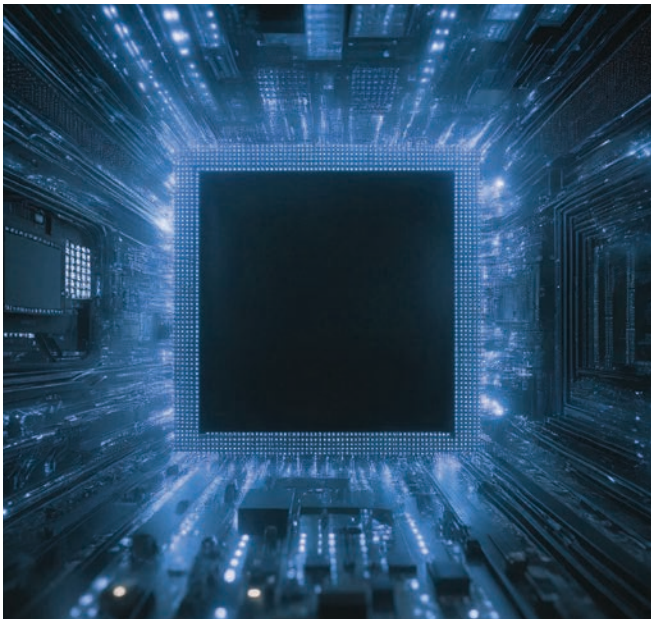
IDENTIFYING STRATEGIC STANDARDS PRIORITIES

This topic area focused on identifying strategic priorities for the semiconductor and microelectronics community, emphasizing standards that drive innovation and fast-track commercialization. The session's objective was to identify and prioritize a short list of strategic standards areas that can deliver the greatest benefits to the semiconductor sector. Both panelists and breakout session participants were asked to consider the following questions.

- What do you see as the most strategic high-level priority areas for the semiconductor and microelectronics community to focus on to drive innovation and speed commercialization, and why?
- What can the semiconductor and microelectronics standards community begin working on today to drive these innovations? What near-term gaps need to be addressed to support this long-term impact?
- What risks, challenges, or technical dependencies should standards setting organizations consider when attempting to address these strategic priority areas?

Topics discussed in plenary and breakout sessions included heterogenous integration, chiplets, supply chain resilience and security, materials, design, fabrication, packaging, assembly, equipment, design automation, modeling, data, testing, and other areas. The following subsections describe five areas that were highlighted by participants in multiple sessions as strategic standards priorities needing near-term attention.

Chiplets



A common theme in Summit discussions was that the semiconductor and microelectronics industry is undergoing a shift from a chip-centric perspective to a systems-centric approach, which is increasing the interest in multi-die systems. Primary drivers cited for this shift included the intricacies of advanced process nodes, the challenges associated with expanding die sizes, and an aspiration for component reusability across multiple products. With chip scaling becoming increasingly challenging, there is increasing interest in integrating multiple chiplets into a single package through advanced packaging and interconnects. While this trend carries the potential for flexible composition of functions, such as logic, memory, and sensors, it was noted that new standards will be essential for the design, assembly, testing, and reliability of these technologies. Areas in which standards needs were cited included chiplet interfaces, dimensions and other form factor aspects, electrical design and electromagnetic interference resilience provisions, thermal modeling and management, testing methods, and models for chiplet and chiplet-based-system design automation.

Data Interoperability

Another prominent theme in the Summit was the need for standards that enable appropriate data sharing while both preserving the security and integrity of the data and protecting intellectual property rights. Shared data can enable optimization across complex processes, enhance operational efficiency, enable traceability and assurance, provide for interoperability, and enable innovation, among other benefits. Standards such as data taxonomies can provide a means for data sharing and interoperability. Two application areas were highlighted as especially important examples of the need for data interoperability standards. The first was in supply chain management and security, including for provenance tracing and assuring component or device integrity and authenticity. The second was in artificial intelligence (AI) enabled systems for use in applications such as process management, equipment and facility maintenance, and fault tracing and reliability analyses.

Digital Twins

There was significant discussion of the expanding roles of digital twin technologies in the semiconductor industry, where a digital representation or simulation of a physical object, system, or process is used to analyze or predict performance in real-time. In semiconductor design and manufacturing, a digital twin can facilitate monitoring, troubleshooting, improving operations and maintenance, and reducing down time and manual intervention. Standards that enable innovation in digital twin technologies were cited as important needs, including in areas such as data interoperability (see above); interoperability and composability among hierarchical models; interfaces with data, equipment, process, and business management systems; and methods for digital twin testing, validation, and verification.

Supply Chain Resilience and Security

Participants highlighted the benefit of a standards framework to ensure consistency, reliability, security, resilience, and quality across complex supply chains. A frequently cited example was in product integrity, with standards needed to enable stakeholders to trace and validate the quality and authenticity of materials and other inputs used in the semiconductor manufacturing process, including having a transparent chip history through each supply chain segment. Other examples of needed standards included provisions for data interoperability (described above); physical- and cyber-security standards, and standards for supply chain monitoring and management. The resilience and security of the supply chain was cited as especially important for applications in critical infrastructures, national security and defense systems, and consumer products with significant safety criticality such as aerospace and automotive systems.

Advanced Packaging and Heterogeneous Integration

Advanced packaging (AP) goes beyond conventional packaging requirements for protection and reliability to provide for significant enhancements in performance and function and for shortening the time to market. Heterogeneous integration (HI) refers to packaging of components of diverse types, characteristics, requirements, and sources. Both AP and HI represent complex and interdisciplinary processes involving interactions between stakeholders in materials, design, substrates, equipment, tools, processes, power delivery, thermal management, and connectors. An important theme at the Summit was the need for robust standards frameworks to link together the diverse steps and components in these complex processes. Examples of needed standards categories include reliable testing and measurement methods; reference materials and reference data; common form factors, component architectures, and connectors that provide for mix-and-match capabilities; and communication and control protocols that enable integration of diverse components. Participants emphasized the importance of ensuring that relevant standards are designed and implemented in ways that promote innovation, facilitate participation by a diversity of vendors, enable optimization across workstreams, and enable agile architectures that can be tailored to specific needs and applications.

Additional Standards Needs

Discussions among participants included a series of additional opportunities for developing standards to meet the needs of industry. Examples included the following, which may be suitable for additional analysis and consideration.

- Testing and quality assurance methods throughout the manufacturing process
- Standards reference materials, reference devices and systems, and reference data
- Improved metrology for high-precision, no-contact and inline measurements, and 3D systems analyses such as thermal measurement, flaw detection, etc.
- Environmental impact and sustainability
- Design automation
- Physical security for equipment, facilities, and products
- Cybersecurity for IT systems throughout the manufacturing sector

ENABLING INNOVATION IN STANDARDS DEVELOPMENT

The plenary and breakout sessions on innovation in standards development explored how new approaches and methods could be leveraged for accelerating standards development and making the process more inclusive and agile. Panelists and breakout session participants were asked to consider the following questions.

- In the context of standards development, how could standards setting organizations adopt new collaborations or operating models to advance concepts that enable standards development to keep pace with rapid technological innovation?
    - For example, are there concepts that could be adapted from the incubator and accelerator environments common in the technology startup sector?
    - What are potential risks associated with adopting such approaches and ideas to mitigate those risks?
- One key aspect of technology-focused incubators and accelerators is their emphasis on broadening industry participation and diversity by supporting new technology entrants and disruptors through early-stage development.
    - How can these principles be translated to standards development to encourage a wider range of stakeholders to contribute?
    - How might this benefit the resulting standards?

Panelists discussed challenges and opportunities, such as how to enable broad and sustained participation in standards, including access for smaller entities, such as small and medium enterprises, and university-based researchers. They explored the need to develop a strong vision for standards development, which includes innovation, community building, and collaboration, and the importance of broadening participation across all levels, from students to experts in industry and academia.

Incubators and Accelerators

There was significant discussion around adapting best practices from technology incubators and accelerators in expediting standards processes, broadening participation, and providing environments for education and workforce development.

Incubators in the technology sector provide a supportive environment for those who have innovative ideas with market potential but who are unfamiliar with market analysis and business startup processes. By analogy, a standards incubator could provide a supportive environment for those who have new ideas with standards potential, but who are unfamiliar with the standards ecosystem. Capabilities identified as important for an effective incubator environment included:

- Mentoring to share insights on the characteristics of effective standards and successful approaches to standards development, provide feedback on plans and proposals, and share pointers on the existing standards landscape, including related standards and the work of relevant standards organizations;
- Education and training resources focused on standards processes and the overall standards ecosystem, including examples of successful standards efforts;
- Working environments, both physical and virtual, that include tools and applications for developing and testing standards ideas; and
- Convening resources, including physical and virtual spaces and staff support, for team meetings, workshops, and conferences that allow participants to test the level of community interest, assemble teams, and increase awareness of emerging standards solutions.

Accelerators in the technology sector provide business support, mentoring, and seed funding to accelerate the transition from an initial startup to a sustainable and growing company. By analogy, a standards accelerator could expedite the transition of a standards startup effort with demonstrated potential – perhaps demonstrated through an incubator effort – to a productive working team within an SSO, consortium, or alliance with defined deliverables on a fast-paced, 12- to 18-month timeline. Capabilities identified as important for an effective standards accelerator environment including funding for:

- Staff support to facilitate scheduling and management of working meetings and events;
- Business and legal support to facilitate the formation of working groups, including provisions for bylaws, intellectual property management, etc.;
- Expert technical support able to translate the input of community experts, who are often volunteers with limited available time, into draft documents for quick working group review and refinement; and
- Managing relationships with existing SSOs, alliances, and consortia to transition, where appropriate, accelerator efforts into relevant standards organizations.

Discussants noted that a combined incubator and accelerator program can speed the standards process, enable access to standards leadership opportunities for small and medium enterprises, provide an exceptional environment for workforce development, and, if effectively targeted, expand diversity at the student, mentor, and leadership levels.

Collaboration among SSOs

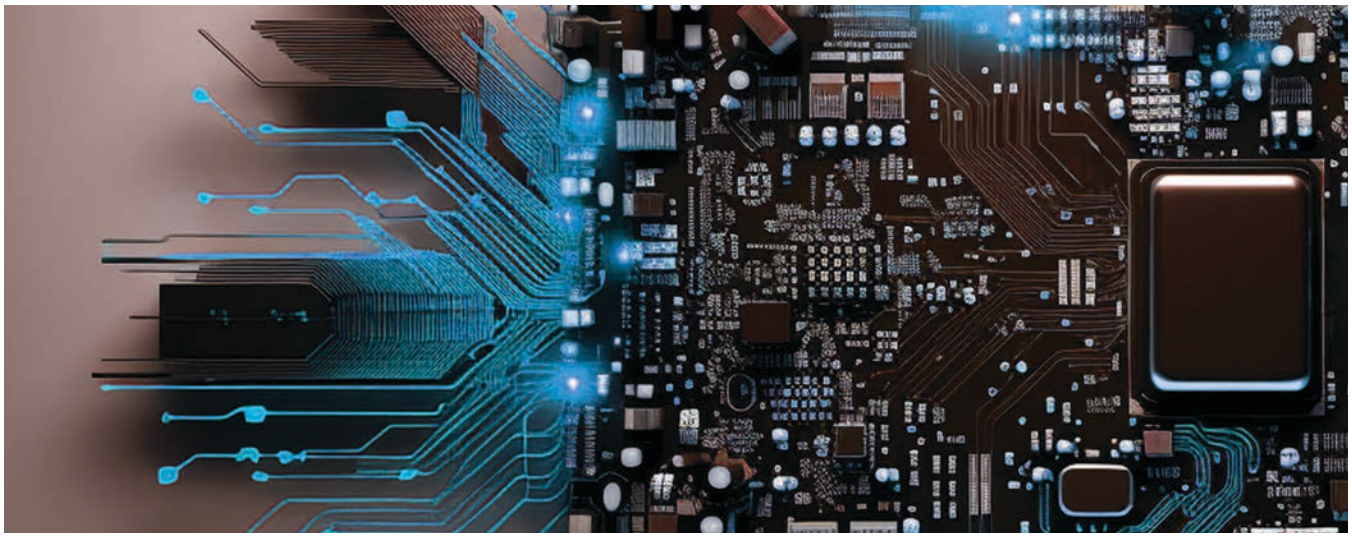
Widely discussed across sessions was the complexity of the semiconductor and microelectronics standards landscape. Within each segment of the industry – for example at the levels of chips, packaging, assembly, design automation, etc., – there may be hundreds to over a thousand relevant standards. Standards development takes place in a range of organizations including numerous robust and highly active international bodies, industry alliances, and consortia.

Participants noted that the existing standards ecosystem serves the industry well, but that there was also an opportunity for standards organizations to work in more collaborative ways to address both rapidly evolving technology needs and increasing interdependencies between sectors. For example, standards for panel form factors or chiplet interconnection have important implications for equipment design, thermal and power management, connectors, design automation, and more. Standards for traceability and cybersecurity require alignment across segments including designers, supply chains, manufacturers, and beyond.

Discussions in multiple sessions covered the potential value of what would effectively be an alliance of alliances, since each SSO represents an alliance among its stakeholders. Examples of roles suggested by participants for a high-level alliance included the following.

- Develop industry-wide standards strategies that optimize benefits across sectors;
- Coordinate efforts among SSOs to promote complementarity and interoperability across standards;
- Combine technical expertise and other capabilities for standards that integrate and interconnect the various segments of the materials, supply, and manufacturing chains;
- Promote awareness of existing standards and ongoing standards development efforts to minimize duplication or conflicting results; and
- Facilitate the development of a standards-capable workforce through partnerships among SSOs, industry, universities, and others.

Participants noted that such an alliance of alliances could be formed by an existing or newly formed non-profit organization with a mission for facilitating information sharing, interaction, and cooperation among existing SSOs.



Community-wide Coordination on Consensus Standards Goals

Participants highlighted several areas where the development of coordinated standards roadmaps, possibly mediated by an alliance of SDOs, could guide coordinated efforts and promote industry progress. Examples cited included the IEEE International Roadmap for Devices and Systems (IRDS) and its predecessor, the International Technology Roadmap for Semiconductors (ITRS).

During breakout group discussions, participants highlighted the need for the development and continued advancement of community-led standards roadmaps in areas such as advanced packaging and heterogeneous integration (HI; focusing on 3D HI), the design and manufacturing of chiplets, and secure inter-chiplet communications protocols. To inform and support roadmap efforts, participants called for means for building consensus, including open forums and technical workshops to consolidate knowledge, identify areas requiring standardization, and promote advancements in the relevant fields.

Navigating the Semiconductor Standards Landscape

A challenge that was widely discussed was the difficulty in navigating the existing semiconductor and microelectronics standards landscape. Participants noted that current standards collections are large and distributed across a variety of SSOs, making it difficult for users to get reliable answers to their questions, such as:

- What is the best standard for my application or need;
- Are there alternatives to the standards I'm using that are a better fit to my application;
- If I choose a particular standard, are there conflicts, interactions, or dependencies with other standards; or
- If I can't find a relevant standard, does this mean there is a gap and a new standard is needed, or is it that I just haven't found the right place?

Discussants noted that SSOs would need to be willing to work together to create comprehensive tools for search and discovery across the many standards databases. A suggested approach was that an alliance of alliances could take this on as part of its mission, seeking to develop an appropriate metadata registry, or its equivalent, powered by AI-enabled analytics. Participants noted that such a tool would be valuable for use across the industry, saving time, reducing inefficiencies, and promoting interoperability. It would also serve to promote broader adoption and use of existing standards and reduce duplication of standards efforts.

PROMOTING A DIVERSE, STANDARDS-CAPABLE WORKFORCE

The plenary and subsequent breakout sessions on education and training goals focused on strategic initiatives to cultivate a diverse, standards-capable workforce. Panelists and breakout session participants were asked to consider the following questions.

- The microelectronics field requires a multidisciplinary approach that includes engineering, materials science, physics, and more. How can collaboration between different disciplines and industries be encouraged to create a well-rounded workforce capable of addressing the holistic standards needs of the sector?
- How can educational institutions ensure that their curriculum and training programs adequately prepare students for the evolving standards landscape in the microelectronics sector, while also promoting diversity and inclusivity in the workforce?
- Standards play a critical role in ensuring interoperability and reliability in the microelectronics sector. How can standards-setting organizations more effectively collaborate with both educational institutions and industry to address skills or training gaps to build a more standards-capable workforce?

There was broad agreement on the need to develop a skilled and diverse workforce as essential to enabling a sustainable domestic semiconductor industry and to achieving the economic and national security goals of the CHIPS and Science Act. Participants emphasized that sustained U.S. microelectronics industry competitiveness will require collaboration between businesses, governments, education and training providers, economic and workforce development organizations, unions, community-based organizations, and other supporting entities to help recruit, train, hire, and retain a highly skilled and diverse semiconductor workforce.

Four areas emerged as important opportunities for initiatives and are summarized below.

Collaboration between Industry and Academia

Participants noted that developing, continuously updating, and effectively delivering meaningful training and educational curricula is especially challenging for the fast-paced semiconductor sector. With the rapid and continuing emergence of new concepts, technologies, architectures, etc., ensuring that education and training content both covers the fundamentals and remains in step with current practice requires collaboration between industry and academia.

Suggestions by participants for promoting effective collaboration included the following.

- Fellowships in industry settings for faculty and training providers to promote awareness of evolving industry practices and technologies.
- Industry experts available for consultation on education, training, and credentialing programs.
- Joint mentoring such as in shared graduate and undergraduate projects.

Certification and Credentialing Programs

In addition to collaborative content and curriculum development, participants emphasized the need for program accreditation and certification mechanisms to ensure consistent, high-quality training producing graduates that can step readily into meaningful roles in industry. Among the needs that were highlighted in this area were the following.

- Develop consistent, high-quality educational standards and evaluation criteria available for all institutions teaching subjects or techniques relevant to the semiconductor industry and standards development.
- Define skill standards, including training and certification requirements, through collaboration between educational institutions and industry.
- Highlight the need for accessible and inclusive training opportunities, especially in areas with a shortage of skilled technicians.

Multidisciplinary and Interdisciplinary Education and Training

Panelists and participants discussed the importance of a multidisciplinary approach to meet industry needs, developing training resources aligned with those needs, and establishing pathways to apply these skills to the semiconductor industry, including in standards development. Stakeholders from industry and academia were encouraged to collaborate across disciplines in developing education and workforce plans. Steps identified by participants to promote multidisciplinary and interdisciplinary programs included the following.

- Expose students at early stages, including in middle school and high school programs, to interdisciplinary approaches that combine concepts from multiple disciplines in addressing complex and challenging technical issues.
- Provide for multiple paths to advanced science and engineering degrees relevant to the semiconductor industry.
- Offer project-based coursework in collaboration with industry that exposes students to agile approaches in solving compelling technical challenges.

Role of Community Colleges

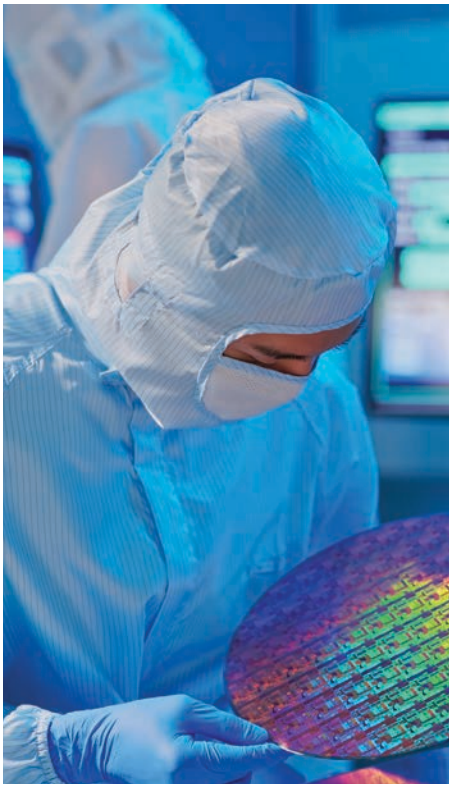
Participants discussed the potential for collaboration between community colleges, research universities, and industry to both prepare students for the industry and promote diversity and inclusivity by offering education and training opportunities to a wider range of individuals. This approach was viewed by participants as building on the strengths of community colleges in providing accessible career entry points for a diverse population that open pathways for students to achieve career success in the semiconductor industry at all levels, including technical, managerial, engineering, and other roles. Among the approaches identified by participants to support community colleges in playing an effective role were the following.

- Promote reciprocal faculty-industry exchanges and fellowships that increase awareness, establish continuing relationships, and enhance course technical content.
- Support joint college-industry student projects and internships that expose students to the exciting opportunities afforded by careers in the semiconductor industry.
- Facilitate the establishment of articulation agreements that allow students to transfer credits from one institution to another.

LINKING STANDARDS AND RESEARCH

The plenary and subsequent breakout sessions focused on pre-standards research in developing the scientific and engineering principles, including appropriate metrology, that can support robust and effective standards. Both panelists and breakout session participants were asked to consider the following questions.

- Ideally, there could be a reciprocal relationship in which the identification of strategic standards priorities helps inform research efforts, while research outcomes inform standards efforts grounded in sound science and engineering. What approaches might enable or strengthen a reciprocal link between research and standards efforts in ways that drive progress? What are the key criteria that need to be met in considering when to start standards development in an emerging technology area?
- Many standards challenges are inherently interdisciplinary. How can collaboration between semiconductor and microelectronics experts, domain scientists, and industry stakeholders be fostered to ensure that new standards reflect real-world applications and technological advancements?
- Standardization is often a global effort. How can pre-standards research contribute to achieving greater harmonization of standards across international boundaries to foster interoperability and support global trade and innovation? Which communities are best positioned to drive this and what collaborations will be needed?



Discussions of the ways in which research can contribute to standards efforts included the following. Focused research and development efforts can provide data and validation services for emerging standards that codify best practices and lead to greater specificity in standards frameworks. Research can provide vetted approaches for adapting existing standards to new technology areas, define performance indicators, and provide measurement metrics and methods for validation and verification. Participants highlighted the benefits of aligning research and standards efforts to ensure that:

1. Research goals and emerging standards are firmly grounded in practical applications aligned with industry needs and operating realities;
2. Investments in research and standards efforts intended to advance industrial competitiveness, such as the CHIPS R&D investments, can be made more efficient and cost-effective; and
3. Development of the supporting metrology and enabling standards that, with careful calibration of timing and focus, can accompany rather than lag the pace of innovation in industry; and
4. Collaborative research and standards efforts can provide the basis for international cooperation for a global semiconductor marketplace that is open, transparent, efficient, and supportive of innovation.

Recommendations for promoting these benefits are summarized in the following sections.

Meeting Industry Needs

Discussions in this area focused on the importance of strengthening partnerships between the pre-standards research and industry/manufacturing communities. Participants noted that insights from industry can inform the pre-standards research process through direct experience in manufacturing processes, technical requirements, and emerging needs and limitations. Academic researchers offer capacity for experimentation with emerging technologies and new science and engineering concepts. The primary recommendation was to establish channels for communication and interaction between industry on the one hand and research and standards efforts on the other. One mechanism that was suggested was for the CHIPS R&D Metrology and Standards programs to co-convene conferences and workshops that bring the pre-standards research and semiconductor manufacturing communities together.

Additional discussions focused on the value of testbeds. Pre-standards research organizations offer testbeds and practical trials that provide a tangible environment to evaluate standards and develop testing and validation methods, enable early identification of issues around feasibility or accuracy, and facilitate quick adjustments focused on facilitating industry adoption. Testbeds were also cited as hubs for collaboration across sectors and between researchers and implementers, and as a tangible means for drawing stakeholders into standards development processes.

Advancing Industrial Competitiveness

Participants discussed mechanisms for ensuring that investments in research and standards efforts are efficient and cost-effective. A key element was in linking strategies between research and standards efforts and aligning those efforts with industry needs. The development of an aligned research and standards roadmap with industry input was cited as a means for guiding investments. Such a roadmap could include both a high-level strategy, identifying priorities across the semiconductor industry, as well as implementation goals and plans at the level of sectors and technologies. Participants recommended engaging with technical societies and consortia to assist in the development of industry-wide frameworks and roadmaps that describe the relationship between standards setting organizations and pre-standards researchers.

Additional discussions focused on highlighting the value of standards as a mechanism for technology transfer from research to industry. Current technology transfer efforts often focus on pathways to commercialization, but participants noted that not all technologies are best transitioned in this way. For example, many technical measurement methods developed in research settings have significant potential benefit to industry but may not be suitable, or even considered, for wide commercialization. While the development of standards can provide a means for enabling such methods to be used in industry, researchers are often unfamiliar with, and typically not rewarded for, standards development. Standards incubator and accelerator environments (discussed in preceding sections) and reward mechanisms for standards contributions by researchers were among recommendations for increasing the effectiveness of standards-based technology transfer mechanisms.

Pace of Innovation

Participants noted that key aspects of a successful roadmap are those of timing and focus. Launching standards efforts too early can unnecessarily constrain innovation by restricting options and making unnecessary assumptions about paths to success. Initiating standards efforts too late can inhibit market growth and create inefficiencies in the form of inefficient workarounds, dead-end silos, and custom solutions that lack interoperability. Thus, a key point of discussion was how to assess timing and focus for an aligned research/standards roadmap.

One recommendation that emerged was to explore the concept of standards readiness level metrics. This concept was described as analogous to technology readiness and manufacturing readiness level metrics already in use. For example, technology readiness levels, or TRLs, are widely used in characterizing where on the pathway between basic research and broad commercial adoption a given technology lies. This allows investors in both public and private sectors to focus on technologies that are appropriate for the intended investment vehicle and desired outcome.

Participants recommended that a community-based effort could be undertaken to explore consensus around a defined set of standards readiness level metrics for use in planning and road mapping. Such metrics could then be used in aligning pre-standards research and standards development efforts. An example of a strategic target might be an emerging standards need identified by industry for which the underlying metrology is inadequate to meet the need. Standards for calibrated thermal measurement in emerging three-dimensional packaging architectures was cited as a possible example of such a need.

Discussions included consideration of a standards readiness level evaluation framework to assess whether emerging technologies are suitable for standardization, including common definitions and metrics to measure, data sufficiency, and scalability. Stakeholder-driven technology roadmaps that describe anticipated schedules for technology development could guide prioritizing specific opportunities for standards development.

International Collaboration

Participants noted that, on the one hand, semiconductors are a global market and companies need the opportunity to compete in that market on a level playing field if they are to achieve their goals for success. On the other hand, countries worldwide are making investments to promote the growth and resilience of their domestic semiconductor sector. Discussions centered on the notion that reconciling these two aspects would require effective international collaboration.

It was widely noted that pre-competitive research and international standards development are uniquely well suited as opportunities for international engagement and cooperation. Standards setting organizations are typically international in character as they support the needs of their global stakeholders.

A recommendation that emerged from discussions was that governments could promote international cooperation on shared research and standards efforts by convening the relevant communities and stakeholders to identify shared priorities, and by supporting joint research and standards efforts centered on those priorities.

OVERVIEW AND NEXT STEPS

Participants in the Standards Summit – comprising experts from industry, academia, standards setting organizations, and government, and representing the full range of semiconductor and microelectronics sectors – came together to provide insights into the path forward for the industry and the CHIPS R&D Standards program. These insights covered strategic standards priorities, innovation in standards development, education and workforce needs, and linking standards and research. Next steps are to convene a series of expert workshops focused on the specific topics and approaches that emerged from the Summit. The goal in these workshops is to develop action plans suitable for implementation across the semiconductor sector, including options for CHIPS R&D support. Collectively, these action plans will provide the basis for working together to create a vibrant microelectronics standards ecosystem that is smarter, faster, and more inclusive and agile in enabling innovation.

Appendix A, B & C

APPENDIX A: SUMMIT DATA COLLECTION

During both days of the CHIPS R&D Standards Summit, moderators and technical facilitators collected data from panelists and breakout session participants to capture their ideas and inputs on both the session topics and ways to improve the agility and efficiency of the standards process, ensuring its continued growth in the rapidly evolving semiconductor industry. Given the length of the summit, the moderators and technical facilitators used multiple knowledge capture methods, including session recordings, meeting minutes, virtual meeting platform chat entries, and Google Form submissions to ensure all contributions were documented. Reviewing all of these data sources allowed the report writers to characterize the discussions that took place over the two days of the event and identify key thematic topics.

APPENDIX B: SUMMIT ORGANIZING COMMITTEE

CHIPS R&D engaged with several key stakeholder organizations within the semiconductor and microelectronics industry to design, publicize, and execute the Standards Summit. The Summit Organizing Committee met on a biweekly basis in the months leading up to the summit to plan a highly collaborative event that aligned with the needs and priorities of the semiconductor and microelectronics standards community. Organizations that participated in Summit Organizing Committee activities included:

1. CHIPS for America: Includes the CHIPS Program Office, responsible for semiconductor incentives, and the CHIPS Research and Development Office, responsible for R&D programs. Both sit within the National Institute of Standards and Technology (NIST) at the Department of Commerce.
2. American National Standards Institute (ANSI): A private, non-profit organization that administers and coordinates the U.S. voluntary standards and conformity assessment system.
3. IEEE Industry Standards and Technology Organization (ISTO): Established in January 1999 as a federation of member alliance programs to support accelerated technology standards development and market adoption for the industry.
4. IPC International: A non-profit, member-driven organization and leading source for industry standards, training, industry intelligence, solutions, and public policy advocacy. IPC is the global association that helps OEMs, EMS, PCBs, advanced packaging manufacturers, and suppliers build electronics better. More than 3,200 companies worldwide depend on IPC programs and services to further their competitive advantage and financial success.
5. International Electronics Manufacturing Initiative (iNEMI): A not-for-profit consortium that roadmaps the future technology requirements of the global electronics industry, identifies and prioritizes technology and infrastructure gaps, and helps eliminate those gaps through timely, high-impact deployment projects.
6. Joint Development Foundation: Provides the corporate and legal infrastructure to enable groups to quickly establish and operate lightweight collaborations to develop technical specifications, standards, and source code.
7. Networking and Information Technology Research and Development (NITRD): This program coordinates and promotes Federal R&D in advanced computing, artificial intelligence (AI), microelectronics, networking, and information technology by leveraging federally funded R&D to address the Nation's most critical priorities.
8. National Nanotechnology Coordination Office (NNCO): The NNCO conducts public engagement on behalf of the National Nanotechnology Initiative (NNI) and provides technical and administrative support to the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee and the interagency nanotechnology community.
9. SEMI: SEMI is the global industry association representing the electronics manufacturing and design supply chain, connecting over 2,500 members and 1.3 million professionals worldwide.
10. Semiconductor Industry Association (SIA): SIA is the voice of the U.S. semiconductor industry—working with Congress, the Administration, and key industry stakeholders to encourage policy and regulations that fuel innovation, propel business, and drive international competition.

APPENDIX C: AGENDA

DAY ONE

Time	Description
8:30am – 9:30am	Session 1: Overview and Keynotes • Richard-Duane Chambers, CHIPS R&D • Lora Weiss, CHIPS R&D • Jayne Morrow, NIST • Joe Stockunas, SEMI
9:30am – 10:00am	Networking Break
10:00am – 11:00am	Session 2: Strategic Standards Priorities – Topic Identification • Stephanie Lin, NSTXL • Donald Davidson, Mission-Critical.org • Lalitha Immaneni, Intel • Grace O'Malley, iNEMI • Daniel Gamota, Jabil • Jeremy Muldavin, GlobalFoundries
11:00am – 12:00pm	Session 3: Strategic Standards Priorities – Topic Scoping • Panel continued from preceding session
12:00pm – 1:30pm	Lunch Break
1:30pm – 2:30pm	Session 4: Innovation in Standards Development • Andrew Updegrove, Gesmer Updegrove LLP • Andy Freed, Virtual Inc. • Jory Burson, Joint Development Foundation • Calista Redmond, RISC-V • Adam Newman, IEEE ISTO

Time	Description
2:30pm – 3:00pm	Networking Break
3:00pm – 4:00pm	Session 5: Diverse, Standards-capable Workforce • Cait Cramer, Micro Nano Technology Education Center (MNT-EC) • David Hernandez, IPC • Paul Trio, SEMI • Osama Awadelkarim, Pennsylvania State University • H.-S. Philip Wong, Stanford University
4:00pm – 5:00pm	Session 6: Pre-Standards Research • Craig Schlenoff, NITRD NCO • Marla Dowell, CHIPS R&D • Marcus Pan, Semiconductor Research Corporation (SRC) • Margaret Martonosi, NSF CISE • John Allgair, BRIDG
5:00pm – 5:30pm	Summary and Closing

DAY TWO

Time	Description
8:30am – 9:00am	Session 7: Overview and Keynote • Representative Paul Tonko, U.S. House of Representatives (D-NY) • Chris Greer, CHIPS R&D
9:00am – 9:15am	Networking Break
9:15am – 10:15am	Session 8: Breakout Strategic Standards Priorities – Topic Identification • All
10:15am – 11:15am	Session 9: Breakout Strategic Standards Priorities – Topic Scoping • All
11:15pm – 12:45pm	Lunch Break
12:45pm – 1:45pm	Session 10: Breakout Innovation in Standards Development
1:45pm – 2:15pm	Networking Break

Time	Description
2:15pm – 2:45pm	Sessions 11 and 12: Plenary Remarks and Recap of Strategic Priorities • Secretary Gina Raimondo, Department of Commerce • Session 2 Panelists
2:45pm – 3:45pm	Session 13: Breakout Diverse, Standards-capable Workforce • All
3:45pm – 4:45pm	Session 14: Breakout Pre-Standards Research • All
4:50pm – 5:00pm	Networking Break
5:00pm – 5:30pm	Session 15: Summary and Closing • Breakout Session Rapporteurs