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Executive Summary

The Department of Defense's (DoD) Defense Advanced Research Projects Agency (DARPA) has supported research and development (R&D) in microelectronics for many decades. DARPA is interested in ways to improve engagement with and support the microelectronics industry, potentially through establishing a public-private partnership (PPP), to advance R&D and technology development goals. To support these interests, DARPA requested the IDA Science and Technology Policy Institute (STPI) identify and analyze prior and ongoing PPPs to inform establishing objectives for a new PPP. DARPA anticipates a new PPP could advance microelectronics R&D and technology development potentially by supporting infrastructure to meet prototyping needs across the industry.

Specifically, the study team set out to identify lessons learned related to the design and implementation of past and ongoing PPPs and develop options for structuring a new PPP. The study team developed a guiding definition to inform the scope of this analysis.

PPP Guiding Definition

PPPs are partnerships that enable the Federal Government to achieve and act on shared goals among multiple parties in which at least one party is a private-sector organization. For the purposes of this report, PPPs provide coordination of shared interests and resources to enable technology development and commercialization.

Methods to collect information included identifying relevant PPPs and broader private sector engagement models; reviewing relevant literature; developing a logic model framework capturing generic PPP activities; conducting semi-structured interviews with 54 general microelectronics experts across sectors and those involved in PPPs; and developing 8 in-depth case studies of PPPs.

Lessons Learned

The review of the various PPPs conducted for this report has informed a few high level keys to success.

- The goals of the PPP must be clearly defined and different visions on topics ranging from basic research, proof of concept testing, prototyping, and workforce development must be reconciled.
- A critical decision is the choice of governance model. Models observed range from consultative decision making by executive leaders to consensus voting by

members. The critical factor for success is that the governance is transparent and has the broad confidence and support of the PPP members. The realm of governance must include the high-level business strategy, the technical agenda and priorities, member engagement, clearly defined success measures, and of course be consistent with the members' authorities and business models.

- The funding structure must be flexible to accommodate varied members' expectations and sufficient to support the PPP's mission. Funding structures tied to governance must permit resolution of different opinions to ensure that members do not exit the PPP and continuously attract new partners as the PPP evolves.
- IP policies and rules must be defined up front and one should expect difficulties given the widely different approaches that exist in industry, university, and government, and the need to harmonize them. These policies must adapt to a range of pre-existing commitments that prospective members have, their general policy approaches, and attitudes towards physical security and export control.
- Measures of success depend on the PPP's goals. These measures include technical milestones as well as economic and social returns, such as the creation of new businesses, jobs, and social well-being. Financial sustainability, or the degree of self-sufficiency from Federal funds, is another success measure. However, the degree and timelines for self-sufficiency may vary depending on the PPP's goals and the scale of investments, for instance in new R&D and prototyping infrastructure. The long-term needs of the infrastructure should be considered as part of the PPP's funding model.

The study team identified 32 lessons learned based on the information collected categorized according to 8 concepts related to the PPPs—governance, funding, operations, intellectual property (IP), security, innovation ecosystems, Federal authorities, and evaluation and success measures (Table ES-1).

Governance

Two types of observed governance models are an executive-leadership model, in which a governing body provides decision-making authority for setting technical direction and allocating resources; and a member-voting model, in which all or a select set of partners are provided with votes for decisions and can strive for consensus among voting members. These models can be executed in various ways throughout the PPP's lifecycle, from origins and design, implementation, to evaluation, evolution, and sunset. The governance model may be selected at the outset by an initial set of partners, for instance, including the U.S. Government partners.

Select Findings

Both governance models have merit; their structure is based on the desired goals for the PPP. For example, an executive-leadership's model to pivot quickly is more suited for high-risk R&D and prototyping activities with uncertain applications, than a consensus-based or voting-member model, which may take more time to make decisions.

Funding

The U.S. Government may contribute directly to a PPP usually with expectations of some ratio of matching funds from other partners. Similarly, State and local governments may contribute to the PPP. These resources need not be monetary, and can include in-kind contributions, such as infrastructure, equipment, materials, and expertise. A primary source of revenue for many PPPs are membership fees from commercial, academia, and other non-profit partners. The membership fees can be arranged to support access to one or more of the following—(1) infrastructure or services, (2) participation in the overall PPP, and/or (3) participation in specific R&D programs or projects the PPP sponsors.

Select Findings

Fair and flexible membership fees can be structured to attract a diverse set of partners, including small and large companies. PPPs with long-term business plans and realistic assumptions about future funding are successful in articulating their value proposition to partners. Instances in which expected funding did not materialize resulted in struggles for PPPs to find alternative sources, quickly, or risk the continuation of their activities. Some PPPs were not able to rebound from these unexpected losses.

Operations

Three aspects of operations were observed, accomplishing work/R&D, workforce activities, and start-up services. PPPs fall into two general categories for accomplishing work, those that work on roadmapping and closing R&D capability gaps, and those that provide R&D and prototyping services. For workforce activities and start-up services, both informal and formal programs were created to support the pipeline talent in the industry and entrepreneurial activities, respectively. Close proximity and connections to academic institutions with strong education programs and venture capital to provide financial investments support the success of these programs, respectively.

Select Findings

PPPs tend to use technical advisory groups, with representation across sectors and market applications, to inform the R&D strategy and directions. However, technical advisory groups were not prominent features for PPPs solely providing or brokering prototyping services. Instead these PPPs relied on their staff expertise to direct the PPP's operations. For these PPPs, building the capabilities of their staff was a primary value for their partners.

Intellectual Property

Four observed IP arrangements are, open source or open access, which makes discoveries open to the public; shared limited IP to all partners, which provides non-exclusive royalty free license to generated IP funded by the PPP; sharing limited to R&D collaborators, which retains IP ownership with select R&D performers; and exclusive ownership, which provides full ownership of IP to a single partner. Some PPPs execute a combination of these arrangements, providing flexibility for partners to accomplish the PPP's activities.

Select Findings

Strategic IP management can be integrated into a PPP's business model. For instance, a PPP can co-own any new IP generated through its R&D collaborations, further building the foundation of knowledge available to existing and future partners. This arrangement has been complemented with flexible IP terms negotiated on a bilateral basis between the PPP and individual partners.

Other Protections

PPPs adopt a range of policies and practices for personnel, information systems, and physical infrastructure protections to support the varied levels of sensitivity of their R&D activities. Commercial and academic standards for security protocols protect partner proprietary information, as well as information shared through the PPP's information technology systems, such as cloud-based design environments. For defense and military technologies, including dual-use technologies, PPPs adhere to relevant regulations, such as the International Traffic in Arms Regulations (ITAR) and export regulations. PPPs of focus for this study did not solely conduct this type of work, but instead these activities were a portion of broader PPP R&D activities for commercial partners.

Select Findings

PPPs with shared infrastructure may likely require uniform practices to protect sensitive information among all partners or participants rather than creating firewalls or enclaves that enable broader participation in the less-sensitive activities. However, classified DoD work presents considerations for PPPs to comply with additional security requirements. For shared infrastructure, access or participation from certain partners may be limited, in particular to foreign researchers, without further approvals.

Innovation Ecosystems

An innovation ecosystem includes the people, organizational entities, infrastructure, stakeholders, and resources that provide the innovations necessary to achieve the PPP's goals. While the concept of an innovation ecosystem is often tied to the physical location of PPPs—for example, within local, state, or regional communities—it also relates to the distributed ecosystems—including national and international—that the PPP accesses.

Select Findings

Select Findings PPPs can partner with innovation ecosystem builders that serve as intermediaries in their local, State, or regional communities to connect people, organizations, and S&T capabilities or technologies with needs. Various forms of intermediaries exist, often non-profits associated with local or State governments or their economic development agencies. Given broader goals for economic development in working with industry, intermediaries are often connected to “non-traditional” companies, such as start-ups and small businesses.

Federal Authorities

Numerous Federal authorities can be used to support the PPP and its activities. DoD can make use of both Federal-wide authorities, such as those that facilitate technology transfer activities through Title 15, and agency-specific authorities. Federal authorities may contain provisions for receiving or exchanging valuable PPP resources, including coordination, data, educational materials, funding, infrastructure, research and technologies, small business services, and workforce or expertise.

Select Findings

Strategic planning in the use of Federal authorities can support combining and stacking authorities in ways that maximize flexibilities to share and exchange resources. Depending on what is allowed, authorities may be used in combination with one another to expand the breadth of different resources that may be required for the PPP’s activities, such as the exchange of funding, people, infrastructure, and data, among others.

Evaluation and Success Measures

A variety of metrics can be used to measure the outcomes of PPPs. Input metrics describe the resources available to the PPP and may be related to finances, personnel, and infrastructure. Activity metrics are used to measure actions taken and may include R&D activities and outreach efforts. Output measurements describe the effects directly stemming from the PPP’s activities and may include publications, patents, and licenses to patents. Outcomes measures describe long-term broader impacts, such as economic growth and social benefits, which are influenced by a large number of other factors not directly attributed solely to the PPP’s activities.

Select Findings

PPPs have focused on several key performance measures, including scientific or technical; operational; workforce and education; and broader impacts, including the eventual transition of technologies into industry applications, local or regional economic growth, and strengthened local innovation ecosystems. Financial sustainability, in terms of non-U.S. Government funding, seems to be a direct or indirect performance target for some but not all PPPs. As such, performance metrics may involve tracking the percentage of funding from cross-sector funding sources.

Table ES-1. Summary of Lessons Learned

	Governance
1	The entity that originates and leads the PPP affects the ability of the PPP to fulfill its goals. For any leading entity, regardless of affiliation, this entity must be a credible and capable leader who is able to speak the language of and garner support from potential partners in targeted sectors.
2	To meet its goals, the leading organization(s) needs to select the right partners with shared goals, be engaged, and participate in roles that leverage their strengths.
3	A member-voting model can be effective in supporting PPPs, building trust among partners, and aligning resources toward shared goals.
4	Hierarchical governance structures (specific advisory groups at different levels with different focuses) can be useful to ensure that operational, technological, and strategic priorities and decisions are aligned.
5	An executive-leadership model was effective in allowing for quick pivoting of strategic direction.
	Funding
6	Developing a long-term business plan associated with achieving the PPP's goals and objectives provides a realistic roadmap of the PPP's technical offerings and how they are expected to generate revenue.
7	Making unrealistic assumptions about the likelihood of resource availability over time can delay or impede the PPP's activities altogether
8	Membership fees structured to be fair and consistent can be used to achieve the desired member demographics.
9	When the PPP is engaged in fee-for-service activities, U.S. Government indirect financial support of the researcher base can enhance the PPP's financial viability.
10	A robust business plan can help alleviate possible complacency resulting from large expected resource commitments for a PPP.
	Operations-Accomplishing Work/R&D
11	Technology advisory boards with subject matter experts from the industry or academic partners are a useful structured body to provide input on R&D and technologies to pursue.
12	Not providing industry members with the opportunity to participate in the project-selection process leads them to place lower value on the results.
	Operations-Workforce Activities
13	Relationships with academic institutions and their proximity supports access to up and coming talent trained on cutting-edge systems.
14	Establishing formalized education and workforce training programs supports cutting edge R&D while developing the next generation talent, in particular local talent, which industry partners can recruit later.

Table ES-1. Summary of Lessons Learned (cont.)

	Operations-Start-Up Services
15	Dedicated programs supporting transfer, technology maturation, and commercialization, have led to successful launches of new start-up and support for innovators.
16	Incubation services may not fully align with an existing PPP non-profit business model, as such, as a for-profit affiliate may be needed to make equity and venture investments in start-ups.
17	Cost-sharing mechanisms that leverage venture capital investments are promising mechanisms to support the financial needs of start-up and small businesses.
	Intellectual Property
18	Early agreement on IP terms delivers stability, in particular as the PPP evolves over time.
19	IP strategies that align with the PPP's business model and growth strategy support financial sustainability over the long run.
20	PPPs with flexible IP agreements ensure that partners can achieve goals in a cost-efficient way aligned with their specific business models.
21	Staff with training in IP valuation and conducting market research safeguards that the true value of potential IP is being evaluated and considered in IP negotiations.
22	Misconceptions from the private sector about U.S. Government IP rights for federally supported R&D may hinder motivations to join PPPs.
	Security
23	A PPP's approach to compliance with export control or other security requirements may constrain the type of partners that may participate in the PPP and how they can participate.
24	Flexibility of PPPs to pivot with technology and market trends can lead to benefits for both national security and commercial interests, even if different from the PPP's original technology targets.
	Innovation Ecosystems
25	PPPs based in locations with relevant pre-existing industry ties and strong academic capabilities may help facilitate effective partnering and staffing. Given a lack of a robust innovation ecosystem, seeking expertise not locally available can also support the PPPs goals.
26	Selecting a location where partners have access to pre-existing facilities and equipment, such as in a technological or manufacturing-oriented local ecosystem, may benefit both the PPP and the individual partners.
27	Participation of state and local governments can support the goals of a PPP through substantial financial contributions to the innovation ecosystem.
28	A PPP in close proximity to entrepreneurial activities can support technology transfer and commercialization of new technologies.

Table ES-1. Summary of Lessons Learned (cont.)

	Federal Authorities
29	A variety of Federal authorities are used to share resources, including funds to establish and implement the activities of PPPs. However, certain authorities may be more effective than others or best suited for certain PPP structures and goals.
30	National coordination units and consortia provide centralization and visibility as well as garner trust and support for the Federal Government's coordination role in PPPs.
	Evaluation and Success Measures
31	Establishing, collecting, maintaining, and using performance-oriented success measures provides insights to measure the effectiveness of current and future PPP operations at the project and enterprise levels.
32	Collecting and highlighting successes builds awareness of the PPP's value and, thereby, helps attract more partners and resources to pursue the PPP's goals.

Options for a New Microelectronics PPP

The governance, financial, and operational models, among other features of PPPs, must align with the broader goals of the PPP and its partners. DARPA did not provide the study team with specific technical goals for a new microelectronics PPP beyond addressing prototyping. As such, the study team formulated three major goals informed from mapping various near- and long-term goals associated with the eight PPP cases to guide the analysis of options. The three major goals are—

1. **Enabling Early-Stage R&D and Prototyping in Design**—microelectronics design is considered a relative strength in the United States, with capabilities across Federal labs, academia, and industry, and, as such, distinct considerations to strengthen existing capabilities should guide a new PPP's structure;
2. **Enabling Early-Stage R&D and Prototyping in Manufacturing and Fabrication**—microelectronics manufacturing and fabrication are considered relative weaknesses at least in terms of market share and capacity in the United States, with capabilities relied upon by entities located across the world, and, as such, distinct considerations to develop this capability should guide the structure of a new PPP;
3. **Maturing Technology through Transfer and Transition**—among the PPP cases, transfer and transition were not primary focus areas; however, the strength of the United States is its entrepreneurial ecosystems and market creation capabilities, and, as such, distinct considerations to leverage PPP activities to guide technologies through technical and commercialization challenges should guide the structure of a new PPP.

Generally, Goals 1 and 2 focus on R&D and prototyping across the entire technology lifecycle throughout the design and fabrication of integrated circuits. Options to achieve these goals include varied emphasis for the roles of the U.S. Government, Federal labs, academia, and industry, including the supply chain and related industries in which technologies are applied. Goal 3 focuses on extending R&D and prototyping and further connecting it to the broader innovation ecosystem, through maturation, technology transfer, and transition of discoveries. Goal 3 emphasizes the importance of start-up incubation and small business development as part of creating future industries and market applications as well as strengthening local and regional innovation ecosystems in the United States. A summary of these concepts are provided in Figure ES-1. This report describes specific options and considerations related to the eight PPP features—governance, funding, operations, IP, other protections, innovation ecosystems, Federal authorities, and evaluation and success measures—to implement each goal.

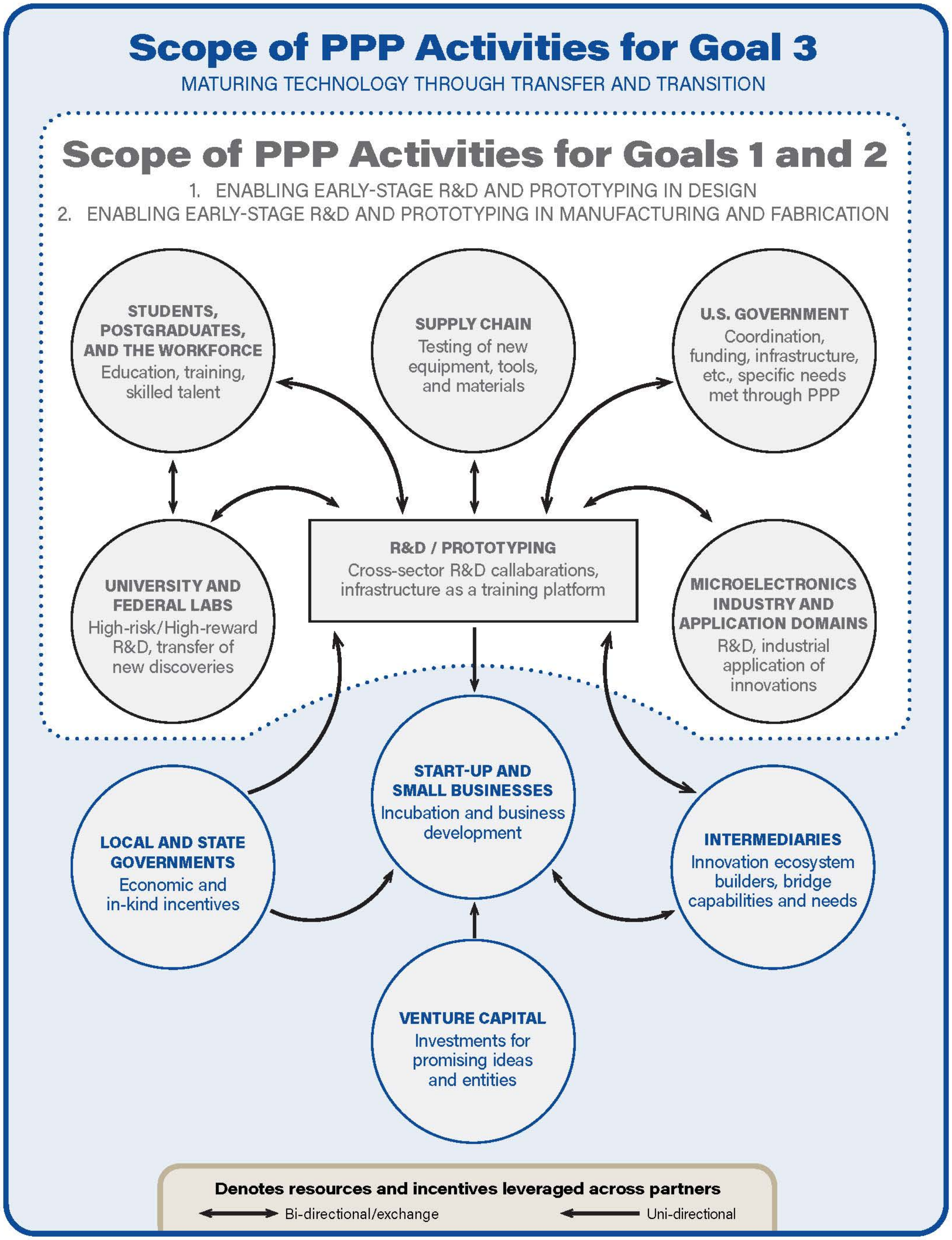


Figure ES-1. Scope of PPP Activities for Three Goals, including Resources and Incentives Leveraged across Partners

Contents

1. Introduction

The Department of Defense's (DoD) Defense Advanced Research Projects Agency (DARPA) has supported research and development (R&D) in microelectronics for many decades. Most recently, new laws enacted by Congress have brought about strengthened attention to the role of DARPA in advancing R&D and technology goals as well as national interests in the microelectronics industry. DARPA engages, funds, and partners with a diverse set of performers in the microelectronics and related industries, including academic institutions, small businesses and start-ups, and medium and large companies focused on commercial products as well as the defense industrial base. DARPA is interested in ways to improve engagement with and support the microelectronics industry, potentially through establishing a public-private partnership (PPP), to advance R&D and technology development goals.

A. DARPA's Request

DARPA requested the IDA Science and Technology Policy Institute (STPI) identify and analyze prior and ongoing PPPs to inform their efforts to better enable the domestic transition of semiconductor innovations to industries of strategic importance, including the possibility of establishing a new PPP. It is anticipated that a new PPP could advance microelectronics R&D and technology development potentially by supporting a broad range of basic research, design, development, and infrastructure to support prototyping needs in the United States. Specifically, DARPA asked the study team to address several study questions related to identifying lessons learned and the functioning of a new potential PPP (Box 1: DARPA's Study Questions).

Box 1: DARPA's Study Questions

- What are the lessons learned from past or ongoing PPPs?
- What partnership structures and funding models may be appropriate?
- What arrangements for intellectual property and U.S. Government-controlled information could be considered prior to establishing the PPP?
- What Federal Government role and Federal authorities could be considered?
- What metrics could DARPA adopt in running a new PPP?

B. Policy Context

This study is situated among a broader Federal Government effort to support the development of microelectronics that address military and economic aspects of national security needs. The National Defense Authorization Act (NDAA) for Fiscal Year (FY) 2021 mandated specific actions to strengthen the U.S. microelectronics R&D ecosystem and commercially viable manufacturing (P.L. 116-283). Some relevant highlights from the 2021 NDAA are in Table 1. 5.Appendix A provides a broader list of relevant provisions.

Table 1. NDAA FY21 Highlights Relevant to Microelectronics

Section	Brief Description	Lead Department
276	Amends 2017 NDAA. Microelectronics and National Security, mandates delivery of a plan for improving commercialization of microelectronics R&D and developing potential PPP models	DoD, DARPA
9902	Semiconductor incentives, establishing a PPP for the development of secure microelectronics	Department of Commerce (DOC), DoD
9903	National network for microelectronics R&D	DoD
9904	Department of Commerce study on status of microelectronics technologies in the United States industrial base	DoC
9905	Funding for development and adoption of measurably secure semiconductors and measurably secure semiconductors supply chains	Department of State
9906	Establishing a National Science and Technology Council Subcommittee; a Manufacturing USA Institute for advanced microelectronics research and workforce development; and national semiconductor technology center	DOC National Institute of Standards and Technology (NIST), DoD

In particular, the DoD and DARPA were directed to analyze and assess the state of the U.S. microelectronics ecosystem, including risks, and "…An approach to ensuring the continuing production of cutting-edge microelectronics for national security needs, including access to state-of-the-art node sizes through commercial manufacturing, heterogeneous integration, advantaged sensor manufacturing, boutique chip designs, and variable volume production capabilities…" (Sec. 276). Sec. 276 also directs the DoD to perform "An assessment of the feasibility, usefulness, efficacy, and cost of" a number of options, including a national microelectronics laboratory for R&D to serve as a commercial incubator of startups. Throughout the NDAA, there is an emphasis on interagency consultation with the lead agencies in Table 1 in many cases directed to work in consultation with other Federal agencies.

Other relevant bills have been introduced to address various related. The Creating Helpful Incentives to Produce Semiconductors (CHIPS) for America Act (S.3933) was introduced in 2020 to provide tax credits for U.S. semiconductor manufacturing, R&D, and supply chain security. Key provisions of the CHIPS for America Act were included in the NDAA for FY21 (P.L. 116-283). Most recently, in June 2021, the U.S. Senate passed the

U.S. Innovation and Competition Act (USICA) (S.1260), which includes an amendment to the NDAA for FY21 to appropriate $52 billion in Federal investments for the domestic semiconductor research, design, and manufacturing provisions in the CHIPS for America Act.

Central to this study is the review of PPP models and options for engaging the private sector in design, wafer fabrication and assembly, to inform DARPA's deliberations in development of a plan for improving the commercialization of microelectronics R&D and developing potential models for a microelectronics PPP.

C. Trends in the Microelectronics Industry

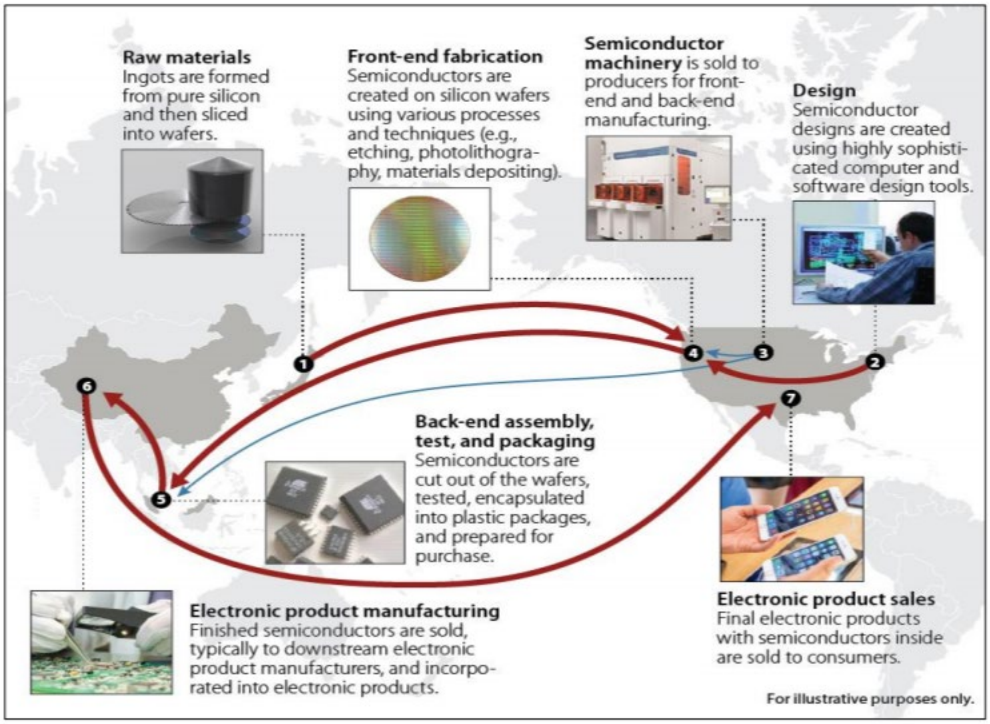
In addition to Federal initiatives, several trends in the microelectronics industry provide further context on the challenges and concerns from the perspectives of the United States and the Federal Government. The following subsections briefly describe these trends.

1. Broad U.S. Perspective and Concerns

Businesses and consumers increasingly depend on semiconductor and microelectronic components, such as integrated circuits (ICs), in their daily lives. Entities along the global supply chains design, manufacture, package, and deliver these microelectronic circuits, known as commercial off-the-shelf (COTS), to end users who incorporate them into everyday products. Defense systems also incorporate COTS IC devices along with specially manufactured military ICs into defense systems.

The complexities of the global microelectronics supply chain and lack of visibility into it create security challenges for defense end users. For example, microelectronic components may travel through multiple countries before they reach the United States and traceability is incomplete. Adversaries have the opportunity to intercept and modify the designs or components for profit, sabotage, or espionage. In addition, if political turmoil or a natural disaster were to affect any point along the supply chain, it can disrupt the entire chain.

Until some 30 years ago, the United States was the dominant global producer of silicon-based microelectronics with a primarily domestic supply chain. Over time, however, as pure-play foundries increased and more U.S. companies became fabless, companies also migrated their assembly, packaging, and testing overseas to take advantage of lower costs, local government subsidies, and access to local markets (Lapedus and Mutschler 2020). Although the United States is still the global leader in microelectronics design, only 12.5 percent of the global wafer processing capacity is located in the United States (SIA 2020). Furthermore, the United States relies on other countries and regions for raw materials, manufacturing, assembly, and test, and this reliance continues to grow (CRS 2020) (Figure 1).



Source: CRS 2020.

Figure 1. Global Semiconductor Production Patterns

In IC fabrication, industry continues to shrink the feature size, and increases the number of transistors in a unit area. This ability to put more transistors into the same area on a die leads to a price drop for a device. In 1965, Gordon Moore at that time the Director of Research and Development Laboratories at Fairchild Semiconductor, documented this trend and it became known as Moore's Law (Moore 1965). The benefit to society of this clockwork reduction in cost has been the mass proliferation of technologies that use ICs, ranging from hand held devices, to massive networks, to high performance computing systems.

For device manufacturers, however, Moore's Law has meant that in order to maintain the cadence of cost reduction, they must continuously invest in increasingly complex and expensive fabs. Today, a state-of-the art fab at the leading-edge node can cost as much as \$20 billion (CRS 2020, Lewis 2019).[1] A single extreme ultra-violet (EUV) lithography tool costs over \$120 million, and a fab needs several of them. A single company, ASML

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[1] For reference, recent announcements from the Taiwan Semiconductor Company (TSMC) in Taiwan's plans to build a new fab in Arizona estimate the costs to be \$12 billion, see Davis, O'Keeffe, and Fitch (2020).

in the Netherlands, manufactures this tool, and it can make only about 40 per year. Its order backlog is almost 2 years (Verheyde 2021). Building a new fab takes a massive commitment of resources for facilities and equipment.

Globally, few companies have the financial resources to build and operate a state-of-the-art fab at the leading-edge nodes, which has led to significant industry consolidation. Only three companies, Samsung in Korea, Taiwan Semiconductor Company (TSMC) in Taiwan, and Intel in the United States have or are building fabs at the most advanced processing nodes below 10 nanometers. China has undertaken major efforts to develop indigenous the state-of-the-art IC fabrication capabilities; in spite of huge investments, however, it still lags behind the current industry leaders.

The globalization of the semiconductor industry presents problems for the U.S. national security interests. The risks range from an embargo against U.S.-based companies, to the need to incorporate foreign made ICs into sensitive civilian and military applications. The use of foreign made components creates the risk of surreptitious modifications to the components that enable adversaries to gather intelligence or to trigger a system failure on command. Other risks arise from IP loss due to unauthorized reverse engineering, or the substitution of counterfeit or substandard parts.

Once a company exits IC fabrication, that decision is essentially final as it is very difficult and nearly impossible to reenter at the advance nodes. Each new node capability builds on the processing steps and knowledge of the preceding node. Without this know-how and experience, developing the necessary process steps is difficult and expensive. Furthermore, as fabs exited the United States, the supply of the highly specialized workers in this area has been negatively affected (Editorial Board 2021).

2. U.S. Government Perspective and Concerns

The loss of domestic IC fabrication capability has raised considerable concerns within the U.S. Government and industry. The U.S. Government has undertaken a number of supply chain analyses to identify vulnerabilities and single points of failure (e.g., see White House 2021). It is also looking into how it can stimulate foreign companies like TSMC and Samsung to set up leading-edge fabs in the United States.

In addition to the loss of domestic leading-edge fabrication capability, the U.S. Government, and especially DoD, have difficulties accessing domestic leading edge fabs. The U.S. Government is a minor customer for ICs relative to the commercial sector; it accounts for less than 2 percent of the global IC market. Furthermore, to ensure it receives ICs free from any malicious insertions, the U.S. Government has special security requirements. For instance, it may require the workforce fabricating devices to be U.S. citizens and fabs to undertake a number of practices to ensure the security of the runs.

Most large fabs are not willing to accept citizenship restrictions on their workforce, since they utilize an international workforce, or to comply with all the security mandates required to produce secure devices for the U.S. Government. Furthermore, IC designs for advanced nodes must take into account limitations set by the processes of individual fabs. Designers need to interact with specialists to ensure yield during fabrication. Fabs have limited numbers of specialists, and therefore dedicating workers to small orders versus larger ones is not an efficient use of a scarce resource. As a result, most commercial fabs may find it difficult to meet U.S. Government's needs, in particular for small or customized orders.

To ensure access to a supply of secure ICs, DoD has set up a Trusted Foundry Program in which the Defense Microelectronics Activity (DMEA) accredits fabs (DMEA 2021). The challenge with this approach has been that accredited fabs under this program tend to be rather small and some are captive to a prime contractor. These fabs cannot fabricate devices at leading-edge nodes. Thus, DoD faces significant challenges in sourcing trusted and assured custom leading-edge ICs.[2]

In June 2017, DARPA launched the Electronics Resurgence Initiative (ERI) as a response to concerns of keeping pace with Moore's Law. ERI is a $1.5 billion, 5-year initiative that funds early-stage R&D in alternatives or augmentation to current semiconductor technologies. As DARPA moves forward with a new phase for ERI, it expects to place emphasis on enhancing domestic manufacturing capacity (DARPA 2018).

A new microelectronics PPP that brings together government and commercial partners can help coordinate and align DoD and commercial sector efforts. The public will benefit from the enhanced security of products that it buys, and DoD will benefit from more secure commercial off-the-shelf IC components.

D. Structure of the Report

This remainder of this report is structured as follows:

- Chapter 2 describes the study approach;
- Chapter 3 describes the study team's findings on lessons learned, including those relevant to governance, funding, operations, intellectual property (IP), security, innovation ecosystems, use of Federal authorities, and evaluation and success measures;
- Chapter 4 describes generalizable PPP goals and options for DARPA's consideration to achieve those goals; and

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[2] For a summary of other relevant DoD programs and DoD IC security concerns, see Odell et al. (2021).

- Chapter 5 provides a conclusion.

Appendixes provide additional supportive information including—recent laws related to microelectronics PPPs (Appendix A); an initial list of PPPs considered for the selection of case studies (Appendix B); literature review findings in two sections—general findings related to PPPs and specific recommendations from literature relevant to development of a new microelectronics PPP (Appendix C); a general logic model for PPPs (Appendix D); a list of interviewees (Appendix E); case studies for eight PPPs of interest (Appendix F through Appendix M), a listing of other private sector engagement models and mechanisms (Appendix N), and a mapping of PPP goals (Appendix O).

2. Study Approach

The study team's approach consisted of: (1) identifying supplemental study questions and defining the scope of PPPs for this effort; (2) conducting literature reviews to understand past PPP experiences, attributes of interest, and success factors; (3) drafting a logic model that provided a framework for our analysis; (4) conducting semi-structured interviews; and (5) developing eight case studies.

A. Supplementary Study Questions and Scope

DARPA requested the study team address several study questions related to the functioning of PPPs. The study team supplemented these questions to lay a foundation for the study team's scoping and analyses (Box 2: Supplementary Study Questions Identified by STPI). In addition, as an important first step to guide the study team's information collection, the STPI team developed a guiding definition for PPPs in the context of this study (Box 3: PPP Guiding Definition).

Box 2: Supplementary Study Questions Identified by STPI

- How are PPPs defined in the context of this study?
- What are broader policy contexts and drivers relevant to this study?
- How are successful PPP outcomes broadly defined and how do these definitions align with outcomes of interest in the context of the study?
- To what extent have past and ongoing PPPs been successful?
- What are the factors that have led to successful or unsuccessful outcomes?
- What lessons learned could be applied to DARPA's efforts?

Box 3: PPP Guiding Definition

PPPs are partnerships that enable the Federal Government to achieve and act on shared goals among multiple parties in which at least one party is a private-sector organization. For the purposes of this report, PPPs provide coordination of shared interests and resources to enable technology development and commercialization.

The PPP guiding definition is intentionally broad and seeks to capture various Federal partnership models used to engage, collaborate, and exchange (including providing or receiving) resources, among other activities, with private sector organizations. The scope of PPPs considered for this study includes:

- Previous or ongoing partnerships—excluding future or planned PPPs; and, STPI did not aim for an exhaustive, comprehensive, and historical listing of PPPs;

- Partnerships in microelectronics and other industries—including industries beyond microelectronics that could provide insights into PPP features and other relevant contexts, e.g., economic or tax incentives; and
- Partnerships as initiatives, programs, or projects—including initiatives, such as multi-sector coordination activities, as well as programs and projects (e.g., at the office, program, or individual principal investigator levels).

The guiding definition does not exclude participation of other non-Federal organizations, such as state and local governments, academic institutions, and non-profits. A preliminary list of PPPs identified of interest for this study given this guiding definition is provided in Appendix B. In addition, the study team developed guiding concepts for identifying lessons learned from the analysis.[3] Lessons learned relate to resources and activities that avoid or are in response to an actual or perceived challenge. As such, lessons learned may be associated with both positive and negative impacts, for example, on the PPP's performance, depending on how effective the response to address the challenge. These concepts provided the study team with a standardized method to analyze the information collected from the PPPs of interest.

B. Literature Reviews

The study team conducted a literature search to identify peer-reviewed publications related to PPPs or R&D consortia and to prototyping infrastructure and technology development. The study team also relied on several studies STPI researchers published related to establishing PPPs and infrastructure partnerships in addition to reports by Federal advisory groups, such as the President's Council of Advisors on Science and Technology, think tanks, policy analysis groups, and the like. In addition, the study team conducted in-depth literature searches on the PPPs selected for developing the eight case studies (Appendix F through Appendix M).

C. Logic Model

The study team developed a logic model to categorize general PPP activities, attributes, and goals that were of interest based on the literature review and given the policy and industry contexts relevant for this study. The logic model provided a basis for systematically comparing the PPPs based on the identified goals and outcomes (Appendix D).

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[3] The study team was informed by and adapted the lessons learned analysis methodology described in McDonald (2014). A lesson learned was identified by analyzing the congruence in relationships among resources, activities, and outcomes related to a PPP. The degree of congruence identifies how well the relationships between resources and activities qualitatively fit to explain an effect, such as an output, outcome, or performance of the PPP.

D. Interviews

The study team conducted interviews with 55 experts on Federal PPPs and the microelectronics sector as well as specific experts on the PPPs of interest for this study. These individuals included those from the Federal, State and local governments, private, academic, and non-profit sectors (Appendix E).

E. Case Studies

The study team developed case studies to analyze the full context of a PPP—including its historical, policy, environmental, and operational contexts. The purpose of the case studies was also to provide a broader perspective and allow the study team to set any lessons learned in context with the industry, institutions, and economic and market conditions at the time the relevant PPP activities occurred.[4] In coordination with DARPA, eight of the PPPs were selected from the initial list for development of case studies (Appendix B) (Refer to Box 4: List of PPPs). The selection of the case studies was based on ensuring the PPPs were primarily focused on the microelectronics and related industries, such as nanotechnology, and related applications. The study team also selected PPPs based on the diverse roles of the PPP in providing or coordinating infrastructure and a diversity of other attributes, such as maturity of the technologies, prototyping support, and geography. In addition, the study team developed a list of broad private sector engagement models used by DoD and across the Federal Government, including uses of specific Federal authorities, of interest for the study. These models extended beyond the microelectronics sectors and were not a focus for in-depth case studies (refer to Appendix N).

Box 4: List of PPPs Selected for Case Studies

- American Institute for Manufacturing (AIM) Photonics
- Bridging the Innovation Development Gap (BRIDG)
- Inter-University Micro Electronics Centre (IMEC)
- Metal Oxide Silicon Implementation System (MOSIS)
- MEMS and Nanotechology Exchange (MX)
- NextFlex
- Semiconductor Manufacturing Technology (SEMATECH)
- Semiconductor Research Consortium (SRC) Joint University Microelectronics Program (JUMP) and its predecessor STARnet, Ncore and its predecessor Nanotechnology Research Initiative (NRI)

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[4] In the development and analysis of the case studies, the study team was informed by the framework developed to assess rigor of case study approaches described in Gibbert, Ruigrok, and Wicki (2008).

3. Lessons Learned

The review of the various PPPs conducted for this report has informed a few high level keys to success.

- The goals of the PPP must be clearly defined and different visions on topics ranging from basic research, proof of concept testing, prototyping, and workforce development must be reconciled.
- A critical decision is the choice of governance model. Models observed range from consultative decision making by executive leaders to consensus voting by members. The critical factor for success is that the governance is transparent and has the broad confidence and support of the PPP members. The realm of governance must include the high-level business strategy, the technical agenda and priorities, member engagement, clearly defined success measures, and of course be consistent with the members' authorities and business models.
- The funding structure must be flexible to accommodate varied members' expectations and sufficient to support the PPP's mission. Funding structures tied to governance must permit resolution of different opinions to ensure that members do not exit the PPP and continuously attract new partners as the PPP evolves.
- IP policies and rules must be defined up front and one should expect difficulties given the widely different approaches that exist in industry, university, and government, and the need to harmonize them. These policies must comprehend a range of pre-existing commitments that prospective members have, their general policy approaches, attitudes towards physical security and export control.
- Measures of success depend on the PPP's goals. These measures include technical milestones as well as economic and social returns, such as the creation of new businesses, jobs, and social well-being. Financial sustainability, or the degree of self-sufficiency from Federal funds, is another success measure. However, the degree and timelines for self-sufficiency may vary depending on the PPP's goals and the scale of investments, for instance in new R&D and prototyping infrastructure. The long-term needs of the infrastructure should be considered as part of the PPP's funding model.

The study team identified 32 lessons learned based on the information collected across the 8 PPPs of interest and broad private sector engagement models. In all cases, the lessons learned were a result of activities to respond to actual or perceived challenges or ways to achieve some expected benefit to the PPP. The lessons learned are categorized according to the following eight concepts related to the PPPs—governance, funding, operations, IP, other protections, innovation ecosystems, Federal authorities, and evaluation and success measures.

A. Governance

1. Description

The governance structure for a PPP affects all stages of the PPP lifecycle, from its origin and design, to its implementation, evaluation, and evolution. Herein, governance structures describe the types of strategic or operational decision-making activities across the PPP's lifecycle. As with other aspects of a PPP's structure, no "one-size-fits-all" governance model will serve all types of PPPs. Two types of governance bodies, however, were used across many of the PPPs in this study:

1. Executive-leadership model—in which a governing body, possibly comprised of select (public or private only) or multiple (public and private) sectors and partners provide decision-making authority for setting the technical direction and allocating resources. Several of the PPPs have an executive leadership team or council and/or Board of Directors that steer the direction of the PPP (refer to examples AIM Photonics, BRIDG, IMEC, MOSIS, MX). Serving as executive leadership is the full-time job of the individuals in these governing roles. They, therefore, make decisions to achieve the best outcomes for the PPP and its partners as a whole.
2. Member-voting model—in which all or a select set of PPP partners, which could include senior executives from industry and U.S. Government representatives, have an equal share of decision-making authority and decisions depend on achieving consensus among voting members; as such, a single "no" vote can halt a decision. This model tended to be used in PPPs funding external R&D projects, for example, at universities, research centers, or companies, which may not necessarily be a *de facto* member of the PPP.

The former tends to be more autonomous than the latter in decision making. In general, these models can also be implemented in combination and in various ways across a PPP's lifecycle:

- Origin and Design—A PPP governance structure must exist before official establishment of the PPP. For example, one or more organizations or individuals may have the original vision for the PPP, deciding to establish the PPP, outlining an initial purpose for the PPP, and recruiting partners to participate. An explicit or formal process may exist by which those decisions are made, and they represent a first critical step in the future success or failure of the PPP.

- Implementation—The individuals or organizations involved in establishing the PPP are often responsible for strategic and technical decision making to oversee and maintain operations of the PPP. In some voting models, the U.S. Government partner has no voting role. This model translates to an industry- or academic-led PPP (depending on the leading organization), in which the U.S. Government's plays an advisory role. Non-Federal partners have autonomy; however, they are incented to ensure alignment of their interests with those of the U.S. Government given their role in providing resources, such as funding, to the PPP. For some PPPs in this study, the governing bodies determined the technical scope and awarded R&D funding to universities, centers, or companies to advance a particular technical area. For other PPPs, the governing bodies made strategic decisions about the technical offerings for the services or access to facilities that they provided to partners, including facility users or service customers.
- Evaluation and Evolution—The governing bodies must have mechanisms to evaluate the progress of the PPP relative to the needs of partners to make strategic decisions on how to allocate resources for the PPP. In response to these evaluations, an effective governance structure allows for the PPP to pivot its technical or operational focus to continue to fulfill evolving partners' needs. Depending on the scope of the goals decided upon by the governing bodies, a PPP may serve a specific purpose. Once that purpose has been fulfilled, the PPP may no longer be necessary. Governance decisions can enable its dissolution given an evaluation of whether the goals and partner needs have been met.

2. Lessons Learned

Lesson Learned 1—The entity that originates and leads the PPP affects the ability of the PPP to fulfill its goals. For any leading entity, regardless of affiliation, this entity must be a credible and capable leader able to understand needs and garner support from potential partners in targeted sectors.

In some PPPs, such as SRC's programs and SEMATECH, a main convener from the private sector allowed for the PPP's activities to be especially effective at engaging industry partners as well as meeting their needs. For other PPPs, a main convener came from academia or was a nonprofit, such as in AIM Photonics, BRIDG, and IMEC, among others. In such cases, an independent organization can provide objectivity in the administration of the PPP. For nonprofits with a smaller budget, working with industry also allows access to revenue and methods to stay abreast of market and industry dynamics, as well as increase their competitiveness for Federal funding (Mendel and Brudney 2012). However, relative to industry, both academia and nonprofits can face challenges in aligning the needs of industry given their roles external to these organizations.

For MOSIS and MX, the U.S. Government served as the convener of the PPP's activities. In these cases, the U.S. Government played a dominant role setting the program's direction without formal or explicit input from industry or academia. Similar to DARPA projects, program managers for these projects had decision-making autonomy and provided vision and direction for the PPP activities. DARPA's prominent role was justified then given its intention to create a completely new service and network for the industry, enabling DARPA contractors to gain access to silicon fab technology more easily.

Lesson Learned 2—To meet its goals, the leading organization(s) needs to select the right partners with shared goals, be engaged in the process, and participate in roles that leverage their strengths.

One of the most critical roles for leading organization(s) of the PPP is to choose the right composition of Federal, private sector, and academic partners. As observed from the PPPs in this study, the three basic criteria for these partners are: (1) they must share common goals, (2) they must be engaged in the PPP, and (3) they must be participating in a role that leverages their strengths. These findings align with lessons identified in relevant PPP literature (for instance Peña et al. 2019, Peña et al. 2014).

The study team found the first criteria has the relatively greatest impact on successful governance of the PPP. For instance, when partners engaged in the PPP do not share common goals, they may make decisions on PPP activities primarily in their own organization's interests. In the case of BRIDG, the local government and industry partners did not necessarily share the leading academic partner's goals, in addition to each partner's goals shifting over time. As such, the PPP's strategic decisions did not meet all partner reasons for participation, in part, leading to the PPP's eventual dissolution. In general, misalignment of shared goals can limit the partners' abilities to appropriate expected gains from participation, possibly spurring disinterest and potential exit from the PPP.

The second and third criteria in selecting partners flow are similar to the first—having shared goals, incentive to engage and commit to providing resources that align with their strengths, such as unique expertise or infrastructure, to make the PPP successful.

Lesson Learned 3—A member-voting model can be effective in supporting PPPs, building trust among partners, and aligning resources toward shared goals.

A member-voting model helps facilitate partners being aligned regarding decisions, which is especially important when the PPP is trying to enable a shift in industry direction (refer to the example of SEMATECH). This model also helps build mutual trust among competitor companies and can ensure that smaller company voices are heard even when larger companies participate. However, making decisions under this model can be more difficult relative to an executive-leadership model. To achieve agreement, a leading organization may need to dedicate a high level of continuous effort to liaise across partners. In practice, the study team observed that building multilateral consensus can require numerous bilateral negotiations. This situation means the leading organization serves as a critical node and intermediary to ensure all partners are in agreement *before* decisions are brought to members for a vote.

In other voting models, some partners have greater voting power than others. For example, in NextFlex, industry members each get a vote and the U.S. Government has a veto and final decision-making authority. This scenario may be more important for PPPs where U.S. Government investment is relatively large and greater oversight of investments may be necessary to align the PPP's activities with the agency's mission. NextFlex's tiered member model means that higher dues paying members also have more voting members on these voting bodies, and thus also provide flexibility in incentives for committing resources. However, if the U.S. Government exercises a veto power frequently or if an industry member with many members votes in contrary ways to the rest, trust could be undermined with other members who feel their input is less valued. Generally, for PPPs with voting models, the PPPs tended to work diligently socializing issues across partners to avoid conflicts that could trigger a veto.

Lesson Learned 4—Hierarchical governance structures (specific advisory groups at different levels with a different focus) can be useful to ensure that operational, technological, and strategic priorities and decisions are aligned.

Several of the PPPs we studied had a hierarchical governance structure, with distinct governing bodies each responsible for different decision-making levels. Conflicts in decisions arising from lower-level governing bodies are raised to higher-level governing bodies. Common hierarchical structures include a Board of Directors, comprised of industry experts, though that may not necessarily be members of the PPP who inform the PPP's strategic direction; an executive council, comprised of members and the leading organization with final authority over decisions; and technical advisory boards that provide recommendations and inform strategic R&D decisions (see examples of SRC, SEMATECH, AIM Photonics, NextFlex).

Lesson Learned 5—An executive-leadership model was effective in allowing for quick pivoting of strategic direction.

An executive-leadership model can facilitate faster pivoting of strategic direction than a voting-member model. For IMEC, the degree of independence and flexibility of its executive leadership model has enabled it to evolve and remain at a decisive point. The PPP's executive leadership needs mechanisms to garner broad input from industry, the public sector, and academia to inform their strategic decision making because, unlike in the voting-member model, these stakeholders are not represented in the governing body. A PPP can encounter challenges if these mechanisms are not effective. This input can come in the form of Boards of Directors made up of academic and industry representatives, technical advisory boards, and/or can be ad hoc and integrated as part of an organization's culture. IMEC is an exceptional model of engaging input from stakeholders in academia and the private sector, including finance, investment, and venture capital organizations, who serve on their Board of Directors. In BRIDG, their technology roadmap was over-diversified, potentially due to lacking clear input and understanding of which industry needs they would be able to meet with their PPP's services.

B. Funding

1. Description

PPP sources of resources vary a great deal. The U.S. Government may contribute directly to a PPP usually with expectations of some ratio of matching funds from other partners. Similarly, State and local governments may contribute to the PPP's expenses. Universities can raise significant resources to fund centers, buildings, and R&D activities associated with the PPP, at times directly funded by U.S. Government sources. In addition, resources may not always be monetary. State or local governments as well as industry partners may also provide in-kind considerations, such as land, municipal services to support new infrastructure, existing facility space, equipment and instrumentation, technologies, materials, loans, and tax credits, among other resources.

The PPP may also charge a fee for services it performs. The services may be technological in nature, such as providing researchers to augment and collaborate with partners on R&D or providing access to specialized equipment and facilities. A primary source of revenue for many PPPs is membership fees from commercial, academia, and other non-profit partners. The membership fees can support access to one or more of the following—(1) infrastructure or services, (2) participation in the overall PPP, or (3) participation in specific R&D programs or projects sponsored by the PPP. Other funding streams include Federal grants or contracts from DoD and other agency programs. In some cases, this funding can be direct, provided to the PPP, e.g., for the services they offer, or indirectly, provided to principal investigators encouraged or required to use the PPP and support it as its user base. In one case, income from investments or other sources not directly related to its prime purpose, such as venture capital or equity investments, provided additional revenue to the PPP (see example of IMEC).

Principally being associated with a U.S. Government funding source is the mechanism through which the PPP receives support, e.g., through a contract, a grant, a cooperative agreement, and OTA. Use of these mechanisms may have advantages or disadvantages. This topic is discussed in more detail in Section G. Federal Authorities.

2. Lessons Learned

Lesson Learned 6—Developing a long-term business plan associated with achieving the PPP's goals and objectives provides a realistic roadmap of the PPP's technical offerings and how they are expected to generate revenue.

Developing and updating a long-term business plan provides a stable blueprint for the PPP's achievements and evolution as well as its proposed value to partners. The time horizon is integral to the business plan and reflects whether and when the PPP is expected to become financially self-sufficient. A research or technology roadmap is also a key element of the plan. This roadmap shows what the PPP will offer partners as it evolves and how resources are expected to be allocated. A roadmap focuses on key market sectors in which the PPP intends to add value, applying realistic assumptions about what benefits will be a function of anticipated market conditions. Consequently, the roadmap guides marketing efforts to maintain existing partners and recruit new ones. The roadmap must reflect goals that do not exceed realistic financial or technological expectations.

Business plans and roadmaps can be revised based on results (e.g., as reflected in revisions or the evolution of the PPP's goals), new external influences (e.g., policy or market conditions or large capital needs to modernize infrastructure), or efforts to enhance the PPP's long-term financial sustainability (e.g., changes to the membership fee structure, U.S. Government commitments).

Lesson Learned 7—Making unrealistic assumptions about the likelihood of resource availability over time can delay or impede the PPP's activities altogether.

This lesson is vitally important. Reducing or eliminating expected funding can have severe impacts on a PPP. At best, costs can increase and the PPP's activities can continue with little interruption; however, consequently some partners may leave the PPP. At worst, the PPP can dissolve itself or be forced to rapidly adjust its operations toward a more achievable business model (see example of MX).

PPPs involving infrastructure and equipment, with substantial investments in design and establishing new facilities as well as maintenance and operations, are especially susceptible to funding variations. In general, operating R&D infrastructure requires sustained funding on timeframes of 40+ years given the general lifecycle of infrastructure, understanding that modernization investments will be necessary throughout this period (Peña et al. 2014). For many PPPs, costs associated with design and development of new infrastructure are completely or largely supported through government funding. However, politically dependent funding sources are especially vulnerable to such funding changes.

Lesson Learned 8—Membership fees structured to be fair and consistent can be used to achieve the desired member demographics.

Fair and consistent membership fees can be structured to achieve the desired member demographics, e.g., large companies, small companies, academia, other non-profits. The desired membership will not materialize without fairness and that in turn could lead to delays in achieving goals. Tiered membership may be a desirable characteristic where different tiers of membership have different influence over the PPP operations. Members paying some part of their fees based on in-kind services may also be desirable. Determine this entire fee structure in advance. The challenge is not to overburden members from any desired demographic. Also, an overly complex structure may be a deterrent to participation from some partners.

Use of a membership fee model is highly dependent on the treatment of IP. Shared IP arrangements are important to the model's fiscal feasibility. Refer to the Section E. Intellectual Property for lessons learned related to this topic.

Lesson Learned 9—When the PPP is engaged in fee-for-service activities, U.S. Government indirect financial support of the researcher base can enhance the PPP's financial viability.

User fees are one source of revenue to the PPP. In some instances, they may have a significant impact on the viability of the business plan. In this model, while the PPP will market its capabilities to attempt to attract new customers, any support the U.S. Government can provide to these efforts enhances the likelihood of success. For example, from 1981 to 1986, more than two thirds of the projects MOSIS fabricated were for DARPA performers or DARPA projects. Similarly, DARPA-funded performers comprised a relatively large share of the initial MX user base. As direct DARPA support for MX was phased out starting in the early 2000s, DARPA required MX to charge increasing user fees as a revenue source. According to anecdote, this occurred during the early 2000s, when the MEMS market and support for MEMS R&D were also in decline, meaning MX users were likely less able to afford this fee, which may have further challenged the PPP's efforts to sustain itself as a broker of distributed fabrication services under reduced DARPA support.

Lesson Learned 10—A robust business plan can help alleviate possible complacency that can result from large expected resource commitments for a PPP.

A caution is associated with a PPP that is provided with relatively large funding and resource commitments, in particular in the short-term. In some PPPs, this situation led to complacency regarding the long-term sufficiency of the PPP. The observed consequences included a lack of or delay in planning for increased self-sufficiency and conducting the outreach necessary to build a robust partner ecosystem. Complacency is a separate matter from the type of leading organizations involved in the PPP. Aspects of complacency are observed in industry- and academic-led PPPs alike. A robust business plan can help to navigate the short- and long-term needs of the PPP and align partner expectations across these timeframes.

C. Operations

The operational model depends in part on the nature of the PPP's activities. PPPs fall into two general categories, those that work on roadmapping and closing capability gaps in the ecosystem, and those that primarily provide prototyping services for members. Of the partnerships studied, BRIDG, IMEC, MOSIS, AIM Photonics, and MX provide some level of prototyping services. IMEC, AIM Photonics, and MX own and operate fabrication facilities, while BRIDG, MOSIS, and MX act as brokers to provide access to facilities with which they have developed a relationship.

Most of the PPPs rely on some form of advisory or working group to identify and prioritize capability gaps in the ecosystem. Some of the PPPs that provide prototyping services use an advisory group to prioritize requests for prototypes. The staff that serve on these advisory groups mostly come from PPP members. Some advisory groups, however, bring in people who are not employees of a member PPP. Examples of such outside advisors include those appointed by government entities that provided funds to the PPP.

1. Accomplish Work/R&D

a. Description

R&D Projects and Topics

PPPs have established processes for selecting R&D projects and topics, for example—

- NextFlex, as well as other PPPs, have a Technical Council and Technical Working Groups (TWG) that develop a technology roadmap to identify gaps. The Technical Council prioritizes the focus areas that will address the gaps, and provides a list to its Governing Council. The Governing Council reviews the focus areas and approves the ones selected for a new project call.
- As part of its R&D strategy, IMEC crowdsources new ideas from its members and researcher base. At IMEC, researchers can propose new ideas for independent R&D every 6 months. IMEC's leadership reviews the ideas and provides internal R&D funding to selected researchers to pursue their ideas.
- SEMATECH relies on technical experts from their rotational assignee program and industry to determine the right technologies to invest in to support their objectives.
- AIM Photonics has a Technical Review Board, which identifies projects that would have the highest impact on baseline and advanced capability. It has four Key Technology Manufacturing Area (KTMA) committees focusing on specific manufacturing areas.

Joint funding solicitations, in which agencies partner with non-Federal organizations, including private companies, to develop joint opportunities for funding researchers, can provide other avenues to support a PPP's initiatives. Partners may contribute funding and access to expertise, for instance, through participation in Federal merit review processes to select awards (refer to example of SRC).

Supplying Prototypes

Five of the PPP cases fabricated prototypes for its partners or users, BRIDG, IMEC, MOSIS, AIM Photonics, and MX.

- BRIDG has a 200mm silicon fabrication facility that supports advanced packaging and high-density multi-chip systems integration.
- IMEC offers vertically integrated state-of-the-art 300-mm silicon processing services, with capabilities to fabricate devices and structures below 20 nm feature sizes. IMEC also has a leading-edge EUV tool from ASML being used

for lithography research. In addition to semiconductor devices, IMEC fabricates microelectronic mechanical systems (MEMS) and biosensors.

- MOSIS offers a low-volume multi-project wafer (MPW) processing service. It aggregates customer-submitted designs and merges them into a shared reticle. MOSIS uses a commercial mask house to make the mask and one of its partner foundries to fabricate the MPW designs. It then performs wafer probing, dicing, packaging, and ships the individual devices to customers.
- AIM Photonics has the Electronics and Photonics Design Automation Center of Excellence, which develops integrated design tools for photonic and combined electronic-photonic components; Multi Project Wafer and Assembly Center of Excellence, which offers processing and assembly services for both Si and InP devices; Inline Control and Test Center, which provides optical testing for photonics applications; and Test, Assembly, and Packaging Center of Excellence, which provides photonics prototype packaging capabilities;
- MX relies on a distributed network of fabrication facilities to offer users more than 4,000 processing steps. It handles the administrative burden of coordination and contracting logistics of moving wafers around the various fabs. It also has some in-house testing and analysis equipment it uses for quality control to avoid compatibility issues or cross-contamination of fabrication tools between process steps.

b. Lessons Learned

Lesson Learned 11—Technology advisory boards with subject matter experts from the industry or academic partners are a useful structured body to provide input on R&D and technologies to pursue.

Several of the PPPs use technical advisory boards to provide input and guidance on technology direction. These boards are particularly useful when composed of employees from companies involved in the PPP. This ensures the technology advisory board members have a stake in the outcomes of the PPP’s efforts. In general, the technical boards make sure the PPP does not focus on technology directions specific to one company’s interests, but rather on advancing the field or collective goals.

Some PPPs operate without a formal technology advisory board to provide technical direction. This situation, however, tends to be more common in PPPs that provide prototypes rather than those that develop new technology.

Lesson Learned 12—Not providing industry members with the opportunity to participate in the project-selection process leads them to place lower value on the results.

Alternatively, if a PPP uses a different governing body rather than a voting model, and industry has limited input into the choice of projects to fund, some members see lower value and less connection to those projects for their company's interests. This was the case for the NSF-funded portions of SRC's NRI and nCORE. In those cases, a typical NSF review panel selected the projects to fund. Industry members had limited opportunities to provide input into the review panel's deliberation; industry had no votes on which projects received funding. STPI received comments that sometimes industry members saw less relevance and placed less value on this potentially more exploratory research.

2. Workforce Activities

a. Description

PPPs have undertaken a wide range of efforts to develop the workforce of the future. They engage with students and STEM educators from K–12, community colleges, trade schools, undergraduate schools, and graduate programs. Some relationships are formal; others evolve as students and academics take advantage of PPP resources and opportunities to work on state-of-the-art equipment. Some PPPs deliberately co-located with academic institutions to facilitate such interactions.

Some PPPs through their R&D programs fund graduate students' research, which in turn creates a hiring pipeline for the partners. Through collaborative R&D with industry, students form relationships with industry sponsors and develop professional networks. Generally, through their participation in the R&D, students graduate with a better understanding of industry needs and established industry connections, which help their career development.

While some PPPs do not have formal programs, they may support workforce activities indirectly through services and activities to connect the R&D community. For example, MX, which did not have formal workforce development activity, had an impact on building and connecting the supply and demand for talent and capabilities through its network service.

b. Lessons Learned

Lesson Learned 13—Relationships with academic institutions and their proximity support access to up and coming talent trained on cutting-edge systems.

Many PPPs have a strong relationship with academic institutions. In some cases, the academic institution is the foundation for much of the R&D and researcher base, at least initially as the PPP developed (see the example of IMEC in Appendix H). Geographic proximity to academic institutions with relevant programs and faculty expertise facilitates the exchange of a growing cadre of talent that can be accessed to support work-based learning experiences.

Lesson Learned 14—Establishing formalized education and workforce training programs supports cutting edge R&D while developing the next generation of talent, in particular, local talent, which industry partners can recruit later.

Some PPPs have created formal programs that prepare students, technicians, engineers, and researchers for industry careers. These programs develop and disseminate education modules and teaching packages for instructors, offer self-paced learning through online edX courses, and provide online access to interactive simulations. Through these efforts, both students and professionals access opportunities for internships, apprenticeships, and mentors, oftentimes working alongside industry partners in shared facilities.

Funding may be a challenge for some PPPs in supporting workforce development. For example, when NSF and DARPA stopped funding the MOSIS educational program, MOSIS was at risk of having to discontinue no-cost device fabrication services for student researchers. Fortunately, a number of large companies, professional societies, and industry associations stepped in and funded the education program. These "customers" were seriously concerned that without the experience the MOSIS educational program provided, graduating engineers would not be able to contribute fully and quickly in industry.

3. Start-Up Services

a. Description

Although most of the PPPs did not focus their efforts on the development of new businesses and start-up services, a PPP's operational model could include informal or formal programs supporting start-ups and small business development. These programs can provide—

- Special access or uses of the R&D infrastructure, tools, and equipment for start-ups and small businesses;
- Business incubation or accelerator services, including entrepreneurial R&D training, in addition to mentorship, business plan development support,

awareness of funding opportunities, including from Federal and non-Federal sources, and exposure to venture capital and other investors, among others;

- Exposure to entrepreneurs-in-residence and other business experts;
- Access to scientific and technical experts involved in the PPP that can add to start-up or small business capabilities and provide guidance, e.g., on design, prototyping, among other areas; and
- Seed or venture funding, in which the PPP itself invests in the start-ups and small businesses.

These support programs may also be integrated into the PPP's business model, for instance by taking equity stake or royalties from start-ups in exchange for services provided through their programs. In this way, these programs can supplement the funding sources from other PPP activities, such as through membership fees.

Dedicated additional resources, such as funding and staffing, are typically needed to operate these programs. Dedicated staff trained in understanding technology transfer, technology maturation, and commercialization mechanisms can help start-ups and small businesses identify pitfalls and opportunities, such as connecting to R&D collaborators that can help further mature technologies or bring them to potential investors.

b. Lessons Learned

Lesson Learned 15—Dedicated programs supporting transfer, technology maturation, and commercialization, have led to successful launches of new start-ups and support for innovators.

Benefits from integrating these programs to the PPP's operations include development of promising researchers, such as those directly participating in the PPP, and their discoveries in commercial technologies. In general, new businesses created from these efforts have bolstered the broader innovation ecosystem and economy (see example of IMEC). In particular, these efforts may be especially beneficial for PPPs situated in local or regional innovation ecosystems without well-developed industry R&D capabilities in close proximity. The growth of start-ups and small businesses can attract further industry expertise and investments to the area, creating a hub of capabilities the PPP can leverage (for further see Section 4.F. Innovation Ecosystems). In turn, business development activities that directly develop innovators and technology innovations can eventually be spun back into the PPP's operations, potentially as new partners or players in the supply chain supporting existing industry partners.

Lesson Learned 16—Incubation services may not fully align with existing PPP non-profit business model, as such, as a for-profit affiliate may be needed to make equity and venture investments in start-ups.

In one PPP case, IMEC, as a non-profit organization, established a for-profit affiliate to operate its incubation and venture fund activities. Incubation services and venture fund programs were established as part of the for-profit affiliates, allowing for the ability to make equity investments in new start-ups. In general, some incubation services could be provided without the need for establishing a for-profit affiliate, such as mentorship and other technical or business training activities, a non-profit organization managing the PPP's operations may need to carefully examine how venture investments would be treated given their non-profit status.

Lesson Learned 17—Cost-sharing mechanisms that leverage venture capital investments are promising mechanisms to support the financial needs of start-up and small businesses.

A PPP's operations may also include cost-sharing mechanisms that leverage venture capital investments to support start-ups and small businesses. Three such mechanisms include—

- Hands-on—a program that requires matching funds from venture capital and other private investment firms or funding sources to be allocated to promising ventures and is managed by the PPP or Federal partners
- Hands-off—a fund or venture arm managed externally to the PPP or Federal partners and leverages the management expertise and experience of the private sector to allocate investment funds
- Hybrid—a program requiring matching funds, though these funds are required from the start-up, rather than directly from the venture capital firm, minimizing risks associated with pooling funds

As a start-up and small business grows, venture capital funding becomes a centerpiece of maturing and growing the business. Acquiring matching venture funds demonstrates a start-up's potential for growth and helps minimize risks associated with the PPP's or U.S. Government's financial support.

D. Intellectual Property

1. Description

The spectrum of IP arrangements implemented across PPPs can range from shared to exclusive models. Within shared models, arrangements can include—

- Public, open source/open access—PPPs can choose to make their results completely open to the public, for instance, by requiring publication of results and providing systems to make their data and research accessible to others in public and relevant communities. These models tend to occur for pre-competitive and early, basic research areas in which IP valuation may be difficult or unnecessary to incent participation.
- Shared limited to all partners only—In these models, an incentive to join the PPP is access to any IP generated funded by the PPP, typically through a non-exclusive royalty free license, that is shared with any of the other partners. The licensing terms may be limited to specific uses, such as for further development or scholarly research, rather than for commercial profit-generation.
- Shared limited to R&D collaborators—In these models, IP ownership lies with the R&D performers only; which may be just a subset of companies and other cross-sector performers involved in the PPP. IP terms can be negotiated by individual partners participating in the R&D collaboration.

On the other side of the spectrum, PPPs can have exclusive IP models that tend to include options to engage directly with private sector partners, most likely under customized negotiated terms. Exclusive models tend to occur with late-stage or proprietary research in which the IP generated from the R&D is of high-value for the private sector partner's competitiveness. DoD and other Federal partners may also take part in this exclusive IP, e.g., for areas in which Federal researchers are involved. PPPs that offer R&D support services or access to unique infrastructure, tools, or equipment tend to use exclusive models. (Examples: IMEC small portion, DOE user facilities, AIM). These models also offer additional flexibility to attract greater participation in the PPP, especially when combined with other shared models to provide a full range of options for potential partners. However, they can also be expensive options for the private sector partner as in most cases the partner will not pay a shared portion of the R&D but rather the full cost, e.g., of operating expenses and research or support services.

PPPs can also implement both shared and exclusive models in combination to accommodate greater flexibilities for the PPP's partners.

2. Lessons Learned

Lesson Learned 18—Early agreement of IP terms delivers stability, in particular as the PPP evolves over time.

Private sector partners tend to desire IP terms that are well clarified and articulated before they participate in the PPP to protect their interests and their own IP. When first establishing a PPP, the main partners initiating or managing the partnership can develop broad IP arrangements. These agreements have been applied across the entirety of the PPP, setting the terms for the conduct of the current partners' R&D as well as any potential follow-on partners' participation. Partners can also develop IP terms over time, revising or adding to general agreements as new situations occur. However, changing broadly agreed upon IP terms part-way through a PPP can be detrimental to its functioning. In at least one PPP case, this situation led to stalled progress and disagreements (see example of SRC). Changing broad and previously agreed-upon IP terms part-way leads to confusion among partners and years of delaying R&D until new agreements can be made adequate for all parties.

Lesson Learned 19—IP strategies that align with the PPP's business model and growth strategy support financial sustainability over the long run.

In certain PPPs, the IP model has been integrated into the PPP's business model. This means that in these PPPs, the IP generated is co-owned by the PPP, typically as co-inventors of patents produced from the collaborative R&D. This strategy may not be appropriate for all PPPs, in particular those without research staff that take part in the collaborations with other partners. However, when implemented, the IP owned by the PPP (typically via the non-profit managing organization as an owner) attracts partners. In the case of IMEC, researchers develop joint IP through collaborative R&D projects with partners. Partners pay fees to participate one of their many industrial research programs and IMEC shares this background IP, as relevant, as well as any foreground IP generated as a result of new R&D.

Lesson Learned 20—PPPs with flexible IP agreements ensure that partners can achieve goals in a cost-efficient way aligned with their specific business models.

PPPs can provide flexible IP ownership models, which can be pre-negotiated at the outset of the relationship. Flexibility in implementing various IP models and agreements ensures that partners' common as well as individual goals are aligned while maximizing benefits given their own business and IP portfolio strategies. PPPs can also provide streamlined processes, such as template IP agreements, to facilitate participation.

Lesson Learned 21—Staff with training in IP valuation and conducting market research safeguards can understand the true potential value of IP being evaluated stemming from pursuing R&D and considered in IP negotiations.

Many organizations in the Federal, academic, and private sectors involved in PPPs have staff that support IP negotiations. These staff can include patent lawyers and IP valuation experts with the capabilities to conduct market research and analyze IP portfolios in the industry and their own organizations to understand the potential value of IP stemming from the R&D being pursued. These capabilities are valuable because this information can effectively inform decisions for the IP terms developed by the partners in the PPP. In particular, staffing for PPPs that have integrated IP into their own business models, e.g., in which their researchers are co-inventors, such as IMEC. These capabilities can be integrated within the organizations managing the PPPs themselves, and can be housed within technology transfer offices across Federal and non-Federal labs, academia, and the private sector.

Lesson Learned 22—Misconceptions from the private sector about U.S. Government IP rights for federally supported R&D may hinder motivations to join PPPs.

When the Federal Government funds R&D, inherent government purpose rights are associated with any discoveries resulting from federally supported work stemming from seminal laws enacted in the 1980s, including—

- Government purpose rights—provides the U.S. Government with a general right to use any discoveries stemming from Federal funding for U.S. Government use. This ensures the U.S. Government is not paying for both the development of *and* the ultimate technology product.
- March-in rights—allows the U.S. Government to provide the use of patents or licenses to others, if certain conditions are met in which the existing patent holder or licensee is not making adequate commercialization efforts.

These rights were not predominant barriers denoted for the effective functioning of the eight case studies selected in this report. However, in general, these rights have been areas of concern for both Federal agencies with programs supporting the private sector; and companies, in particular start-ups and small businesses, which often require exclusive rights to grow their business ventures (NIST 2019). Although some of these concerns are not well substantiated,[5] they remain important aspects to consider as part of engagement and communication strategies with the private sector to clarify potential misperceptions, such that the Federal Government can easily take ownership of the IP.

E. Other Protections

1. Description

PPPs adopt a range of policies and practices for personnel, information systems, and physical infrastructure protections to support the varied levels of sensitivity of their R&D activities. Such work may involve business proprietary technologies and information; defense and military technologies, including dual-use technologies, and classified R&D.

For business proprietary technology and information, most organizations institute digital and physical access controls as part of a risk management strategy to help protect their own or customers' confidential or proprietary business information, trade secrets, IP, personal identifiable information (PII), private communications, and capital equipment from theft or sabotage.

Any PPP should comply with some minimum acceptable business standard protections, for example, guided by frameworks and standards developed by organizations such as NIST or the International Organization for Standardization. The PPPs studied reported protections specific to their operational models and participants. As examples, NextFlex established a privacy policy for visitors to its website, and AIM photonics engaged security protocols to protect user information in its membership networking web site. MOSIS developed a secure cloud-based design environment, and MX built access and other controls into its enterprise process sequence management system.

When business assets have a high value, a PPP, partner, or user of shared infrastructure may take additional steps to protect their own business interests. Anecdotes suggest some industry researchers working at shared facilities would bring their own portable hard drives for data storage to further reduce their risks when conducting collaborative R&D and to provide additional protections from potential vulnerabilities to working with data stored locally.

For defense and military technologies, including dual-use technologies, relevant regulations such as the International Traffic in Arms Regulations (ITAR, 22 C.F.R. I.M.120) prohibit sharing with foreign entities any technology or information deemed a defense article or defense service.[6] In addition, the Export Administration Regulations

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[5] In particular, the U.S. Government has not used march-in rights since the authority was provided by Congress in 1980, see NIST (2019).

[6] As identified in the United States Munitions List (22 CFR 121.1).

(EAR, 15 C.F.R. 730 et seq.) prohibit sharing with foreign entities certain unclassified dual- and civil-use technologies regardless of intended use, with a few exceptions.

Any U.S. organization must comply with ITAR and EAR regulations, and must exclude foreign entities from activities involving export-controlled technologies or information, unless a license is explicitly granted by the U.S. Department of State. PPPs may choose whether to engage in R&D activities involving export-controlled technologies or information and need only apply the necessary protections to specific activities that require them. Of those we studied, MOSIS and MEMS exchange were equipped to broker fabrication involving export-controlled information or technology, and could select ITAR-certified facilities from among their participating fabs to engage under these circumstances. Both services employed only U.S. citizens or permanent residents. Similarly, NextFlex has one facility, in San Jose, able to take on work subject to ITAR. AIM Photonics required all members to be ITAR-compliant, and to identify any export-controlled information.

To serve as a "Trusted Supplier" of integrated circuits to DoD, eligible foundries must be "accredited" by the Defense Microelectronics Activity, which requires that facilities and personnel be approved and cleared by the Defense Counterintelligence and Security Agency. None of the PPPs we examined fell into this category (though BRIDG was working toward this accreditation when its funding fell through).

For classified R&D, the most sensitive information and technologies to U.S. national security are classified by the United States Government, and must be handled or undertaken only by cleared personnel in secure physical and digital environments. Among the PPP cases examined, the BRIDG facility was the only one designed to accommodate classified work at the Secret level. It had corresponding access controls for the entire facility and required confirmation of U.S. citizenship of any visitors prior to entry. In another example, MX staff working in the clean rooms at Federal labs also hold security clearances to access the facility.

In general, a PPP may be designed to address or exclude R&D at each level of sensitivity. A PPP that does not accommodate any of these security categories is less likely to yield high commercial technological advances, in the case of proprietary R&D, or national security interest, in the case of classified R&D. At the other end of the spectrum, a PPP designed to address only the most security-sensitive research will generally be unable to engage foreign entities as partners and may impose constraints limiting the value for a potential commercial partner. In between is a hybrid approach where a PPP engages in activities that address one or more of the above categories, and limits participation to only those partners legally permitted, technically equipped, and inclined or incentivized to do so for some subset of their activities. All the PPPs studied addressed, implicitly or explicitly, U.S. national or economic security needs by working to accelerate technological advances or capabilities of immediate- or longer-term interest to the DoD or the high-technology industry.

2. Lessons Learned

Lesson Learned 23—A PPP's approach to compliance with export control or other security requirements may constrain the type of partners that may participate in the PPP and how they can participate.

For example, the ability of MOSIS and MX to enlist a range of independent fabrication facilities, such as university or commercial fabs or foundries, to fulfill a customer's prototyping request, involves selecting those that are ITAR-compliant only when necessary. This approach maximizes the fabrication facility options for users and may help sustain commercial or academic activity at facilities outside of the defense industrial base (DIB) and grow the broader innovation ecosystem. Some PPPs that support basic, typically unclassified, research may maintain policies and practices that enable R&D in areas subject to export controls in compliance with ITAR, which enables it to support work of varying levels of sensitivity from R&D performers supported by the U.S. Government.

A PPP that itself provides and runs a shared facility (rather than simply brokering services at outside facilities) might be more likely to require uniform security practices among all partners or participants rather than creating firewalls or enclaves that enable broader participation in the less-sensitive activities. For example, AIM Photonics was in part motivated by a desire to onshore and reshore photonics industry talent to the United States. As such, all members were required not just to comply with applicable export control laws, but also to obtain approval from the U.S. Government before providing foreign entities access to any of its facilities, tools, information, IP, or technical data.

A lack of flexibility on access could be burdensome or provide a barrier to participation for some partners that might otherwise bring value to the PPP—namely, commercial entities that operate in highly competitive and international markets. This situation possibly represents a tradeoff between the ability of a PPP with shared resources to address certain national security goals and its efficacy in building an innovation ecosystem and a domestic, private-sector industry for economic and supply-chain security.

In contrast, other PPPs are created to maintain open infrastructure, and have no or minimal restrictions in place for foreign researchers to access and participate in the R&D. For some PPPs, foreign researchers are relied upon as a bridge to global innovation and expertise (see example of IMEC).

Lesson Learned 24—Flexibility of PPPs to pivot with technology and market trends can lead to benefits for both national security and commercial interests, even if different from the PPP's original technology targets.

The precursor of NextFlex, the U.S. Display Consortium was a PPP launched to address specific display technology needs of the Navy, Army, and Air Force. For example, in working to address specific Air Force imaging needs, performer dpiX developed a high resolution active matrix liquid crystal display (Keller 1998). Given the flexibility to further develop and adapt this technology, the performer ultimately developed the basis for digital x-ray technologies, removing the need for wet chemical processing of x-ray films when diagnosing injured soldiers in the field. The technology is also used for medical imaging for civilians, and its sensitivity enables a significant reduction in levels of radiation (and thus lowering the health risks) of X-ray imaging.

F. Innovation Ecosystems

1. Description

An innovation ecosystem includes the people, organizational entities, infrastructure, stakeholders, and resources that provide the innovations necessary to achieve the PPP's goals. While the concept of an innovation ecosystem is often tied to the physical location of PPPs—for example, within local, State, or regional communities—it also relates to the distributed ecosystems—including national and international—that the PPP accesses. Proximity to academic, industry, and entrepreneurial activities may lead to synergies that a PPP could not achieve if these innovation ecosystems occur (1) over a large geographic distances or (2) are in ecosystems not sufficiently robust or are lacking altogether.

Despite many components of a healthy innovation ecosystem of engaged partners, offering a qualified workforce, facilities and equipment, financial incentives, and entrepreneurial activities are most relevant to PPPs:

- Access to a qualified workforce—The PPP may be located near the headquarters of an industry partner, or in a region
- Access to equipment and facilities—University students and faculty may support research at the PPP, the PPP can benefit from existing Federal and federally supported labs/infrastructure as well as provide their own to academic, industry, and government partners
- Financial support of State and local governments—Governments may provide land, infrastructure, or other financial incentives to entice the PPP to locate in a specific place
- Proximity to entrepreneurial activities—Facilitates spin-offs and entrepreneurial activity within the PPP, as well as provides potential partners and customers for the PPP

In establishing its innovation ecosystem, a PPP may work with ecosystem connectors, which serve as an intermediary between stakeholders and sectors to bridge needs with capabilities. These services can be provided through non-profit partners, which serve as intermediaries across the network of organizations throughout an innovation ecosystem. In particular, these partners can be established through Partnership Intermediary Agreements (PIAs) used by Federal labs. PIAs were found to be effective mechanisms to engage the private sector and, in particular, bridge DoD's needs with capabilities available across non-traditional entities such as start-ups (Peña et al. 2020). In addition, Federal non-profit foundations also play a role in connecting an agency's mission with private and other public sector interests. Refer to Section G. Federal Authorities for further on PIAs and non-profit foundations.

2. Lessons Learned

Lesson Learned 25—PPPs based in locations with relevant pre-existing industry ties and strong academic capabilities may help facilitate effective partnering and staffing. Given the lack of a robust innovation ecosystem, seeking expertise not locally available can also support the PPPs goals.

A qualified, effective workforce can be important to a PPP's success. A PPP located in an innovation ecosystem with relevant industry ties and academic programs may find it easier to partner with the organizations best suited and capable in performing the R&D and staffing the PPP. In particular for PPPs that hire staff as researchers (refer to IMEC), if the PPP depends on expertise not available locally, it may need to incentivize the expert(s) to relocate or expend resources to physically access the infrastructure. In some PPPs, the most pertinent expertise may only be available internationally. Depending again on the goals of the PPP, for instance, if the PPP is focused on developing domestic capabilities, it may not be appropriate to include international partners.

Lesson Learned 26—Selecting a location where partners have access to pre-existing facilities and equipment, such as in a technological or manufacturing-oriented local ecosystem, may benefit both the PPP and the individual partners.

Academic, commercial, and government partners within an innovation ecosystem can both offer and take advantage of shared infrastructure and equipment. The development of an industry-oriented local ecosystem, such as a research park or industrial innovation hub, can facilitate connections between partners to work collaboratively and share infrastructure and equipment costs. However, sharing infrastructure and equipment may result in the need for varied approaches to accommodate differing IP positions (refer to Section D.

Intellectual Property). In particular, DoD-sponsored R&D in shared facilities may have additional security considerations (refer to Section E. Other Protections).

Lesson Learned 27—Participation of State and local governments can support the goals of a PPP through substantial financial contributions to the innovation ecosystem.

State and local governments attempting to build or strengthen their local innovation ecosystems may be incented to participate in a PPP to meet their economic development goals. This was the case, for example, with BRIDG and SEMATECH, and various other private sector engagement models, in which the State or local governments provided funding and other in-kind resources, such as real property or municipal services for new infrastructure development (Appendix N). State and local government goals may include diversifying their economy and attracting new industries, and consequently new jobs, to their local, State, or regional communities. In such cases, the State and local governments might offer broader economic incentives, such as tax incentives and loans, to establish or use already existing facilities or to incentivize private sector relocation to the local community. State and local government incentives in these cases are generally sufficiently large such that benefits exceed the expected costs and may prompt the private sector to develop or move to new locations. Refer to Section B. Funding Models for more on this topic and Appendix N for examples of State or local government participation in supporting Federal infrastructure.

Lesson Learned 28—A PPP in close proximity to entrepreneurial activities can support technology transfer and commercialization of new technologies.

Centers of economic activity near universities, Federal labs, and non-profits that serve as innovation ecosystem builders may enhance opportunities to spin off entrepreneurial endeavors enabled by the PPP and therefore expand the local innovation ecosystem. For example, IMEC is a renowned catalyst for spinoff companies, including those focused on maturing IMEC's own IP as well as commercial start-ups external to IMEC that show promise.

G. Federal Authorities

1. Description

Various Federal authorities have been used to establish and implement a PPP's activities. These authorities allow Federal agencies, including DoD, and other partners the ability to provide or exchange valuable resources necessary for the effective functioning of a PPP. Eight types of shared resources across the PPPs in this study included:

1. Coordination and Policy—includes opportunities for non-Federal organizations to engage with Federal agencies in coordination of science, technology, and investment priorities, programs, and policies
2. Data—includes information and requirements for maintaining operations of shared data management systems, and the like
3. Education—includes related educational materials, training, and tools, such as for entrepreneurship, and development of a pipeline of talent and skills for technology maturation, commercialization, and stimulating business
4. Funding—including for research, development, and technology maturation, and access to venture capital networks
5. Infrastructure—includes mechanisms for the use of laboratories, real property, and research space, including equipment and tools, to harness R&D capabilities
6. Research and Technology—includes intellectual property (patents), licensing, material transfers, collaborative research, and development
7. Small Business Services—includes incubation and accelerator services, access to information resources, among others
8. Workforce/Expertise—includes exchanging or collaborating with personnel and experts across Federal and non-Federal sectors, and access to entrepreneurs and technical experts as mentors

The eight PPP cases provided some information on experience and effectiveness when using certain contracts versus others. Drawing largely from Federal authorities used in broader private sector engagement models, the study team identified additional Federal authorities and mechanisms enabled by legislation that were of interest. Examples of notable Federal authorities, including mechanisms enabled by Federal legislation, and shared resources are provided in Table 2 and summarized below:

- Cooperative research and development agreements (CRADAs) (15 U.S.C. § 3710a)—formal research contracts between Federal and non-Federal organizations to advance technologies toward commercial applications. CRADA partners may be industry, universities, and nonprofits, but preference is given to small businesses to agree to manufacture resulting products in the United States.
- Education Partnerships (e.g., 10 U.S.C. § 2194)—agreements between educational institutions or other nonprofits and Federal laboratories. For example, defense laboratories can enter into partnerships with educational institutions (e.g., universities) and nonprofits whereby the laboratory can loan or gift equipment to

the institution, make laboratory personnel available to an educational institution to teach courses, and allow faculty and students at the institution to conduct research at the laboratory

- Enhanced Use Lease (e.g., 10 U.S.C § 2667)—leases of U.S. Government-owned property to private entities. Rent may be paid in the form of cash or in-kind services, such as renovations or other property improvements. Agencies with this authority have varied rules for property types that can be used for these leases and how the earned funding is used, among other restrictions.
- Gift authority (e.g., 10 USC § 2601)—agencies with gift authority are allowed to receive monetary or in-kind considerations, including real or personal property. The authorities have varied rules for the types of gifts received.
- Grants and cooperative agreements (31 U.S.C. §6305)—agreements to carry out "public purpose" benefits rather than acquire services for the U.S. Government. In practice, cooperative agreements allow for sharing and pooling of resources, such as cost-shares from partners.
- Other transaction authority (OTA) (e.g., 10 U.S.C. § 2371 and § 2371b)—flexible procurement instruments (other than contracts, cooperative agreements, and grants) used to support basic, applied, and advanced research projects.
- Partnership Intermediary Agreement (PIA) (15 U.S.C. § 3715 and 10 U.S.C. § 2368)—contract, agreement, memorandum of understanding, or other transactions between Federal laboratories and non-profit partnership intermediary to facilitate technology transfer through cooperative or joint activities between small businesses, institutions of higher education, and Federal laboratories.
- Prizes (15 U.S.C. § 3719, and 10 U.S.C. § 2374a for advanced technology achievements)—used to achieve a variety of goals, such as improving government service delivery, finding and highlighting innovative ideas, solving a specific problem, advancing scientific research, developing and demonstrating technology, informing and educating the public, engaging new people and communities, building capacity, and stimulating markets.
- Technology Investment Agreement (TIA) (10 U.S.C. § 2371, 32 CFR Part 37)—instrument used to stimulate or support R&D and demonstration programs by reducing barriers and promoting relationships with commercial firms. TIAs are similar to cooperative agreements with additional provisions on their use.
- National coordination units/consortia—offices or initiative that typically involve high national visibility R&D goals, with multiple Federal entities coordinating relevant resources and developing common strategic directions, including moonshots, to advance a technology or scientific or technical field.

- Non-profit foundations—stand-alone non-profits entities intended to foster collaboration among researchers across sectors and Federal agencies. Foundations can receive gifts (including from private companies) to support R&D, training activities, technology transfer, and public education materials.
- Personnel exchanges—focused on exchanging or receiving personnel from other sectors and hiring for short ‘tours of duty.’ Personnel exchange programs may be legislatively mandated and require Congress to provide the authority to exchange Federal employees with other sectors.
- Regional hubs—relatively large initiatives to select multiple sites across the Nation with the aim of building or leveraging regional R&D capabilities, for instance in academia or industry. Regional hubs may also have a national network component, in which capabilities can be coordinated across sites to provide nationally networked infrastructure and experts.
- Venture capital initiatives—investments programs or arms of Federal entities established internally or externally to an organization, such as through a non-profit or as part of an agency’s innovation unit. These programs invest seed funding or leverage funds from venture capital for promising companies to conduct R&D and have been combined as part of other R&D programs, such as the agency’s Small Business Innovation Research (SBIR) program.

Table 2. Examples of Federal Authorities and Mechanisms Used in PPPs

	Coord. and Policy	Data	Edu.	Funding	Infra.	Res. and Tech.	Small Bus. Serv.	Workforce/ Expertise
Cooperative research and development agreements (CRADAs) (15 U.S.C. § 3710a)		X		X	X	X		X
Education Partnerships (e.g., 10 U.S.C. § 2194)			X		X			X
Enhanced Use Lease (10 U.S.C § 2667)					X			
Gift authority (e.g., 10 U.S.C. § 2601)				X	X			
Grants and cooperative agreements (31 U.S.C. §6304–6305)				X		X		
Other transaction authority (10 U.S.C. § 2371 and § 2371b)						X		
Partnership Intermediary Agreement (PIA) (15 U.S.C. § 3715, 10 U.S.C. § 2368)	X					X	X	X
Prizes (15 U.S.C. § 3719, and 10 USC § 2374a for advanced technology achievements)		X		X		X	X	X
Technology Investment Agreement (TIA) (10 U.S.C. § 2371, 32 CFR Part 37)				X		X		
National coordination units/consortia[1]	X	X			X	X		
Non-profit foundation[2]			X	X		X		X
Personnel Exchanges[3]				X				X
Regional hubs[4]	X		X		X	X		X
Venture capital initiatives[5]				X		X	X	

[1] e.g., Quantum Economic Development Consortium (QEDC) established under the National Quantum Initiative Act, P.L. 115-368—DEC 21, 2018.

[2] e.g., The Foundation for the NIH established under 42 U.S.C. § 290b.

[3] e.g., Cyber and Information Technology Exchange Program established in Section 1106 of the NDAA for FY 2014.

[4] e.g., Manufacturing USA Institutes established under the Network for Manufacturing Revitalize American Manufacturing and Innovation Act of 2014.

[5] e.g., Army Venture Capital Initiative created from P.L. 107- 117 Section 8150—JAN 10, 2002.

2. Lessons Learned

Lesson Learned 29—A variety of Federal authorities used to share resources, including funds to establish and implement the activities of PPPs. However, certain authorities may be more effective than others or best suited for certain PPP structures and goals.

The U.S. Government has numerous vehicles for funding and providing other resources PPPs, including contracts, grants, and cooperative agreements. In particular, the use of cooperative agreements and OTAs are observed to provide PPPs and DoD stakeholders with agility on the scope of work. Observations on the use of cooperative agreements compared with TIAs demonstrated cooperative agreements have greater flexibility, especially for early-stage R&D involving uncertainty and in which specific work has yet to be clearly defined (see examples of AIM and NextFlex). Cooperative agreements have allowed for Federal partners to identify a broad scope when first establishing the agreement and later identifying specific projects under that umbrella.

For infrastructure, the use of Enhanced Use Leases enables the U.S. Government to leverage its real property assets, such as land, to co-develop new or modernize existing infrastructure through private sector financing (NIST 2019).

Strategic planning in the use of Federal authorities can support combining and stacking authorities that maximize flexibilities to share and exchange resources. For example, Federal agencies can use a PIA to develop an agreement with a non-profit that supports a variety of PPP activities and R&D goals, in turn, using other authorities. In one example, the partnership intermediary under a PIA supported the implementation of prizes to obtain ideas and designs related to a technical goal, using this process to inform DoD's needs for advanced hardware and software prototypes later supported through OTAs (Peña et al. 2020).

Lesson Learned 30—National coordination units and consortia provide centralization and visibility as well as garner trust and support for the Federal Government's coordination role in PPPs.

National coordination units, for instance coordination offices or consortia, have been established around specific technology domains, such as nanotechnology and quantum sciences (see Appendix N). While the structure of these units may vary—Federal-only or multi-sector, with participation from industry partners—they serve to provide national visibility, accountability, and coordination of resources that can support the PPPs goals.

H. Evaluation and Success Measures

1. Description

Evaluation and success measures are aligned with clear goals articulated at the early stage planning process. During the PPP, rigorous and regular program-based evaluations allow analysis of the success of goals and outcomes to be measured (NRC 2003). A variety of metrics can be used to measure the outcomes of PPPs. Input metrics describe the resources available to the PPP and may be related to finances, personnel, and infrastructure. Activity metrics are used to measure actions taken and may include R&D activities and outreach efforts. Output measurements describe effects directly stemming from the PPP's activities and may include publications, patents, and licenses to patents. Outcome measures describe long-term broader impacts, such as economic growth and social benefits, which are influenced by a large number of other factors not directly attributed solely to the PPP's activities. For all these metrics, benefits may depend on the partner's perspective, for example differing partner's business models and expected returns from their participation.

Metrics can either be quantitative or qualitative, and may be reliant on raw counts of parameters, ratios of PPP inputs to outputs (efficiency metrics), comparisons of program outputs to stated goals (effectiveness metrics), future projections (leading), and the past (lagging) (Hughes et al. 2011).

Some of the principal ways that evaluation and success measures contribute to PPPs include:

- Strategic—including tracking progress on goal achievements, calculating returns on investments, informing stakeholders (including the public) about how their resources were used, and justifying contributions from government, commercial, and not-for-profit partners and stakeholders
- Program and Project-Level—including evaluating the effectiveness and efficiency of the R&D accomplished by the PPP's programs and activities and highlighting successes and achievements
- Evolution and Growth—including attracting additional partners and additional resources from partners, and validating and improving the PPP value proposition.

Examples of measures and metrics used across PPPs in this study categorized as input, outputs, and outcomes measures are provided in Table 3.

Table 3. Examples of PPP Measures and Metrics

Type	Measures and Metrics
Input	Number of partners and signed agreements across sectors
	Percentage of small- and medium-sized companies as members
	Total financial contributions and revenues
	Share of government and external funding sources
	Staffing
Activity	Cross-sector R&D collaborations
	Prototyping, designs fabricated and process runs
	Developing infrastructure
	Education/training engagements—number of student interactions
Output	Scientific productivity and quality—peer-reviewed publications, productivity and quality of active R&D projects, projects meeting key technical objectives
	Partners' greater awareness—of opportunities for advanced R&D and applications of new technologies, showstoppers or mitigation of high risks
	Technology transfer—patents and filings, presentations, commercialization of technologies via partners or start-ups, licenses and licensing revenue
	Policy-making/standards development
Outcome	Leveraged investments
	Growth of domestic capabilities—manufacturing with domestic equipment
	Growth of workforce and skills—number of student hires into member companies
	Ecosystem development—start-ups and spin-offs created, jobs created
	Fiscal return (e.g., taxes on new companies) on investment to the governments and the economy
	Achievement of social goals

2. Lessons Learned

Lesson Learned 31—Establishing, collecting, maintaining, and using performance-oriented success measures providing insights to measure effectiveness of current and future PPP operations at the project and enterprise levels.

Analyses of performance data drives changes to goals, governance, operations, among others. Failure to make changes based on the analysis of performance may have detrimental effects on the PPP. For example, SEMATECH did not revise its mission after its initial goals were achieved around the 1990s. As a result, justifying its value proposition to members became difficult. In some PPPs goals are re-evaluated every 5 years or more often as part of strategic planning efforts. Evaluation and success measures can represent targets, for example, for process or operational efficiencies as well as technology benchmarks. Such metrics can help prioritize the PPP's strategic research direction.

In some PPPs, performance measures are collected and analyzed by third parties to provide independent analysis of the PPP's outcomes. For example, a third party evaluated NextFlex's achievements in technology advancement, workforce development, and ecosystem development. Similarly, independent assessments have been made of IMEC's accomplishments in R&D excellence, economic returns, and partner arrangements every 5 years to inform the Flemish Government's renewal of its funding. PPPs can internally self-assess and measure their progress and supplement these activities with independent, third-party analysis.

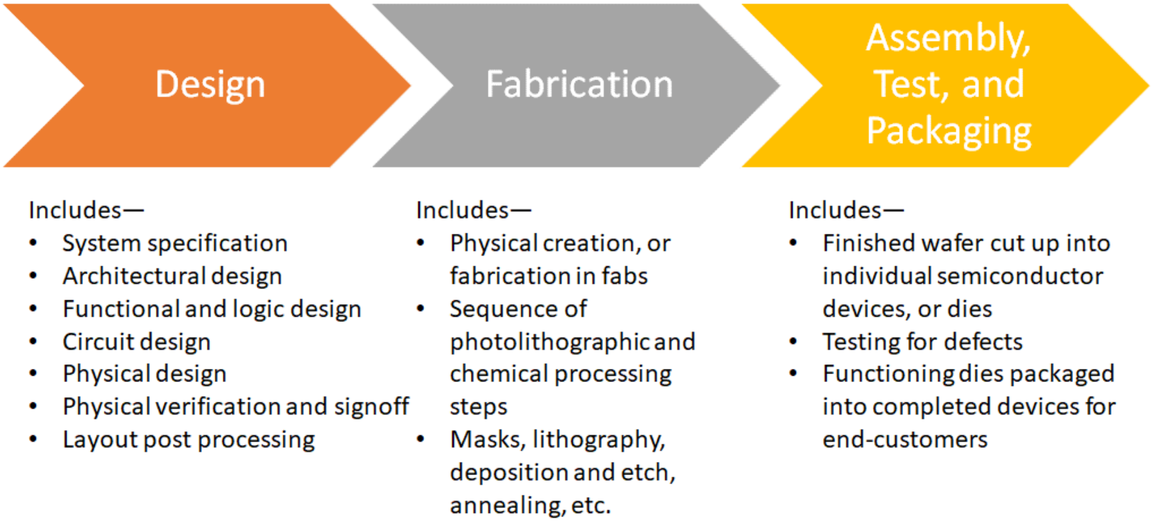
The scale and complexity of the PPP goals may make developing meaningful metrics a challenge. Even when a meaningful metric is defined, collecting relevant data may not be easy. In addition, outcome measures, such as economic or broader societal impacts, may not be readily obtainable and additional efforts may be necessary to collect relevant information about these measures.

Lesson Learned 32—Collecting and highlighting successes builds awareness of the PPP's value proposition and, thereby, helps attract more partners and resources to pursue the PPP's goals.

One output metric is both useful and common across all PPPs—the development of a portfolio of success stories. Many mechanisms may be used to disseminate these success stories, e.g., press releases, journal articles, and public speaking engagements. Such dissemination activities not only make members aware of the PPP's benefits, they also publicize successes to a broader community. As a result, new members may be attracted to join the PPP, additional resources generated, and existing partners better able to justify their participation and resource contributions. One challenge to be aware of is the possible generation of negative publicity in response to some of the PPP's activities. Non-optimal decisions may result as a response to negative publicity affecting the PPP's future viability (see example of SEMATECH).

4. Options for Establishing a New Microelectronics PPP

Based on our study findings, including analysis of the eight PPP case studies and lessons learned, the study team identified several options that DARPA could consider as it pursues goals for establishing a new microelectronics PPP. DARPA did not provide the study team with specific technical goals for the PPP beyond addressing prototyping. As such, the study team formulated three major goals informed from mapping various near- and long-term goals associated with the eight PPP cases to guide the analysis of options (Appendix O). The major goals generally focus on R&D, prototyping, and technology maturation cutting across the process lifecycle for fabricating semiconductor and microelectronic devices



Includes—
- System specification
- Architectural design
- Functional and logic design
- Circuit design
- Physical design
- Physical verification and signoff
- Layout post processing

Includes—
- Physical creation, or fabrication in fabs
- Sequence of photolithographic and chemical processing steps
- Masks, lithography, deposition and etch, annealing, etc.

Includes—
- Finished wafer cut up into individual semiconductor devices, or dies
- Testing for defects
- Functioning dies packaged into completed devices for end-customers

Source: Authors, based on Yinug (2015), Figure 2.

Figure 2. Simplified Semiconductor Process Lifecycle

The three major goals are—

1. **Enabling Early-Stage R&D and Prototyping in Design**—microelectronics design is considered a relative strength in the United States, including the most R&D-intensive activities, such as electronic design automation, chip design, and advanced manufacturing equipment (Varas et al. 2021), with capabilities across Federal labs, academia, and industry, and, as such, distinct considerations to strengthen existing capabilities should guide the structure of a new PPP;
2. **Enabling Early-Stage R&D and Prototyping in Manufacturing and Fabrication**—microelectronics manufacturing and fabrication, including assembly, test, and packaging, are considered relative weaknesses at least in terms of market share and capacity in the United States, with capabilities relied upon by entities located in East Asia and across the world, and, as such, distinct considerations to develop this capability should guide the structure of a new PPP;
3. **Maturing Technology through Transfer and Transition**—among the PPP cases, transfer and transition were not primary focus areas; however, a strength of the United States is its entrepreneurial ecosystems and market creation capabilities, and, as such, distinct considerations to leverage PPP activities to guide technologies through technical and commercialization challenges should guide the structure of a new PPP.

While not reflective of all the goals reviewed across the PPP cases, these three major goals, depending on the structure, can provide necessary incentives for industry participation. Considerations for ensuring DoD's access to secure devices can be embedded within all these goals.[7]

In addition, these goals are not mutually exclusive, meaning a new PPP in practice could include one or more goals as part of its activities. However, the study team found that distinct options and considerations arise when considering a particular focus on one of these goals versus another.

The detailed options describe considerations focused on the three major goals and detailed considerations of the possible models to structure a PPP including governance, funding, operations, IP, security, innovation ecosystems, Federal authorities, and evaluation and success measures. A summary of the scope of the PPP activities for each of these goals and options are provided in Figure 3 and Table 4.

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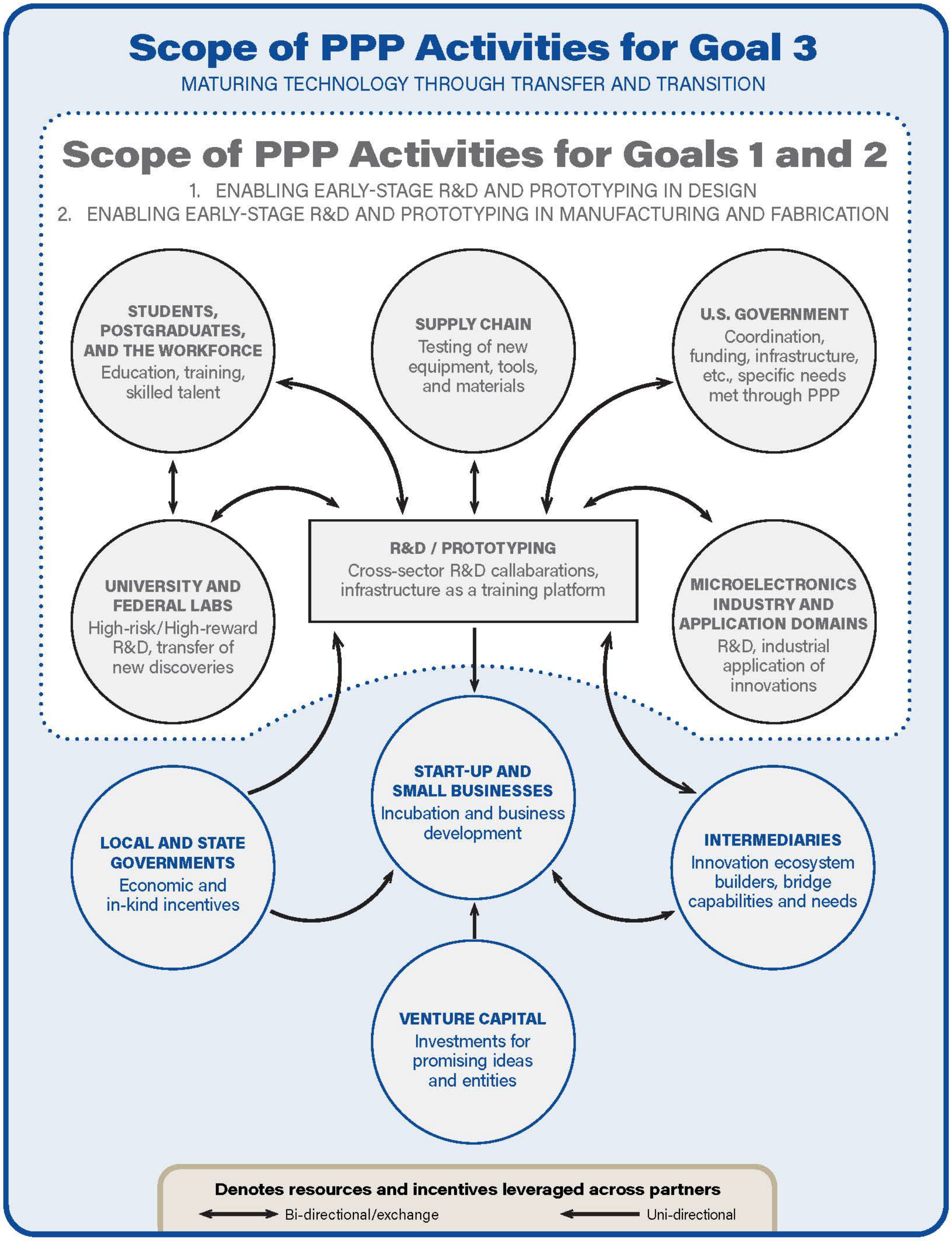
[7] This study's focus was on PPPs with broader goals beyond meeting DoD-specific technical needs. For instance, the study did not focus on extracting lessons learned from federally supported PPPs operating classified-only R&D.



Scope of PPP Activities for Goal 3

MATURING TECHNOLOGY THROUGH TRANSFER AND TRANSITION

Scope of PPP Activities for Goals 1 and 2

1. ENABLING EARLY-STAGE R&D AND PROTOTYPING IN DESIGN
2. ENABLING EARLY-STAGE R&D AND PROTOTYPING IN MANUFACTURING AND FABRICATION

STUDENTS, POSTGRADUATES, AND THE WORKFORCE
Education, training, skilled talent

SUPPLY CHAIN
Testing of new equipment, tools, and materials

U.S. GOVERNMENT
Coordination, funding, infrastructure, etc., specific needs met through PPP

UNIVERSITY AND FEDERAL LABS
High-risk/High-reward R&D, transfer of new discoveries

R&D / PROTOTYPING
Cross-sector R&D callabarations, infrastructure as a training platform

MICROELECTRONICS INDUSTRY AND APPLICATION DOMAINS
R&D, industrial application of innovations

LOCAL AND STATE GOVERNMENTS
Economic and in-kind incentives

START-UP AND SMALL BUSINESSES
Incubation and business development

INTERMEDIARIES
Innovation ecosystem builders, bridge capabilities and needs

VENTURE CAPITAL
Investments for promising ideas and entities

Denotes resources and incentives leveraged across partners
⟷ Bi-directional/exchange
← Uni-directional

Figure 3. Scope of PPP Activities for Three Goals, including Resources and Incentives Leveraged across Partners

Table 4. Summary of PPP Options Across Three Major Goals

Options	Enabling Early-Stage R&D and Prototyping		Maturing Technology Through Transfer and Transition
	In Design	In Manufacturing/Fabrication	
Governance	Strong DARPA and academia leadership Executive council with autonomy Research strategy, e.g., a national roadmap	Strong DARPA and industry leadership Consensus voting/non-voting model Research strategy, joint programs to accommodate differing partner interests	All partners with potential leadership roles Hybrid voting or consensus-based model
Funding	Long-term DARPA/Federal funding Interagency/national coordination units, establishment of sister Federal programs Supplements from private sector match	Phased down DARPA/USG funding, potential for largely or completely self-sustainable Growing private sector match over time	Increasing role of seed funding and venture funding, cost-shared programs requiring private financing Continued government-industry funding
Operations Accomplishing Work/R&D	Pre-competitive-early-stage R&D Cross-sector collaborative R&D Access to existing infrastructure Staffing from partners, academia emphasis	Leans towards market applications Leans towards bi-lateral, small teams Access new and existing infrastructure Staffing from industry partners	Hybrid, including early stage transitioned to later stage, dedicated staffing of fab specialists, and staff with IP valuation and technology transfer skills
Workforce Activities	Education and training tied to academic programs (community college, 2–4 year)	Workforce training, using infrastructure as training platforms	Hybrid, including entrepreneurial R&D training
Start-Up Services	None or minimal		Incubation services, seed funding, venture capital programs
IP	Flexible models, including shared open, shared limited, and exclusive IP, such as for propriety R&D; PPP co-ownership of IP		
Other Protections	Academic and industry standards; security firewalls Emphasis on DoD's role in validation and verification		Hybrid, including an emphasis on ITAR and export control
Innovation Ecosystems	Open campuses, networks of U.S. domestic capabilities	New innovation hubs, supply chains, international allies as strategic partners	State and local governments, non-profit foundations, Federal innovation programs
Federal Authorities	Grants, Cooperative Agreements, Prizes, OTAs	Grants, Cooperative Agreements, Prizes, OTAs, EUL	Hybrid, including CRADAs, PIAs, education partnerships
Evaluation and Success Measures	Scientific and technical excellence; enhanced security of devices; and strengthened domestic design and manufacturing capabilities		Hybrid, including strengthened innovation ecosystems, U.S. economic and societal impacts, high-risk culture/fail fast

A. Governance

The literature review provided some insights on U.S. Government and other partners' roles; however, the study team did not find one type of governance structure was more valuable than another. Both the executive-leadership and member-voting models have merit. A factor in their effectiveness and success depends on leaders who are part of the governing bodies of either model. The selection of partners, in particular the individuals placed in leadership positions, is a primary consideration for a new PPP. Interviewees stated these leaders must be visionaries and highly-respected in their fields to help facilitate clearly articulated common goals and garner trust among potentially competing partners.

Another governance consideration is the leading organization that anchors the PPP, which could be an academic institution, industry-based, or a non-profit serving as a neutral broker operating distinctly differently than other sectors. Generally, a non-profit organization has managed the relationships across partners and served as an intermediary to align their interests. Non-profits provide unique opportunities within PPPs compared to government and industry due to their operational flexibility and mission focus on economic growth. They also have an advocacy role in presenting information for policymakers and industry partners.

For the first goal of enabling early-stage R&D and prototyping in design, a new PPP could be structured with strong representation from DARPA to help guide R&D beyond the status quo. DARPA's leadership could give a voice to U.S. Government interests and ensure appropriate oversight of the PPP's activities. Strong leadership from academia as part of the PPP's governing structure could further align high-risk R&D with potential industry applications. An executive council could help meet this goal to provide the PPP's leadership with sufficient autonomy in decision making.

According to interviewees, the microelectronics industry's technical roadmap for the next 10+ years is uncertain. Consequently, an autonomous executive council working with a technical advisory team may be worthwhile to ensure that new ideas are carefully considered and adjudicated when developing new technology roadmaps. In addition, the development of a new *national* roadmap outlining possible early-stage R&D strategies for the PPP could be the basis for aligning public, academic, and private sector interests.

For the second goal of enabling early-stage R&D and prototyping in manufacturing and fabrication, industry plays a critical function. It may be necessary to build out new capabilities and infrastructure in order to meet this goal, and a decision-making process should be established that reflects the members relative investments in the PPP. This model could reflect fair and flexible membership fees, for instance, based on each partner's total revenue, and accommodate in-kind contributions, such as equipment, tools, and materials, in particular for smaller businesses that may not be able to meet monetary requirements for participation. The membership fee structure should support building on existing capabilities from a diverse set of national and potentially international partners.

For the third goal of maturing technologies through transfer and transition, hybrid approaches may be necessary to maximize flexibilities given uncertainties in future applications, markets, and technologies. An executive leadership council with voting-member models, e.g., applied for joint transfer or transition programs with high industry risks, could be implemented at appropriate stages of a technology's development and to anticipate the PPP's evolution.

B. Funding

A new PPP should be funded in consort with its goals. Sustained and continued resources are needed given the potential long-term nature of all three goals. Many PPPs strive for self-sufficiency, some even proceeding without U.S. Government funding. However, depending on the scale of the effort, and continued needs for early-stage R&D and prototyping even as new technical, transfer, and transition goals are accomplished, this effort should adopt time horizons of at least 10 to 20 years. For infrastructure investments, this time focus should align with an infrastructure's lifecycle, which can be up to 40+ years, and supporting modernization throughout that period. Achieving zero government sponsorship, whether directly for the PPP or indirectly in support of PPP partners and broader R&D initiatives, may not be feasible. Ultimately, the partners should determine the longevity of a PPP. The value the PPP provides, and the prospective access to resources, will ultimately influence those decisions.

Long-term U.S. Government funding, such as from DARPA as well as other agencies with aligned interests, is necessary. Financial models may require cost-sharing from industry partners; however, given the scope of the research, the majority of funding to attract industry partners initially may need to come from DARPA and other U.S. Government partners. One means of achieving stability and long-term planning is to require time commitments for partner funding, e.g., of at least 2 years or longer.

For the first goal, early-stage R&D and prototyping in design, Federal funding could be further supported by creating coordinated, cross-agency sister programs to accomplish the R&D activities under the PPP. NSF, DOC/NIST and other science agencies have the potential to provide varying-sized awards, including smaller funding for R&D projects at the principal investigator level and larger awards for research centers, equipment, and tools. Collectively, Federal sister programs could leverage and advance the researcher base and first adopters in specific directions the PPP outlines.[8] As demonstrated by the PPP cases, this support may be particularly important in the business model for new infrastructure.

For the second goal, early-stage R&D and prototyping for manufacturing and fabrication may necessitate large capital investments to build or modernize existing infrastructure. This goal aligns with the potential to provide new services and benefit the competitive advantage of partner companies. As such, a PPP providing these services could capitalize on its capabilities and grow the private sector's match over time.

For the third goal, technology transfer and transition activities may necessitate an increasing role for seed and venture funding programs to attract a range of partners, including start-ups and larger companies. Tiered funding programs, in which higher levels of funding are based on prior successes, could also support transfer and transition as technology and business development milestones are met.

Membership fees should be flexible and affordable to align with business models of partner companies. Fees that are too high can drive away partners, in particular smaller businesses. These entities are a necessary component to achieve the transfer and transition goal. Considerations for attracting venture and other private financing for these efforts can include cost-sharing programs that require R&D performers to seek external matching funds. Transfer and transition programs may also provide another funding stream for the PPP; albeit, this portion should be expected to be smaller compared with the PPP's overall funding.

C. Operations

1. Accomplishing Work/R&D

A new PPP could focus on a wide range of technology readiness levels (TRL) or manufacturing readiness levels (MRL), and have specific programs based on more narrowly defined TRL/MRLs. For the first goal, pre-competitive R&D and prototyping and cross-sector collaborative R&D provides a way for industry to access and strengthen their own design capabilities. A PPP could coordinate and provide access to existing infrastructure capabilities, such as through a broker model, to support project-level needs. As demonstrated by the PPPs, a broker model can be successful in pooling available capabilities for common needs. Existing prototyping infrastructure could be supported, in particular, through federally owned and federally funded infrastructure, equipment, and tools across academic institutions. The U.S. Government can also leverage its existing network of R&D programs and coordinate existing infrastructure capabilities supported by

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[8] The creation of sister programs aligns with NDAA for FY21, USICA, and other Congressional proposals.

DoD, the Department of Energy, in particular its National Labs, DOC/NIST, NSF, and industry-university centers. However, these efforts will likely require dedicated staff to facilitate integration of the network's capabilities for PPP activities. Dedicated staffing could be provided by the partners, including staff from academic institutions and federally supported labs, to facilitate exchange of knowledge from academia to industry.

For the second goal, the nature of the R&D and prototyping in manufacturing and fabrication may align with higher TRL/MRL in which specific market applications may be identified as focus areas. This scenario may necessitate a PPP offer prototyping services as part of its overall R&D efforts. As such, a research strategy or roadmap should account for potential markets of focus for R&D projects. Project teams may be comprised of small bilateral academic-industry or industry-industry collaborative teams given specific applications may differ across partners. In this scenario, agreement on IP terms will likely be necessary before performing the R&D. Similar to the first goal, access to existing national research infrastructure could be leveraged, in particular capabilities through the Manufacturing USA initiative, such as the Manufacturing Institutes and the Manufacturing Extension Partnership, for additional expertise and infrastructure. The development of new infrastructure may also be necessary to build on limited domestic infrastructure capabilities used for prototyping in fabrication and later-stage IC processes. Staffing could be supported by requiring industry partners to dedicate full-time researchers on collaborative teams.

For the third goal, the transfer and transition of technologies can be supported through activities that bridge early to later-stage R&D and span across the IC design lifecycle. This scenario may require dedicated staffing to guide early-stage R&D discoveries and identify opportunities and partner interests in later-stage R&D and prototyping. In particular, dedicated staffing with skills and know-how in fabrication, as well as staff with skills in IP valuation and technology transfer strategies, can be critical to ensure partners receive adequate and fair value from these activities.

2. Workforce Activities

Workforce activities are an essential part of developing the next generation of talent to perform the R&D in government, academic, and industry settings. Past and ongoing PPPs have demonstrated these efforts can be supported indirectly, or through concerted formalized programs, such as development of internships, fellowship, and training programs. For the first goal, given the strengths in design capabilities, education and training programs could be developed with ties to existing academic programs, such as related certifications at community colleges and other 2- or 4-year degree-granting programs. For the second goal, a PPP could create a formalized workforce training program, in particular using new and existing infrastructure as training platforms to develop the future workforce's hands-on skills.

For the third goal, entrepreneurial R&D training could be developed for researchers associated with the PPP's R&D, for instance focused on those from academia, researchers staffing the PPP, and more broadly promising start-ups and entrepreneurs. Various Federal models target federally funded researchers across NSF and DOE, among others. Workforce activities aligned with the third goal could also provide facilitated access to new and existing infrastructure and expertise brought together by the PPP. Implementation considerations include how and to what extent these activities are funded and opportunities to leverage other Federal funding opportunities potentially across Federal agencies. Supporting mobility of the workforce, such as through dual-appointments of PPP staff and researchers as academic faculty and entrepreneurs-in-residence programs, could also support transfer of knowledge across sectors.

3. Start-Up Services

Start-up services geared toward supporting entrepreneurship and business development are not necessary components to achieve the first two goals focused on early-stage R&D and prototyping. However, for the third goal of maturing technologies through transfer and transition, start-up services, such as activities such as establishing incubation or accelerator programs with seed funding, equity financing options, independent R&D funding, and venture capital matching, can enable acceleration of transitioning a technology to market.

D. Intellectual Property

Relevant to all goals, IP arrangements should be flexible and clearly established at the outset of the PPP or R&D activities. Flexibility is necessary to accommodate the differing interests and value derived across all potential partners, government, academia, and small, medium, and large businesses alike. All models—shared open (non-exclusive), shared limited to select partners, and exclusive or proprietary IP—should be provided as options to enable a diverse range of partners participating in R&D and prototyping activities. These arrangements could be streamlined by having template IP agreements as a standard provided to all partners to communicate the default preferences for the PPP's activities. However, specific projects may require bilateral negotiations with industry partners.

A new PPP, structured with research staff, could also find it valuable to co-own IP. For instance, researchers in collaborative, cross-sector R&D team could share ownership of newly generated IP from projects. In this arrangement, the PPP's co-owned IP could be shared under the PPP's R&D programs across relevant partners, serving as the foundation for incentivizing new partners to join the PPP and providing value to existing partners. In this way, newly generated IP is part of the business model for the PPP. In addition, a PPP could strategically manage its owned IP to promote transfer, transition, and the formation of start-ups for specific technologies and focus areas, in particular for dual use technologies. Dedicated staff with commercialization and transfer know-how, not limited to patent lawyers and IP valuation experts, would be necessary components of this activity.

E. Other Protections

Several dimensions of protection are relevant in structuring a new PPP. PPPs may target establishment of secure technology supply chains; development of new technology solutions to meet a mission-critical DoD and national security need; or improvements in security-driven design and fabrication of critical technologies and technical advances. For all goals, a new PPP could rely on academic and industry standards and procedures for ensuring sensitive or propriety information is secure and firewalled from vulnerabilities to access and dissemination. Additional security procedures may be warranted for classified or government-sensitive information for a portion of the PPP's R&D activities specific to DoD and other Federal partner needs. The study team acknowledges classified environments will likely not be the entirety of a PPP, but could be a portion of it. The PPP could create silos of access and R&D workspace, for example, within prototyping infrastructure, which are siphoned off from the rest of the R&D and prototyping activities to create efficiencies for non-sensitive work. Accommodating classified work and work relevant to the defense industrial base, in particular, may require special considerations for researcher access, including foreign researchers, and obtaining appropriate security clearances.

For all goals, DoD has unique interests and specialized capabilities to advance validation and verification for secure devices, addressing concerns from both the public and private sectors. Regarding counterfeit products, typically affecting higher nodes, industry has similar concerns as DoD and these common interests could be used to align R&D efforts and resources to advance testing of these products.

Opportunities are also available to integrate DoD's defense posture in the PPP's activities through appropriate international coordination of R&D and prototyping, in particular as the U.S. domestic industry builds its capacity for manufacturing and fabrication. Only three companies, one domestic, Intel, and two foreign, Samsung and TSMC, have existing capabilities in lower nodes. Strategic international collaborations to ensure access to capabilities and infrastructure as the U.S. develops its own capabilities may be warranted. This last point may be especially important for the third goal to mature technologies through transfer and transition, including applications in foreign markets. Compliance with ITAR and export control regulations in these contexts may require standard assurance procedures to be developed, in coordination with DARPA, DoD, and other stakeholders. Dual-use discoveries and technologies could also be advanced through these efforts.

F. Innovation Ecosystems

A new PPP could target efforts to strengthen already developed innovation ecosystems and strategically build new innovation ecosystems in areas with promising capabilities, including expertise, start-ups, and new markets. For the first goal, a new PPP could establish a centralized network leveraging existing domestic design capabilities, thereby increasing access to relevant infrastructure and experts for the research community. Akin to establishment of open research campuses across Federal labs, these efforts could enable the necessary conditions and platforms to facilitate connections and synergies among existing and potential new partners.

For the second goal, companies supporting the microelectronics supply chain will be valuable partners, as they can provide new materials and tools, among other resources, to integrate into advanced manufacturing and fabrication processes. International allies may also be necessary as strategic partners, for example, to accomplish specific technical goals or access unique infrastructure relevant to relevant R&D programs the PPP supports. Participation of international partners can also facilitate identification of global market opportunities, which for multinationals, may be a necessary function of their business model.

Local and State governments could be key players in providing economic incentives and further attracting new partners to the PPP. These contributions are relevant to all goals. For the second goal, in the case of new infrastructure, this support could be especially valuable in incenting relocation of industries to create one or more hubs of centralized capabilities to bolster connections across partners, akin to research or industrial parks. Regarding new infrastructure, open solicitations for PPPs and their site selection, in which partners submit proposals involving local or State governments as partners, can be useful to maximize cost sharing. In addition, local tax incentives and financing, such as loans, can provide additional incentives for private sector partners. In particular, for the third goal in facilitating transfer and transition, local and State government contributions could directly support localized economic development goals and returns.

Other options to engage private sector partners and leverage their resources for the PPP’s goals include establishment of non-profit foundations to provide additional flexibilities in receiving private sector funding and potentially facilitate funding for focused efforts on DoD’s mission-specific needs and commercialization of Federal IP for dual use technologies. A nonprofit foundation could also focus on complementary engagement across the defense industrial base or ensuring opportunities reach rural and under-represented communities. In addition, a variety of complementary efforts can strengthen the defense industrial base and DoD research enterprise. DARPA could ensure such efforts engage and leverage these and other relevant innovation ecosystem programs, for instance through the U.S. Small Business Administration, DOC/NIST, and others.

G. Federal Authorities

DARPA, DoD, and other Federal agencies involved in a new PPP should take advantage of the full breadth of Federal authorities available across partner agencies. Federal authorities that are especially flexible in supporting R&D and prototyping activities related to all goals include grants, cooperative agreements, OTAs, and prizes. Strategic planning in the use of Federal authorities to implement the PPP's goals could reveal ways to optimize their use by stacking or combining authorities for associated activities. For instance, regarding the development of new infrastructure aligned with the second goal, EULs are successful approaches to develop real property such as research parks through Federal contributions and private financing. Grants, cooperative agreements, and OTAs could follow to support the R&D and prototyping activities supported by new infrastructure once developed. Prizes are increasingly used across the Federal Government. They could be designed to meet initial requirements necessary to secure follow-on funding through other contracts, such as OTAs.

Related to the third goal to facilitate transfer and transition, PIAs and prizes could be used to engage with ecosystem connectors, entrepreneurs, and start-ups to strengthen local, State, and regional innovation ecosystems. These mechanisms can be used to target entities that may not traditionally be associated with Federal R&D activities or have knowledge of collaboration opportunities but that may add value as partners. Education partnerships may also provide additional ways to engage with academic entities, in particular to achieve related workforce activities.

H. Evaluation and Success Measures

Performance management and measurement are core elements to the evaluation of the success and outcomes of PPPs. A new PPP should establish success measures based on the expected goals to be achieved through its activities. Continuous learning, for instance to guide governance decisions and resource allocations can be facilitated through robust tracking and management of key performance indicators related to organizational and programmatic objectives. In addition, transparency of evaluation and success measures can be useful in attracting new partners and growing the PPP's activities.

For all goals, relevant measures could include scientific and technical excellence, enhanced security of or access to secure devices; and strengthened domestic capabilities for both design and manufacturing. For the third goal, a focus on transfer and transition could include performance measures related to the development of broader innovation ecosystems, including the defense industrial base, and catalyzing economic and societal impacts from bridging technologies to applications and markets.

The extent of financial sustainability, e.g., portion of non-U.S. Government funding, may be an additional performance measure to consider. However, whether a new PPP should strive for complete or partial sustainability in this context should be based on the PPP's value position to its partners, the viability of its business model, and its goals.

The development of performance measures must also not hamper high-risk activities, as failures serve as validation and learning with new knowledge facilitating further advancement of technologies in follow-on activities. DARPA has a strong culture of failing fast and pivoting a project's technical milestones as necessary based on new information. A new PPP could incorporate other models to facilitate a fail fast culture including the development of competitive R&D teams and tournaments, similar to prizes, which could set R&D teams in competition with one another to achieve a technical target. Other models could include requirements for interdisciplinary teams to leverage creativity and innovations across disciplines and their applications to future technologies.

Federal oversight, including decisions for renewal or sun-setting of funding, should be based on analysis of the outcomes of the PPP. Evaluation of successes could be informed by assessments conducted internally and by independent entities to ensure objectivity in the analysis. Oversight and renewal decisions could be conducted every 5 years, and more frequently depending on Federal contributions to specific PPP R&D programmatic or project-level activities.

5. Conclusions

Public-private partnerships (PPPs) can play an important role in fostering U.S. competitiveness by enhancing Federal mission-related R&D and accelerating the development of new technologies from conceptualization to the market. Through the in-depth review of 8 PPP through case studies, the study team identified 32 lessons learned from experiences in structuring past and ongoing PPPs.

The study team identified three major goals for DARPA's consideration as they deliberate on efforts to support a new microelectronics PPP—enabling early-stage R&D and prototyping in design, in manufacturing and fabrication, and maturing technology through transfer and transition. Distinct structural considerations in the design of the PPP, including models for governance, funding, operations, IP, security, innovation ecosystems, use of Federal authorities, and evaluation, arise when considering the focus of a new PPP on any one or more of these three goals.

There are considerable opportunities to develop a new microelectronics PPP that can address increasing concerns for security and the nation's economic competitiveness. In particular, recent legislation and new Congressional proposals have raised the U.S. Government's stake in future investments to advance R&D in this industry. DARPA's role could be part of a broader whole-of-government effort to establish a PPP at a national scale that align public, academic, and private sector interests and resources towards a critical national priority in line with recent legislative mandates and focused on one or a combination of the three main goals.

Appendix A.
Recent Laws Related to a Microelectronics PPP

STPI reviewed the National Defense Authorization Act (NDAA) for FY21 and identified sections relevant to microelectronics R&D and partnerships. STPI identified the entities that are part of the mandate and summarized the section (Table A-1).

Table A-1. Sections of the NDAA for FY21 Pertinent to Microelectronics R&D and Partnerships

Citation	Subject of the Mandate	Other Involved Entities	Summary
SEC. 276, Microelectronics and National Security, (14)	The DoD (including DARPA)	None	A plan for increasing commercialization of intellectual property developed by the DoD for commercial microelectronics research and development
SEC. 276, Microelectronics and National Security, (15)	The DoD (including DARPA)	None	An assessment of the feasibility, usefulness, and cost of developing a national laboratory for microelectronics R&D and an incubator to support early-stage microelectronics startups
SEC. 276, Microelectronics and National Security, (16)	The DoD (including DARPA)	None	Develop multiple models of public-private partnerships and a semiconductor manufacturing corporation
SEC. 9902, (a) Financial Assistance Program, (1) In General	Department of Commerce	None	The DoC will establish a Federal assistance program to incentivize investment in microelectronics infrastructure

Citation	Subject of the Mandate	Other Involved Entities	Summary
SEC. 9903, (a) Department of Defense Efforts, (1) In General	The Secretary of Defense	Secretary of Commerce, the Secretary of Energy, the Secretary of Homeland Security, and the Director of National Intelligence	The DoD will establish a public-private partnership for the development of secure microelectronics
SEC. 9903, (a) Department of Defense Efforts, (2) Risk Mitigation	A participant in a consortium	National Security Advisor and the Secretary of Defense	Defines what entities may be considered to participate in a consortium and risk mitigation strategies expected
SEC. 9903, (a) Department of Defense Efforts, (3) National Security Concerns	The Secretary of Defense and the Director of National Intelligence	Participants for each consortium/partnership; Defense Counterintelligence and Security Agency; Office of the Director of National Intelligence	Defines how consortia participants should be evaluated on the basis of national security concerns
SEC. 9903, (a) Department of Defense Efforts, (4) Nontraditional Defense Contractors and Commercial Entities	The Secretary of Defense	Nontraditional defense contractors or commercial entities	The Secretary of Defense may incentivize the participation of nontraditional defense contractors and commercial entities
SEC. 9903, (a) Department of Defense Efforts, (5) Implementation	The Secretary of Defense	The Office of the Under Secretary of Defense for Research and Engineering; the Office of the Under Secretary of Defense for Acquisition and Sustainment; Department of Defense	The Secretary of Defense can coordinate on implementation with any component of the DoD it deems necessary
SEC. 9903, (a) Department of Defense Efforts, (6) Other Initiatives, (A) Required Initiatives	The Secretary of Defense	Secretary of Energy and the Administrator of the National Nuclear Security Administration	The Secretary of Defense can dedicate initiatives to advance radio frequency, mixed signal, radiation tolerant, and radiation hardened microelectronics that support national security and dual-use applications

Citation	Subject of the Mandate	Other Involved Entities	Summary
SEC. 9903, (a) Department of Defense Efforts, (6) Other Initiatives, (B) Support Plan Required	The Secretary of Defense	Heads of appropriate departments and agencies of the Federal Government	The Secretary of Defense will develop a plan for maintaining capability to produce trusted microelectronics
SEC. 9903, (a) Department of Defense Efforts, (6) Other Initiatives, (C) Assessment of Public Private Partnerships and Activities	The Secretary of Defense	The National Academies of Science, Engineering, and Medicine	The Secretary of Defense will work with National Academies on a study on recommendations and policy options for PPPs
SEC. 9903, (a) Department of Defense Efforts, (7) Reports, (A) Reports by Secretary of Defense	The Secretary of Defense	Congress	The Secretary of Defense will submit a report to Congress on plans for DoD efforts within 90 days of NDAA enactment
SEC. 9903, (a) Department of Defense Efforts, (7) Reports, (B) Biennial Reports by Comptroller General of the United States	Comptroller General of the United States	Congress	The Comptroller General of the United States will submit a report to Congress on DoD activities every two years for a period of 10 years
SEC. 9903, (b) National Network for Microelectronics Research and Development, (1) In General	The Secretary of Defense	The national network for microelectronics research and development	Secretary of Defense may establish a national network for microelectronics research and development
SEC. 9903, (b) National Network for Microelectronics Research and Development, (2) Activities	The national network for microelectronics research and development	The Secretary of Defense	The national network for microelectronics research and development will enable cost effective microelectronics R&D and accelerate tech transfer

Citation	Subject of the Mandate	Other Involved Entities	Summary
SEC. 9904, Department of Commerce study on status of microelectronics technologies in the United States industrial base, (a) In General	Secretary of Commerce	Heads of other Federal departments and agencies, including the Secretary of Defense, Secretary of Homeland Security, and the Secretary of Energy	Secretary of Commerce will study the microelectronics capability of the United States and foreign entities
9905, (a) Multilateral Semiconductors Security Fund.	Secretary of the Treasury	Secretary of State; Congress	Secretary of State will establish multilateral semiconductors security fund with a reporting requirement to Congress
9905, (a) Multilateral Semiconductors Security Fund, (4) Use of funds	Secretary of State	Secretary of Commerce; partner governments	Amounts in the fund may be used to support the development of measurably secure semiconductors and supply chains
9905, (b) Common Funding Mechanism for Development and Adoption of Measurably Secure Semiconductors and Measurably Secure Semiconductors Supply Chains, (1) In general	Secretary of State	Secretary of Commerce, the Secretary of Defense, the Secretary of Homeland Security, the Secretary of the Treasury, the Secretary of Energy, and the Director of National Intelligence	The Secretary of State (along with other involved entities) will establish a common funding mechanism, in coordination with foreign partners, to support the development and adoption of secure semiconductors and supply chains

Citation	Subject of the Mandate	Other Involved Entities	Summary
SEC. 9906, (a) Subcommittee on Microelectronics Leadership, (1) Establishment Required - (2) Membership	President, NSTC	The Secretary of Defense, Secretary of Energy, Director of the National Science Foundation, Secretary of Commerce, Secretary of State, Secretary of Homeland Security, the United States Trade Representative, the Director of National Intelligence, the heads of such other departments and agencies of the Federal Government as the President determines appropriate	The President will establish a NSTC subcommittee on microelectronics competitiveness
SEC. 9906, (a) Subcommittee on Microelectronics Leadership, (3) Duties, (A) National Strategy on Microelectronics Research	The NSTC Subcommittee on Microelectronics	Advisory committee; other appropriate stakeholders in the microelectronics industry and academia	The NSTC Subcommittee will develop a national strategy on microelectronics R&D, manufacturing, and supply chain security
SEC. 9906, (a) Subcommittee on Microelectronics Leadership, (3) Duties, (B) Fostering Coordination of Research and Development	The NSTC Subcommittee on Microelectronics	Federal agencies	The NSTC Subcommittee will coordinate microelectronics related research, development, manufacturing, and supply chain security activities and budgets of Federal agencies
SEC. 9906, (a) Subcommittee on Microelectronics Leadership, (3) Duties, (C) REPORTING AND UPDATES	President	Congress	The President will brief Congress on subcommittee progress a year after formation. Subcommittee will update strategy once every 5 years and will terminate 10 years after formation

Citation	Subject of the Mandate	Other Involved Entities	Summary
SEC. 9906, (b) Industrial Advisory Committee, (1) Establishment	Secretary of Commerce	The Secretary of Defense, the Secretary of Energy, and the Secretary of Homeland Security	Establish an advisory committee including representatives of industry, federal laboratories, and academic institutions, who are qualified to provide advice on microelectronics
SEC. 9906, (C) National Semiconductor Technology Center, (1) Establishment	Secretary of Commerce	Secretary of Defense, private sector, the Department of Energy, and the National Science Foundation.	The Secretary of Commerce will establish a national semiconductor technology R&D center operated as a public private-sector consortium
SEC. 9906, (d) National Advanced Packaging Manufacturing Program	Secretary of Commerce	Director of the National Institute of Standards and Technology	Establish a National Advanced Packaging Manufacturing Program led by the Director of the National Institute of Standards and Technology to strengthen semiconductor advanced test, assembly, and packaging capability in the domestic ecosystem
SEC. 9906, (e) Microelectronics Research at the National Institute of Standards and Technology	Director of the National Institute of Standards and Technology	None	The NIST Director will carry out a microelectronics research program
SEC. 9906, (f) Creation of a Manufacturing USA Institute	Director of the National Institute of Standards and Technology	None	The NIST Director will establish a Manufacturing USA institute focused on advances improvements in semiconductor manufacturing, equipment, and workforce

Appendix B.
Initial List of Identified PPPs

The study team developed an initial list of PPPs (Table B-1). The latter represented examples of models and mechanisms used across the Federal Government, such as initiatives that used specific Federal authorities of interest or provided insights on the Federal role in technology development.

Table B-1. Initial List of PPPs, Locations, and Industry Focus

PPP Name	Location	Industry Focus
Domestic/U.S.-Based and Microelectronics Related Industries		
AIM Photonics	New York	Microelectronics
BRIDG	Florida	Microelectronics
Global 450 Consortium	New York	Microelectronics
Honeywell/Kansas City National Security Center	Kansas	Microelectronics, among others
Lockheed Martin/Sandia National Laboratories	New Mexico	Microelectronics, among others
MEMS and Nanotechnology Exchange (MX)	Virginia	Microelectronics
MOSIS	California	Microelectronics
NEXTFLEX	California	Microelectronics
Power America	North Carolina	Semiconductors
SEMATECH	Texas, New York	Microelectronics
Semiconductor Research Consortium (JUMP and predecessor STARnet, Ncore and predecessor NRI)	Multiple Sites	Microelectronics
Trusted Foundries Program	Multiple Sites	Microelectronics
Domestic/U.S.-Based and Other Industries		
Electric Power Research Institute	Multiple Sites	Electricity/Energy
NIST Advanced Technology Program	Multiple Sites	Multiple
Partnership for a New Generation of Vehicles	Multiple Sites	Automobile
Internationally-Based and Microelectronics Related Industries		
Advanced Semiconductor Technology Research Organization	Taiwan	Semiconductors
Electronics and Telecommunications Research Institute	South Korea	Electronics and Telecommunications
Internationally-Based and Microelectronics Related Industries (cont.)		

PPP Name	Location	Industry Focus
Electronics Research and Service Organization	Taiwan	Electronics
Inter-University Micro Electronics Centre (IMEC)	Belgium	Microelectronics
Industrial Technology Research Institute	Taiwan	Microelectronics
Taiwan Semiconductor Manufacturing Corp (TSMC)	Taiwan	Microelectronics
Shanghai Industrial Technology Research Institute	China	Microelectronics
Internationally-Based and Other Industries		
Fraunhofer Institutes	Germany	Multiple
Tekes-Finnish Funding Agency for Technology and Innovation	Finland	Multiple

Appendix C.
Literature Review Findings and Recommendations for a New Microelectronics PPP

The literature findings are described in two parts—(1) general findings related to PPPs, including U.S. Government and partner roles, Federal considerations for establishing PPPs, and success factors; and (2) specific recommendations from literature relevant to development of a new microelectronics PPP. The recommendations summarized in Table C-1 identify the source publication and a summary of the recommendations.

General Findings

U.S. Government and Partner Roles

Regarding participation, each entity in PPPs fills a specialized role, unique to their structure, function, and interests that can bring specific advantages to the PPP. Government entities are uniquely positioned to support longer-range, fundamental research that may reduce risk for private entities. Because of this, agencies may help the private sector to develop high-risk technologies (NAS 1999), and serve as testbed for new solutions, while providing input from citizens and professionals, while the private entity holds the technical knowhow and innovative skills (Munksgaard et al. 2017). PPPs also serve as mechanisms for public partners to gain access to private financing, use managerial expertise, or implement cost-saving mechanisms (Rybnicek, Plakolm, and Baumgartner 2020). Universities partnering with industry are able to access new data, skills or equipment, and can gain real-world applications. Conversely, universities help to disseminate knowledge by promoting open publication of research results, develop new technologies or techniques, de-risk research investments, and extend the capabilities and expertise of industries (Elsevier 2021).

In conjunction, U.S. Government funding of R&D across universities and industry allows balancing of long-term objectives and real-world problems to link practical goals with technical capabilities (NAS 1999). Within an emerging technology field with increased transboundary flows of people, items, and information, it is important for the U.S. Government to support the broader innovation ecosystem for potential technological spillover within various technology domains (Weber et al. 2013).

Considerations When First Establishing a PPP

Peña et al. (2019) describe broad considerations for Federal agencies contemplating establishing a PPP (summarized in Box C-1: Considerations for Federal Agencies When Establishing a PPP).

Box C-1: Considerations for Federal Agencies When Establishing a PPP

- What is the context for the partnership; how does it relate to the agencies' goals?
- What authorities do Federal entities have to engage in a partnership? (e.g., do authorities exist to engage in formal partnerships? Can statutory or regulatory limitations or guidelines aid in the process?)
- What are the risks, responsibilities, and returns potential partners could expect from developing a partnership?
- Does the Federal entity initiating the partnership have the capabilities and resources to manage it? (e.g., internal and external staffing levels, organizational placement, structure, and culture)
- For more formal partnerships, what alternatives or procurement approaches are available; are they adaptable to a partnership model?

Source: Peña et al. (2019), as adapted from U.S. Department of Transportation. 2007. User Guidebook on Implementing Public-Private Partnerships for Transportation Infrastructure Projects in the United States.

According to the authors, the structure and other attributes of PPPs could be configured along a spectrum of activities including—

- the use of formal funding with contractual and monetary obligations or informal funding with in-kind support or resources;
- shared or weighted U.S. Government and partner risks, such as financial and reputational stakes;
- topical reach focused on broad, moonshot-like or specific goals; and
- decentralized participation, such as crowd-sourced partnerships, or concentrated in a select set of partners (Figure C-1).

Source: Peña (2019).

Figure C-1. Spectrum of Select PPP Attributes

Success Factors for PPPs

Several studies analyzed success factors for PPPs related to the partners and their dynamics, funding and operations, market and economic incentives, and IP.

- Partners and Their Dynamics—bringing together diverse participation early on in PPP formation (Brogaard 2021); overlapping core business strategies, geographical markets, and functional skills (Lockshin et al. 2011); and incorporating a high level of interaction among key partners, including universities, the players supporting the value-chain, and end-customers (Costa and Matias 2020).
- Funding and Operations—using contracts that are short-term, modular, and flexible to provide opportunities for mid-course corrections and support the highly volatile nature of early-stage R&D (Brogaard 2021); and integrating diverse modes of financial support for R&D, such as direct funds for R&D and procurement, that can aid in balancing open-ended R&D with more directed technological development (NAS 1999).
- Market and Economic Incentives—operating in global and diverse markets is more likely to use dynamic strategies, and innovative behaviors can be reinforced using incentives that promote access to foreign markets (Costa and Matias 2020); various goals will be best achieved through a mix of policies and incentives; one single approach may not work for each country, economy, or goal, for example, with countries successful at promoting innovation having built a tax platform

containing a number of elements (e.g., R&D tax incentives, IP tax regimes, investment tax credits), while in more mature economies, taxes are often applied to R&D output and IP patent regimes are used, to promote domestic capabilities; any strategy can be effective if funding is directed toward performance, and highlights the importance of developing performance metrics (PWC 2010).

- Intellectual Property[9]—addressing limitations of IP protections on the semiconductor industry's rapidly complex and changing processes requiring tacit know-how (Brody 1996); integrating IP considerations, such as which product or process is protected by law, who provides that protection, what that protection provides, what procedures are undertaken to receive that protection, and the duration of the protection (Sharp 2003); as well as identifying the type of transaction (e.g., contract) and its associated rights, ensuring protections span the lifecycle of the technology development process, and updating IP terms to adapt to early planning decisions and program strategies, among others (Gross 2014).

The field of literature is sparse, in particular regarding empirical studies, on success factors for Federal PPPs. While several reports summarize lessons learned and exemplary practices, empirical studies specific to Federal PPPs tend to be lacking; this could potentially be due to the relatively large numbers of PPPs and data that would be needed for meaningful analyses.

Recommendations for a New Microelectronics PPP

Several reports provided recommendations for establishing a new microelectronics PPP. The study team summarized the recommendations across several categories—goals, partners and roles, funding and resources, innovation ecosystems, IP, and outcomes and metrics.

Goals

Economic development and international competition are key drivers for Federal involvement in microelectronics PPPs. The U.S. semiconductor industry is important to the economy and national security, and disruptions to accessing semiconductor technologies due to conflict or trade disputes should be minimized (Platzer et al. 2020). Considering the commercial interests of firms are not always in line with innovation and R&D investments, a national microelectronics strategy should address the economic and social costs of falling behind on Moore's Law (Mody 2017). Supporting U.S. microelectronics competitiveness will lead to a stronger industrial sector and more innovation and growth (Mody 2017). Having a secure microelectronics supply is also

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[9] Intellectual property is typically comprised of four categories: patent, copyright, trademark, and trade secrets, and are most relevant to Federal legal provisions in 10 U.S.C Sections 2320 and 2321.

essential for national security; the U.S. military needs access to specialized semiconductors that adversaries don't have, and civilian cybersecurity is a growing concern (PCAST 2017). A microelectronics PPP for strengthening national security should enhance access to strategic radiation hardened microelectronics parts, support assured access for high-end microelectronics, and accelerate the discovery of novel microelectronics for DoD needs (DSB 2019). Along with onshoring critical technology areas from China for economic and national security, the United States may consider a coordinated campaign for microelectronics leadership like European peers, looking to IMEC as an example (Adler et al. 2021).

In addition to economic and national security-related goals, some recommendations focused on setting new PPP technical goals, such as:

- Using a co-design approach, developing vertically integrated roadmaps, and investing in capabilities and infrastructure common across industry members to increase collaboration on PPP research activities (Armbrust et al. 2018).
- Focusing on the entire semiconductor and electronic systems supply chain in its design, setting goals beyond processing speed, keeping in mind technology limitations and Moore's Law extrapolations, and reflecting the diversity of computing system needs (Armbrust et al. 2018).
- Coordinating technologies to ensure necessary components of combined hardware-software stack and developing R&D that reduces hardware design costs (Armbrust et al. 2018).
- Supporting the most promising innovations that address gaps in microelectronics R&D and focusing on the pre-competitive strategic horizon, selecting projects that could yield a breakthrough in 10 years, in turn accelerating the technology development pipeline and shortening the lag time from discovery to market (Armbrust et al. 2018, PCAST 2017). These include foundational technologies, such as the "design and manufacture of advanced semiconductor, quantum and other materials for next generation logic and specialized accelerator hardware and its utilization through algorithms and application software" (Armbrust et al. 2018).
- Compensating for weak industry investment in domains such as advanced materials science, advanced manufacturing, and modeling essential to microelectronics advancement, but are not yet profitable, especially later-stage development of promising technologies for DoD applications (PCAST 2017, PIPS 2017).

Partners and Roles

A microelectronics PPP must clearly define the role of Federal partners. The U.S. Government should consider how to effectively use its regulatory and funding powers to bolster the domestic microelectronics industry (PCAST 2017). The USG should set ambitious and clear goals, but should not dictate individual activities (PCAST 2017). Instead of dictating specific PPP activities, the USG may pose ambitious challenges/moonshots to drive semiconductor and computing innovation toward shared objectives (PCAST 2017). The USG may follow the lead of industry and support companies of all sizes in key advanced technology areas, but should maintain independence and avoid not targeting particular firms for assistance (PIPS 2017, Adler et al. 2021). USG should also focus on critical areas the private sector is unable to meet, and align academia, industry, and National labs to pursue common goals (Platzer et al. 2020). A key challenge and opportunity is multi-sector engagement: having the Federal government, academia, and the private sector work together effectively requires the USG addressing longstanding administrative barriers (PCAST 2021). The U.S. Government can also leverage its existing network of R&D programs, for instance those supported by DoD, DOE, NIST, DARPA, ARPA-E, Manufacturing USA Centers, and NSF industry-university centers (Adler et al. 2021).

Generally, it is easier for academic microelectronics research centers to pursue alliances and broader research than industrial consortia (Mody 2017). Centers are typically the most efficient way to broker and interact with a university, and centers are frequent partners with consortia (Mody 2017). A PPP should encourage flexibility at centers to determine organizational structure and governance (PCAST 2021).

Funding and Resources

The Federal Government needs to determine the funding level necessary to achieve its microelectronics objectives and how that funding will be allocated. (Platzer et al. 2020). PPP budgets need to be sufficient and stable over time (>5 years) to fit the scope of a PPP's goals (PIPS 2017). Finally, the USG should consider how the U.S. tax code penalizes capital-intensive industries, and consider how tax system reforms and funding mechanisms such as Other Transaction Agreements (OTAs) may enable microelectronics PPPs (PCAST 2017, PIPS 2017).

Innovation Ecosystems

A PPP must consider the costs and benefits of potential locations and its position within an innovation ecosystem. Establishing a PPP in an area with a developing innovation ecosystem can result in broader benefits to the surrounding region and economy (Adler et al. 2021).

Having a strong domestic microelectronics workforce of the future is a critical issue. Without a consistent future microelectronics workforce, the U.S. microelectronics industry may fall farther behind (Armbrust et al. 2018). The U.S. Government needs to incentivize the growth of a diverse, highly skilled, multi-generational and interdisciplinary workforce through mentorship opportunities and addressing financial barriers (PCAST 2021). A PPP may contribute to its surrounding innovation ecosystem by offering experienced-based learning programs for students and STEM educators from K–12 to community college/trade and undergraduate/graduate programs (PCAST 2021).

Intellectual Property

Determining IP terms that are both industry-friendly and encourage innovation is important for a PPP. While flexible IP terms incentivize participation in a PPP, a lack of clear roles and rights of industry members can result in IP disagreements (Khan, Hounshell, and Fuchs 2015). A PPP may establish IP rights that are negotiable but weighted toward those providing major funding (PCAST 2021). If a PPP is seeking to develop the domestic industry, it could offer IP licenses on competitive terms to industry members, based on their desire to benefit companies with U.S. headquarters and/or operations. (Armbrust et al. 2018).

Outcomes and Metrics

The President's Council of Advisors on Science and Technology provided a list of potential metrics for a PPP focused on emerging industries (PCAST 2021):

- Organizational performance (number of patents filed, awarded, licensed)
- Number of technologies transferred and successfully deployed
- Number of participating organizations
- Reduction in time for transition from innovation to deployment
- Creation of startup companies and other translational activities
- Increased diversity and inclusion within ecosystem
- STEM education and workforce—e.g., facilitating the design and offering of new educational programs, Increasing the size of the STEM-enabled workforce; clear evidence of increasing engagement of traditionally underrepresented and underserved groups in STEM; evaluation of mentorship experience from former trainees
- Policy impacts—e.g., reduction of administrative burden on researchers; demonstration of whether new IP strategies drive changes in policy nationally, new models for collaboration, and coordination among the R&D sectors

Table C-1. Summary of Recommendations

Source	Recommendations	1	2	3	4	5	6	7	8	9
Adler, David, Robert D. Atkinson, Dean Bartles, William B. Bonvillian, Robbie Diamond, Stephen Ezell, Jeffrey Gerlach, David P. Leech, Andrew Reamer, Marc Stanley, Gregory Tassey, Carroll A. Thomas, and Patrick Windham. 2021. Next Steps for Ensuring America's Advanced Technology Preeminence. Information Technology & Innovation Foundation.	• The Federal Government needs to establish and fund a national advanced technology strategy to avoid losing market share in several advanced industries, and falling behind in innovation, national security, and living standards • Support for semiconductor R&D should include both supply-side policies (through programs such as DARPA, ARPA-E, Manufacturing USA Centers, and NSF's industry-university centers), as well as "demand-side" policies through procurement • Policies should link supply and demand together, bringing technologies past the valley of death, and allowing innovators to sustain growth • It is important for there to be a number of regions in the U.S. are capable of attracting and growing high-tech innovators, so that high-tech wealth and jobs are not concentrated in just a few regions	X	X							
Armbrust, Daniel, Bob Colwell, Patrick Naulleau, Ramesh Ramamoorthy, and John Shalf. 2018. Assuring Continued US Leadership in Semiconductor Technology and Manufacturing Beyond 2025. Berkeley Lab. 2018	• A microelectronics PPP should consider the entire semiconductor and computing supply chain in its design, and should set goals beyond processing speed, keeping in mind CMOS limitations and Moore's Law extrapolations, reflecting the diversity of computing system needs • The technology focus of a microelectronics PPP may be determined by down-selecting to support the most promising innovations and address gaps in microelectronics R&D, in turn accelerating the technology development pipeline • A PPP may consider using a co-design approach, developing vertically integrated roadmaps, and investing in capabilities and infrastructure that are common across industry members to increase collaboration on PPP research activities • Without a consistent future microelectronics workforce, the U.S. microelectronics industry may fall farther behind • If a PPP is seeking to develop the domestic industry, it could offer IP licenses on competitive terms to industry members, based off of their desire to benefit companies that are headquartered and/or have operations in the U.S • The main measurement of success should be the reduction of time it takes to move innovations to industry adoption compared to how long it would take if the program did not exist		X		X		X			X

Source	Recommendations	1	2	3	4	5	6	7	8	9
Defense Science Board (DSB). 2019. Report of the Defense Science Board on Technology Strategy. Washington, D.C.: Office of the Under Secretary of Defense for Research & Engineering.	• A microelectronics PPP with the goal of strengthening national security should strengthen access to strategic radiation hardened microelectronics parts, support assured access for high-end microelectronics, and accelerate the discovery of novel microelectronics fabrics for DoD needs	X	X							
Khan, Hassan and Hounshell, David A and Fuchs, Erica. 2015. Scaling Moore's Wall: A Public-Private Partnership in Search of a Technological Revolution.	• A lack of clear roles and rights of industry members can result in IP disagreements • A PPP can have a coordinating role within the scientific community, incorporating industry expertise into academic research		X					X		
Mody, Cyrus M. 2017. Academic Centers and/as Industrial Consortia in American Microelectronics Research, Management & Organizational History, 12:3, 285–303.	• Academic microelectronics research centers have more flexibility to forge alliances than industrial consortia • Academic entrepreneurs were a crucial component of the formation of industry-oriented microelectronic research centers • Institutional entrepreneurs within government fostered the emergence of both academic MRCs and industrial semiconductor research consortia, and built strong connections among them • Academic centers can pursue more untraditional alliances and promising research trajectories than an industrial consortium can, and the industry benefits by sharing the burden of supporting the centers • Academic centers are the most effective and appropriate broker of the relationship with consortia and universities • In consortia, semiconductor product and process innovations are typically covered by patents that are held by multiple firms which cross-license their intellectual property, which avoids monopoly		X		X			X		
Platzer, Michaela D., John F. Sargent Jr, and Karen M. Sutter. 2020. Semiconductors: U.S. Industry, Global Competition, and Federal Policy. Congressional Research Service, R46581.	• There is less criticism for Federal involvement in supporting the technologies, products, and industries deemed central to U.S. national security • The federal government needs to exercise caution in becoming involved in industries and avoid the appearance of targeting a specific company for assistance • The federal government should not attempt to excessively influence market forces and policies should not favor one technology, company, and industry over another	X	X	X		X			X	

Source	Recommendations	1	2	3	4	5	6	7	8	9
	• The Federal Government needs to determine what level of funding is necessary to achieve its microelectronics objectives and how that funding will be allocated. • Key questions to determine Federal funding include: what incentives are needed to onshore semiconductor manufacturing, how much funding is necessary to ensure U.S. leadership of the semiconductor market, how long funding would need to be sustained, what workforce education and investments are necessary for an adequate semiconductor workforce, and what budgets funding should come from • Congress should evaluate U.S.-China technology ties that contribute to the development of China's semiconductor industry, assess the effectiveness of current U.S. authorities to address Chinese government subsidization of the Chinese semiconductor industry, and consider whether new authorities are necessary									
Potomac Institute for Policy Studies (PIPS). 2017. Consortia Analysis and Recommendations Trade Study.	• The USG may follow the lead of industry and support companies of all sizes in key advanced technology areas but should maintain independence • PPP budgets need to be sufficient and stable over time (>5 years) to fit the scope of goals • The U.S. should compensate for weak industry investment in domains such as advanced materials science, advanced manufacturing, and modeling that are essential to microelectronics advancement, but are not yet profitable, especially later TRL stage development of promising technologies for DoD applications • The USG should consider how tax system reforms and funding mechanisms such as Other Transaction Agreements (OTAs) may enable microelectronics PPPs	X	X			X				
President's Council of Advisors on Science and Technology (PCAST). 2017. Ensuring Long-Term U.S. Leadership in Semiconductors.	• Having a secure microelectronics supply is also essential for national security; the U.S. military needs access to specialized semiconductors that adversaries don't have, and civilian cybersecurity is a growing concern • A PPP should focus on pre-competitive strategic horizon, select projects that could yield a breakthrough in 10 years, focus on developing R&D that reduces hardware design costs, and shorten the lag time from discovery to market	X	X	X	X	X	X	X		X

Source	Recommendations	1	2	3	4	5	6	7	8	9
	• It is important for a microelectronics PPP to clearly define the role of Federal partners. Considering that the U.S. microelectronics sector has never been an entirely free market, the USG should consider how to effectively use its regulatory and funding powers • The Federal government should set ambitious and clear goals, but should not dictate individual activities • Instead of dictating specific PPP activities, the USG may pose ambitious challenges/moonshots to drive semiconductor and computing innovation toward shared objectives • The U.S. should compensate for weak industry investment in domains such as advanced materials science, advanced manufacturing, and modeling that are essential to microelectronics advancement, but are not yet profitable, especially later TRL stage development of promising technologies for DoD applications • The Federal Government should consider how the U.S. tax code penalizes capital-intensive industries, and consider how tax system reforms and funding mechanisms such as Other Transaction Agreements (OTAs) may enable microelectronics PPPs									
President’s Council of Advisors on Science and Technology (PCAST). 2021. Industries of the Future Institutes: A New Model for American Science and Technology Leadership.	• A key challenge and opportunity is multi-sector engagement: getting the Federal Government, academia, and the private sector to work together effectively requires the USG to address longstanding administrative barriers • A PPP should encourage flexibility at centers to determine their own organizational structure and governance • The USG needs to incentivize the growth of a diverse, highly skilled, multi-generational and interdisciplinary workforce through mentorship opportunities and addressing financial barriers • A PPP may contribute to its surrounding innovation ecosystem by offering experienced-based learning programs for students and STEM educators from K–12 to community college/trade and undergraduate/graduate programs • A PPP may establish IP rights that are negotiable but weighted towards those providing major funding • Potential metrics for evaluation may include: organizational performance, STEM education and workforce, and policy impact	X		X	X	X	X	X		X

1=Goals, 2=Partners and Roles, 3=Workforce, 4=Governance, 5=Funding, 6=Operation, 7=IP, 8= Other Protections, 9=Evaluation and Outcomes.

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Appendix D.
Logic Model

A logic model can be defined as: "a systematic and visual way to present and share your understanding of the relationships among the resources you have to operate your program, the activities you plan, and the changes or results you hope to achieve" (W.K. Kellogg Foundation 2004). The development of a general PPP logic model informed the study team's understanding of a PPP, including the relationships among resources, activities, outputs, and outcomes stemming from the PPP's activities. The logic model also provides a common framework for identifying: the (1) outputs directly attributed to a PPP's activities, and (2) how those outputs contribute to expected near- and mid-term outcomes and broader long-term impacts (Figure D-1). The development of the logic model was informed by initial interviews with general PPP experts, and refined as new information was collected throughout the study.

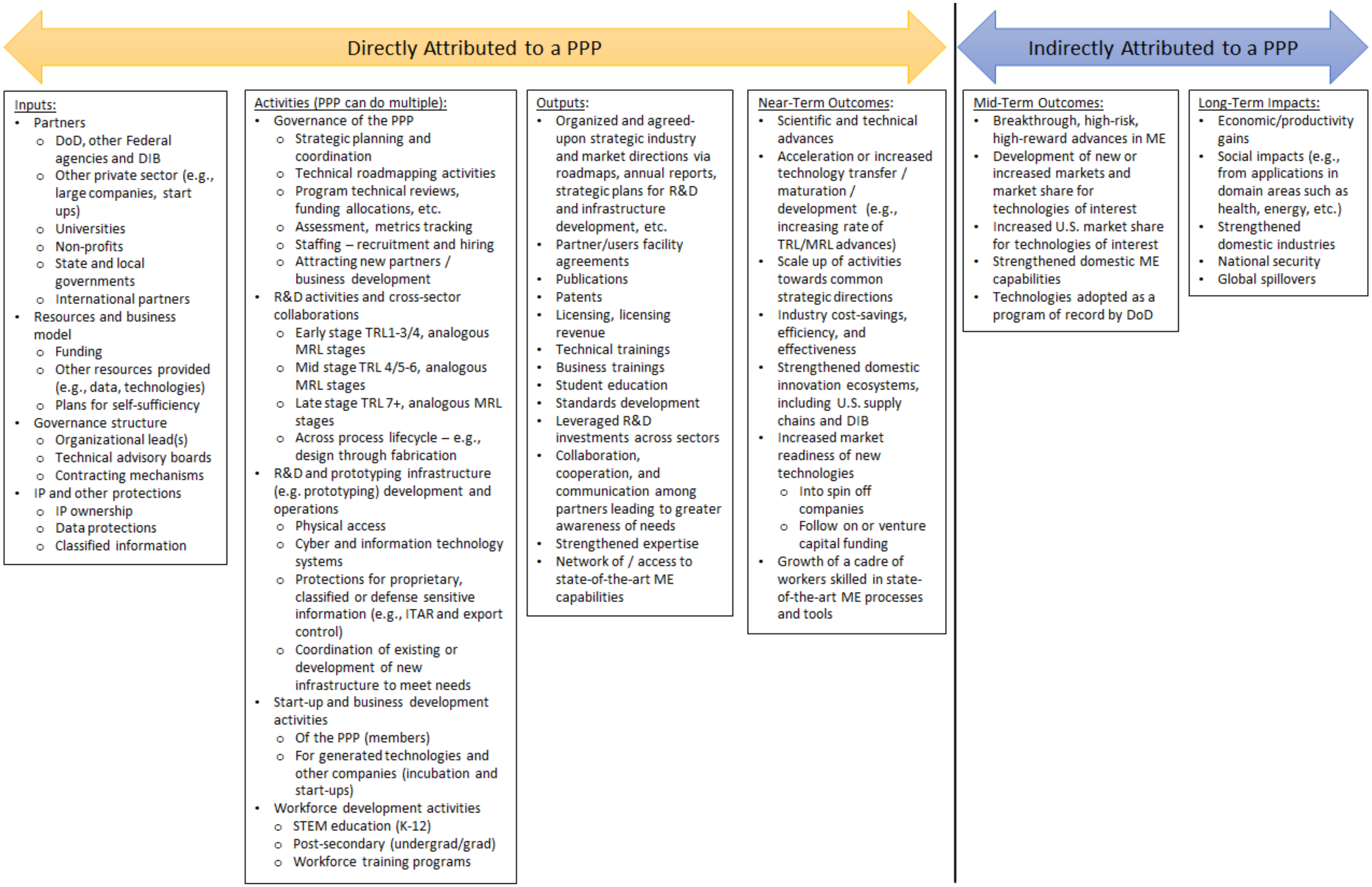
The logic model may also provide a useful reference for DARPA, DoD entities, and other relevant stakeholders involved in a PPP to strategically outline how the varied PPP activities can contribute to broader impacts. Logic models can inform the scope for successful technology development and guide the development of performance measures (Landree and Silberglitt 2018).

The logic model in Figure D-1 describes—

- Inputs—include the PPP's partners, the resources they provide, and governance structures and policies, such as those for IP and other protections;
- Activities—include those supporting governance and decision making, R&D and cross-sector collaborations, infrastructure operations, start-up and business development, and workforce training;
- Outputs—include directly attributable tangible and intangible results from the PPP activities, such as roadmaps, strategic plans, partner and user facility agreements, publications, patents, licensing and licensing revenue, training and education, standards, leveraged R&D investments, greater awareness of needs across partners, strengthened expertise, network of and access to state-of-the-art ME capabilities;
- Near-Term Outcomes—includes scientific and technological advances, acceleration or increased technology transfer, maturation, and development (e.g., increasing rate of technology readiness level (TRL) and manufacturing

readiness level (MRL) advances), scale up of activities toward common strategic directions, industry cost-savings, efficiency, and effectiveness, strengthened domestic innovation ecosystems, increased market readiness of new technologies, and growth of a cadre of workers skilled in state-of-the-art ME processes and industry tools;

- Mid-Term Outcomes—includes breakthrough, high-risk, high-reward advances in ME, development of new or increased markets and market share for technologies of interest, increased U.S. market share for technologies of interest, strengthened domestic ME capabilities, and technologies adopted as a program of record by DoD; and
- Long-Term Impacts—includes economic and productivity gains, social impacts, strengthened domestic industries, national security, and global spillovers.



Directly Attributed to a PPP

Indirectly Attributed to a PPP

Inputs:
- Partners
  - DoD, other Federal agencies and DIB
  - Other private sector (e.g., large companies, start ups)
  - Universities
  - Non-profits
  - State and local governments
  - International partners
- Resources and business model
  - Funding
  - Other resources provided (e.g., data, technologies)
  - Plans for self-sufficiency
- Governance structure
  - Organizational lead(s)
  - Technical advisory boards
  - Contracting mechanisms
- IP and other protections
  - IP ownership
  - Data protections
  - Classified information

Activities (PPP can do multiple):
- Governance of the PPP
  - Strategic planning and coordination
  - Technical roadmapping activities
  - Program technical reviews, funding allocations, etc.
  - Assessment, metrics tracking
  - Staffing – recruitment and hiring
  - Attracting new partners / business development
- R&D activities and cross-sector collaborations
  - Early stage TRL1-3/4, analogous MRL stages
  - Mid stage TRL 4/5-6, analogous MRL stages
  - Late stage TRL 7+, analogous MRL stages
  - Across process lifecycle – e.g., design through fabrication
- R&D and prototyping infrastructure (e.g. prototyping) development and operations
  - Physical access
  - Cyber and information technology systems
  - Protections for proprietary, classified or defense sensitive information (e.g., ITAR and export control)
  - Coordination of existing or development of new infrastructure to meet needs
- Start-up and business development activities
  - Of the PPP (members)
  - For generated technologies and other companies (incubation and start-ups)
- Workforce development activities
  - STEM education (K-12)
  - Post-secondary (undergrad/grad)
  - Workforce training programs

Outputs:
- Organized and agreed-upon strategic industry and market directions via roadmaps, annual reports, strategic plans for R&D and infrastructure development, etc.
- Partner/users facility agreements
- Publications
- Patents
- Licensing, licensing revenue
- Technical trainings
- Business trainings
- Student education
- Standards development
- Leveraged R&D investments across sectors
- Collaboration, cooperation, and communication among partners leading to greater awareness of needs
- Strengthened expertise
- Network of / access to state-of-the-art ME capabilities

Near-Term Outcomes:
- Scientific and technical advances
- Acceleration or increased technology transfer / maturation / development (e.g., increasing rate of TRL/MRL advances)
- Scale up of activities towards common strategic directions
- Industry cost-savings, efficiency, and effectiveness
- Strengthened domestic innovation ecosystems, including U.S. supply chains and DIB
- Increased market readiness of new technologies
  - Into spin off companies
  - Follow on or venture capital funding
- Growth of a cadre of workers skilled in state-of-the-art ME processes and tools

Mid-Term Outcomes:
- Breakthrough, high-risk, high-reward advances in ME
- Development of new or increased markets and market share for technologies of interest
- Increased U.S. market share for technologies of interest
- Strengthened domestic ME capabilities
- Technologies adopted as a program of record by DoD

Long-Term Impacts:
- Economic/productivity gains
- Social impacts (e.g., from applications in domain areas such as health, energy, etc.)
- Strengthened domestic industries
- National security
- Global spillovers

Figure D-1. General PPP Logic Model

References

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Appendix E.
Interviews

STPI conducted interviews with 55 individuals during the study period (Table E-1). The interview subjects included industry and government leaders of the selected PPPs, subject area experts, and other leaders of other Federal programs and initiatives aimed at engaging the private sector. The interviewees consented to have their names included in this Appendix.

Table E-1. Interview Subjects

Name	Affiliation	Interview Date(s)
Akintunde Ibitayo (Tayo) Akinwande	Professor, Electrical Engineering and Computer Science Department of MIT	4/20/2019
John Allgair	Program Manager, Advanced Systems Integration at BRIDG	4/19/2021 5/12/2021 6/14/2021
Robert Bernhard	Vice President for Research, University of Notre Dame	7/1/2021
Jason Boehm	Director, NIST Program Coordination Office	4/12/2021
Anthony M. Boccanfuso	President & CEO, University-Industry Demonstration Partnership	3/10/2021
William B. Bonvillian	Lecturer, Massachusetts Institute of Technology (MIT)	3/19/2021
John Bowers	Professor, UC Santa Barbara	3/24/2021
John J. Callahan	Former Vice President of Technology, BRIDG	4/2/2021
Nancy Campbell	Director, Government Engagement, Office of the Director of IBM Research	4/8/2021
Lifu Chang	Director, MOSIS Service, University of Southern California (USC)	4/9/2021
An Chen	Executive Director, Nanoelectronic Computing Research (nCORE) Program at Semiconductor Research Corporation (SRC)	3/30/2021
John Christensen	DoD, Office of the Undersecretary of Defense, Research & Engineering	4/29/2021
Steve Crago	Associate Director, USC Information Sciences Institute (ISI)	4/9/2021
John Damoulakis	Director of Advanced Electronics, USC ISI	4/13/2021

Name	Affiliation	Interview Date(s)
Chris Daverse	Consultant, Daverse Strategies Former Manager of External Affairs, SEMATECH	3/24/2021 3/24/2021
Daniel DiMase	President & CEO, Aerocyonics, Inc.	4/30/2021
Don Fisher	County Manager, Osceola County	4/20/2021
Eric Forsythe	DoD United States Army Futures Command	4/30/2021
Lisa Friedersdorf	Assistant Director for Microelectronics, Materials, and Nanotechnology, OSTP	4/16/2021
Tracy Frost	Director, Manufacturing Technology (ManTech) Program at the Office of the Secretary of Defense	4/29/2021
Erica Fuchs	Professor, Department of Engineering and Public Policy at Carnegie Mellon University	3/5/2021 6/25/2021
Aman Gahoonia	Technical Advisor/Chief of Special Programs, Defense Microelectronics Activity (DMEA)	4/2/2021
Dario Gil	Senior Vice President and Director, IBM Research	4/8/2021
Lawrence S. Goldberg	Senior Engineering Advisor, NSF Division of Electrical, Communications and Cyber Systems, Directorate for Engineering and Lead Program Officer, National Nanotechnology Coordinated Infrastructure (NNCI)	6/9/2021
Tim Green	Director, Innovative Research & JUMP at SRC	4/7/2021
Bert Gyselinckx	Vice President and General Manager IMEC, USA	3/26/2021 6/23/2021
Michael Huff	Founder and Director, MEMS Exchange	4/1/2021
David Hunter	Senior Advisor and Head of Federal Affairs, Electric Power Research Institute (EPRI)	4/13/2021
Mark Jackson	DoD, Office of the Undersecretary of Defense, Research & Engineering	4/29/2021
Robert E. Kahn	Chairman, CEO and President, Corporation for National Research Initiatives (CNRI)	5/3/2021
Hassan Khan	Former Graduate Student Researcher, Carnegie Mellon University	6/25/2021
Jonathan Klamkin	Professor, Electrical and Computer Engineering UC Santa Barbara	4/26/2021
Steve Kramer	Principle Engineer, Micron Technology	4/5/2021
Mark Lewis	Executive Director, National Defense Industrial Association Emerging Technologies Institute	2/23/2021
W. Clark McFadden II	Senior Counsel, Orrick Law Firm	3/12/2021
Celia Merzbacher	Executive Director, Quantum Economic Development Consortium (Q-EDC) at SRI International and Former Vice President, SRC	4/21/2021
Graciela Narcho	Senior Advisor, NSF Directorate for Computer & Information Science & Engineering	5/27/2021

Name	Affiliation	Interview Date(s)
Clark Nguyen	Professor, Electrical Engineering & Computer Sciences Department at UC Berkeley	4/30/2021
Manish Parashar	Office Director, Office of Advanced Cyberinfrastructure at NSF)	4/8/2021
Chris Peters	Executive Director, U.S. Partnership for Assured Electronics (USPAE)	4/30/2021
Ron Piccolo	Chair, Department of Management at the University of Central Florida	4/28/2021
Al Pisano	Dean, Jacobs School of Engineering at UC San Diego	5/7/2021
Daniel Radack	Research Staff Member, IDA	3/5/2021
Mihail C. Roco	Founding Chair, U.S. NSTC Subcommittee on Nanoscale Science, Engineering and Technology (NSET) and Senior Advisor for Science and Engineering, NSF	4/13/2021
Michael Rosenfeld	Vice President of Strategic Partnerships, IBM Research	4/8/2021
John Sargent	Specialist in Science and Technology Policy, Congressional Research Service	3/10/2021
William Tang	Professor and Associate Dean for Research, The Henry Samueli School of Engineering at UC Irvine	4/16/2021
Malcom Thompson	Executive Director, NextFlex	5/5/2021
Chris Toffales	President, CTC Aero	2/22/2021
Nicholas Usechack	DoD, Air Force, Air Force Research Laboratory	4/6/2021
Chris VanMetre	President & CEO, Advanced Technology International (ATI)	6/2/2021
"Grace" Jinliu Wang	Executive Vice President, Ohio State University and Former Senior Vice Chancellor for Research and Economic Development, State University of New York (SUNY)	4/14/2021 6/2/2021
Jacob Ward	Director (Acting), U.S. DRIVE Government-Industry Partnership (DOE)	5/26/2021
Jeffrey Welser	Chief Operating Officer for IBM Research and Vice President, Exploratory Science and University Partnerships	3/22/2021 6/16/2021
Stephen Zimmer	Executive Director, United States Council for Automotive Research (USCAR)	5/26/2021

Appendix F.
Case Study—American Institute for Manufacturing (AIM) Photonics

Note: For all case studies, information is based on interviews unless otherwise cited. Lessons learned are the study team's own analysis.

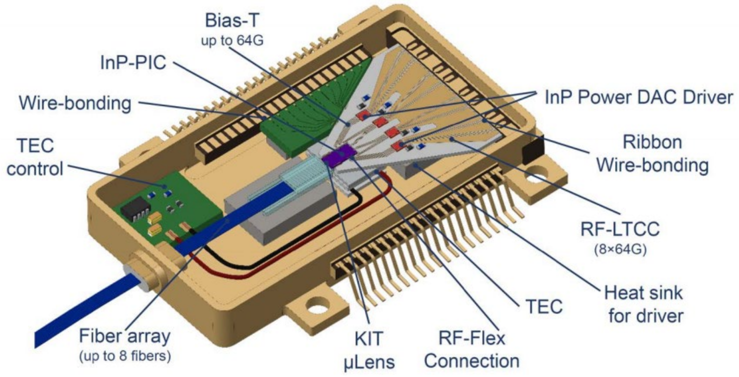
Table F-1. Summary of AIM Photonics

Goal(s)	Put in place an end-to-end integrated photonics "ecosystem" that addresses the design software, device packages, packaging techniques, and testing protocols for integrated photonics. Establish an ecosystem that enables small and medium-sized enterprises to fabricate integrated photonics devices without having to invest in expensive facilities and tools.
Origins	The America COMPETES Reauthorization Act of 2014, the Reinvesting in American Manufacturing Innovation (RAMI) Act, and the 2015 National Defense Authorization Act (NDAA) for FY 2015 contained language supporting photonics. The Advanced Manufacturing National Program Office chose photonics to be the focus area of one of the 16 public-private manufacturing innovation institutes created as part of the federal initiative to revitalize American manufacturing.
Partners and Roles	More than 126 members. **Government:** One of 16 Manufacturing Innovation Institutes, one of 6 institutes established by DoD; Air Force Materiel Command executed the cooperative agreement **Private:** Collaborators in analog photonics—process design kit (PDK) for MPW runs. **Academic:** Worcester Polytechnic Institute and Quinsigamond Community College—Laboratory for Education and Application Prototypes (LEAP) facility; Stonehill College, and Bridgewater State University—Laboratory for Education and Application Prototypes (LEAP) facility; Massachusetts Institute of Technology—Laboratory for Education and Application Prototypes (LEAP) facility; State University of New York (SUNY) Poly—300 mm wafer fabrication facility; University of California at Santa Barbara (UCSB)—research on integrating lasers onto silicon; Rochester Institute of Technology (RIT), University of Rochester, University of Albany, and Columbia University—packaging, assembly, and test. **State and Local:** Commonwealth of Massachusetts funded LEAP facilities.
Governance	Research Foundation for The State University of New York (Foundation) is the administrator of the PPP and provides the staff

	Officers: Executive Director, Chief Operating Officer, Chief Technology Officer, Chief Marketing Officer, Chief Financial Officer, Education and Workforce Training Executive, Director of Program Management Leadership Council (12 members): Chairman (non-voting), Government representative (voting), New York State representative (voting), Commonwealth of Massachusetts representative (voting), Other appointed by Leadership Council and Foundation (voting)
Funding	**Federal**: Originally AIM Photonics received $110 M over five years from DoD. Currently, it is negotiating an agreement for seven years of follow-on funding. **State and Local:** Commonwealth of Massachusetts funded LEAP facilities. **Industry**: Industry committed about $240 M for the center.
Operations	**Years:** 2015 to present. **Accomplishing Work:** Mid-range TRL 4–7 with transition capability to MRL 8 and 9; Technical Review Board provides operational oversight; Key Technology Manufacturing Area (KTMA) committees are (1) high speed digital data and communications links, (2) Analog radio frequency (RF) applications, (3) Integrated photonic sensors, and (4) Phased array technologies.
IP	The member that creates IP during an AIM Photonics-funded project owns it. Active members and their affiliates receive a worldwide, irrevocable, non-exclusive, non-transferable, royalty-free, perpetual license to use the IP solely for internal research and development, academic research, and other not-for-profit scholarly purposes. They need to negotiate for commercial rights and any background IP. U.S. Government receives a Government Purpose license.
Other Protections	AIM Photonics members must comply with all applicable export control laws and regulations of the United States, including the Export Administration Act, the Arms Export Control Act, International Traffic in Arms Regulations, the Department of Commerce Export Administration Regulations, and any other U.S. government directives related to export control. Project proposals must identify any export-controlled information that a member expects to disclose or develop in an AIM Photonics project. AIM Photonics does not hold a facility clearance; all work is at the unclassified level.
Evaluation and Outcomes	Technical Review Board meets twice a year where it reviews proposed projects, prioritizes new projects, and makes recommendations for existing project sunsets. Manufacturing USA commissioned Deloitte Consulting, LLP) to conduct a third-party review and evaluation of the Manufacturing Innovation Institute Program. This review developed evaluation strategies and metrics.
Lessons Learned	One PPP's membership model is not necessarily appropriate for another PPP. The PPP must be flexible to meet the diverse needs of industry, government (DoD), and to satisfy academic research objectives. Non-profit tied to a university reduced long-term stability concerns; however, universities and non-profits do not typically have experience in developing the level of income stream that AIM Photonics required for self-sufficiency. A relatively large amount of funding coming in early may lead to the lack of planning for self-sufficiency

Goals

The goal of American Institute for Manufacturing (AIM) Photonics is to put in place an end-to-end integrated photonics "ecosystem" addressing the design software, device packages, packaging techniques, and testing protocols for integrated photonics. Photonic devices combine digital CMOS with optical circuits on a silicon substrate called an interposer. Silicon's native oxide supports good quality waveguides that can move light from one location on the chip to another. Photonic circuitry also requires structures that generate, modulate, separate (by wavelength), and detect light. Silicon does not support a good light source, nor does it support a detector that matches the wavelengths needed. Photonic devices use heterogeneous integration to incorporate materials such as indium phosphide for lasers and germanium for photodetectors into photonic integrated circuits (PIC). Figure F-1 shows an example of a PIC.



Source: Bozovich (2020).

Figure F-1: An example of a photonic integrated circuit in a package

PICs are different from traditional electronic integrated circuits (IC). Traditional IC design software, packages, packaging techniques, and testing protocols are not appropriate for PICs. PICS require their own ecosystem, which consists of:

- Domestic foundry access;
- Integrated design tools;
- Automated packaging, assembly and testing;
- Workforce development; and
- Industry-wide standards to make it easier to scale the technology across multiple markets for companies of all sizes.

Such an ecosystem was not available to most small to medium-sized enterprises. They could not fabricate integrated photonics devices without investing in expensive facilities and tools. The goal of AIM Photonics was to establish an ecosystem to provide these capabilities.

Another goal of AIM Photonics is workforce development. In 2018, it formed the AIM Photonics Academy. (AIM Photonics n.d.a) The Academy prepares students, technicians, engineers, and researchers for careers in the integrated photonics industry. It creates and disseminates education modules or teaching packages for instructors, and offers self-paced online learning through online edX courses and online interactive simulations. Through the Academy, students have access to internships and apprenticeships. Classes are given on photonic system modeling, design automation, materials and processing, metrology and testing, packaging, and applications.

Origins

Around 2000, photonics manufacturing was beginning to move to Asia, causing the United States to lose expertise. By the late 2000s, both the U.S. industry and government recognized this shift as a problem. The National Research Council (NRC) initiated a study, and in 2013 published a report on optics and photonics (NRC 2013), which characterized photonics as a critical enabling technology for the country. The NRC study called for the formation of the National Photonics Initiative (https://www.lightourfuture.org/home/). Five organizations—The Optical Society of America (OSA); SPIE, the international society for optics and photonics; the IEEE Photonics Society (IPS); the Laser Institute of America (LIA); and the American Physical Society (APS) Division of Laser Science, worked together to form a National Photonics Initiative (NPI) (https://www.lightourfuture.org/home/about-npi/history/).

The NPI as well as the professional society OSA and the industry association Optoelectronic Industry Development Association (OIDA) took up educating Congress about the importance of photonics. As a result of their efforts, the America COMPETES Reauthorization Act of 2014, the Reinvesting in American Manufacturing Innovation (RAMI) Act, and the 2015 National Defense Authorization Act (NDAA) for FY 2015 contained language supporting photonics (Willner 2015). In 2015, the Advanced Manufacturing National Program Office (AMNPO n.d.) chose photonics as the focus area of one of the 16 public-private manufacturing innovation institutes (Manufacturing USA n.d.) created as part of the Federal initiative to revitalize American manufacturing.

The American Institute for Manufacturing (AIM) Photonics established the infrastructure for integrated photonics based on an open foundry model. It offered multi project wafer (MPW) and small production runs for research. This provided smaller companies a way to obtain prototypes of their designs.

Partners and Roles

Currently, AIM Photonics has more than 126 consortium members. Each member brings its unique expertise to the effort.

- Air Force Materiel Command executed the Cooperative Agreement.
- The State University of New York (SUNY) Poly provides the 300 mm wafer fabrication facilities that support the multi-project wafer (MPW) runs (https://www.aimphotonics.com/mpw-details).
- The Massachusetts Institute of Technology (MIT) and the University of California at Santa Barbara (UCSB) perform research on integrating lasers onto silicon.
- Rochester Institute of Technology (RIT), University of Rochester, University of Albany, and Columbia University contribute packaging, assembly, and test expertise.
- Analog Photonics developed the process design kit (PDK) that supports the multi project wafer (MPW) runs.
- The MOSIS Service aggregates MPW fabrication runs, distributes the PDK, runs final design rule checking, and inserts IP blocks from library.

Governance

The Research Foundation for The State University of New York (Foundation) provides administrative services to SUNY. The Foundation executed the Cooperative Agreement with the Air Force Materiel Command, and is the administrator for AIM Photonics. It provides the staffing from its 13,772 employees, (RF SUNY n.d.) enters into contracts on behalf of AIMS Photonics, administers financial matters, and manages the operations. Members that participate in Government-directed projects enter into a Project Award Agreement with the Foundation.

The Executive Director of AIM Photonics is responsible for day-to-day management of AIM Photonics and implementing the strategy, tactics, and policies of the Leadership Council. The Executive Director appoints the other executive officers and may remove an executive officer from their position at any time. Currently, Professor John Bowers from The University of California at Santa Barbara is the Executive Director. The other executive officer positions are the Chief Operating Officer, Chief Technology Officer, Chief Marketing Officer, Chief Financial Officer, Education and Workforce Training Executive, and Director of Program Management. AIM Photonics fills these positions with members.

The Leadership Council provides advisory input to the AIM Photonics executive officers and the Foundation concerning the operation of AIM Photonics. It approves any changes to the Membership Agreement and Bylaws, and designates committees, including a Technical Review Board, Roadmapping Committee, and Conflict of Interest Subcommittee. The Leadership Council has 12 representatives consisting of: (AIM Photonics n.d.b)

- Government—the government representatives serve for the duration of the Cooperative Agreement or any other agreement with the Federal Government that provides funding.
- New York State—New York State designates a representative that the Leadership Council approves. New York State, a New York State agency or Foundation the New York must employ the representative, or the representative must act on behalf of SUNY Poly.
- Commonwealth of Massachusetts—Massachusetts designates a representative that the Leadership Council approves. The Commonwealth of Massachusetts or a Massachusetts Commonwealth agency must employ the representative.
- Chairman of the Leadership Council—the chairman of the Leadership Council is a non-voting, non-executive representative.
- Other—the Leadership Council in collaboration with the Foundation approves the remaining representatives that come from the membership.

Each Leadership Council representative, other than the non-executive Chairman, is entitled to one vote on Leadership Council decisions. All Leadership Council decisions require a two-thirds vote of the voting members of the Leadership Council present at a meeting. Quorum requires the presence of two-thirds of the number of members' representatives serving at the time of the vote.

Funding

AIM Photonics relies on three sources of funding: Federal, State, and industry (GAO 2017, 55).

- **Federal:** Originally AIM Photonics received $110 M over five years from DoD. (DHHS n.d.) Currently, it is negotiating an agreement for seven years of follow-on funding. (Sharpe 2021)
- **State:** New York State provided about $250M; California, Arizona, and Massachusetts put in about $10M total, much of which was in kind contributions.
- **Industry:** Industry committed about $240M for the center.

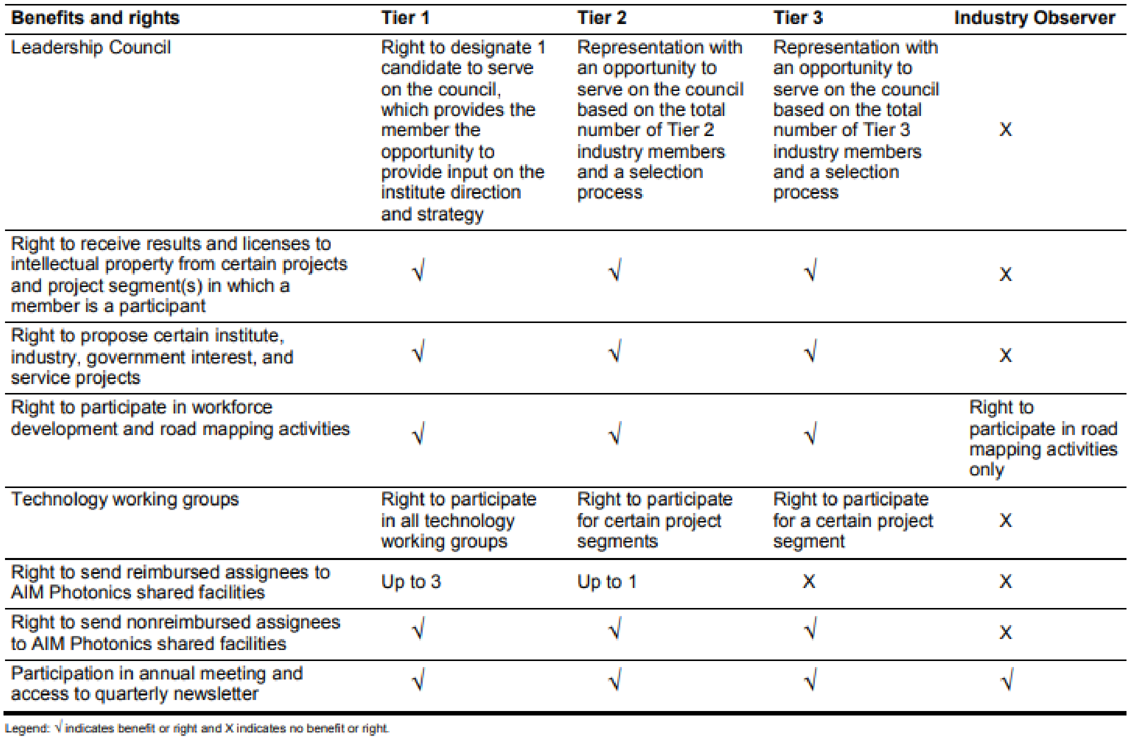
In 2017, the Commonwealth of Massachusetts funded the Laboratory for Education and Application Prototypes (LEAP) at MIT to focus on packaging. In 2018, it provided $4 M in funding for a second site at the Worcester Polytechnic Institute, which also serves Quinsigamond Community College. In 2019, it provided $3.8M in funding to Stonehill College and Bridgewater State University for a third LEAP site. (AIM Academy n.d.)

The AIM Photonics business model divides into two phases. The first, AIM 1.0, covers the first five years. That business model, however, did not match its membership structure, so AIM Photonics changed its business model to reflect its membership better. We call this second phase AIM 2.0.

AIM 1.0 Business Model

AIM 1.0 had a tiered membership dues scheme modeled after Sematech. Tier 1 participants contributed $1 million annually to join with a five-year commitment. Tier 2 contributed $500,000 and Tier 3 $100,000 annually with three-year commitments. Both Tier 1 and Tier 2 members could make in-kind contributions as part of their fee, but the cash contribution had to be at least $100,000. Tier 3 members could include in-kind as their contribution. Industry observers paid $2,500 in cash, with a one-year commitment. Table F-2 summarizes the industry membership rights and benefits.

Table F-2. AIM 1.0 Industry membership rights and benefits



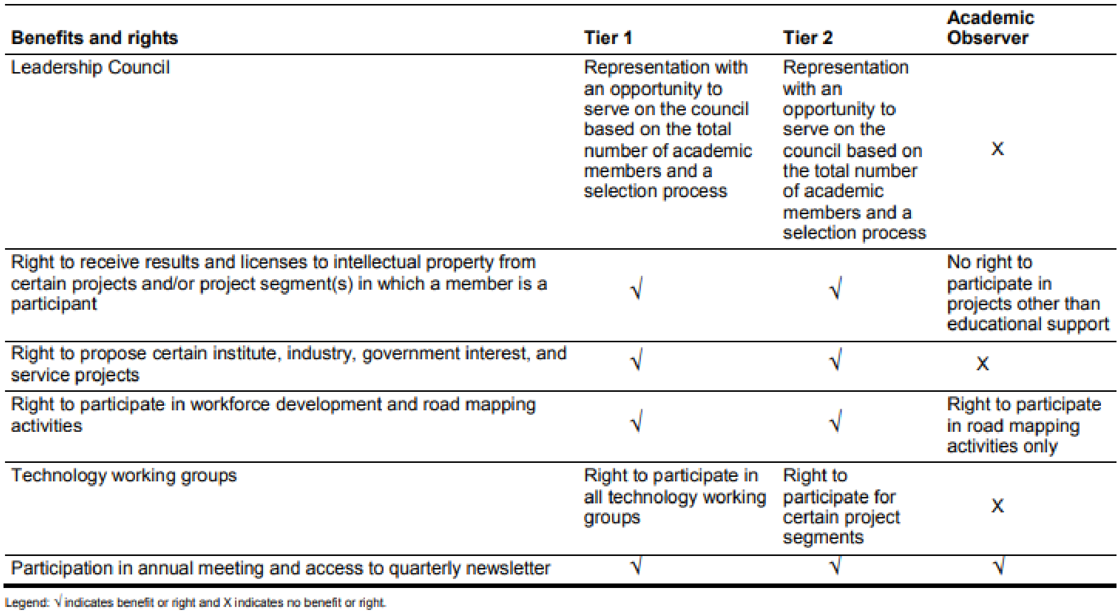
Benefits and rights	Tier 1	Tier 2	Tier 3	Industry Observer
Leadership Council	Right to designate 1 candidate to serve on the council, which provides the member the opportunity to provide input on the institute direction and strategy	Representation with an opportunity to serve on the council based on the total number of Tier 2 industry members and a selection process	Representation with an opportunity to serve on the council based on the total number of Tier 3 industry members and a selection process	X
Right to receive results and licenses to intellectual property from certain projects and project segment(s) in which a member is a participant	√	√	√	X
Right to propose certain institute, industry, government interest, and service projects	√	√	√	X
Right to participate in workforce development and road mapping activities	√	√	√	Right to participate in road mapping activities only
Technology working groups	Right to participate in all technology working groups	Right to participate for certain project segments	Right to participate for a certain project segment	X
Right to send reimbursed assignees to AIM Photonics shared facilities	Up to 3	Up to 1	X	X
Right to send nonreimbursed assignees to AIM Photonics shared facilities	√	√	√	X
Participation in annual meeting and access to quarterly newsletter	√	√	√	√

Legend: √ indicates benefit or right and X indicates no benefit or right.

Source: GAO (2017, 57).

AIM 1.0 had two tiers of membership for academic institutions and nonprofit organizations. Tier 1 required in-kind, and tangible and intangible contributions such as software licenses, hardware, services, and expertise as provided in their membership agreement, which is not public. Tier 2 required the same in-kind contributions with the difference being that it accepts overhead costs instead of expertise. Academic observers paid no fee. Table F-3 summarizes the academic and nonprofit membership rights and benefits.

Table F-3: AIM 1.0 academic and nonprofit membership rights and benefits



Benefits and rights	Tier 1	Tier 2	Academic Observer
Leadership Council	Representation with an opportunity to serve on the council based on the total number of academic members and a selection process	Representation with an opportunity to serve on the council based on the total number of academic members and a selection process	X
Right to receive results and licenses to intellectual property from certain projects and/or project segment(s) in which a member is a participant	√	√	No right to participate in projects other than educational support
Right to propose certain institute, industry, government interest, and service projects	√	√	X
Right to participate in workforce development and road mapping activities	√	√	Right to participate in road mapping activities only
Technology working groups	Right to participate in all technology working groups	Right to participate for certain project segments	X
Participation in annual meeting and access to quarterly newsletter	√	√	√

Legend: √ indicates benefit or right and X indicates no benefit or right.

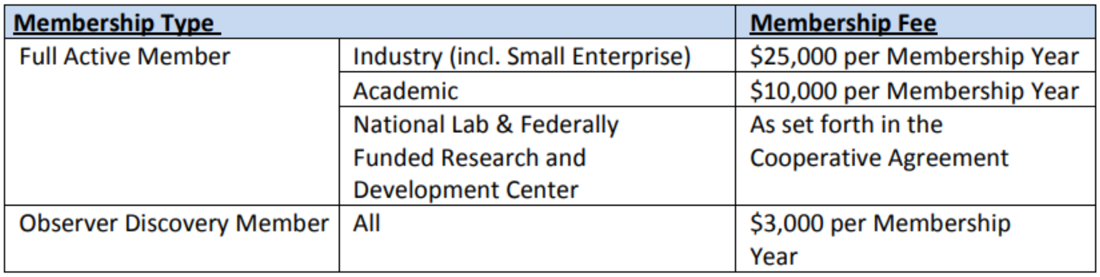
Source: GAO (2017, 58).

This dues structure worked well for large companies like GE and Cisco, but was not appropriate for smaller companies. Many smaller companies wanted to cover their entire dues with in kind resources. The dues structure prevented them from joining AIM Photonics.

AIM 2.0 Business Model

AIM Photonics revised its membership structure. It substantially lowered its dues and simplified the membership categories. Currently, membership is only at two levels of engagement, observer and participant. The observer level annual membership fee is $3,000. Participant membership fees are $25,000 for industry, and $10,000 for academic institutions. National Laboratories, and Federally Funded Research and Development Centers pay an amount set in the terms of the Cooperative Agreement, which is not a public document. Table F-4 summarizes the membership fee structure and Table F-5 summarizes membership rights and benefits.

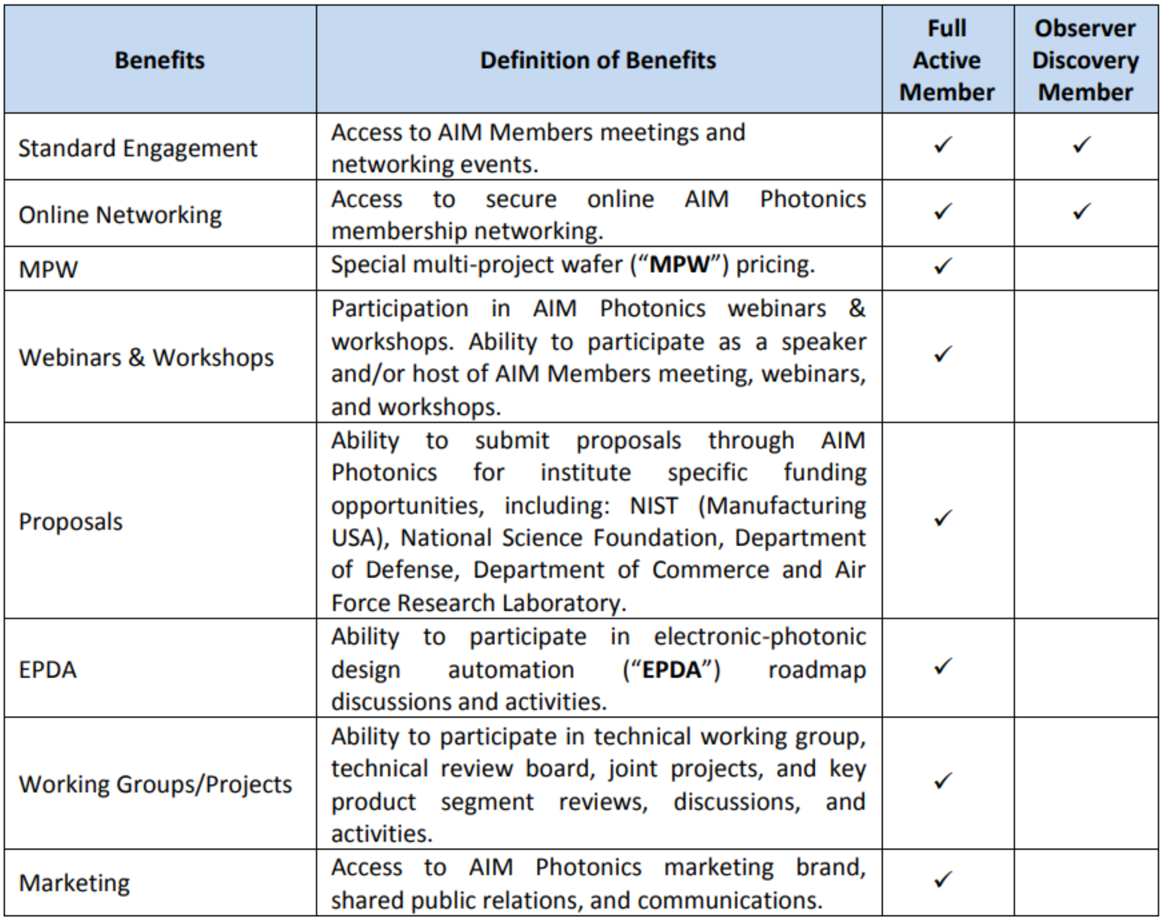
Table F-4 Summary of AIM 2.0 membership fee structure



Membership Type		**Membership Fee**
Full Active Member	Industry (incl. Small Enterprise)	$25,000 per Membership Year
	Academic	$10,000 per Membership Year
	National Lab & Federally Funded Research and Development Center	As set forth in the Cooperative Agreement
Observer Discovery Member	All	$3,000 per Membership Year

Source: AIM Photonic Membership Agreement. AIM Photonics (n.d.c)

Table F-5: AIM 2.0 membership rights and benefits



Benefits	**Definition of Benefits**	**Full Active Member**	**Observer Discovery Member**
Standard Engagement	Access to AIM Members meetings and networking events.	✓	✓
Online Networking	Access to secure online AIM Photonics membership networking.	✓	✓
MPW	Special multi-project wafer (“**MPW**”) pricing.	✓	
Webinars & Workshops	Participation in AIM Photonics webinars & workshops. Ability to participate as a speaker and/or host of AIM Members meeting, webinars, and workshops.	✓	
Proposals	Ability to submit proposals through AIM Photonics for institute specific funding opportunities, including: NIST (Manufacturing USA), National Science Foundation, Department of Defense, Department of Commerce and Air Force Research Laboratory.	✓	
EPDA	Ability to participate in electronic-photonic design automation (“**EPDA**”) roadmap discussions and activities.	✓	
Working Groups/Projects	Ability to participate in technical working group, technical review board, joint projects, and key product segment reviews, discussions, and activities.	✓	
Marketing	Access to AIM Photonics marketing brand, shared public relations, and communications.	✓	

Source: AIM Photonic Membership Agreement. AIM Photonics (n.d.c)

With this new structure, academic and small enterprise members can also receive a credit toward their membership fee for up to the amount the member books on multi-project wafer (MPW) runs, full wafer runs, and assembly, test, and packaging services purchased in that membership year. If the amount spent exceeds the fees for that year, the remaining amount does not roll over to the following year's membership. A small enterprise has 500 or less employees.

Operations

AIM Photonics has targeted their activities towards Manufacturing Readiness Levels (MRL) 4 to 7 with transition capability to MRL 8 and 9.(AIM Photonics n.d.d)

The Technical Review Board (TRB) provides operational oversight of AIM Photonics. (NPI n.d.) It identifies projects that would have the highest impact on baseline and advanced capability. It has four Key Technology Manufacturing Area (KTMA) committees:

- High speed digital data and communications links;
- Analog radio frequency (RF) applications;
- Integrated photonic sensors; and
- Phased array technologies.

The high-speed digital data and communications links KTMA focuses on the challenges of manufacturing high volume, low cost, terabit-scale photonic interconnectivity technology for advanced, high performance, embedded computing and data centers. It works on ultra-high-speed, high quality, multi-wavelength communications links that exceed Tb/s bandwidth densities, and multi-port spatial and wavelength selective reconfigurable switches.

The analog radio frequency applications KTMA develops manufacturing technologies that target high volume, chip-scale, microwave photonics for applications requiring high optical performance fidelity. It addresses the challenges of integrating high-dynamic range, ultra-low loss broadband PICs and microwave frequency electronic ICs for communication links using analog RF transmission.

The integrated photonic sensors KTMA addresses the manufacturing challenges of chemical and biochemical sensors fabricated from glass and silicon materials. It also demonstrates how the proposed solutions can facilitate high-volume production of embedded sensors connecting to, or integrated in, mobile platforms. It develops and demonstrates manufacturing methods that enable the miniaturization of sensor systems based on glass and silicon integrated photonics, and on novel engineered glass surfaces.

The phased array technologies KTMA addresses the manufacturing challenges associated with PIC phased arrays. Phased arrays enable steered projection and imaging without any moving parts. Its focus includes free-space communications, light detection and ranging (LIDAR), biomedical imaging, and display technologies.

The consortium focuses on several specific technical areas: high-speed digital-data and communication links; LIDAR; and new sensors. AIM Photonics has set up four Manufacturing Centers of Excellence:

- Electronics and Photonics Design Automation (EPDA);
- Multi Project Wafer and Assembly (MPWA);
- Inline Control and Test (ICT); and
- Test, Assembly and Packaging (TAP).

The Electronics and Photonics Design Automation Center of Excellence is developing a set of integrated design tools for photonic and combined electronic-photonic components. It has developed modeling capability for both silicon (Si) and indium phosphide (InP) devices, an integrated electronic-photonic design environment, design tools, and a PDK.

Multi Project Wafer and Assembly Center of Excellence provides multi project wafer processing and assembly services for both Si and InP devices. It acts as the foundry broker and manages foundry operations. It provides in-house InP and 300 mm Si fabrication facilities,[10] performs laser integration, and fabricates interposers for 2.5 dimensional (D) and 3D integration. NextFlex issues project calls to develop technologies that are critical to FHE manufacturing. NextFlex has a transparent process for selecting new projects. First, the Technical Council works with the TWGs to develop a technology roadmap, which identifies gaps. It prioritizes the focus areas that will address the gaps, and provides the Governing Council with a list.

Project topics fall in one of two categories. NextFlex-Funded Topics focus on developing and qualifying manufacturing processes, methods, or tools identified via the roadmapping process and in discussions with TWG leads, members, and government partners. DoD agencies that will provide funding for the projects develop Agency-Funded Topics.

The Governing Council reviews the focus areas for NextFlex-Funded Topics and approves the ones selected for a new project call. The Technical Council issues a project call with both NextFlex-Funded and Agency-Funded Topics to NextFlex members.

Each project call publishes a guidebook. The guidebook identifies the project focus areas, as defined in the FHE roadmap. It contains all the relevant dates, the duration of the

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[10] Note that at only two to six-inches diameter, indium phosphide wafers are much smaller than the 300 mm diameter silicon wafers.

project, maximum level of available Federal funding, a description of the efforts sought, the evaluation criteria, and a detailed format for proposals. NextFlex projects do not call for performers to deliver a prototype device, but rather, to develop capabilities that close gaps.

Members form teams to respond to the project call with a proposal. NextFlex holds Teaming Events where members can pitch their proposal ideas and capabilities to other NextFlex members who are looking to collaborate. Each company can pitch only one proposal idea. Each presenter gets one minute and one slide for their pitch. The teams form, and develop proposals they submit in response to the project call.

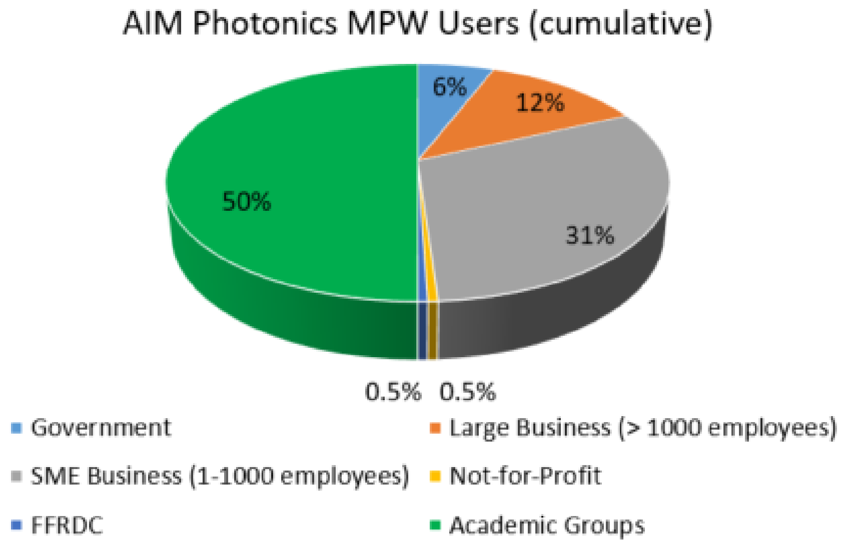
The Technical Council, member volunteers, NextFlex staff, and government subject matter experts (SME) review the submitted proposals. Reviewers evaluate the proposals, score each proposal based on the published evaluation criteria, and provide comments. NextFlex compiles and analyzes the reviews, and summarizes the comments for the NextFlex Technical Council.

The Technical Council recommends the proposals addressing NextFlex-Funded Topics to the Governing Council for funding. The Governing Council votes to select the projects for award negotiation and funding. Agency-Funded Topics proposals go through a similar review process. The DoD agencies, however, select and fund the performers. NextFlex executes the contracts with the performers.

NextFlex underwrites up to 50 percent of a project's costs. The teams provide the rest as cost-share, which can include labor, materials, use of equipment, and travel. The project cost, however, may not include a profit or fee. The cost-share requirement applies to the entire team. Individual team members can contribute less than 50 percent, but the team as a whole must contribute over that amount. This allows larger, better-financed companies to shoulder the funding burden for smaller, less financially resourced companies.

All recipients of NextFlex funding must be members. This requirement applies to every member of the project team. Companies supplying standard commercial off-the-shelf (COTS) components to team members, however, are not required to be NextFlex members.

At the end of the project, the performers deliver the project reports. Teams deliver the NextFlex-Funded Topic reports to NextFlex. It publishes the project reports on the NextFlex Member Portal and includes them in quarterly update webinars to the members. Teams deliver Agency-Funded Topic reports to the funding agency. The agency, at its discretion, may share them with NextFlex members. Figure F-2 shows the distribution of MPW users.



Source: Figure courtesy of Nicholas Usechak, Program Manager of AIM Photonics, developed under Air Force Research Laboratory agreement FA8650-15-2-5220.

Figure F-2: AIM Photonics—SUNY Poly MPW subscription profile

The Inline Control and Test Center provides optical testing for photonics applications using inline and stand-alone approaches. It offers high-throughput, high functionality, wafer-scale optical probe testing on wafer photonic test cells for process control and multi-channel input/output (I/O) fiber array test interfaces.

The Test, Assembly, and Packaging Center of Excellence, located in Rochester N.Y., is an in-house photonics prototype packaging center. It develops standardized, automated, no-touch processes for PIC test, assembly, and packaging. It integrates 2D, 2.5D, and 3D subassemblies into a system-level package using fiber and waveguide attach, and pick and place capabilities. It uses sub-micron 3D inspection tools.

The AIM Photonics' PIC development team in Albany, N.Y. is available to help AIM Photonics members with their PIC designs. The photonics member community can access design libraries created by AIM Photonics and then transfer that design to the chip development team in Albany. After AIM Photonics fabricates the PIC, it transfers it to the TAP facility for final testing, assembly, and packaging.

Intellectual Property

AIM Photonics Bylaws (AIM Photonics n.d.e) set the intellectual property rights of the members. Project participants own all intellectual property (IP) that their employees working on an AIM Photonics project create. Every other active member and its affiliates receives a worldwide, irrevocable, non-exclusive, non-transferable, royalty free, perpetual license to use the IP solely for internal research and development, academic research, and other not-for-profit scholarly purposes.

To use project IP that another AIM Photonics member developed for commercial purposes, the member needing the IP must negotiate a license with the member owner(s) for the IP and any necessary background IP. The government obtains government purpose license rights. All member licenses are non-exclusive with some narrow exceptions where AIM Photonics may grant exclusive licenses. (AIM Photonics n.d.f)

If a member leaves AIM Photonics, the remaining members retain the rights to the leaving member's IP that the departing member developed as a project participant. A terminating member will continue to have all the rights to project IP that they have developed while they were a member of AIM Photonics.

Other Protections

AIM Photonics members must comply with all applicable export control laws and regulations of the United States, including the Export Administration Act, the Arms Export Control Act, International Traffic in Arms Regulations, the Department of Commerce Export Administration Regulations, and any other U.S. government directives related to export control. (AIM Photonics n.d.g) Project proposals must identify any export-controlled information that a member expects to disclose or develop in an AIM Photonics project.

Each AIM Member must develop and adopt its own procedures that comply with export control regulations. AIM Photonics members must obtain the U.S. Government's approval before assigning or granting foreign entities access to any work, equipment, or technical data generated under the Membership Agreement, Bylaws, or a Project Award Agreement. It must also notify the Research Foundation of the State University of New York of such approval.

Leadership Council representatives are subject to confidentiality and conflict of interest policies that the Leadership Council adopted. If a member receives confidential information, it must protect it for five years following the date of the initial disclosure. (AIM Photonics n.d.h)

Evaluation and Outcomes

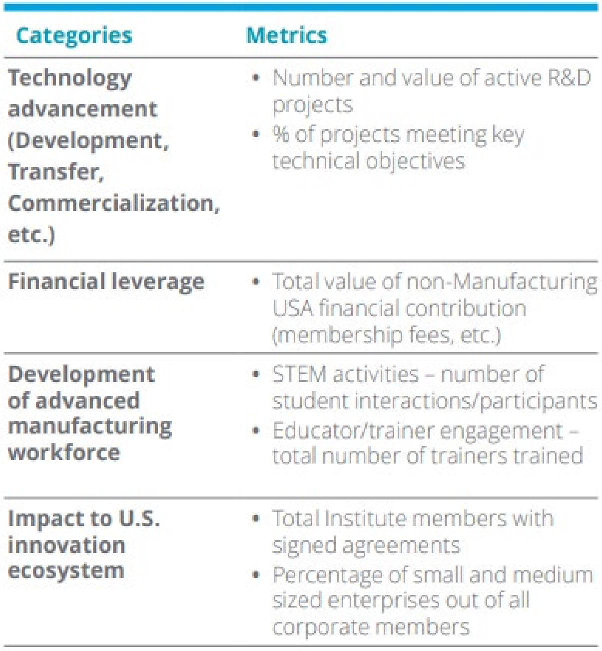
The TRB meets twice a year. Together with AIM Photonics executive management and government oversight, the TRB reviews proposed projects. It then prioritizes new projects and makes recommendations for existing project sunsets to the AIM Photonics executive team and the Leadership Council. This activity provides the executive team and the Leadership Council visibility into project status, linkages, and project management issues.

Manufacturing USA commissioned Deloitte Consulting, LLP (Deloitte) to conduct a third-party review and evaluation of the Manufacturing Innovation Institute Program

(Deloitte 2017). The study focused on the overall Program, and did not address the detailed operations of any individual Institute. The Institutes and their members, however, provided perspectives and information to assist in developing the Program-level analysis.

The scale and complexity of the Manufacturing USA's goal of establishing America as a global leader in manufacturing make developing metrics meaningful across all Institutes. Deloitte put considerable effort into developing appropriate evaluation strategies. Table F-6 shows the metrics that the Program, Institutes, and the governing agencies developed to measure the Program's progress.

Table F-6. Metrics that Manufacturing USA has in place to evaluate the Manufacturing Innovation Institutes



Categories	Metrics
Technology advancement (Development, Transfer, Commercialization, etc.)	• Number and value of active R&D projects • % of projects meeting key technical objectives
Financial leverage	• Total value of non-Manufacturing USA financial contribution (membership fees, etc.)
Development of advanced manufacturing workforce	• STEM activities – number of student interactions/participants • Educator/trainer engagement – total number of trainers trained
Impact to U.S. innovation ecosystem	• Total Institute members with signed agreements • Percentage of small and medium sized enterprises out of all corporate members

Source: Deloitte (2017, 60).

Lessons Learned

Note: Based on the study team's analysis of information.

One PPP's membership model is not necessarily appropriate for another PPP.

AIM Photonics adopted the membership dues model of Sematech. Sematech members, however, were mostly large semiconductor fabrication companies. Adopting this dues model worked well for big companies like GE and Cisco, but did not work well for smaller companies. The dues were too high and allowed in-kind contributions only in excess of a minimum cash contribution.

To better reflect its target members, AIM Photonics reduced the dues significantly and simplified membership structure by establishing only two levels of engagement, observer and participant. It eliminated the floor on cash contributions and accepted in kind for the full membership fee. Participants receive additional benefits, like reductions in multi-project wafer run cost, reductions in process design kit (PDK) costs, IP rights, and invitations to meetings. Money spent on multi-project wafer runs and PDKs count toward the dues.

The PPP must be flexible to meet the diverse needs of industry, government (DoD), and to satisfy academic research objectives.

Both DoD and industry want state-of-the-art technology, but they may not necessarily be interested in the same application areas. Small companies have different needs than large companies. Academics want to work on topics that lead to publications and areas that will generate follow-on research grants. If the PPP is to attract members from each of these diverse groups, it must offer each of them benefits to justify their joining. This requires open communication channels, finding areas of overlap, and adjusting accordingly.

Non-profit tied to a university reduced long-term stability concerns; however, universities and non-profits do not typically have experience in developing the level of income stream that AIM Photonics required for self-sufficiency.

Most universities have endowments that provide a level of stability in turbulent economic times; a foreign entity will not take over a university. Universities regularly raise larger chunks of funding for centers, buildings, and other activities. They do not have much experience, however, in developing the large income stream AIM Photonics would need to maintain that level. It would require raising over $125 million per year—a daunting task.

A relatively large amount of funding coming in early may lead to the lack of planning for self-sufficiency.

AIM Photonics started with funding in excess of half a billion dollars. This much money, early in the development process, had a negative effect. It created a degree of complacency, and the partnership did not begin the necessary efforts to identify and secure funds that would make it self-sufficient early in implementation of the PPP.

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Appendix G.
Case Study—Bridging the Innovation Development Gap (BRIDG)

Note: For all case studies, information is based on interviews unless otherwise cited. Lessons learned are the study team's own analysis.

Table G-1. Summary of BRIDG

Goals	For the three foundational partners: Osceola County—Job creation, tax revenues (e.g., to the State), and other economic benefits. University of Central Florida (UCF)— Access to a facility for faculty to conduct research for themselves as well as its graduate students in order to provide improved educational and vocational benefits to its student body. BRIDG—From a technical perspective, BRIDG wanted to accelerate technology commercialization by providing semiconductor R&D and high-mix, low-volume manufacturing capabilities to industry and government.
Origins	UCF and Orange County, Florida were working with some SEMATECH to create the BRIDG facility. When arrangements to establish a facility broke down, Osceola County stepped in to replace Orange County to fund the construction of the fab in 2014. Also, in 2014, BRIDG was established as a research consortium to operate the facility.
Partners and Roles	**Federal:** Defense Microelectronics Activity, U.S. Economic Development Administration; Provided resources as a fee for service. **Private:** Evercell, L3Harris, IMEC, Massey services Inc., Photon Delta, Photon-X, Secure Foundry, Semiconductor Systems Corporation, Siemens, Mentor, SPTS, Synopsys, Tokyo Electron; Provided resources as a fee for service or in a cooperative agreement relationship. **Academia:** University of Central Florida, Arizona State University, Florida International University, Florida Atlantic University, Florida Polytechnic University, Northern Arizona University, State University System of Florida, SUNY Polytechnic Institute, University of Florida, University of South Florida **Nonprofit:** Argonne National Laboratory, Florida Department of Economic Opportunity, Florida Makes, Greater Osceola, Orlando Economic Partnership, Enterprise Florida, MIST Center, Space Florida; Provided resources as a fee for service or in a cooperative agreement relationship. UCF paid some facility operating and some equipment costs. UCF incentivized some partnership arrangements. **Others:** Osceola County, Florida High Tech Corridor Council; Osceola County built the facility, an adjacent office building, a STEM magnate high school, and paid some equipment costs. The County also incentivized some partnership arrangements. The State of Florida earmarked funds for equipment and operating costs.

	Generally, the BRIDG website defines any organization with a one-on-one relationship with BRIDG (including customers) as a partner.
Governance	BRIDG was organized as a 501(c)6 not for profit corporation. It has a Board of Directors and corporate officers. BRIDG operated the Center for Neovation, marketed its capabilities, and sought contracts, grants, and partner relationships.
Funding	Osceola County (~$100M). UCF (~$16.7M). State of Florida (~$36M funded through UCF). The State of Florida was expected to contribute $25M annually. DoD contracts (~$29M).
Operations	**Years:** BRIDG was incorporated in 2014 under UCF. The Center for Neovation opened in March 2017. In August 2020, UCF terminated its agreement with BRIDG and laid off most of its employees. Today there are only two BRIDG employees. **Accomplishing Work:** Partners would generally begin with TRL 3–4 technologies and mature them to TRL 5–6 as a result of the partnership. BRIDG engaged in one-on-one relationships with its partners/customers. There were supplier relationships, one membership agreement, fee for service arrangements, and production relationships. **Relevant Federal Authorities:** Not applicable.
IP	In general, any partner/customer with background IP retained that IP. Any IP produced during a partnership/contract/grant was jointly owned.
Other Protections	The Center for Neovation was a controlled access facility cleared to performed work at the SECRET level.
Evaluations and Outcomes	Although no formal metrics were maintained, BRIDG publicized the formation of partnerships, jobs created, and winning grants and contracts. The BRIDG goals were not met and the PPP was effectively dissolved. The Center for Neovation is now being operated by SkyWater Technology, and UCF is no longer the lease holder of the facility.
Lessons Learned	BRIDG relied on funding in which its availability was political (approval by legislative and executive bodies was needed), and disruption of funding led to the transition from BRIDG to SkyWater. Not all BRIDG foundational partners had a realistic understanding of their responsibilities associated with the overarching PPP goal of commercializing technology, so when funding was disrupted, one foundational partner was unprepared and only sought to extricate itself because of the financial liability it faced. BRIDG had an over diversified technology roadmap at startup and, consequently, the business model and market niche did not materialize as expected, which may have delayed the formation of new partnerships as the business model evolved over time. Realism is necessary in determining the PPP's goals, and developing contingency plans, in advance, for situations that affect the PPP viability can manage the risks and uncertainties associated with achieving the PPP's goals.

Goals

Three foundational organizations formed the BRIDG PPP—Osceola County, the University of Central Florida (UCF), and BRIDG[11] which was a 501c(6) not for profit corporation established by UCF to operate and manage a 200mm microelectronics fabrication and research facility called the Center for Neovation.[12] Interviews identified that each organization had different goals for the PPP and that these goals remained constant over time.

- Osceola County. The County's goals were job creation and the realization of associated tax revenues (some of which would be for the State) and other economic benefits. Five fiscal and economic analyses were carried out. At the start, the expectation was that the Neovation facility could generate 1800 direct jobs and 80,000 indirect jobs after ten years. These estimates were later scaled back to 400 direct jobs and 16,000 indirect jobs. A later study indicated the possibility of high job creation and corresponding local and state tax revenues (Florida TaxWatch 2020, 6–11). Although that report based its estimates on analogies to SEMATECH and State University of New York Polytechnic Institute (SUNY Poly), its projections were attributed to the entire NeoCity commercial complex, a 500-acre planned community that includes other commercial, retail, and residential development (Perkins and Will, 2017). It should be noted BRIDG and UCF, the other partners, projected ~200 new jobs in five years (Soderstrom 2021b). These jobs were directly associated with the Center for Neovation; employment from the creation or relocation of partner infrastructure was excluded.
- UCF. The UCF goal was access to a facility for faculty to conduct research for themselves as well as graduate students in order to provide improved educational and vocational benefits to its student body.[13] Part of UCF's mission is to serve the local region. 90 percent of its students are from Florida and 70 percent stay in Florida. Developing a technology center and a regional institute was considered an extension of that mission.[14]
- BRIDG. From a technical perspective, BRIDG wanted to accelerate technology commercialization by providing semiconductor R&D and high-mix, low-volume

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[11] When the term BRIDG is used by itself, it represents the not for profit company. The term BRIDG PPP is used to represent the entire public private partnership.

[12] The Center for Neovation is also referred to as the BRIDG facility. It was originally called Florida Advanced Manufacturing Research Center.

[13] One term of the transition agreement between UCF and SkyWater Technology is a further indication of the consistency of the UCF goal. UCF will have free access to the Center for Neovation for eight years.

[14] One interview pointed out that the UCF goal might not have been realistic because it would be difficult for any university to use a facility designed for standard manufacturing technology.

manufacturing capabilities to industry and government. (BRIDG n.d.a) BRIDG operated the Center for Neovation, marketed its capabilities, and sought contracts, grants, and partner relationships.

Some consistency was found between BRIDG's goals and those of the County and UCF. UCF researchers using the facility would be included among the partner relationships that BRIDG pursued. All the research activity also serves as a catalyst for economic growth and strengthening the STEM talent pipeline. (BRIDG n.d.a) However the limited UCF value proposition was detached from Osceola County and BRIDG. Having a place for faculty and student research was not dependent on BRIDG creating jobs or BRIDG attracting partners. UCF was therefore a beneficiary of the other value propositions, but did not directly contribute to them. That situation was not conducive to optimal decision making for two principal reasons:

- Despite its limited goal, as will be discussed later, UCF, as the organization leasing the Center from the County, was responsible for the operating costs of the facility. In the beginning of the partnership, UCF appears to have not understood all that this entails because it assumed someone else would be paying those costs.
- UCF was not heavily engaged in BRIDG's principal activities.

Consequently, UCF may have acted somewhat in its own limited self interest in BRIDG decision-making processes, including those of the BRIDG Board of Directors where UCF was represented.

With its focus on commercialization, BRIDG operated at technology readiness levels between 3 and 6. Ideally, a potential partner would begin with a technology level of 3–4 (i.e., proof of concept), bring that technology to the BRIDG facility, conduct research at the facility to mature that technology to levels 5–6 where components and subsystems are demonstrated in a relevant environment, and then take the technology back to its own facility for full scale commercialization. The BRIDG facility could also support low volume production. All of the work was characterized as high-risk, high-reward. It was not considered to be incremental research.

Origins

Interviews indicated that Osceola County commissioned a cluster study in 2010 to diversify its economy from agriculture and tourism. The study identified technology and manufacturing as candidate areas of expansion. The County was therefore seeking investment opportunities and a reliable partner to promote job and other economic growth in these areas.

In the summer of 2012, UCF and community leaders from Orange County, Florida visited SEMATECH in Austin, Texas to explore the establishment of the SEMATECH Phase III Photovoltaic Manufacturing Consortium (PVMC) in Orange County, also known as Project Galaxy. In fact, a memorandum of understanding to proceed with Project Galaxy was signed August 23, 2013. Those plans did not come to fruition because SEMATECH had been in the process of a piecemeal relocation from Austin, TX to SUNY Albany and New York State was offering far greater incentives than Florida to move the remaining pieces (including PVMC) to Albany. This effort however created close working relationships between SEMATECH people, UCF and Orange County.

Building on that relationship, in the 2013–2014 timeframe, UCF and the SEMATECH people (then at SUNY Albany) approached Orange County with the idea of expanding upon the SEMATECH model[15] and persuaded Orange County to fund a semiconductor fab. Orange County backed out of the partnership at the last minute because it was unable to secure the necessary level of commitment from potential site partners. Meanwhile Osceola County was still looking for investment opportunities and took Orange County's place in the partnership in a very short time frame because it viewed UCF as the reliable partner it was seeking.

The net result was that Osceola County paid for building the Center for Neovation along with purchasing some of its equipment. The County already owned the land where the Center was built (Brinkmann 2017b). It agreed to lease the facility to UCF for $1 per year for 40 years, at which point UCF would assume ownership of the facility (Florida TaxWatch 2020, 10). UCF was also responsible for the operation and maintenance the facility. To meet the PPP goals, BRIDG was established as a research consortium to operate the facility, by UCF, Osceola County, and the Florida High Tech Corridor Council in 2014 (Martin 2020a). BRIDG was originally referred to as the International Consortium of Manufacturing Research (ICAMR).[16] The name change was attributed to confusion about the name and the potential to be denied grants because of international connotations (Santana 2017). Also, as part of the arrangement, the people working at SEMATECH who collaborated on the PPP relocated to BRIDG and BRIDG ultimately established a memorandum of understanding with SUNY Poly to help connect researchers with industry (Florida TaxWatch 2020, 13).

The BRIDG facility opened in March 2017. (BRIDG n.d.b) The facility occupies 109,000 square feet has the capability to fabricate 200mm wafers. The facility includes

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[15] At different times, BRIDG has exhibited characteristics of both the SEMATECH and SUNY PPPs. BRIDG initially planned to charge membership dues like SEMATECH. That business model was not successful; it transitioned to partners establishing a presence in NeoCity (or nearby) per the SUNY research park PPP model. Also, the concept of a university leasing the facility was closer to the SUNY model.

[16] Technically, ICAMR is doing business as BRIDG.

60,000 square feet of laboratory and manufacturing space with two cleanrooms, one operating at Class 100 standards and the other at Class 10,000 standards (Florida TaxWatch 2020, 4).

Over the next approximately three years, BRIDG entered into partnerships and competed for and won some DoD contracts. BRIDG had been facing difficulties covering its operating costs as a result of cutbacks by the State of Florida (see Funding and Business Model section). In December 2019, the UCF Board of Trustees deferred a decision to provide another $5M to support BRIDG (Santana 2019). UCF terminated its management services agreement with BRIDG in August 2020 (Soderstrom 2021a).

On January 25, 2021 Osceola County Commissioners approved a lease agreement with SkyWater Technology, a Minnesota based company, to operate the facility until 2044. UCF later transferred its obligations for operating the facility to SkyWater. What remains of BRIDG is supporting the transition to SkyWater. SkyWater intends to operate the facility as a commercial entity through an IPO.

Partners and Roles

Osceola County, the University of Central Florida, and the Florida High Tech Corridor Council are the founders of the BRIDG organization. The BRIDG website uses the word partners in a broad sense. The list seems to include customers, organizations involved in STEM education, organizations that provided equipment or other capabilities to the facility, organizations that could use the facility to mature technologies, organizations promoting economic development in Florida, etc.

Other partners include Argonne National Laboratory, Arizona State University, Defense Microelectronics Activity, Enterprise Florida, Evercell, Florida Department of Economic Opportunity, Florida International University, Florida Atlantic University, Florida Polytechnic University, Florida Makes, Greater Oceola, L3Harris, imec, Massey services Inc., MIST Center, Northern Arizona University, Orlando Economic Partnership, Photon Delta, Photon-X, Secure Foundry, Semiconductor Systems Corporation, Siemens, Mentor, SPTS, Space Florida, State University System of Florida, SUNY Polytechnic Institute, Synopsys, Tokyo Electron, University of Central Florida, University of Florida, University of South Florida, and U.S. Economic Development Administration.

Note: This list was created from the logos appearing at https://gobridg.com/what-is-bridg/partners/.

In general, the BRIDG partnerships were one-on-one engagements that benefited both parties. On the basis of the interviews, STPI categorizes them as follows:

- Supplier relationships where equipment suppliers could demonstrate process flow to their prospective customers.
- Production relationships where BRIDG and its partner jointly develop a capability that will become a production offering (from the partner[17]).
- Fee for service relationships where partners do not want to invest in the equipment necessary to demonstrate a new technological capability.

Some partnership examples are as follows (Florida Tax Watch 2020, 12–13):

- Enhance the reduction of systems through advanced interconnections. (L3Harris[18] Technologies)
- Develop tool and process technology to accelerate the commercialization of emerging technologies. (Tokyo Electron)
- Provide BRIDG with tools enabling faster smaller and lighter designs using low power. (Suss Micro Tec)
- Supply BRIDG with PLM software for the development of digital twin technologies. (Simmons)

BRIDG had a special, long standing partnership arrangement with IMEC. "IMEC USA also facilitates collaboration between its Belgium headquarters and U.S.-based semiconductor and system companies, universities and research institutes, and can offer critical services to companies seeking to develop and manufacture innovative electronics. These activities also significantly enhance the BRIDG fabrication operation by acting as a feeder to BRIDG's manufacturing development facility to align capabilities, produce prototypes, and support low-volume production." (i4 Business 2019) IMEC is located in the NeoCity office building adjacent to the Center for Neovation.

Governance

BRIDG was organized as a 501(c)6 not for profit corporation. This structure, which was the same as SEMATECH's, and allows the collection of membership fees from partners. BRIDG has a Board of Directors and corporate officers. While BRIDG employees were technically UCF employees (i.e., they were paid by UCF), UCF had no supervisory control (other than having representation on the BRIDG Board of Directors)[19] over the

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[17] As a not for profit, it would be difficult for BRIDG to sell semiconductor products to commercial entities or the government.

[18] The partnership was originally with Harris Corporation. L3 Technologies and Harris Corporation merged in 2019.

[19] All BRIDG employees reported to a BRIDG-employed supervisor. The BRIDG CEO reported to the BRIDG Board of Directors.

BRIDG functions in operating the Center for Neovation, seeking partnership opportunities, and soliciting financial and other support for the facility.

Funding

About $100M in investments were made by Osceola County into the BRIDG facility (Brinkman 2017b). This includes the Center for Neovation ($70+M), an adjacent office building, and NeoCity Academy, a magnet high school ($15M).

Interviews described that the overarching business model for BRIDG anticipated funding from four sources:

- State funding
- Member dues
- Revenue from selling time in the facility
- Grants and contracts

State Funding:

At the start of the PPP, State funding was anticipated to be ~$25M per year to cover operating expenses. For a fab such as the BRIDG facility, utility costs are estimated to be $2.5M annually without any production. STPI estimates labor costs for full employment of ~200 people to be ~$25.5M (Martin 2020b).[20] State funding was always expected to be the main source of revenue for the first several years of operation. A comparison was drawn to IMEC, which took 11 years to reach breakeven. It's unclear why state funding at this level did not materialize. Some felt that it was an unrealistic expectation. Others attributed it to a change in political priorities. One opinion suggested that unrelated tension between UCF and the State was partly to blame.

BRIDG did receive some funding from the state of Florida and UCF to cover operating expenses (which included the salaries for BRIDG employees) and tooling. Since UCF is funded by the State and State funding earmarked for BRIDG flows through UCF, different sources have attributed different amounts to the two sources.

- For State of Florida funding, one source reported $36M in funding and another reported $22.5M. The difference may be explained by whether or not the total included both recurring and nonrecurring funding. Recurring funding covered operating expenses while the nonrecurring investment was used for the purchase of tooling.

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[20] This estimate is based on $63,703 as the average annual advanced manufacturing salary in Florida (attributed to ZipRecruiter by the March 2020 TaxWatch report p. 15) with a multiple of 2.0 for indirect and overhead costs.

- Other sources report that UCF has invested \$25.7M in BRIDG. However, \$9M of that amount was a pass through to IMEC to incentivize its partnership with BRIDG.

Member Dues:

BRIDG was originally conceived as a consortium where partners would pay membership fees to use the facility to conduct research. Instead it became a manufacturing center focused on obtaining grants and contracts to test and package semiconductor chips for federal agencies (Martin 2020b). The rationale for pursuing a membership model is that members would find it advantageous to gain access to technology and share ideas with other members. Then each member would agree on how projects funded with the collected membership fees would be developed and carried out. IP arrangements would also be established. The difficulty in implementing a successful membership model with BRIDG is that there was no demonstrated capability for members to share. In addition, since BRIDG was focused on maturing technologies for commercialization, there could have been competitive or IP barriers to the membership fee model. Only Harris Corporation, which was one of the first partners, actually paid a membership fee.

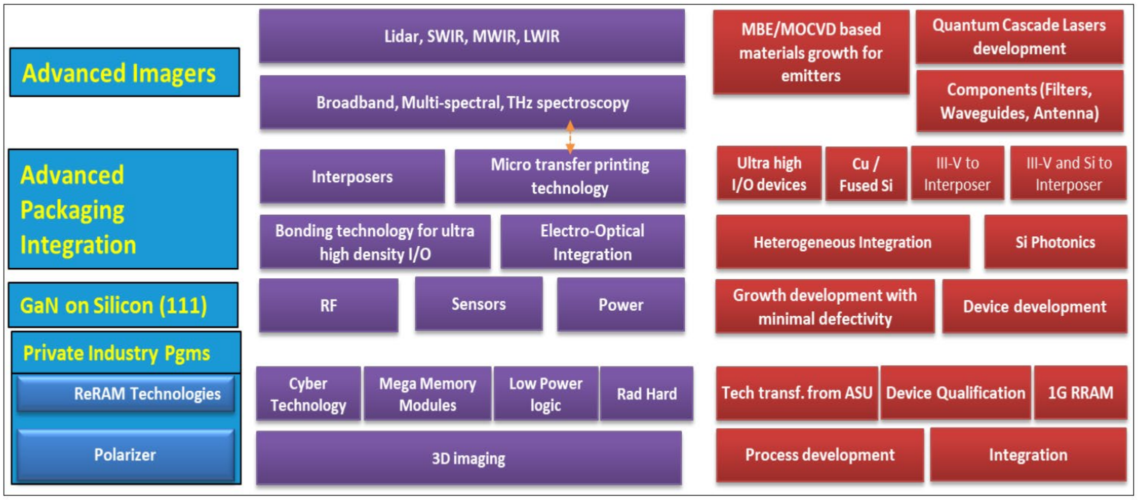
Revenue from selling time in the BRIDG facility

Although some partnership arrangements may have resulted in revenue to BRIDG, such arrangements were not a major source of income. BRIDG also accepted equipment or a reduced price to purchase equipment in lieu of revenue. Some partnerships, e.g., Tokyo Electron, were even subsidized by Osceola County. In the case of IMEC, the partnership was subsidized both by the County and by UCF.

Contracts or Grants

As of January 2021, BRIDG had been awarded \$29M in three ongoing defense contracts that have a ceiling value of \$70M (Soderstrom 2021a). One contract is with Air Force Research Laboratory and a second contract is with the Navy. The third contract is from the Industrial Base Analysis and Sustainment Program managed by the Industrial Policy Office in the Office of the Secretary of Defense.

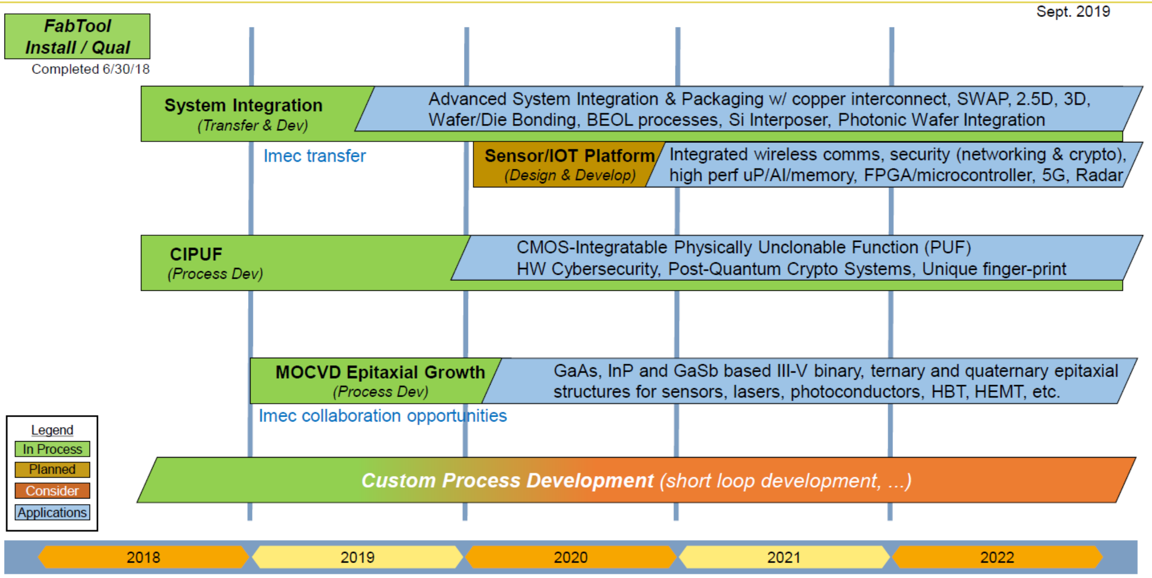
The business plan for attracting revenue from selling time in the facility or from grants and contracts has been criticized for being too diffuse (the technology roadmap was too broad). Figure G-1 shows an early BRIDG technology roadmap containing more than 50 different technologies.



Source: Obtained from interviews.

Figure G-1. Early BRIDG Technology Roadmap

Based on conversations with potential partners, Figure G-2 is a later version of the BRIDG technology roadmap focusing on a few critical niche areas that differentiated BRIDG in the marketplace. Although potential partners were confused about what BRIDG was doing, there was no evidence that this early over diversification detracted from business performance. It may have hindered the decision-making process for the acquisition of tooling.



Source: Obtained from interviews.

Figure G-2. Focused BRIDG Technology Roadmap

Operations

The PPP was based on customer/partner access to the Center for Neovation and the BRIDG technical staff to mature partner's technologies and to perform work on customer contracts and grants. Business development was incorporated in two ways.

- BRIDG marketed the capabilities of its facility and its people to develop additional partnerships and obtain revenue through contracts and grants.
- From a partner's perspective, the results of the partnership would be used to increase its own business endeavors.

Incubation services may have been a consideration, but they did not materialize to any great extent. It was clearly in the interest of Osceola County, UCF, and BRIDG for partners to establish a presence in the NeoCity area, possibly in the office building the County built adjacent to the BRIDG facility. BRIDG was situated in a larger industrial area that was not exclusively focused on the semiconductor or electronics sectors.

BRIDG has partnerships in place with academic institutions—including NeoCity Academy, a STEM-based high school in Osceola County—to develop a skilled microelectronics workforce in the United States. (BRIDGE n.d.c) The high school was to include hands-on-work with BRIDG professionals (Brinkmann 2017a).

Once a project had been established with a partner or customer, the work was carried out per an operating agreement which was created to define all of the terms and conditions of the arrangement. Internal review processes associated with BRIDG and the partner or customer would apply, similar to any commercial business arrangement.

IP

IP arrangements were defined in the operating agreements between BRIDG and its partners/customers. In general, if either party had IP prior to the partnership, then that party retained the IP. Any IP produced as a result of a partnership/contract/grant was jointly owned.

If more than one partner had been involved in a project, BRIDG, as a not for profit, could help establish the IP arrangements. No multi-partner relationships were identified in the interviews.

Other Protections

The Center for Neovation was a secured building thereby allowing BRIDG to be in a position to conduct sensitive work. Therefore, BRIDG was required to confirm the citizenship of its visitors. BRIDG held a secret clearance which would allow it to work on classified programs if required.

The DoD Trusted Foundry program provides a cost-effective means to assure the integrity and confidentiality of integrated circuits during design and manufacturing. (DMES n.d.) BRIDG worked with the Defense Microelectronics Activity to become an accredited supplier. It was on a pathway to become part of the trusted foundry program but had not yet met all of the requirements when UCF terminated the BRIDG work.

Evaluation and Outcomes

BRIDG's partnerships and contracts led to technological advancements. For example:[21]

- CMOS-Integratable Physically Uncloneable Function (PUF). PUF capability leaves no trace in hardware and consequently can become the basis of usable low-cost cryptography. In partnership with Arizona State University and Northern Arizona University, BRIDG made it producible. The significance is that it provides a root-of trust for multiple layers of security that is low power, highly integratable, difficult to hack, radiation hardened, and protected against reverse engineering and cloning.
- Advanced System Integration Program. BRIDG's partnership with technology companies provided solutions for size, weight, and power reduction to address challenges faced by conventional scaling. BRIDG developed a fabrication and assembly process for an order of magnitude beyond current state-of-the-art 2.5D/3.5D integration. BRIDG also demonstrated wafer-to-wafer bond yields (defined as 1M electrically connected i/O per die) of 87 percent across the entire wafer and drove the development of a next generation W2W automated bonder with 100 nm alignment accuracy.
- Silicon Interposer. BRIDG's partnership with IMEC enabled a conduit for IMEC technologies to be utilized by BRIDG. As a result, BRIDG won a $20.4 million multi-year Industrial Base Analysis and Sustainment contract award using IMEC's process technology and process design kits. The contract will deliver a bridge interposer, a digital high-density interconnect interposer, a high bandwidth/high speed digital interconnect interposer, and an RF interposer with integrated passive components.

Nevertheless, the overarching goals were not met and the PPP effectively fell apart.[22] Although no formal metrics were maintained, BRIDG publicized the formation of partnerships, jobs created, and winning grants and contracts. In December of 2019, BRIDG employed about 45 people (Santana 2019). That number appears to have decreased

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[21] Examples extracted from BRIDG-provided viewgraphs.

[22] The ongoing transition to SkyWater is not discussed in the case study.

significantly in August 2020, when UCF laid off nearly all BRIDG employees (Martin 2020a). Today, two BRIDG employees remain. A consistent theme among the interviews was that ROI metrics, although hard to develop, should be used. UCF attributes fewer than 10 new doctoral students and no additional microelectronics-related faculty positions to the PPP.

Lessons Learned

Note: Based on the study team's analysis of information.

BRIDG relied on funding in which its availability was political (approval by legislative and executive bodies was needed), and disruption of funding led to the transition from BRIDG to SkyWater.

There are risks associated with relying on politics to secure the funding necessary to operate. The external funding necessary for the PPP to successfully operate did not materialize as expected. Furthermore, the expectations of the organizers about the likelihood of receiving that funding may not have been realistic.

At the start of the PPP, the State of Florida indicated it would provide \$25M annually for five years for facility operating costs. Legislative priorities changed; only \$36M was forthcoming with a clear indication that there would be no funding in the future. Consequently, UCF was on the hook to cover the shortfalls and those resources would have to come from State funding for the University itself. Consequently, UCF extricated itself from the lease and the transition to Skywater took place.

Not all BRIDG foundational partners had a realistic understanding of their responsibilities associated with the overarching PPP goal of commercializing technology, so when funding was disrupted, one foundational partner was unprepared and only sought to extricate itself because of the financial liability it faced.

The second lesson learned is related to the first. It focuses on the UCF goal for the partnership which was simply to have a facility that could be used by its faculty and students. That goal did not substantially contribute to the BRIDG goal of attracting partners to commercialize their technologies. Spending money for operating costs (which could run \$2.5M annually just for utilities plus BRIDG employee salaries) was considered by UCF to be too high a cost for the benefits received.

BRIDG had an over diversified technology roadmap at startup and, consequently, the business model and market niche did not materialize as expected, which may have delayed the formation of new partnerships as the business model evolved over time.

Some aspects of the business plan were not sufficiently developed at the start of the PPP. The original business plan was based on a membership fee model and the associated

501c(6) status. That model was not practical because there were limited central core capabilities that potential partners would be willing to pay for. Even communications with potential partners were confusing because of the 501(c)6 status of BRIDG. In addition, BRIDG initially had too broad a technological focus and it did not know the technological areas where the bulk of its business partnerships would form. Consequently, the business model and market niche did not materialize as expected. BRIDG was able to adapt to overcome these issues with no major ill effects. A delay may have occurred in the formation of new partnerships or winning DoD contracts as the business model evolved over time.

Realism is necessary in determining the PPP's goals, and developing contingency plans, in advance, for situations that affect the PPP viability can manage the risks and uncertainties associated with achieving the PPP's goals.

Overall, the roles of the PPP organizers were not well understood at the start. There were inconsistencies in their visions and value propositions that were exacerbated by the funding shortages. Decisions were influenced by factors associated with the organizers outside of the overall PPP value proposition. In addition, decisions on how to use the limited operating funds were suboptimal.

To varying extents each of the above lessons learned can be attributed to overoptimistic expectations associated with situations that could have serious financial repercussions on the viability of the PPP. In the first case, the likelihood of external funding was overestimated. For the second lesson learned, the probability of a financial calamity was largely underestimated. Lastly, the PPP's leadership were overly optimistic about attracting partners and winning contracts and grants. Although it had no direct bearing on the PPP's outcome, the unrealistic estimates of job creation clearly fall into the same pattern. Risk management approaches, such as developing contingency plans for accomplishing the PPP's activities can help alleviate the potential impacts from these risks and the inherent uncertainties in R&D associated with the PPP's activities.

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Appendix H.
Case Study—Inter-University Micro Electronics Centre (IMEC)

Note: For all case studies, information is based on interviews unless otherwise cited. Lessons learned are the study team's own analysis.

Table H-1. Summary of IMEC

Goal(s)	Promote the microelectronics industry in Flanders, Belgium, supporting both industry and universities and excellence in scientific research and education
Origins	Part of the Flemish Government's regional science and technology strategy focused on building a microelectronics industry in the region
Partners and Roles	**National:** Flemish Government, provided initial full funding for infrastructure and continues to fund a portion of IMEC's activities **Private:** >600 industry partners and private sector collaborations; joint ventures; partner in regional research centers; and spin-offs, including ASML (Netherlands) for EUV lithography equipment **Others:** University of Leuven; KU Leuven, among other universities provide expertise and jointly affiliated researchers, targeted partners across Europe, now international
Governance	Governance Board (government, industry, academia) Technical Advisory Boards (global and cross-industry and sector) Leadership team combines roadmaps/directions across users Decisions are not consensus-based
Operations	**Years:** 1984—present **Accomplishing Work:** equivalent to TRL 1–4, higher TRLs for proprietary industry, evolving now to higher TRLs; About 5,000 (initially ~50 from University of Leuven), Vertically integrated services, computer-aided design, VLSI systems design methodologies, advanced semiconductor processing, materials, packaging, etc.; Research projects for customers negotiated bilaterally; Training division of IMEC supports universities in ASIC design and trains industry in chip design, makes software available; Provides Multi Project Chip—Multi Project Wafer services
Funding	Flemish Government provided $72M in 1984 (about $185M in 2021$US) Total revenues: $640M Euros in 2019 (about $770M in 2021$US); About 80% external/industry, 15% from Flemish Government; 5–10% from the European Union; initial goal was 50% external
IP	Bilateral agreements Existing: Background IP shared, non-exclusive licensing (for members of its Industrial Affiliation Programs)

	New IP: Users can pay more for full IP rights, otherwise shared and part of background IP pool at IMEC under Industrial Affiliation Programs
Security	Treated as business proprietary; no / minimal defense or government R&D users
Evaluation and Outcomes	Status as global research base (sponsored research, publications, patents) Operational excellence and financial sustainability (varied income streams) Status in educational excellence (PhD, joint projects with universities, presentations, cooperative projects) Contributions to the economy and industry (spin-off companies, start-up survival rate, jobs, fiscal returns to the region and Flemish Government) Social impacts Evaluation by Flemish Government conducted every 5 years inform update to business plan, independent consultants conduct impact studies Accomplished goals—Flanders transformed, and renowned catalyst for new technologies and spin-off companies, returns to the economy, field, and industries
Lessons Learned	Sustained and ongoing funding provided long-term support for infrastructure modernization and de-risking as IMEC's infrastructure and the technology needs evolved Cooperation and strategic partnering, including among industry competitors, accommodates differing value propositions for small and large established companies alike IMEC's autonomy and independence has allowed it to pivot and remain at the cutting edge Strategic management of IP and background IP are integrated into the business model to attract partners IMEC's infrastructure provides training platforms to develop and attract talent Strong connection to universities in early years to staff with experts and continued relationships with academia shape IMEC's expertise and value proposition today Historical and continued attention to spin-offs and support for start-ups bolsters focus to strengthen the innovation ecosystem Development of the local and regional innovation ecosystem takes time, and long-term vision and global touch points to support local and regional economic goals are necessary

Goals

The Inter-University Micro Electronics Centre (IMEC) was founded in 1984 with an initial investment by the Flemish Government in Flanders, Belgium. The goal of IMEC is to promote the microelectronics industry in Flanders, Belgium, supporting both industry and universities. Growing the domestic microelectronics capability in Flanders as well as supporting commercialization, start-ups, and the regional economy, such as by driving foreign investments into the region, were goals when establishing IMEC. In addition, cooperation with industry has been one of the prime goals of IMEC. These broad goals have not evolved since IMEC's establishment.

IMEC also has scientific-oriented goals, including excellence in research and education. Since its inception, IMEC was intended to function as a "*program-driven* institute coherently organized around forward-looking, multidisciplinary, open-ended and highly networked projects" (Mina, Connel, and Hughes 2009). It performs "research and development [R&D], ahead of industrial needs by 3 to 10 years, in microelectronics, nanotechnology, design methods and technologies for information communication technology (ICT) systems" (Bruynseraede n.d.). As such, the majority of the research projects at IMEC are at technology readiness level (TRL) 1 to 4. The research at these TRLs are pre-competitive in nature and relates to semiconductor process developments. However, IMEC also conducts collaborative and proprietary research, including the transfer of technologies to industry. These projects tend to be at higher TRL levels as they are important for a company's competitive edge. The nature of this work tends to focus on transfer of technologies to application domains and represents about 40% of their work.

Overall, IMEC's goals have been largely met due in part to its establishment as an independent and reputed, cross-sector research hub, providing access to state-of-the-art equipment and global talent (*see* D. Organizational Structure), its range of service offerings to meet prototyping and full volume production (*see* F. Operational Model), and its flexible intellectual property (IP) ownership model (*see* G. Accomplishing Work).

In addition, the Flemish Government initially had a goal of reaching 50 percent external (non-government) funding from IMEC partners. They met this goal around the mid-1990s.[23] Today, Flanders' industrial ecosystem and economy have been transformed. Based on an impact analysis of IMEC conducted by an independent consultant, from 2002 to 2011, IMEC supported about 35 percent employment growth (5,621 employees), about 70 percent in total value added to the economy (about $420M in in 2021$US), and about 50 percent in fiscal returns (e.g., through social security and corporate taxes) to the Flemish Government (about $280M in 2021$US) (VanRossum n.d., IDEA n.d., IDEA 2015).[24]

IMEC is also a renowned catalyst for new technologies and spin-off companies. Its first spin-off company was established in 1986 and the number of spin-offs have grown over the years with 6 spin-offs in 2019 and 5 in 2020. Since 1986, IMEC has helped spin out 131 companies (IMEC n.d.a). In terms of its intellectual property (IP) portfolio, IMEC

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[23] From funding source information on slide 4 of Bruynseraede (n.d.).

[24] Data from IDEA Consult's 2012 Impact Evaluation, as reported in VanRossum (n.d.); for further on IDEA's impact analysis, *see* https://www.ideaconsult.be/en/projects/impact-of-imec, and for further on IDEA Consult's methodologies for impacts, *see* https://www.earto.eu/wp-content/uploads/EARTO_Economic_Footprint_Report_-_final2015.pdf.

has had more than 1,700 patents issued by the European Patent Office and more than 600 by the U.S. Patent and Trademark Office.[25]

As IMEC leadership looks into the future, they plan to focus on higher TRLs and research with a higher and direct value proposition to industrial partners. This evolution is driven in part by the uncertainties in the microelectronics industry looking beyond the next decade of technologies and the unknowns in the industry over the next few years, such as what new technology applications and markets will develop.

Origins

At the time when IMEC was established, the Flemish Government was implementing a regional-specific technology policy focused on the creation of infrastructure to provide a supportive environment for industrial development (Segers 1992). The government focused on the microelectronics industry as part of its science and technology program to promote the third industrial revolution in Flanders. IMEC was established as a laboratory for advanced research in microelectronics alongside the establishment of a foundry and a training program for very large scale integration (VLSI) design engineers.

Universities were at the center of forming IMEC in its initial years, including the Catholic University of Leuven (KU Leuven) and the University of Leuven. At that time, research across different universities was fragmented, and KU Leuven Prof. Van Overstraeten's vision was to create a more collaboration between universities with the involvement of industries from across the globe.

Partners and Roles

Initially, the main partners in starting IMEC were the local universities, which provided their faculty as experts to build IMEC's knowledge base, and the Flemish Government, which provided the majority (about two-thirds) of IMEC's research and development (R&D) budget through its subsidiaries, such as the Ministry for Economic Affairs and the Ministry for Education. The Flemish Government's roles include informing the governance of IMEC and ensuring that IMEC is meeting its economic-oriented goals. The European Commission is also a partner with IMEC and provides researchers with R&D funding, which supports new research directions and the overall European economy.

Over time, the Flemish Government established joint centers in partnership with IMEC and the government in the Netherlands. In 2005, IMEC and the Netherlands Organisation (TNO), established by the Dutch Government for applied scientific research, established the Holst Centre, a joint research center focused on applications in mobility,

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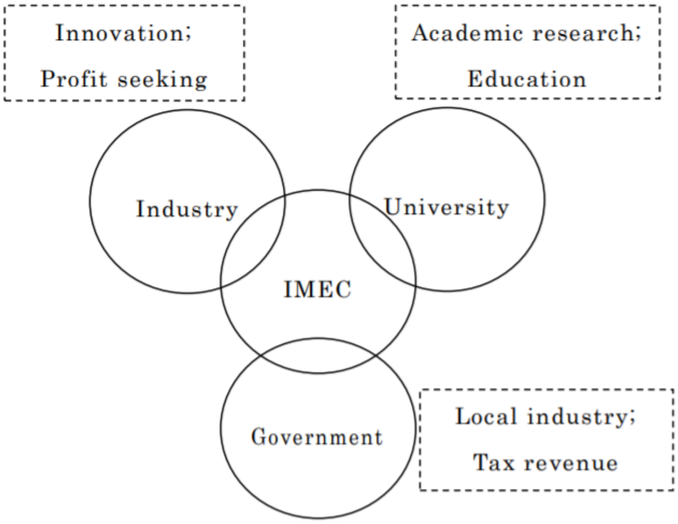
[25] Based on searches on Espacenet and USPTO.gov for "IMEC VZW," https://worldwide.espacenet.com/patent/search?q=IMEC%20VZW, https://patft.uspto.gov/netahtml/PTO/search-adv.htm.

health, and energy (Holst Centre n.d.). The Holst Centre merger further extends the applications of IMEC's microelectronic R&D and technologies in a few markets of national importance.

IMEC serves as an intermediary across its partners, coordinating R&D that benefits industry as innovative profit-seekers, academia as educators and researchers in advancing the field, and the Flemish Government as promoters of the local and regional industry and economy (Figure H-1). An analysis of the Flemish Government's role in supporting IMEC rationalized that given globalization and that knowledge flows for innovation are occurring in an increasingly open environment, government's role in supporting intermediaries to facilitate coordination and cooperation with innovators is important and well justified (Suenaga 2012).



Source: Suenaga (2012).

Figure H-1. IMEC's Intermediary Role Among Industry, University, and Government Partners

IMEC does not historically have a partner base of defense industrial partners or government sponsors for R&D aimed at providing the government with specific products or services. Rather, the R&D conducted is aimed at supporting the needs and interests of its industry partners and academic researchers. Industry partners can provide their knowledge base, experts, funding, and other resources, such as materials, as part of their collaborative R&D.

At present, IMEC has grown to partner with more than 600 companies globally, including the world's largest semiconductor companies. The partner companies range in size and across technology applications and global markets. Companies may be in direct competition with one another. For instance, IMEC collaborates with Intel, Samsung, GlobalFoundries, and the Taiwan Semiconductor Manufacturing Company (TSMCTSMC has been a core partner with IMEC since 2005. Under a 2010 agreement, TSMC had access to IMEC's foundry and process research. However, in 2011, IMEC signed an agreement with GlobalFoundries mirroring that of TSMC's, which provided access at the time to IMEC's 22nm and below process research and their extreme ultraviolet (EUV) lithography tool, as well as focused collaborative R&D in the area of gallium nitride-on-silicon technology (Dempsey 2011). These trends point to trends in increasing cooperation and common partnerships among competitors in cutting-edge microelectronics R&D.

Industry partners only share generated IP that is pre-competitive in nature (*see* H. IP Arrangements and Other Rights). Industry partners may also use IMEC's fabrication services for their own proprietary research. Other industry partners may not be in competition at all, making up small and medium sized businesses that function across the supply chain or varied technology applications, sectors, and markets.

Industry partners can play a role in the development of new research units within IMEC. For instance, IMEC and Philips Research, who has been a long-time industrial research partner in IMEC's lithography and ultra clean processing programs, announced in 2000 the development of a permanent department within IMEC's laboratory (Clarke 2000). Through this partnership, Philips Research joined all of IMEC's process-oriented industrial research programs. Their history of collaboration provided the foundation for expanding Philips Research's partnership with IMEC (Clarke 2000).

It was initially intended that IMEC would focus on solely supporting regional activities with regional partners. However, there was insufficient critical mass in the region, for instance universities and a center of excellence in the microelectronics industry. As such, IMEC expanded to be internationally-focused, emphasizing activities to build its brand internationally as well as attract foreign talent (Mina, Connel, and Hughes 2009).

Other innovation ecosystem stakeholders involved in IMEC's activities include venture capital or private investors and entrepreneurs, either as representatives as part of its governance structure (*see* D. Organization Structure) or start-up incubation and venture funding activities (*see* F. Operational Model).

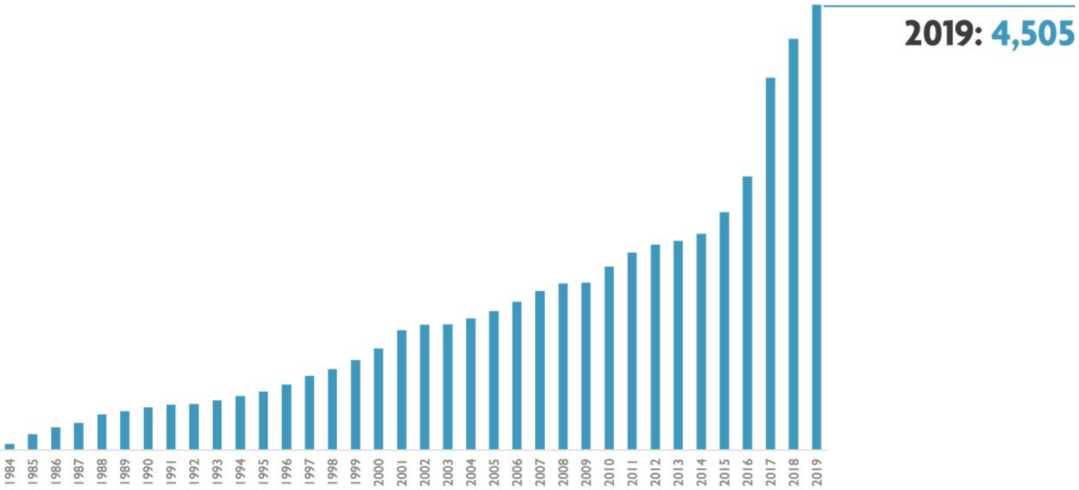
Governance

Although IMEC has strong ties to the Flemish Government and the local universities, IMEC is an independent, non-profit organization. IMEC is led by an Executive Board, which comprises C-suite level executives, and a Senior Leadership Team comprised of vice-presidents and other executives leading corporate strategy, R&D programs, its satellite sites across the globe, as well as legal, human resources, and other functions (IMEC n.d.a.). IMEC's past presidents and CEOs have historically been professors of KU Leuven (Suenaga 2012). Prof. Roger Baron Van Overstraeten led IMEC from its inception to 1999, Prof. Gilbert Declerck from June 1999, and Prof. Luc Van den Hove from 2009 to present (Abusol 2009).

IMEC is supervised by a Board of Directors, which includes representatives from Flemish universities, the Flemish Government, industry across varied sectors, and finance, investment, and venture organizations. The majority of members are selected from academic staff of Flemish universities, indicating the intentional focus and influence of academic research in IMEC's operations and decision making (Suenaga 2012).

IMEC is an independent organization with a centralized decision-making structure. IMEC's leadership team ultimately decides on the focus of its programs and direction of its R&D. These are communicated through a 5-year business plan, which is reviewed by the Flemish Government every 5 years. However, this process is informed by Technical Advisory Boards that are established around specific technology areas and made up of carefully selected global experts across sectors. IMEC's leadership also gathers information from its industry partners and company-specific roadmaps to understand the industry's needs and future directions to inform what products and services IMEC should try to develop. It also leans on its strong researcher base of experts under its research programs. IMEC communicates its strategic plans to its partners through annual reports, which present highlights of successes, its balance sheet, among other information (IMEC 2010).

In 2019, about 4,500 staff are part of IMEC's research staff, including about 300 to 400 PhDs (IMEC n.d.a.). IMEC's staff has been growing since its inception (Figure H-2). Researchers comprise academic researchers from partner universities, such as those at initially involved in the establishment of IMEC across Belgium. IMEC's research staff are international and come from universities all over the world. IMEC staff can hold dual appointments at their universities. IMEC staff are highly international, representing over 70 nationalities (VanRossum n.d.). Industry partners also comprise the non-payroll staff, making up hundreds of researchers at IMEC. Industry researchers can have their employees be on-site at IMEC while working on collaborative research with other IMEC researchers. IMEC's research staff work across semiconductor, microelectronics, market application domains. For their multi-project wafer service, IMEC has about 200 dedicated staff running that program.



Source: IMEC (n.d.).

Figure H-2. IMEC's Staff from 1984 to 2019

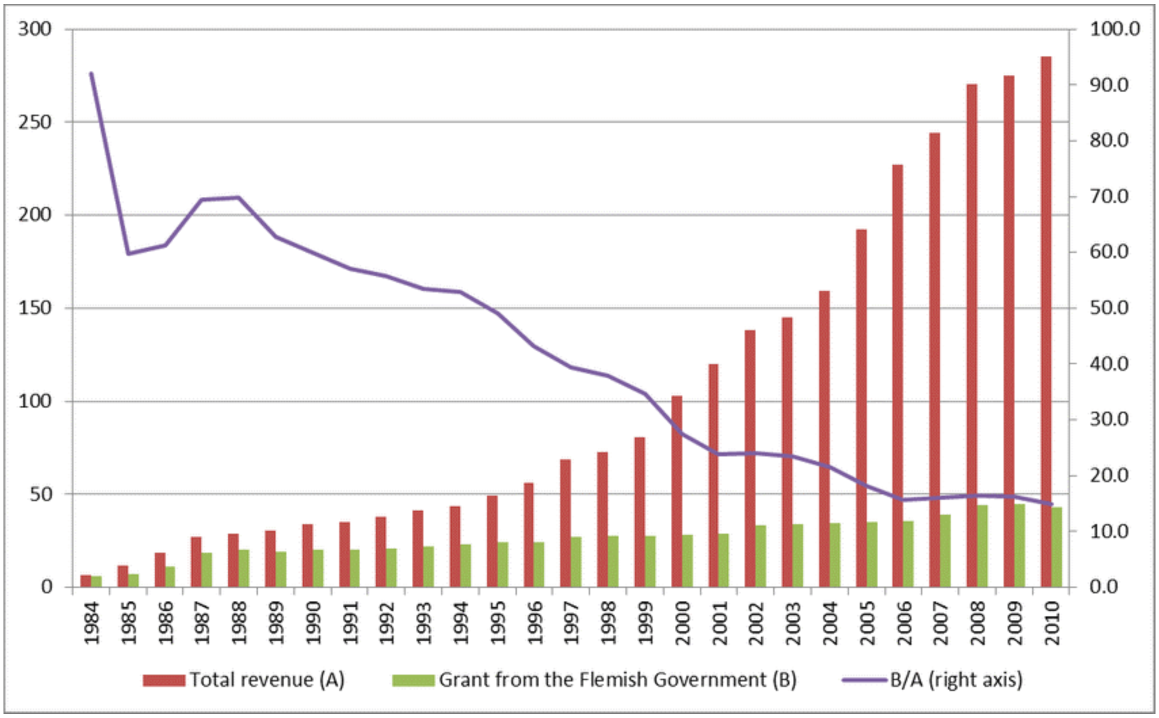
IMEC began establishing satellite offices across the world. In addition to its facilities in Belgium, it now has offices in the Netherlands, India, China, Japan, Taiwan, and two offices based in San Francisco, California and Orlando, Florida in the United States (Figure H-3). Satellite offices offer an opportunity for IMEC to reach into global markets and connect companies in those regions with the capabilities and expertise offered by IMEC in Belgium. These satellite offices may also leverage relevant infrastructure in those regions. For instance, IMEC is a partner with BRIDG, a non-profit that managed a prototyping facility established in Florida (now managed by Skywater Technologies, *see* Appendix G). IMEC's offices are on the facility's campus.

Source: IMEC (n.d.).

Figure H-3. IMEC's Satellite Offices

Funding

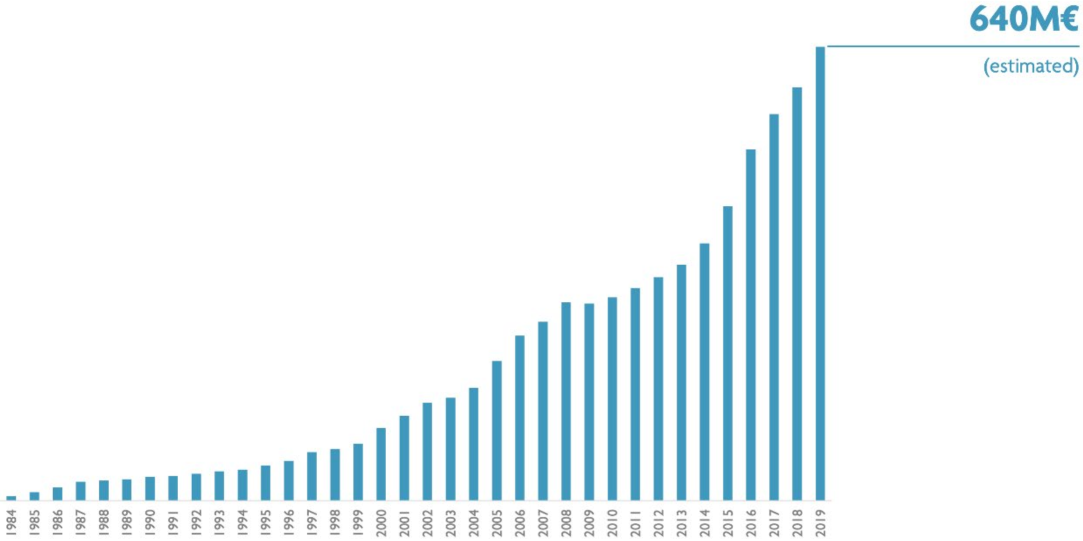
IMEC's revenues have grown substantially since its inception (Figure H-4). The Flemish Government initially provided about $72M euros in 1984 (about $185M in 2021$US). In 2019, its revenues reached $640M euros (about $770M in 2021$US). Initially, the Flemish Government's funding made up the full portion of IMEC's revenues. By 1996, the Flemish Government's portion had decreased to 50 percent, with 50 percent funded mostly by industry partners (Suenaga 2012).



Source: Suenaga (2012).

Figure H-4. IMEC Revenue (M€) and Ratio of Flemish Government Funding (%) over time

Today, about 10 to 15 percent of revenues are provided by the Flemish Government. About 5 to 10 percent of funding is provided by the European Commission through its Horizon 2020 framework program to support research on smart cities, health, mobility, industries, energy, and education. (IMEC n.d.) The remainder, about 80 percent, is funded by industry partners. Industry partners provide funding for membership into IMEC's Industrial Affiliation Programs, or can establish contract-based research, for example, to access IMEC's services and expertise for proprietary research (*see* H. IP Arrangements and Other Rights).



Source: IMEC n.d.g

Figure H-5. IMEC's Revenue from 1984 to 2019

Historically, the Flemish Government's total funding amounts have increased slightly over time (Suenaga 2012). However, this share remains a small portion relative to IMEC's total revenue. There are instances in which the Flemish Government supported funding increases to IMEC based on new needs. More recently, in 2017, the Flemish Government increased its funding for IMEC to 108M Euros (about $135M in 2021$US) to support long-term strategic research (IMEC 2017). This amount was more than double that provided to IMEC in 2010.

Another instance was when IMEC was expanding in the mid-2000s. IMEC faced large modernization needs that required large-capital investments in the mid-2000s. IMEC planned to expand its infrastructure to support R&D on sub-32 nanometer CMOS nodes, solar cells, and biomedical electronics. The expansion included building about 30,000 square feet of research labs, which improved its clean room infrastructure capacity from 300-mm to 450-mm diameter wafers and extended its space by 13,000 square feet (Laser Focus World 2008). The expansion was estimated to cost more than $90 million. IMEC requested assistance from the Flemish Government, however, the Flemish Government would only support about 50 percent of the costs, with IMEC covering the remainder. Without this expansion, IMEC faced a threat of not keeping pace with technological development and industry needs (Clarke 2009). However, as a non-profit organization, IMEC is constrained in operating like a commercial entity and is not expected to have had savings to cover its share of the expansion. IMEC took on loans to cover the infrastructure development, but does not typically take on loans for new equipment and tools.

To accommodate IMEC's financial needs, in October 2008, IMEC announced that it would change its business model to convert its 200-mm pilot wafer fab into a commercial flexible fab, replacing its R&D component on that line, which included technologies such as packaging, microelectronic mechanical systems (MEMS), biosensors, 3-D integration, among others (Clarke 2008). IMEC stated that the line was conducive to both prototype and full volume production for specialized applications, with about three-quarters of the work at the time covered by customer contracts.

IMEC was also supported by other government economic incentives in Flanders and throughout Europe. For instance, financial and fiscal incentives were provided including soft loans, capital grants, and state guarantees. Support for venture capital, several funds were established (e.g., seed capital fund, start-up fund). The Fund for Industrial Research provided financing for industry to conduct pre-competitive and competitive research in Flanders. Other financial incentives included development credits, such as prototype development aid, interest subsidies for R&D loans, and accelerated depreciation to support equity financing models for start-ups (Segers 1992).

Operations

One of the major advantages of IMEC's operational model is it has established itself as a hub with shared prototyping and manufacturing infrastructure platforms accessible by both academic and industry researchers (Bruynseraede n.d.). Researchers are motivated to partner with IMEC to conduct the latest research with high-quality academic experts using the most cutting-edge equipment and tools available in the industry. IMEC's ability to maintain its state-of-the-art infrastructure is due in part because partner companies can provide tools, equipment, and materials for free and that can be provided and tested by other partners when conducting R&D at the facility (Suenaga 2012). In addition to its research strategy, IMEC also offers other services, such as consulting, servicing using their infrastructure (e.g., analysis, testing), training, and prototyping through its multi-project wafer service (Van Helleputte and Van Overstraeten 1993).

In 2016, as part of a strategic effort to address market readiness and entrepreneurship, IMEC merged with iMinds, Flanders' digital research and entrepreneurship hub founded by the Flemish Government in 2004 (Schuurman et al. 2017). iMinds comprises 21 research groups across five research departments with more than 1,000 researchers across the five largest universities in the region (Ghent, Lueven, Brussels, Hasselt, and Antwerp) and involvement from the Flemish media and ICT industry (Schuurman et al. 2017). iMinds was integrated as a business unit of IMEC to facilitate technology transfer of early stage research results. In 2016, iMinds launched its 101 Program, focused on supporting IMEC researchers with PhD or post-graduates with promising technologies and to develop their entrepreneurial and business skills. The program launched in 2016 focused on 3 phases of training over a 12-week period (Figure H-6).

Source: Schuurman et al. (2017).

Figure H-6. IMEC's 101 Program Phases and Areas of Focus

Since its inception, IMEC has promoted spin-offs. IMEC's market readiness activities have grown and are becoming more important to IMEC as the industry, technologies, and their applications evolve. In 2011 IMEC formalized imec.istart, a program that provides start-up accelerator services, such as entrepreneurial training, coaching, and seed funding to IMEC or other promising researchers. IMEC's for-profit affiliate becomes a shareholder and takes an equity stake in the return for these services. In the first 5 years of the program, more than 120 start-ups were supported, with a 75–80% survival rate.

In 2016, IMEC set up an investment fund, imec.Xpand, aimed at providing resources to start-ups companies. About $36M in cost-shared funding has been provided by the Flemish Government, and IMEC aims to build out another $100M from private investors. In another effort, IMEC's Living Lab Innovatrix provides services to industry regarding venture investments and valuation (IMEC n.d.b).

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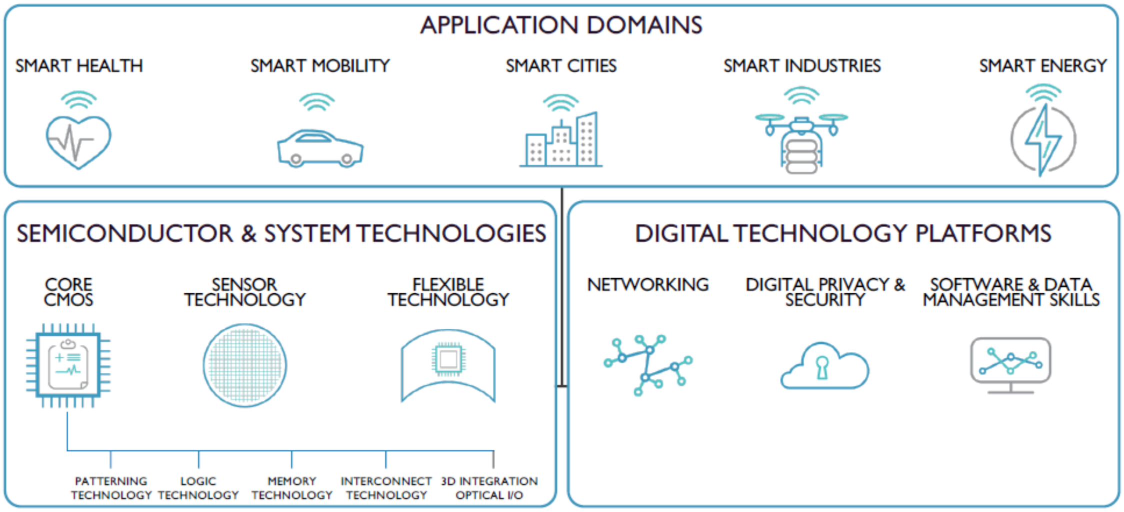
IMEC also partners with the Flemish Government and European Union to help companies interested in breaking into the Belgium or European markets, offering workshops to raise awareness of tax, legal, privacy regulations, and the like. These activities aim to attract foreign direct investments and companies to work and do business with IMEC and the region.

As previously mentioned, education and workforce development opportunities are central to IMEC's goals towards achieving scientific excellence. IMEC initially was part of a broader effort by the Flemish Government supporting the development of the region's microelectronics workforce. In addition, IMEC's infrastructure in itself serves a training platform for students (including PhDs) and the workforce. The state-of-the-art equipment attracts talent globally. It also established IMEC Academy, which provides training seminars and courses to academia and industry. IMEC Academy developed its own custom training and offered it both on-site and virtually through streaming on demand web-based videos (IMEC 2010).

Accomplishing Work

IMEC offers a range of vertically integrated services, from computer-aided design, VLSI systems design methodologies, advanced semiconductor processing, materials, and packaging, among others. IMEC identifies program focus areas to guide its R&D activities through its Industrial Affiliation Programs. R&D conducted at IMEC spans across multiple application domain areas, including health, smart cities, mobility, logistics and manufacturing for smart industries, and energy (IMEC n.d.d). IMEC's research strategy focuses on its core semiconductor and system technologies, including CMOS, sensor technology, and flexible technology, as well as these application domains and digital technology platforms (Figure H-7).



Source: Received from IMEC.

Figure H-7. IMEC's Research Strategy

Ideation is an important part of identifying research opportunities to inform IMEC's focus areas. IMEC conducts annual research review meetings and workshops with researchers globally to continuously understand the most novel ideas. Its research strategy is a result of continuous interactions with industry and academia and an iterative process to identify market demand and technology push opportunities (Van Helleputte and Van Overstraeten 1993).

In addition, IMEC hosts twice-yearly presentations of its research projects. These presentations include academic and company researchers from IMEC's core partners who conduct a critical evaluation of research projects and provide recommendations for IMEC on research directions. These reviews have incentivized companies to partner with IMEC to better understand other partners' research interests and directions (Suenaga 2012).

IMEC first instituted its Industrial Affiliation Programs in the 1990s to develop joint research with industry around key technology focus areas. The Industrial Affiliation Programs allow companies to be part of IMEC's strategic research programs. Through membership, companies dedicate one of their researchers to join IMEC for at least one year to work on a collaborative team on a research topic of interest to both the company and IMEC (Van Helleputte and Van Overstraeten 1993). Companies pay a fee to become members of these research programs. Specific collaborative research is negotiated on a bilateral, case-by-case between IMEC and the member company. Depending on negotiated terms, the research results may become part of the shared background knowledge with other members in the research program. The member company may also negotiate limited sharing or exclusive ownership of the results.

Other contract-based research can also be established between companies and IMEC. This research can include proprietary research that is completely defined by the company to be performed at IMEC. Contract-based research is also negotiated on a case-by-case basis, allowing companies to carry out competitive and application-oriented research using infrastructure that the company would likely not have access to on their own site or without significant additional investment (Van Helleputte and Van Overstraeten 1993).

Intellectual Property

It is IMEC's existing (or background) IP that provides an initial value proposition to attract members to its Industrial Affiliation Programs (Figure). *Relevant background IP*, or IP in which IMEC research are patent co-inventors or have know-how, is shared with members of the respective Industrial Affiliation Programs. Members pay an entrance fee to join a research program and to share IMEC's background IP that is relevant to the research area. Members also receive a non-exclusive non-transferable license for use of *foreground IP* that is generated through the research collaborations. IMEC shares this IP as well, and, as such, new foreground IP grows over time, becomes part of IMEC's background IP, and builds up IMEC's technological base and background knowledge (Figure H-8).

Figure H-8. IMEC's IP Model

The IP model in the Industrial Affiliation Programs allows for IMEC and each industry partner to own as much value, in terms of ownership of IP rights, from the discoveries generated through joint research as they would like. Companies can request limited or exclusive rights to generated IP, which is negotiated on a bilateral, case by case basis through separate contracts. Limited or exclusive IP rights usually means incurring additional costs to the company as part of their bilateral negotiation for IMEC to support the collaborative R&D. Depending on the terms, IMEC may share in the ownership of IP in contract-based research with limited IP rights, and, as such, IMEC's background knowledge would to grow. Through this flexible IP model, partner companies can use their most preferred, cost-effective way to build up their own IP portfolios.

Negotiations are supported by a cadre of IMEC IP valuation experts, patent lawyers and the like with capabilities to evaluate the IP so IMEC's interests are well represented in contract-based research. In addition to non-exclusive licenses provided to member companies, IMEC can negotiate IP terms that include remuneration with a minimum royalty or a commitment for IMEC to receive a fixed percentage of royalty on net sales for IP that is commercialized by the industry partner (Van Helleputte and Van Overstraeten 1993). IMEC's IP valuation takes into consideration the following (Van Helleputte and Van Overstraeten 1993):

- Its development phase
- Its medium-term market potential
- The availability of interested and valuable candidate licensees
- The commercialization efforts needed
- The remuneration through further in-house development or own commercialization (through spin-off activities)
- The financial coverage of previous research efforts
- The long-term strategy of the research center.

Other Protections

IMEC's culture supports open innovation and shared IP, in at least under its Industrial Affiliation Programs. IMEC follows commercial practices to secure sensitive or proprietary information and IP. They do not focus research on defense or national security applications, and, as such, no classified or special firewalls are put into place. Generally, IMEC does not enforce IP theft or pursue litigation for IP matters.

Evaluation and Outcomes

Historically, the Flemish Government evaluates IMEC every 5 years to assess performance based on three key areas: scientific excellence in exploratory work, operations, and economic impacts (Bruynseraede n.d.). An independent consulting firm, IDEA Consult, evaluates IMEC's impacts as part of these efforts. Since 2004, they have been evaluating IMEC's impacts to the regional and country's economies on a bi-annual (every two years) basis (IDEA Consult n.d.). According to IDEA Consult, in more recent years, due to IMEC's growth and breadth of activities, the evaluation extended its measures beyond the three key areas to include the following domains: (i) scientific-technological, (ii) economic, (iii) catalytic and (iv) broad social impacts.

Some measures and metrics used in these evaluations include—

- R&D excellence—scientific productivity and quality, such as number of peer-reviewed publications, patent filings, presentations, and number of PhDs supported
- Economic returns for the region—collaborations with local companies, number of start-ups and spin-off companies created, number of new jobs created
- Operational—number of industry partners, total contract revenue with international industry and government programs

IDEA Consult has used company-specific information to estimate the direct and indirect economic and technological impacts of IMEC's research strategy. They also estimated the fiscal returns on investments back to the Flemish Government, e.g., in the form of taxes, based on IMEC's activities. Related to social impacts, IDEA Consult evaluated IMEC's contributions to achieving the Flemish Government's social goals as proposed in its Vision 2050 for Flanders, which outlines a strategy for social "transformations" in the ways society lives, works, and enjoys life (IDEA Consult n.d.).

Lessons Learned

Note: Based on the study team's analysis of information.

Sustained and ongoing funding provided long-term support for infrastructure modernization and de-risking as IMEC's infrastructure and the technology needs evolved.

The Flemish Government made a relatively significant investment into the development of IMEC and its infrastructure. Initially, it supported the majority of the costs associated to support its expertise and tools. Decades later, the Flemish Government continues its investment, and, throughout this time, at times, increasing its funding to support IMEC's expansion and infrastructure modernization efforts so that it could continue to keep pace with the cutting-edge platforms. The Flemish Government's sustained efforts more broadly continue to be justified by the economic and fiscal returns brought about to the region from IMEC's activities.

IMEC's autonomy and independence has allowed it to pivot and remain at the cutting edge.

IMEC does not have a voting member model. It is IMEC's leadership that makes decisions on its strategic priorities, programs, and projects. There are more than 600 industry partners, and hundreds of industry researchers on-site as part of IMEC's non-payroll staff. These staff collaborate closely with IMEC's thousands of researchers and, in turn, IMEC researchers better understand a company's roadmaps, interests, and needs. IMEC also leverages connections to global research communities through workshops and technical councils to understand promising research directions. These aspects have allowed IMEC to pivot quickly and stay on the cutting edge, acting as an intermediary between academic and industry R&D interests.

Cooperation and strategic partnering, including among industry competitors, accommodates differing value propositions for small and large established companies alike.

IMEC's strategic partnering activities have allowed for effective cooperation among competitors in the microelectronics industry. Partners can set up separate agreements with IMEC, take part in their core research programs through the Industrial Affiliation Programs, and conduct independent proprietary research for more niche or specific company needs. Through these activities, IMEC researchers gain knowledge of the broader market applications for their technologies and the needs across the microelectronic industry. IMEC serves as an intermediary that accommodates the ideas and needs of small and large businesses alike. Through its strategic planning efforts, IMEC leadership strives to identify promising R&D that equitably supports all its partners, aligning their R&D plans and projects with the value propositions of all partners.

Strategic management of IP and background IP are integrated into the business model to attract partners.

IMEC's flexible IP model allows companies to use their preferred, cost-effective way to build up their own IP portfolios through collaborative R&D. In addition, IMEC understood at the outset the value in ownership of their IP to the broader operations of IMEC. Since IMEC shares any related background IP with Industrial Affiliation Program partners, their IP provides an immediate value-add to attract potential new partners and grow their research areas. IMEC's IP portfolio grows with each new collaborative R&D project, adding to the value proposition to new and existing partners.

IMEC also has a cadre of staff, including patent lawyers and valuation experts, who provide input on the potential IP generated through new R&D projects. Their input informs contract negotiations with partners.

IMEC's infrastructure provides training platforms to develop and attract talent.

An important aspect of IMEC's goals towards R&D excellence includes the development of the future workforce and talent with skills necessary for the microelectronics industry. Through its activities, IMEC hosts 300 to 400 PhDs annually. IMEC leverages their unique infrastructure as training platforms for these students. The infrastructure also provides opportunities for work-based learning through the interactions with industry partners on collaborative R&D projects, helping grow their understanding of how their research can be applied to industry's needs.

Strong connection to universities in early years to staff with experts and continued relationships with academia shape IMEC's expertise and value proposition today.

IMEC relied heavily on the local university faculty to staff the early years of its operations. Relationships with universities, locally, regionally, and across the world have expanded since IMEC's inception. For example, IMEC staff also carry dual appointments with regional universities, which helps maintain the relationships with these institutions and supports interactions with the institution's students. The academic expertise brought together through IMEC provides a value add to industry partners that can leverage their ideas towards industrial innovations.

Historical and continued attention to spin-offs and support for start-ups bolsters focus to strengthen the innovation ecosystem.

Since its inception, IMEC has promoted spin-offs. Through imec.istart, a program that provides start-up accelerator services, IMEC has formalized its activities to strengthen its interests in support of transition and commercialization of its technologies. IMEC established a for-profit affiliate given the limitations of taking equity in the start-ups supported through these efforts as a non-profit organization. Through imec.start and other venture programs, IMEC has become a growing player in supporting entrepreneurs in their local and regional innovation ecosystems.

Development of the local and regional innovation ecosystem takes time, and long-term vision and global touch points to support local and regional economic goals are necessary.

When establishing IMEC, its leadership and the Flemish Government had to expand their scope, recognizing that despite goals to create local and regional economic returns, that the lack of a rich hub in microelectronics and entrepreneurial culture in the region made it difficult to close themselves off from international partners. IMEC's initial partnership with Philips and other companies in neighboring Netherlands, in part, supported its initial expansion and growth of its capabilities. Later, expansion of IMEC's satellite offices provided a network of touch points to other regions, and their relevant industries, across the world.

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Appendix I.
Case Study—Metal Oxide Silicon Implementation System (MOSIS)

Note: For all case studies, information is based on interviews unless otherwise cited. Lessons learned are the study team's own analysis.

Table I-1. Summary of MOSIS

Goal(s)	Provide quick, low-cost, small volume custom microelectronic device fabrication
Origins	Initially, DARPA wanted to help spread the adoption of VLSI design in the academic community, and needed a quick way for those designs to be fabricated. MOSIS was formed when VLSI design was just emerging. Foundry partners: get additional business from smaller customers on MPW runs that they otherwise wouldn't have Customers: access to state-of-the-art foundries and low-cost, small volume fabrication
Partners and Roles	MOSIS Lead: University of Southern California (USC)'s Information Sciences Institute (ISI) Customers: Now, domestic and foreign universities, commercial companies, US government laboratories and agencies. Originally, only DARPA performers. Foundry Partners: Currently, TSMC, Global Foundries, Intel and Samsung, but has evolved over time. Federal Partner: None currently. Previously DARPA.
Governance	Currently, MOSIS has 10 staff who span engineering, operations, accounting and legal. Advisory group provides input on strategic direction for MOSIS to maintain value add in a changing foundry landscape.
Funding	USC ISI: Leadership and management of MOSIS Federal: In the first 15 years, DARPA and NSF funding allowed MOSIS to become established and well known in academia and industry. Self-sustaining from commercial customers since 1994. From 1981–1994, majority of funding from DARPA, some from NSF.
Operations	MOSIS provides foundry process design kit (PDK) and design tools to customers, and then combines customer designs onto multi-project wafers (MPWs) for fabrication at one its current foundry partners. TRL: Primarily 3–6, but can also span other TRLs.
IP	The foundries maintain all of their own IP (of the PDK and design tools). Universities or companies maintain IP for their designs.

Other Protections	MOSIS is ITAR compliant, some of its foundry partners are as well. MOSIS uses a cloud-based secure design environment (first silicon fabrication process to totally operate in such an environment) to help protect the design files.
Evaluation and Outcomes	Fabricated 60,000+ designs, from 12+ foundries From 1990–2003, 66,000+ students learned integrated circuit (IC) design using MOSIS-associated programs and 13,000+ designs were fabricated.
Lessons Learned	Support for MOSIS' researcher user base increased the financial viability of the service. MOSIS fabricated student designs at no cost, supporting the next-generation microelectronics workforce. Continuous evolution of the MOSIS business model has allowed its value proposition to remain relevant. The small staff of MOSIS limits its ability to compete with larger service providers. The MOSIS workforce training program is no longer operational due to changes in funding and misuse.

Goals

In the 1970s, very large-scale integration (VLSI) design had begun to get traction in the microelectronics community. Early on, each company's process and fabrication facility (fab) configuration was unique and integrated circuit (IC) design had to couple tightly to the manufacturing processes. As a result, designs were not portable among fabs. Furthermore, unless a researcher in academia and government had a relationship with a company that had fabrication capabilities, they could not get access to a fab.

Even with access, researchers in academia and government encountered difficulty and expense in fabricating an IC. Each design required them to model the process and simulate the circuit at the basic transistor level. They needed to understand and model the physics behind each device. They also had to master the highly proprietary, process-specific design rules of the fabrication facility. Lastly, they had to shoulder the full cost of the mask set and processing.

The overarching goal of MOSIS was to provide access to rapid, low-cost, small volume, custom microelectronic device fabrication capability. To do this, MOSIS had to develop a process design kit (PDK) that operated at a higher level of abstraction and was agnostic of the specific fabrication facility that implemented it. The PDK used pre-characterized device components that MOSIS had simulated together as a system. This separated device manufacturing and characterization from the design. Users no longer needed to understand the physics behind their circuit implementation and could design using functional blocks with input, output, and timing being the primary parameters. This in turn broadened the scope of who could use its services to users that did not have a detailed physics background.

MOSIS serves as the broker between the users and the foundries that provide the fabrication services. It aggregates multiple designs on one wafer, and distributes the cost of fabrication among multiple users. This significantly reduces the cost of a fabricated device. Originally, MOSIS provided its services only to DARPA performers, and subsidized the fabrication costs. Later, DARPA expanded access to include NSF and NSA grant recipients, and eventually to any academic or commercial customer.

When NSF and DARPA discontinued funding MOSIS in 1994, MOSIS started catering to its commercial customer base. MOSIS began excluding unproven or risky technology offerings due to an insufficient number of paying customers (Piña 2002). This, in turn, led MOSIS to stop accepting requests based on purely research-driven technologies (Piña 2002).

Another goal of MOSIS is to train the next generation of the microelectronics workforce. Through MOSIS, students get hands-on experience in IC design before they enter the workforce.

Because MOSIS serves a wide array of customers, it can span all TRLs. MOSIS largely addresses TRLs 3–6, as much of its work is helping customers do prototyping and production scaling, with some volume production (TRLs 7–9) and some basic research (TRLs 1–2).

Origins

In the late 1970s, the DARPA Information Processing Office (IPTO) started a number of programs to help engage the academic research community in VLSI design and architecture. However, these academic researchers were limited in their ability to have their designs fabricated, given companies fabricated ICs in their own fabs (the foundry model had not been introduced yet). The cost and timeline for academic researchers that wished to fabricate designs were prohibitive. Each company had a set of proprietary design rules that were specific to the fabrication process itself.

Initially, DARPA experimented with different approaches for facilitating IC fabrication quickly and inexpensively. It established MOSIS to act as a broker between the IC designers and the fabricators. MOSIS also provided users with standardized, simplified rules that were valid across commercial fabs. To reduce the fabrication costs, MOSIS pioneered multi-project wafers (MPW), where the fab fabricates multiple designs on a single wafer in a single run. Then a packaging house dices and packages them as separate chips. Finally, MOSIS leveraged the newly developed ARPANET allowing users to mail their designs electronically to MOSIS. This ended up being one of the strengths of MOSIS (Van Atta 1991).

Partners and Roles

Though DARPA formed MOSIS as a supported program, rather than a collection of public and private stakeholders, its broker model involved a number of partners and stakeholders, whom we discuss below.

Federal partners

Initially DARPA was the only Federal partner. It served as the sole funder for MOSIS, and DARPA performers were the sole "customers" of MOSIS's services. Shortly after that, NSF became involved and in 1982 assumed the responsibility for managing it. At that time, NSF-sponsored researchers and affiliated institutions also became eligible to use MOSIS (NAP 1999). In 1982, DARPA and NSF began funding the MOSIS educational program, which enabled students to both learn VLSI design in their coursework or research and have those designs fabricated (Van Atta 1991).

In the early years of MOSIS, the value of DARPA and NSF funding MOSIS was the ability to expand and foster the VLSI research community and advance the development of VLSI technology.

For DARPA, MOSIS allowed its performers to fabricate integrated circuit designs at a fraction of the cost of working directly with commercial fabricators. From 1981–86, more than two-thirds of the projects that MOSIS fabricated were for DARPA performers or DARPA-affiliated projects at government labs (Van Atta 1991). It has been estimated that in these early years, MOSIS allowed for a three-to-six-fold leveraging of DARPA's budget due to the cost savings of MOSIS's fabrication services (Van Atta 1991).

The technical developments that MOSIS fabrication services enabled, presented additional value adds to the DoD. MOSIS can take partial credit for the development of a large number of direct defense applications, including RISC-based architectures and MOSAIC message passing systems among others (Van Atta 1991).

Customers (university and commercial researchers)

When MOSIS started in 1981, it was a service only for DARPA performers and later for NSF researchers. In 1987, MOSIS became available to non-government customers. Over the past 40 years, 50 U.S. government laboratories and agencies, 800 domestic and foreign universities, and over 100 commercial companies have used MOSIS to fabricate their IC designs.

For MOSIS customers, the value of MOSIS is the unique mechanism it provides for researchers to fabricate their designs. MOSIS enables a dramatic reduction in cost compared to using commercial fabrication services, and for activities that meet the requirements of the MOSIS educational program, the user does not pay at all. MOSIS lowered barrier to entry when it developed the PDK that allowed users with limited background in device physics to design and fabricate IC devices. Finally, customers are able to have their designs fabricated relatively quickly, which is particularly important for the educational program activities, which must align with academic semester timelines.

Foundries

In the early 1980s, MOSIS worked with 11 foundries. By 1989, most of MOSIS work was with Hewlett-Packard-NIT, ORBIT Semiconductor Services, IMP Inc., and VLSI Technology (Van Atta 1991). Today, MOSIS actively uses two foundries, Global Foundries and Taiwan Semiconductor Manufacturing Company (TSMC). It has announced new partnerships with Samsung and Intel.

For these foundries, the value proposition of dealing with a single entity, ISI, rather than hundreds of individual designers provided the motivation to participate in MOSIS (Van Atta 1991). However, there have been some challenges in obtaining or maintaining buy in from foundries. In the beginning of MOSIS, some companies, such as Xerox PARC, which was one of the first partners in developing the multi project wafer methodology with DARPA, did not feel that they could provide the "community service" that MOSIS would offer researchers, as they needed to focus on their own fabrication needs (Van Atta 1991). Today, several foundries, including some current MOSIS partners, operate their own multi-project wafer services, which can compete directly with MOSIS for customers.

Governance

The University of Southern California Information Systems Institute (ISI) is the not-for-profit research institute that has operated MOSIS for the past 40 years. In 1980, ISI received several contracts from DARPA to conduct VLSI design and fabrication activities, which included the creation of MOSIS.

Currently MOSIS has about 10 employees, though over its 40 years of operation, it has had as many as 20 employees. The MOSIS staff span a number of roles, including engineering, accounting, operations, and legal. The staff is identifying foundries and mask houses that use increasingly sophisticated technology and are willing to work with MOSIS. In the beginning, MOSIS staff developed the procedures for specifying and transmitting designs, and introduced testing and quality control procedures, which were very important when offering a new technical service.

Today, MOSIS staff is still implementing new services, like the recently launched cloud-based secure design environment, which provides additional safeguards to protect foundry process design kits. MOSIS is the first silicon fabrication provider to operate totally in a cloud based secure design environment. The bottom line is the MOSIS staff wants to make the fabrication process easy for the designers and to secure access to the state-of-the-art foundries for them.

MOSIS has a director, who together with the ISI's executive leadership, are responsible for the strategic direction of MOSIS. Through regular coordinating meetings with experts, including USC faculty, MOSIS leadership has strategic discussions about how to remain competitive and maintain a value add to customers.

Funding

Originally, DARPA fully funded MOSIS as a part of its VLSI program. Funding for the VLSI program grew from less than $15 million in 1979 to over $93 million in 1982, likely in large part to the beginning of MOSIS (NAP 1999).

MOSIS had four phases on its evolution from being DARPA funded by to being fully self-sufficient (Piña 2002).

- 1981–1985: DARPA sponsored 100% of MOSIS revenue.
- 1984–1994: Federal government provided 95% of MOSIS revenue (80% from DARPA, 7% from NSF, 8% from DoD, mostly NSA) and 5% from commercial firms.
- 1994–1998: Commercial sources provided 98% of MOSIS revenue, 2% from Federal government (DARPA, NSF, DoD combined).
- 1998–present: Customers provide 100% of MOSIS revenue.

The shrinking Federal budget is said to be responsible for withdrawal of direct DARPA funding in 1994, and NSF funding in 1999. The transition away from Federal funding occurred somewhat abruptly. In 1991, 85 percent of MOSIS revenue came from Federal government agencies, and by 1994, 100 percent of MOSIS revenue came from purchase orders from industry, universities, and other research laboratories (Piña 2001).

Educational program

From 1985–1995, DARPA (40%) and NSF (60%) jointly funded the MOSIS educational program. In 1994, DARPA ended its funding for the educational program, and in 1999, NSF did too. Without sustained Federal funding, the educational program was at risk of ending. MOSIS was able, however, to continue fabricating student designs "with generous donations of chip processing, masks, and administrative services by AMI, HP, IBM, DuPont Photomasks, and the MOSIS organization, and with cash donations from AMD, Intel, Motorola, QUALCOMM, and the IEEE Computer Society Design Automation Technical Committee" (June & Marr 2000). In 2000, the Semiconductor Industry Association (SIA) announced that it would sponsor the MOSIS education program with $500,000 per year support (June & Marr 2000). SIA's decision to fund MOSIS was due to member companies' "serious concern that without the experience offered through the MOSIS Educational Program, graduating engineers will not have the experience and maturity needed to fully and quickly contribute in industry" (June & Marr 2000).

Operations

Customers submit their designs to MOSIS by email. MOSIS staff aggregates the designs and allocates mask real estate to each project. It merges as many designs as it can into one reticle, a pattern by chrome etching on a glass plate which is then transferred to silicon wafers. MOSIS then sends the design files to a mask house to create the mask for the merged designs. MOSIS then uses one of its partner foundries to fabricate the MPW design, which is then wafer probed, diced, packaged, functional, tested and shipped to the customers. There are two tests conducted during the dicing process. The wafer level test eliminates clearly defective die so that they are not put into an expensive package, and the final test then checks the functionality.

As the core purpose of MOSIS is to provide a low-volume custom silicon prototyping service, much of the work conducted at MOSIS spans TRLs 4–6. Given that, some MOSIS activities, such as the designs fabricated as part of the MOSIS educational program (discussed in greater length below) may be at lower TRLs, while the dedicated fabrication runs that MOSIS provides to customers needing higher volume production (The MOSIS Service n.d.) may be at higher TRLs.

MOSIS has continued to upgrade the technologies and services it provides to keep up with user needs and with evolving industry fabrication capabilities. When preparing to use a new technology, MOSIS conducts a "technology development run" which has a longer turnaround time of 3–6 months due to its experimental nature (Van Atta 1991). In 1981, MOSIS provided fabrication services in NMOS with a 5-micron feature size (Van Atta 1991). Today, MOSIS provides access to 12 nm technology nodes, and is pursuing access to even more advanced nodes and other technologies (The MOSIS Service n.d.).

Intellectual Property

The customer retains all IP rights to the design. This element of the IP arrangement is straightforward, and MOSIS uses nondisclosure agreements with customers to maintain the necessary confidentiality.

The foundry maintains all of the IP associated with the foundry PDKs. This element of the IP arrangement presents more challenges as the universities and students do not necessarily understand the security requirements of the foundries in protecting their PDKs. Previously, MOSIS would require a sizable security deposit from any new customer to ensure that they were serious. MOSIS staff would monitor inactive customer accounts, which might indicate that a customer only sought to access to foundry PDKs without an intention of using the MOSIS service.

Recently, MOSIS launched a secure cloud-based design environment, which provides better safeguards for the confidentiality of foundry PDKs. Specifically, this environment uses a state-of-the-art virtual private cloud based on the Amazon Web Service GovCloud for EDA applications. MOSIS is the first silicon fabrication provider to operate fully in a cloud-based secure design environment.

Other Protections

The new cloud-based secure design environment discussed above, also provides a global solution to managing security issues.

MOSIS is able to facilitate the fabrication of ITAR-controlled designs at the request of a customer. In order to handle ITAR-controlled designs, all of the MOSIS employees are U.S. citizens or permanent residents. For ITAR designs, MOSIS can only use ITAR-compliant foundries to fabricate the designs.

Evaluation and Outcomes

Since the beginning, MOSIS has tracked of the number of designs fabricated based on customer type, technology used, etc. to provide a metric of their services.

Lessons Learned

Note: Based on the study team's analysis of information.

Support for MOSIS' researcher user base increased the financial viability of the service.

Long-term Federal funding and support for the user base allowed MOSIS to ultimately become self-sustaining. DARPA encouraged adoption of VLSI design and use of MOSIS among its performers, and sustained this support over 13 years.

MOSIS fabricated student designs at no cost, supporting the next-generation microelectronics workforce.

Student designs are fabricated at no cost, which enabled training of the next-generation microelectronics workforce over several decades (from 1990–2003, 66,000+ students learned chip design using MOSIS-associated programs and 13,000+ designs were fabricated)

Continuous evolution of the MOSIS business model has allowed its value proposition to remain relevant.

Evolution of the business model and identifying a unique value add is critical to keep up with the technology, market, and industry. Initially, MOSIS was the first and only MPW service, and provided standardized design rules for its users. Currently, there are many competitor services. MOSIS is now considering a range of new elements that would increase its value proposition.

The small staff of MOSIS limits its ability to compete with larger service providers.

The staffing level matters. MOSIS can’t necessarily scale services with such a small organization (staff of 10), and cannot compete with TSMC (staff of 400) to provide the same services to customers.

The MOSIS workforce training program is no longer operational due to changes in funding and misuse.

Largely due to changes in its funding, the MOSIS Educational Program has evolved several times over the years and is currently not operational. It was challenging to sustain the program without a funding stream, and some misuse of the program occurred where research projects that could obtain funding submitted requests for no-cost fabrication. Ultimately, MOSIS lacks the resources to fund the volume of designs that requested fabrication.

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Appendix J. Case Study—MEMS and Nanotechnology Exchange (MX)

Note: For all case studies, information is based on interviews unless otherwise cited. Lessons learned are the study team's own analysis.

Table J-1. Summary of MX

Goal(s)	Provide a means for MEMS researchers and developers (with an emphasis on DARPA performers) to prototype or fabricate their ideas even if they lacked the necessary fabrication capabilities or access to foundries or ideas that could not be produced at any single facility. Lower barriers to MEMS R&D/prototyping; foster advances in MEMS technologies.
Origins	DARPA-funded project, developed from a need identified by DARPA and R&D community
Partners and Roles	**Federal:** DARPA (1998–2013, contract), ARL (2003–present, CRADA) and NIST labs (ca. 2016–present); DARPA provided funding, oversight/project management through 2012; ARL and NIST provided facilities for MX-based fabrications. **Private:** Companies with MEMS fabrication process facilities; private facilities entered into agreements with MX to participate in distributed network. **Academia:** Universities with fabrication facilities. Originally (1999): University of California, Berkeley; University of Michigan; Case Western Reserve University; Stanford University; Cornell University; others subsequently; each site had 1–3 staff subcontracted and assigned to MX work. **Customers:** University researchers, companies, government; MEMS researchers and developers came with their ideas, paid for fabrication **Nonprofit:** Corporation for National Research Initiatives (CNRI) was the performer; built and operated MX. **Others:** MEMS researchers and developers (users).
Governance	CNRI runs MX as a nonprofit business. CNRI leadership and board of directors provide advice/oversight. DARPA provided oversight as funder from 1997–2012.
Funding	DARPA grants: 1) 1997–1999 (via SPAWAR); 2) 1999–2003; 3) 2003–2012 (with mods). Today, user fees for consulting and MX-performed or brokered processes.
Operations	**Years**: 1997–present. First DARPA grant in late 1997; first process run 1999; first partnership with Federal Labs 2003; last DARPA contract ended in 2012. **Accomplishing Work**: Wide range, mostly TRL 1–7. Staff ~15 at present (~25 at peak). Users access information about fabrication processes available at distributed fab sites via online catalogue, establish accounts, request fab services.

	Relevant Federal Authorities: DARPA grant authority; OTAs
IP	All users retain IP of the devices they manufactured. Facilities retained IP for the fab processes used. IP was mutually licensed between users and facilities for the purpose of fabrication. MX maintains legal agreements with facilities and users, removing the need for users to enter into agreements with each fab directly.
Other Protections	Controls in place to protect customer/proprietary information. MX only works with U.S.-based facilities and customers, can accommodate export-controlled technologies.
Evaluation and Outcomes	DARPA's metrics were business-oriented: # process runs, # users, revenue points, # processes (these were met); achieving self-sufficiency (this occurred only at a smaller scale) Affordable cost points for academic users, and developing and sustaining sufficient user base to maintain scale of activities (not achieved) Enabled fabrication and development of devices that probably would not have otherwise been made (e.g., accelerometers used in today's phones) MX still exists, but with more in-house fab, a less-distributed model, no subcontractors at universities, with a much smaller fab network, including 2 government facilities and only ~15 other labs
Lessons Learned	Funding and revenue instability inhibited the full-scale realization of MX's brokered, distributed fabrication model. The substantial size of the first DARPA grant, choice of CNRI as a neutral broker, and the deep technical expertise of the MX director provided MX with credibility in eyes of the the MEMS community as it was launched, developed its initial network of facilities, and became operational. As an infrastructural service that coordinated the logistics of prototype generation while maximizing the availability of design freedom and process options, MX enabled researchers to focus on realizing innovative MEMS devices. MX's operational approach to enabling technology prototyping was tailored to the maturity level and diversity of MEMS. Anxieties about technical risks of participating in the distributed fab model were addressed early on through by a knowledgeable director able to engage on technical issues and by empowering participating facilities to opt in or out of specific work orders at their own discretion. Without fully standardized processes that could be implemented on multiproject wafers, economies of scale were hard to achieve; this was inherent to the highly custom nature of the technology. MX fulfilled its original goal of providing a robust distributed-fabrication MEMS prototyping service for a window of time. It ultimately did not pivot to meet emerging needs and opportunities at the cutting edge, though some ideas were considered. MX did not fully explore alternate funding models or development of collaborative partnerships, which might have helped to boost revenues or core support as it worked towards financial independence. Changes in leadership and priorities at DARPA contributed to a decline in its support of MX within the activity's first five years.

Goals

The primary goal of the MEMS Exchange (MX) was to provide a means for microelectromechanical systems (MEMS) researchers and developers (with an emphasis on DARPA performers) to prototype their ideas even if they lacked the necessary fabrication capabilities or access to foundries. This is similar to the primary goal of DARPA's MOSIS service (described in Appendix I) though for a technology somewhat more diverse in material, structure, and process than CMOS-based integrated circuits. MX was thus originally intended to maximize researchers' design freedom and enable them to leverage a large and diverse set of process capabilities by distributing the process sequence steps across multiple facilities for a single device. Underlying this goal was a desire to spur progress in MEMS R&D in order to advance the state of knowledge and technological capabilities in MEMS.

Additional goals for implementing this service included forming a network of fabrication sites whose process capabilities would be made available through MX in an a la carte fashion, and determining whether commercial foundries would be willing to participate. Another key implementation goal was to create a user-facing web-based catalogue of processes (MEMS Exchange n.d.c) available through the network, coupled to a user software system for managing user requests, legal agreements, process steps, and work orders, and coordinating distributed fabrication jobs.

Origins

In the early 1990s, DARPA became interested in funding R&D in the area of microelectromechanical systems (MEMS). DARPA initiated an effort to provide MEMS fabrication services to researchers, the Multi-User MEMS Process Sequence (MUMPS) program at the Microelectronics Center of North Carolina (MCNC). MCNC provided a fixed process sequence for silicon-based MEMS devices to enable multi-project wafer fabrication processes (an approach that had worked well to reduce costs for CMOS integrated circuit [IC] prototyping via MOSIS service). However, some users found this model too restrictive for pushing the boundaries of MEMS fabrication; MEMS devices are much more diverse in structure and materials than ICs, and typically highly customized on a project-by-project basis.

DARPA subsequently met with researchers, DoD officials, and companies to learn the kind of infrastructure that would best serve development of new MEMS technologies. The general consensus was MEMS prototyping infrastructure should maximize process and design freedom. This outcome led to the idea to support a brokerage model of access (inspired by MOSIS) to a distributed network of MEMS fab facilities: the MEMS Exchange (MX). In this model, fabrication was to be completed via what was termed a "traveling wafer" approach (unlike MOSIS)—that is, the process wafer would be sent from site to site as needed to complete each step of a range of diverse fabrication processes required to construct any particular MEMS device. (MEMS n.d.c)[26] After some debate and disagreement about who would act as the broker, with several Universities expressing interest, DARPA selected the Corporation for National Research Initiatives (CNRI), a nonprofit organization based in Reston, Virginia and led by Bob Kahn, former DARPA program manager, initiator of the MOSIS program, and co-inventor of TCP-IP, the protocol underlying Internet communications.

The first grant for MX was awarded to CNRI in 1997 as a contract through SPAWAR (now the Naval Information Warfare Systems Command) before partner facilities were identified. In 1997 and 1998, the newly-hired MX Director, Michael Huff, traveled to universities to identify facilities with unique capabilities as the first nodes in a network of fabs. The first university sites included the University of California, Berkeley, University of Michigan, Case Western Reserve University, Stanford University, and Cornell University. Much of the early fabrication work was conducted at Berkeley as Huff worked to engage additional facilities.

Partners and Roles

Originally, the major players in MX were DARPA, CNRI, UC Berkeley and the other original universities in the fab network, and the users (largely DARPA performers). The participants and their roles evolved somewhat over time

Nonprofit

CNRI, as a nonprofit organization not previously involved in MEMS R&D, was viewed as a neutral broker and selected by DARPA to run the MX service. CNRI hired technical experts in MEMS, including engineers from different application domains with deep knowledge of the strengths and weaknesses of different MEMS fabrication processes. CNRI's MX technical staff originally brokered interactions between users (MEMS researchers and developers) and a host of fabrication facilities around the country while providing process design services, technical and logistical coordination via an elaborate MX-built software system, and quality control. Today, CNRI primarily conducts device fabrication in-house or at Federal laboratories with which it partners near its headquarters in Reston, VA.

Federal participants

DARPA was the original funder, providing funding for all MX staff and operations (hereafter referred to as "core" funding) and oversight. CNRI's contracts with DARPA

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[26] For example, MX's website lists a host of deposition, patterning, curing, wet oxidation, spin casting, etching, doping, mask making, and packaging processes, involving materials from polymers to semiconductors to piezoelectric crystals to photonics modules to precious medals.

spanned 1997–2012. Phase out of core funding began around year 5, while some contract modifications were made, including support for MX to develop new process sequences at DARPA's request. DARPA no longer provides core support, but MX has partnered with the government through cooperative research and development agreements (CRADAs) and other agreements with Federal Labs to conduct device prototyping activities at government fabrication facilities (the Army Research Lab in Adelphi, MD, and a NIST research lab).

Academic and private sector participants

University (beginning in 1999) and commercial (beginning in early 2000s) facilities engaged directly with MX to provide fabrication services. University facilities stood to gain additional revenue on existing capital equipment, and commercial entities likely valued the opportunity to engage in new spaces. Initially, five or six universities provided the bulk of fabrication services as the network grew. At the peak network size, MX engaged more than 80 university and commercial facilities. Today, MX has 15 participating fabrication facilities, including two government laboratories.

Users

MEMS Exchange existed to provide a service for researchers and developers with a vision for a MEMS device. At first, MX served mostly DARPA performers funded through DARPA's MEMS programs. The user base later grew, including academic, industry, startup, and other participants, with a range of technical backgrounds and expertise. One of the values of MX for users is that they only needed to know how they wanted the device to be configured, rather than the details of processes required to realize it—MX staff could take on much of the design coordination.

Governance

The MEMS Exchange (MX, today also known as the MEMS and Nanotechnology Exchange, MNX) was formed to provide microelectromechanical systems (MEMS) researchers and developers with access to a broad range of fabrication capabilities that they did not have available in-house and could not find in combination at any single facility that they might enlist. MX is a relatively small organization, currently with ~12 staff total (~25 during peak operations), including several technical experts. MX has been run by Executive Director Michael Huff since its inception, with oversight provided by CNRI CEO Bob Kahn and CNRI's Board of Directors, which is comprised of information technology and physical science experts

Funding

DARPA provided funding for MX through DARPA awards from 1997–2012. The first award for $10M over 3 years (extended to 5 years) was made via Space and Naval

Warfare Systems Command (SPAWAR). The contract itself was canceled early (in 1999) and restarted directly through the DARPA contracting office. Within the next several years, MX began operations, got the software system up and running (while continuing to make improvements), and enlisted six university facilities as the pilot network (each had between one to three staff supported via subcontract of the main award). The first process run was completed in 1999, and the work was routine by the early 2000s. A large number of runs were conducted for a range of customers (many DARPA MEMS performers, some startups, and others), some of which led to devices that were groundbreaking (and some of which were not successful or useful). During this time, MX designed and coordinated process runs across multiple facilities, each of which invoiced MX for the work. MX billed the users the combined total of all costs for their work request, and MX passed funds received to each facility according to invoice.

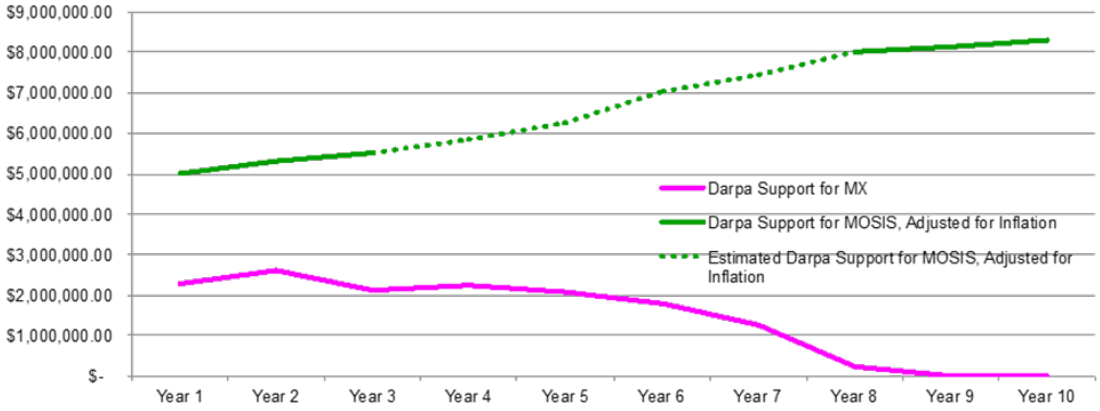
In 2001, the telecommunications industry bubble burst, which had a significant adverse impact on MEMS companies, and contributed to a drop in the number of facilities available through MX (one anecdote suggests that the drop was on the order of 50 percent). In the same year, a new DARPA director came in with a distinct approach to DARPA project management and a different set of priorities that impacted MX funding. MX instituted its first user fees (costs for using the service) in late 2001 at a flat 10 percent surcharge on top of the cost of a process run to go towards MX operational costs (Huff 2012). That year, attacks of 9/11 shifted DoD and DARPA priorities, which, according to an anecdotal source, may have contributed to a decreased interest in MEMS activities.

STPI learned through anecdote that DARPA's overall MEMS program budget experienced a shortfall (the reason for this is not entirely clear) around 2002, when MX funds were understood to be pending, but did not arrive as expected. MX ended up out a significant amount of money (~$1M) from DARPA, most of which it ultimately received, but it is unclear whether other MEMS performers received the funds they expected. DARPA MEMS performers comprised a significant share of MX's user base, but DARPA support of MEMS research declined. In September 2002, MX increased its user fee to 25 percent of the cost of a process run (Huff 2012).

The next DARPA award for MX began in 2003; the contract was ultimately extended through 2012. Securing DARPA funding was significantly harder for MX at this stage. MX had to justify new funding increments, and it has been suggested there was an inconsistency in or lack of communication about DARPA's and expectations and requirements. A customer satisfaction survey conducted in 2003 suggested that users saved between 25 and 50 percent of the costs they would incur working with fabrication sites directly (Huff 2012).

In year 6 CNRI staff met with the DARPA director about their request for sustained support for MX, which included a budget increase over the next 5 years, and learned that funding levels could be decided on an annual basis, based on performance. MX reporting requirements and performance metrics became primarily business-oriented—e.g., the number of customers and process runs completed and fee-based revenues in excess of operational costs (which were deducted from core DARPA funding). While some believed that it was too early to be on a fast-path to self-sufficiency, DARPA aimed to accelerate the transition. This shift may have been due in part to the DARPA Director's desire to move away from funding infrastructure, combined by non-ideal outcomes in other DARPA MEMS projects around this time, possible "overhyping" of MEMS, a decline in industrial focus on MEMS at the time (due in part to broader market instability), and thus a skepticism about the value of MEMS programs.

While funding beyond the first 3 years had not been guaranteed by DARPA, MX had been designed similarly to the MOSIS model, under the assumption of longer-term, sustained Federal support. Instead, core DARPA funding for MX began decreasing within a few years, and more rapidly in year 6, rather than increasing as requested, and as it had for MOSIS (see Figure J-1 for a comparison of core funding of MOSIS and MX). Core funding dropped to near zero by year 8.



Source: Figure provided by Michael Huff.

Note: Dashed line indicates estimated funding levels. Here, Year 1 for MX and MOSIS corresponds to approximately 1998 and 1981, respectively. The funding levels for MOSIS were adjusted for inflation at the time the plot was made (ca. 2007–2012).

Figure J-1. Annual DARPA core funding for MX (bottom curve) and MOSIS (top curve) by year post-launch.

From 2006–2010, MX increased its user fees (to 38 percent in 2006, 42 percent in 2008, and 52 percent in 2011), which ultimately led to some users attempting to contact fabs directly to avoid the fee. To mitigate this, MX removed the identities of fabs and some other process details from its online catalogue (MEMS Exchange n.d.c). In addition, DARPA programs encouraged their performers to use the MX service. MX met the DARPA target for self-sufficiency in 2008 (it covered 70 percent of costs via user fees), but was unable to reach 100 percent. The economic downturn of the Great Recession contributed to these challenges. At this time, costs through the MX service were still lower than costs of enlisting commercial fabs directly, but not lower than costs at academic facilities. MX efforts to offer new capabilities stalled, partially due to delays in funding in the final years of its contract. Formal business marketing efforts were not begun until 2008 (Huff, 2012), and ultimately MX did not bring in sufficient business to sustain its original operational model—it had to cease funding technical staff at universities, decreased spending for software development and process efficiency improvement, and ceased managing its newsletter (Huff 2012).

One suggestion made is that MX could have done more to engage a broader user base to bring in more business. Also acknowledged is that a longer period of sustained core support would have given the organization more time to build a user base that would sustain operations while enabling MX to continue to make process efficiency improvements that might boost revenue. MX considered but found no viable option for receiving private sector funding, which could have assisted during the transitional period, but may have been infeasible given MX's commitment to its IP model. MX attempted to secure NSF funding after DARPA funding decreased but was not successful.

A variety of modifications were made to the final MX contract, including to hire a project manager, fund a new MX marketing specialist selected by DARPA, buy an electron-beam lithography tool to be used at ARL, and directly support new process capabilities for other DARPA activities. MX had begun conducting fabrication at ARL in 2003 and relied less and less on remote facilities. Today, MX partners with ~15 fabrication facilities in total, going outside of ARL and NIST as needed.

Operations

MEMS Exchange was designed as an infrastructural service, to enable researchers and developers to build devices they otherwise could not make in-house, or even at a single off-site fab. Researchers were able to operate at a high-level of abstraction, and no longer needed to understand all nuances of fabrication processes and steps in order to design, experiment with, and use MEMS devices in new ways. MX staff acted as brokers between MX customers and the fabrication sites, exercising technical oversight and coordination of processes. MX core support came from DARPA, some of which was used to support facility staff (to run fabrication processes for MX customers, perform maintenance to maximize equipment up-times, help improve on-site processes, and help ensure that processes could be completed in a timely manner) and it passed funds from users to the facilities enlisted.

MX catalogues all process capabilities (and associated specifications and tolerances) of participating facilities, listing much of this information on a web site that users can consult to inform their work order. They mapped instrument and process compatibilities to guide engineering of fabrication process sequences, provided some engineering consulting services for designing process sequences (briefly for free, later with a fee for the service), and oversaw custom, multistep fabrication processes. MX staff also built an enterprise software system for accepting work orders and coordinating and tracking process sequences and steps (via virtual/digital "runcards") and the location of wafers around the country (through direct link to FedEx tracking). Over time, MX acquired some equipment in house, namely microscopy equipment for wafer inspection between process steps, and some fabrication tools associated with government work.

MX leveraged existing physical infrastructure that may have been funded through other government programs and otherwise used relatively infrequently despite a large overhead (in terms of capital investment). This distributed network of fabrication facilities enabled completion of process steps in the manufacture of MEMS prototypes designed by users. MX interfaced with the facilities, taking on the administrative burden of coordination and contracting logistics on behalf of the user, removing the need for users to work with the several facilities involved in their process sequence, enabling them to remain anonymous, and protecting their IP. As part of this work, MX catalogued more than 4,000 process steps, defined wafer cleanliness protocols and compatibility maps, and built an enterprise software system to coordinate all fabrication sequences. MX also had some in-house testing and analysis equipment that could be used for quality control (in particular to avoid compatibility issues or cross-contamination of fabrication tools) between process steps. MX staff worked to improve the software design and process sequence optimization for as long as they could afford to do so.

Business development activities at MX involved outreach to MEMS researchers, developers, and facilities. In the early days, UC Berkeley took on most of the work, and MX staff flew around to facilities to pitch and enlist participation in the MX network. This included addressing each facility's concerns over potential cross-contamination directly. Universities were more likely to embrace participation as means of generating additional revenue; commercial foundries took more convincing, but many did partner. It was likely easier to engage with a wide range of small customers via MX than directly. MX successfully engaged more than 80 facilities at its peak of operations, representing ~200 unique process capabilities. MX also developed standard legal agreements 1) between MX and users, 2) between MX and facilities, and 3) for each work order. MX administers and manages these electronically for all facilities and customers via their enterprise software system.

Early on, MX engaged with the R&D community via networking at conferences with the aim of introducing itself to the MEMS community. MX launched a newsletter, "MEMS Express," that digested research advances and other news about MEMS for the R&D community, and took ownership of a MEMS community website, MEMSnet.

Assisting users in transitioning their prototypes to the marketplace was not a part of the operational model. In fact, MX generally did not know the intended use of the parts whose fabrication they coordinated—they were a service to MEMS researchers and developers. Workforce development efforts were indirect. The work generated for participating facilities increased their staffing requirements. Overall, MX operations helped to develop and connect the MEMS R&D community and supported its early growth as a field.

Accomplishing Work

A user with an idea for a new MEMS device can access the MX website to review its catalogue of available processes. (MEMS Exchange n.d.c) They can register as a customer, establishing a web account and consenting to the user agreement electronically. Work requests are also submitted online via the user portal, and agreed to by the user electronically. MX staff review the order and generate an electronic "runcard" that details the process steps and associated facilities required, accounting for material and equipment compatibility across wafer process steps. Facilities are contacted and consent to the work order agreement via the software system, but they reserve the right to decline any work request (MEMS Exchange n.d.a).

Early on, MX staff worked closely with users to advise on process engineering design, including for inexperienced MEMS device designers. This effort proved time consuming, and MX later shifted to either allow staff experts to specify process sequence details, consult on process sequence design for a premium, or make process sequence decisions at its own discretion. MX also instituted a "generic" sequence that enabled MX staff to optimize it independently to optimize efficiency of completing common process steps. Today, MX staff conduct work at ARL (since 2003) or NIST (since ca. 2016) lab sites, and enlist other (mostly commercial) facilities as needed.

Intellectual Property

MX casts distinct lines on intellectual property (IP) ownership. Customers retain all IP associated with the device they wish to fabricate, and their identities are not revealed to the fabrication facilities. Facilities retain all IP associated with their fabrication processes and methods. IP is mutually licensed for the sole purpose of completing a work order. These terms are consented to by facilities through the MX facility agreement and by the customer through the MX customer agreement, (MEMS Exchange n.d.b) via click-through in the MX software interface.

The ability to retain their IP is a significant feature for users who may have commercial product applications in mind. While commercial foundries tend to want IP rights to parts that they fabricate, MX was able to successfully enlist them. Even the government has no IP rights to technology fabricated for outside users at government facilities.

Other Protections

Users and facilities have online accounts with access controls to protect account and project information. Firewalls are in place to protect the IP and identities of users within the enterprise software system. Because users' IP is protected, and user identities are shielded from facilities, MX generally does not have knowledge of the intended use of the device. MX engages only domestic (U.S.-based) facilities and customers. , and is able to work with export-controlled technologies User agreements require users to disclose whether any aspect of their work order (device to be fabricated or associated technical data) is subject to ITAR or EAR restrictions, to mark any information submitted that may be subject to these controls, and to warrant that they are in compliance with all associated legal requirements, such as registration with the U.S. Department of State (MX, n.d.). Fabrication facility agreements enable fabs to opt-in to receiving work orders subject to the ITAR or EAR, and require fabs to warrant that any such fabrication activities will be conducted in full compliance with these regulations (MEMS Exchange n.d.a).

Evaluation and Outcomes

As an infrastructural service, the goal of MX is to enable the R&D of its customers. Because MX does not typically know the intended use or application of the devices fabricated for its customers, and does not disclose user identities, tracking R&D successes can be challenging. However, between 1999 (the date of the first MX-brokered process run) and 2012 (the end of the final DARPA contract), DARPA had oversight over both MX and its other MEMS performers, and thus has information about R&D successes enabled by MX. STPI researchers heard anecdotes of several significant technical advances in MEMS enabled by MX, namely in the areas of on-chip sensors, accelerometers and gyroscopes (such as those that have become ubiquitous in today's smart phones), microphones, and electrodes that interface with biological systems (e.g., for sensing and signaling in cells).

DARPA's instituted performance metrics focused on business-related measures as indicators of progress, such as the number of user agreements, fabrication facility agreements, process runs, revenue from newly increased user fees (which were subtracted from core DARPA support), and percentage of costs covered by user fees (see section on Funding). DARPA set targets for MX in these areas, all of which were met. Between 1999 and 2012, MX had a cumulative 7,497 registered users and 971 registered business accounts, and had completed 2,621 process runs (Huff 2012).[27,]

Ultimately, costs of fabrication through MX remained competitive with other commercial services, but more expensive than fabrication at academic facilities. This may have priced many academic groups out of using MX, in favor of sticking with their own

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[27] By comparison, MUMPS completed 24 process runs between 1992 and 1998.

internal capabilities, or those of collaborators. For the calendar year of 2008, MX met DARPA's goal of 70 percent self-sufficiency. It subsequently struggled to make the full transition to financial independence, likely exacerbated by the Great Recession, and ran a deficit as of 2012 (Huff 2012).

Lessons Learned

Note: Based on the study team's analysis of information.

Funding and revenue instability inhibited the full-scale realization of MX's brokered, distributed fabrication model.

Today, CNRI still operates the MEMS Exchange, though the original operational model has been scaled back, with a significant reduction in efforts to improve efficiency of the service. Some of the experts to whom STPI researchers spoke suggested this current status, and the difficulty that MX had in transitioning to financial independence as DARPA funding was phased out, are indicative of a failure of the distributed fabrication model, or of CNRI in not working harder (and sooner) to build a user base and work flow sufficiently large to keep prices low. Others have suggested the activity was not nurtured by DARPA for long enough to enable its establishment as a robustly self-sustaining service through process flow improvements, pointing to the longer-term support for other DARPA infrastructural services, such as MOSIS, which is widely viewed to have been successful. Nonetheless, experts we interviewed named several key successes achieved and best practices exemplified by the MX activity that could be extensible to future prototyping infrastructure plans.

The substantial size of the first DARPA grant, choice of CNRI as a neutral broker, and the deep technical expertise of the MX director provided MX with credibility in eyes of the the MEMS community as it was launched, developed its initial network of facilities, and became operational.

MX built a reputation in the community as a trusted, technically-savvy broker of services. The size of the initial DARPA investment in MX ($10M over several years) was rare in 1997, especially in the time of PAYGO when large programs risked being cut to pay for new activities. This initial funding level signaled that DARPA was serious about the endeavor and helped to build the network of fabrication facilities. Launching the activity required a project manager willing to commit to a large-scale activity with substantial risks. The technical director, Michael Huff, has been consistently described as someone with deep technical expertise who had knowledge of the potential participants and an ability to engage at an appropriate level of abstraction for each.

As an infrastructural service that coordinated the logistics of prototype generation while maximizing the availability of design freedom and process options, MX enabled researchers to focus on realizing innovative MEMS devices.

At its peak activity level, MX helped researchers to push the boundaries of the field by opening up a wider range of process steps than they might otherwise access on their own. The service also lowered the barrier for many researchers and developers to innovate, test, and refine their ideas, without having to buy new capital equipment, coordinate directly with multiple fabrication facilities, or understand the details of the varied process steps required. It also helped to build a community of MEMS users and facilities to advance MEMS R&D, including by connecting facilities with new revenue streams and, in some cases, by providing direct funding to support staff at facilities.

These successes were facilitated by the willingness of CNRI and the MX director to take on complicated technical, logistical, and administrative tasks, which can manifest as grunt work. STPI learned via anecdote that the Director's drive to realize the distributed fab model enabled him to act as a force multiplier, accelerating the performance of others who would not be able to achieve their goals in his stead. CNRI also brought experienced administrators with deep collective understanding of infrastructure requirements, the ability to think architecturally, and good legal knowledge.

MX's operational approach to enabling technology prototyping was tailored to the maturity level and diversity of MEMS.

In many ways, MX is similar to MOSIS. Both were DARPA activities designed to provide access to existing infrastructure for device fabrication. For both, the location of the foundry was irrelevant to the device design. The broker did not compete directly with any of the fabrication facilities (at least in the beginning, in the case of MX) which helped for building trust in the service. The fabricator simply completed a design as requested by the user, but the broker's expertise in identifying simple process design rules could help to flag poor designs. Anyone could access the service, regardless of their geographic location within the U.S., and the broker enabled individuals with good ideas but few resources to build and experiment with prototypes.

However, MEMS technology presented a unique challenge in that there was no standard fabrication process for MEMS devices, as with CMOS for ICs, so the multi-project wafer approach to driving down the fabrication costs that was adopted by MOSIS was not feasible. Furthermore, MEMS devices could incorporate multiple materials and require a diverse range of fabrication processes that were not typically available at a single facility. MX thus established the traveling wafer model for MEMS, despite anxiety among fabs about the potential for cross-contamination.

Anxieties about technical risks of participating in the distributed fab model were addressed early on through by a knowledgeable director able to engage on technical issues and by empowering participating facilities to opt in or out of specific work orders at their own discretion.

The MX director's technical expertise enabled him to address facilities' cross-contamination concerns directly, and to propose technical approaches to mitigate risks. Lingering concerns were assuaged by building into the fab facility agreement the option to decline any work request for any reason. Nonetheless, recruiting fabrication facilities to participate under MX's uniform IP model required persistence and commitment. It has been suggested that anxieties associated with a distributed fab model for prototyping would be further alleviated if facilities maintained two sets of the same equipment: one dedicated to shared wafers, and one to streamlined, one-process fabrications, though financial costs could be prohibitive.

Without fully standardized processes that could be implemented on multiproject wafers, economies of scale were hard to achieve; this was inherent to the highly custom nature of the technology.

After DARPA began to decrease and ultimately phase out its funding for MX, financial sustainability of the infrastructural service depended on: 1) instituting user fees that would not be prohibitive to customers and 2) bringing in enough business such that these user fees would cover all MX overhead and operational costs.

While MX experimented with different fee levels, the pace at which it transitioned to a fully fee-based model and the volume of work that came in required fees currently believed to have been prohibitive to many academic users. Whether MX's shift to a hybrid broker-foundry model affected the willingness of facilities to participate, and also whether MX was viewed as a competitor were unclear.

MX fulfilled its original goal of providing a robust distributed-fabrication MEMS prototyping service for a window of time. It ultimately did not pivot to meet emerging needs and opportunities at the cutting edge, though some ideas were considered.

Some interviewees viewed MX as having fulfilled its purpose during the timeframe in which it was needed. It provided DARPA MEMS performers with fabrication services, leading to some important R&D breakthroughs, and developed new process capabilities requested by DARPA. Today, integrating MEMS into circuits is now fairly routine, so the MX model is less relevant at higher TRLs. However, anecdotes suggest researchers may only consider materials and processes that they can access readily, and that less high-risk, high-reward research is undertaken because researchers often hew to more established or readily available processes.

Nonetheless, processes are emerging for next level materials (e.g., flexible materials and biomaterials) not widely used in MEMS devices that, if made more widely accessible, could lead to new innovations. Additionally, had the distributed fab model persisted it might have helped to facilitate this. Also MX, if more affordable and more widely used, could possibly still fill an important gap today by providing services to non-expert users who lack the access to fab capabilities likely available to large research groups with significant funding or companies with the capital to build their own foundries. One interviewee saw it as a missed opportunity that MX did not shift focus to accelerating the next wave of MEMS technologies, for example, by integrating new material sets, batteries, biological materials, or flexible or 3-D circuits into its process capabilities.

STPI researchers also learned that a range of technological advances in recent years could make a brokered traveling wafer model easier to implement today. For example, fab process equipment cleaning and residue monitoring techniques have improved, further reducing cross-contamination risks. Today's Internet bandwidths and telecommunications tools would make remote process monitoring, wafer inspection, and user updates much easier. Finally, advances in ML could be used to optimize process sequence implementation further than MX was able to. In applying ML methods to the substantial quantity of data about process runs held by the broker of an infrastructural service, common process sequences could be detected and potentially standardized as process sequence blocks to move closer to an MPW model, at least for a subset of process steps, even for devices with a large range of potential process steps.

MX did not fully explore alternate funding models or development of collaborative partnerships, which might have helped to boost revenues or core support as it worked towards financial independence.

The MX brokership model for distributed fabrication had low revenue potential; and the business model seems to have been too challenging to sustain without core (Federal) support, though some of the difficulties may have been due to economic conditions and the pace of the phaseout of DARPA funds. Without government support, MX was too expensive for academia to use, though industry could still afford it. Some experts STPI interviewed suggested that longer-term, sustained funding is necessary for research infrastructure (as with MOSIS), especially if it is in support of technology with niche markets or requiring several years to shape into a marketable product. Sustained funding could be provided by the Federal Government if the infrastructure is in support of a broader national need, or from industry if broad market potential is there—depending on the fiscal environment.

Interviewees suggested that other partnerships could have been pursued, for example, with National Labs, Advanced Manufacturing Institutes, or the private sector. Several suggested that MX waited too long to launch an advertising campaign to build a user base and generate the volume of work that would have lowered user fees.

Changes in leadership and priorities at DARPA contributed to a decline in its support of MX within the activity's first five years.

Some interviewees attributed MX's challenges in achieving self-sufficiency to a shift in priorities that came about with a new DARPA Director—namely a disinclination to support infrastructure and a waning interest in MEMS. Some suggested that if DARPA had funded MX fully for longer (for example, for as long as MOSIS had been funded; see Figure A.I.1), the activity might have grown its industrial user base or had enough stability to develop alternative approaches to lowering costs (potentially even moving toward some analogue of the multiproject wafer model). Another suggestion has been that even higher funding levels would have helped MX to better achieve its goals throughout its DARPA-funded period, for example, by supporting dedicated, rather than cost-shared, technicians and additional equipment at fab sites.

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Appendix K.
Case Study—NextFlex

Note: For all case studies, information is based on interviews unless otherwise cited. Lessons learned are the study team's own analysis.

Table K-1. Summary of NextFlex

Goal(s)	Facilitate Flexible Hybrid Electronics (FHE) technology innovation and commercialization, accelerate manufacturing workforce development, promote a sustainable ecosystem for advanced manufacturing, and promote the growth, profitability, and success of the flexible and printed electronics supply chain and application areas
Origins	NextFlex roots go back to the U.S. Display Consortium founded by DARPA in 1993 and Flexible Display Center at Arizona State University established by the U.S. Army in 2004. USDC became the FlexTech Alliance, which currently leads NextFlex.
Partners and Roles	**Government:** One of 16 Manufacturing Innovation Institutes, one of 6 established by the DoD. **Private:** FlexTech Alliance, Inc. administers NextFlex **Academic:** Massachusetts Manufacturing Innovation Initiative leads NextFlex Massachusetts Node; University of Massachusetts at Lowell, University of Massachusetts at Amherst, Northeastern University, and Binghamton University supports the Massachusetts Node; Binghamton University—The Center for Advanced Microelectronics Manufacturing (CAMM) is the New York Node **State and Local:** The Center for Advanced Microelectronics Manufacturing (CAMM) at Binghamton University is the New York Node; Massachusetts Node, led by the Massachusetts Manufacturing Innovation Initiative is distributed across universities.
Governance	Governing Council, which consists of members from industry, academia, and government, serves as the broad oversight and advisory body.Each Tier 1 corporate member gets one seat (currently 2 members). Corporate Tier 2 members as a class get one voting seat for every three members.Corporate Tier 3 members, as a class, get only one voting seat, there must be at least 15 Tier 3 members, if fewer, no seat. Academic and non-profit Tier 1 members get one voting seat for every three members, with a maximum of three seats for the class. Academic and non-profit Tier 2 members get one voting seat, there must be at least 15 Tier 2 members, if fewer, no seat. Academic and non-profit Tier 3 members get no voting seats. The Massachusetts Node gets one voting seat. The Executive Director of NextFlex, serves as an *ex officio* member and gets one vote. The U.S. Government can have up to 25% of the voting seats; the U.S. Government Program Manager appoints the representatives.

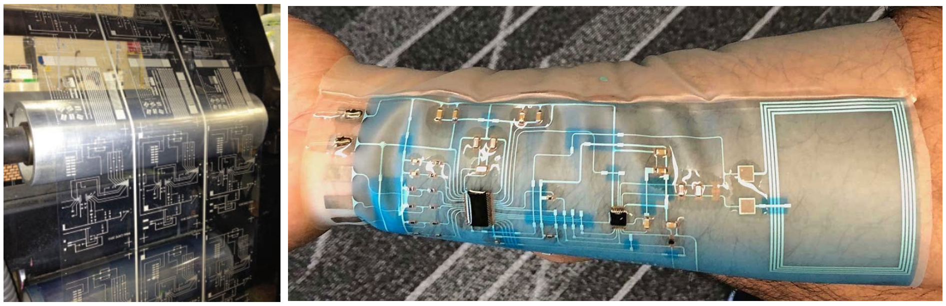
Funding	**Government:** In 2015, NextFlex received $75 M over five years. In 2020, NextFlex received an additional $154 M over seven years. NextFlex has competed for and won 86 projects for a total of $114 M.
Operations	**Years:** 2015 to present. **Accomplishing Work:** Mid-range, TRL 4–7; Staffed via an assignee model with temporary staff from members; key aspect of success was temporary staff, top talent sent from companies; roughly 200 employees; Technical Working Groups (TWG) develop roadmaps, identify key technology gaps, and do the necessary technology planning. There are 10 TWGs with subject matter experts from corporate, academic, non-profit and government members. NextFlex issues project calls to develop critical technologies. Members respond with teams.
IP	The member that creates IP during a NextFlex-funded project owns it. Most members get internal evaluation and R&D license to project IP. May negotiate for commercial rights. U.S. Government receives a Government Purpose license. Members retain own background IP, but cannot use it to block another member from practicing project generated IP.
Other Protections	NextFlex IP Policy also sets the standards for confidentiality and protection of information. The IP Policy confidentiality provisions call for a no less than reasonable standard of care when dealing with confidential and proprietary information, require appropriate document markings, and written documentation of oral disclosure. NextFlex does not hold a facility clearance; all work is at the unclassified level. The NextFlex fabrication facility in San Jose complies with International Traffic in Arms Regulations (ITAR) and the Food and Drug Administration's medical device manufacturing Quality Systems Regulations (QSR).
Evaluation and Outcomes	A key metric in the first phase was the development of a DRAM process using all U.S. supplies. NextFlex has accumulated a significant portfolio of success stories, including flex circuit Arduino, flexible antenna elements for Boeing, flexible sensor array for NASA, and a flexible safety monitoring armband.
Lessons Learned	DoD's use of a cooperative agreement provided a flexible umbrella for specific task orders, and the opportunity for the public-private partnership (PPP) to grow without limits to cost-shared funding. A PPP must grow and change as technology and markets evolve or risk becoming irrelevant. Transparency and structuring projects with participation from multiple member companies helped build trust. Highlighting successes builds awareness of the PPP's value proposition, leading to more partners following suit. Effective governance and operations appropriately balances structure, which can constrain members, with flexibility, which can hinder focus or provide insufficient direction.

Goals

In August 2015, the DoD Manufacturing Technology Program entered into a cooperative agreement with the FlexTech Alliance (SEMI 2015) establishing NextFlex, the Flexible Hybrid Electronics (FHE) Manufacturing Innovation Institute (White House

2015). NextFlex is a public-private partnership (PPP) of more than 160 companies, universities, and non-profits, and is one of the 16 Manufacturing Innovation Institutes (Manufacturing USA n.d.) established to date. NextFlex's goals are to facilitate FHE technology innovation and commercialization, accelerate manufacturing workforce development, promote a sustainable ecosystem for advanced manufacturing, and promote the growth, profitability, and success of the flexible and printed electronics supply chain and application areas. (NetFlex n.d.a)

Flexible hybrid electronics uses manufacturing processes that are at the intersection of the electronics industry and the high-precision printing industry. It uses roll-to-roll printing to fabricate flexible, conformable, and stretchable circuit substrates that replace the conventional rigid printed circuit board. See Figure K-1. The resulting circuits are lighter, can conform to the curves of a human body, and stretch across the shape of an object or structure. The process uses conductive and active inks to print conducting traces and some components, and high precision handling to integrate ultra-thin silicon components.



Source: Image of roll-to-roll printing from Savastano (2016); wearable FHE image from https://www.jabil.com/blog/flexible-electronics.html.

Figure K-1: Roll-to-roll printing of FHE and wearable FHE

Origins

NextFlex had a rather convoluted origin. In 1989, DARPA started the High Definition Systems Program. The program had two major technical components, processors and algorithms for processing, compressing, and transmitting high definition signals, and high resolution, full color, flat panel displays that could display videos (Tullis et al. 2001). On the display side, the bulky and heavy cathode ray tube was the only mature technology available. DARPA sought to find alternatives that were flat, thin, lightweight, and could support color video.

Each of the Services had different display requirements, and each focused on a different technology. The Army favored electroluminescent displays (EL) because they were very rugged and could withstand wide temperature ranges. The Air Force sought active matrix liquid crystal displays (AMLCD) because the technology could support high brightness, full color, high resolution panels that could replace the mechanical instrumentation in the cockpit.[28] The panels had to be bright enough that over the shoulder direct sunlight would not wash them out. The Navy needed large area displays that could replace the mechanical plotting table on ships and submarines, which plasma displays could do. All three Services and the DoD needed projectors that could project computer-generated images and videos for meetings and in situation rooms.

DARPA funded efforts in all four of the technology areas. As the program developed the technologies, it became apparent that it would need a parallel effort in materials and processing equipment. AMLCDs required large sheets of very thin glass that could withstand all of the processing conditions and new liquid crystal materials that had fast response and could provide high contrast. EL and plasma needed a blue phosphor, which did not yet exist. On the processing equipment side, the challenge became prioritizing across multiple technologies with different requirements, establishing performance benchmarks that satisfied multiple users, and ways for monitoring performance.

To help address these concerns DARPA established the U.S. Display Consortium (USDC) in 1993. (Internet Archive 2001) USDC members were U.S. flat panel display manufacturing companies. The premise of USDC was that the ultimate users knew best in which areas research and development (R&D) and infrastructure development could have the highest pay-off. DARPA structured USDC so that members themselves could not get USDC funding, they could only provide input on which infrastructure projects to fund. This approach fostered cooperation and alignment of interests within the display industry and focused them on establishing an infrastructure that supported all.

In February 2004, the U.S. Army established the Flexible Display Center (now the Flexible Electronics and Display Center) at Arizona State University to spearhead the next revolution in information displays. (ASU n.d.) The Center has 250,000 square feet of facilities, including 25,000 square feet of Class 10/100/1000 clean rooms. These facilities house a 6-inch (150 mm) wafer-scale pilot line for R&D, and a GEN II (370 mm x 470 mm) pilot line for low volume glass panel processing.

By 2008, most flat panel manufacturing had migrated to Asia and USDC had to change its mission and focus to stay relevant. USDC broadened its mission to serve the common interests of the display industry and the flexible, printed electronics industry, which overlapped in certain areas. It changed its name to FlexTech Alliance and promoted collaboration within industry, academia, and government to identify and resolve critical technical challenges of FHE (Laser Focus World 2008). In October 2015, FlexTech Alliance became the first SEMI Strategic (Association) Partner, a form of inter-industry

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[28] The growing popularity of the liquid crystal digital watch caused the decline in the popularity of mechanical wristwatches. This in turn, created a shortage of people skilled in repairing compact, highly complex mechanical systems. Non-functioning instrument clusters grounded planes.

cooperation (SEMI 2015). This relationship allows the FlexTech Alliance to engage with a new set of companies and R&D organizations, and leverage the international community through SEMI's global platforms.

In August 2015, DoD Manufacturing Technology Program established NextFlex, the Flexible Hybrid Electronics Manufacturing Innovation Institute (White House 2015). NextFlex is a public-private partnership of more than 160 companies, universities, and non-profits that is one of 16 Manufacturing Innovation Institutes. The Air Force selected the FlexTech Alliance to lead NextFlex.

Partners and Roles

NextFlex sponsors two regional nodes, one located in Massachusetts and the other in New York. The nodes bring together a combination of regional companies, universities, and economic development groups that work collaboratively to build out the FHE ecosystem.

The NextFlex Massachusetts Node, (NetFlex MA Node n.d.) led by the Massachusetts Manufacturing Innovation Initiative, focuses on manufacturing processes. It leverages prior state investments at the University of Massachusetts at Lowell, University of Massachusetts at Amherst, and Northeastern University, to focus on:

- Accelerating competitiveness of the regional FHE supply chain;
- Serving as a complement to the NextFlex Technology Hub in San Jose, California.[29]

The Center for Advanced Microelectronics Manufacturing (CAMM) (CAMM n.d.) at Binghamton University is the New York Node. Its mission is to demonstrate the feasibility of roll-to-roll (R2R) flexible electronics manufacturing by acquiring prototype tools and establishing processes capable of producing low volume test bed products. Its goals are to:

- Map emerging flexible electronic technologies;
- Validate the design of flexible electronic manufacturing capabilities;
- Develop process technologies and manufacturing know-how; and
- Demonstrate technologies and products through test-bed projects and low-volume device manufacturing.

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[29] NextFlex has pilot-scale manufacturing line in San Jose, California.

The CAMM has a 10,000-square-foot facility in Endicott, N.Y. The facility has a panel line for process/product development and an integrated R2R research line for product development using R2R manufacturing.

The DoD put out a solicitation seeking an entity that would manage NextFlex. SEMI FlexTech Alliance (SEMI n.d.) wrote the winning proposal to DoD. Currently, an entity that it spun off, FlexTech Alliance, Inc. administers NextFlex.

Funding

NextFlex relies on three sources of funding, Federal direct funding, bidding on Federal projects, and industry funding of various activities (GAO 2017).

- **Federal:** Initially, NextFlex received $75M over five years. In 2020, NextFlex received an additional $154M over seven years (Businesswire 2020).
- **Federal Projects:** In addition to the Federal funding, NextFlex has competed for and won 86 projects for a total of $114M.
- **Industry**: Industry has committed about $96M.

NextFlex has a membership structure with three tiers for corporate members, and one with three tiers for academic and non-profit members. There is separate group for government members. (NextFlex n.d.b) The dues scale accordingly. (NextFlex n.d.c.)

<u>Corporate</u>

- Tier 1—$100 K cash, $75 K in-kind, with a three-year commitment.
- Tier 2—$50 K cash, $30 K in-kind, with a three-year commitment.
- Tier 3—$10 K cash, in-kind encouraged, with a three-year commitment. Tier 3 offers a reduced rate of $6 K for small companies with fewer than 500 full time equivalent employees.
- Observer—$2.5 K cash, in-kind encouraged, three-year commitment. It only allows start-ups with less than $5M in revenue and fewer than 20 employees in this category for a maximum of three years.

<u>Academic and non-profit</u>

- Tier 1—$15 K cash, $300 K in-kind with a three-year commitment.
- Tier 2—$7.5 K cash, $150 K in-kind with a three-year commitment.
- Tier 3—$2.5 K cash, in-kind contributions encouraged.

Governance Model

The Governing Council and Technical Council provide the governance for NextFlex.

Governing Council

The Governing Council, which consists of members from industry, academia, and government, serves as the broad oversight and advisory body of NextFlex. The Participation Agreement allocates the seats on the Governing Council based on membership type. (NextFlex n.d.d) Each Tier 1 corporate member gets one seat. Currently, there are only two Tier 1 corporate members, Lockheed Martin and Boeing. They each have one voting seat on the Governing Council. (NextFlex n.d.e)

Corporate Tier 2 members have one voting seat for every three members, with a maximum of three voting member that represent the class. Corporate Tier 3 members, as a class, get only one voting seat and the right this seat vests with a minimum of 15 members. If there are fewer than 15 Tier 3 members, the class does not get a seat. Observers do not get any seats on the Governing Council.

As a class, Tier 1 academic and non-profit members get one voting seat for every three members, with a maximum of three voting seats. Tier 2 members, academic and non-profit members get only one voting seat and the right this seat vests with a minimum of 15 members. If there are fewer than 15 Tier 3 members, the class does not get a seat. Tier 3 members do not get any seats. The Massachusetts Node gets one voting seat.

Malcolm Thompson, as the Executive Director of NextFlex, serves as an *ex officio* member and gets one vote. The U.S. Government can have up to 25 percent of the voting seats on the Governing Council. The U.S. Government Program Manager appoints the representatives for these positions. Currently, the government has three representatives on the Governing Council, each with a vote. Tracy Frost, one of the government members, represents all of the DoD Manufacturing Institutes. In addition to its voting rights, the government has veto power.

The position of Governing Council chair rotates among the Governing Council members. The chair, however, must be a U.S. citizen.

The participation Agreement provides for a number of non-voting observers. These include Nodes, state-based economic development agencies, and other members at the discretion of the Governing Council. SEMI FlexTech gets non-voting observer status.

Technical Council

The Technical Council ensures that NextFlex pursues high quality projects that advance TRLs and MRLs of FHE technology. (NextFlex n.d.e) It prioritizes projects for the Governing Council. The Council advises the Director of Technology and the Chief Technology Officer of actions that enable rapid innovation and commercialization. It also assists in the development of education and training materials and roadmapping. It can draw on expertise from outside the membership. The Technical Council can with a simple majority vote initiate roadmapping activities and project calls.

The Technical Council consists of the following members:

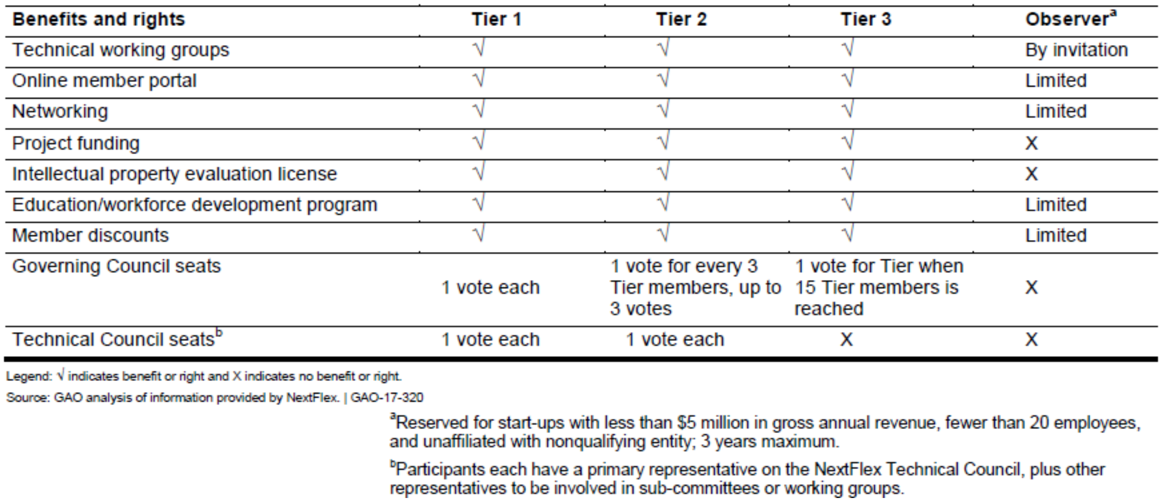
- A representative of each of the Tier 1 and Tier 2 corporate members, with each having one vote.
- A representative of each of the Tier 1 and Tier 2 academic and non-profit members, with each having one vote.
- U.S. Government representatives who have up to 25% of the seats and votes on the Technical Council.
- Other members that the Executive Director appoints and the Governing Council approves.

NextFlex's Director of Technology and the Chief Technology Officer co-lead the Technical Council.

Benefits and rights of members

Table K-2 summarizes benefits and rights of NextFlex industry members, and Table K-3 summarizes benefits and rights of NextFlex academic and non-profit members.

Table K-2. Summary of NextFlex industry membership benefits and rights (GAO 2017, 60)



Benefits and rights	Tier 1	Tier 2	Tier 3	Observer[a]
Technical working groups	√	√	√	By invitation
Online member portal	√	√	√	Limited
Networking	√	√	√	Limited
Project funding	√	√	√	X
Intellectual property evaluation license	√	√	√	X
Education/workforce development program	√	√	√	Limited
Member discounts	√	√	√	Limited
Governing Council seats	1 vote each	1 vote for every 3 Tier members, up to 3 votes	1 vote for Tier when 15 Tier members is reached	X
Technical Council seats[b]	1 vote each	1 vote each	X	X

Legend: √ indicates benefit or right and X indicates no benefit or right.

Source: GAO analysis of information provided by NextFlex. | GAO-17-320

[a] Reserved for start-ups with less than $5 million in gross annual revenue, fewer than 20 employees, and unaffiliated with nonqualifying entity; 3 years maximum.

[b] Participants each have a primary representative on the NextFlex Technical Council, plus other representatives to be involved in sub-committees or working groups.

Table K-3. NextFlex academic and nonprofit membership benefits and rights (GAO 2017, 61)

Benefits and rights	Tier 1	Tier 2	Tier 3
Technical working groups	√	√	By invitation
Online member portal	√	√	Limited
Networking	√	√	Limited
Project funding	√	√	√
Intellectual property evaluation license	√	√	X
Education/workforce development program	√	√	√
Member discounts	√	√	Limited
Governing Council seats	1 vote for every 3 Tier members, up to 3 votes	1 vote for Tier when 15 Tier members is reached	X
Technical Council seats[a]	1 vote each	1 vote each	X

Legend: √ indicates benefit or right and X indicates no benefit or right.

Source: GAO analysis of information provided by NextFlex. | GAO-17-320

[a] Participants each have a primary representative on the NextFlex Technical Council, plus other representatives to be involved in sub-committees or working groups.

Brief descriptions of the member benefits listed in the tables that follow. Later sections of this document have more detailed discussions of key benefits. The technical working groups (TWG) consist of subject matter experts from member companies that collaborate on roadmaps, key technology gaps, and the technology required to advance the flexible hybrid electronics ecosystem. Part of the NextFlex website is only open to members.

NextFlex provides members with networking opportunities. Innovation Days (NextFlex n.d.g) is a three-day event with technical sessions, exhibits, and networking breaks where members can meet informally with other members and government officials. Members can choose to be included on the networking page where other members can reach out to them.

NextFlex members can submit proposal in response to project calls. Project call topics address identified gaps where the manufacturing readiness lags other aspects of the FHE ecosystem. NextFlex holds Teaming Events (NextFlex n.d.h) where members can pitch their proposal ideas and capabilities to other members looking to collaborate.

Members receive an internal evaluation and R&D license for project-generated intellectual property (IP). Should a member wish to commercialize a product based on that IP, however, they must negotiate a license with the IP owner.

Members can take advantage of the workforce education and training opportunities that NextFlex offers.

NextFlex holds a quarterly webinar in which all Tier 2 and Tier 3 members can participate, and can ask the Executive Director questions.

Operations

NextFlex relies on TWGs to develop roadmaps, identify key technology gaps, and do the necessary technology planning required to advance the flexible hybrid electronics ecosystem. Currently, there are 10 TWGs with subject matter experts from corporate, academic, non-profit and government members. (NextFlex n.d.i)

The working groups organize around technical areas. Each working group has a government lead, an industry lead, and university representatives. The working groups are:

- **Human monitoring systems**—wearable, unobtrusive, non-invasive, and minimally invasive devices for sensing and reporting the physiological state of warfighters, athletes, geriatric populations, and medical patients in varied environments.
- **Asset monitoring systems**—conformal or integrated devices for sensing and reporting the state of infrastructure, vehicles, logistics, or the environment. Networks of sensors or devices for Internet of Things concepts.
- **Integrated array antennas**—printed wideband array elements on flexible or conformal surfaces and integration of thinned electronics with printed wideband array elements.
- **Soft robotics**—soft, compressible sensors and devices for robotic functionality, that enable active clothing, wearable robots or robotic tools, and advanced prosthetics. Improved robot-human interactions for surgery, manufacturing, and consumer electronics.
- **Flexible power**—power and energy storage subsystems for FHE devices including batteries, supercapacitors, wireless power, and energy harvesting approaches. These devices are compatible with small, unobtrusive, flexible form factors.
- **Device integration and packaging**—develop new tools for handling and integrating thin flexible silicon dies, integrate circuits, passive components, and sensors on flexible, stretchable, foldable substrates and three-dimensional surfaces. Leverage advanced precision printing and high-speed automated pick and place for integrating device components, interconnects, and data lines.
- **Printed flexible components and microfluidics**—develop and mature contact and non-contact printing processes that support hybrid device concepts, including sensors and discrete device components. Print and integrate microfluidic channels and fluidic control elements.

- **Materials**—supply scale-up and FHE manufacturing processes for conductive and dielectric inks and pastes, adhesives, encapsulant materials, and flexible substrates.
- **Modeling and design**—Leverage existing software and hardware design capabilities, simulation techniques, and manufacturing process control tools while also integrating novel manufacturing design rules for FHE.
- **Standards, testing and reliability**—Develop tools and test protocols to evaluate device-level and system-level FHE performance as well as reliability in both commercial and military environments. Collaborate with standards organizations and professional societies to develop specifications and standards.

NextFlex issues project calls to develop technologies that are critical to FHE manufacturing. NextFlex has a very transparent process for selecting new projects. First, the Technical Council works with the TWGs to develop a technology roadmap, which identifies gaps. It prioritizes the focus areas that will address the gaps, and provides the Governing Council with a list.

Project topics fall in one of two categories. NextFlex-Funded Topics focus on developing and qualifying manufacturing processes, methods, or tools identified via the roadmapping process and in discussions with TWG leads, members, and government partners. DoD agencies that will provide funding for the projects, develop Agency-Funded Topics.

The Governing Council reviews the focus areas for NextFlex-Funded Topics and approves the ones selected for a new project call. The Technical Council issues a project call with both NextFlex-Funded and Agency-Funded Topics to NextFlex members.

Each project call publishes a guidebook. (NextFlex 2021a) The guidebook identifies the project focus areas, as defined in the FHE roadmap. It contains all the relevant dates, the duration of the project, maximum level of available Federal funding, a description of the efforts sought, the evaluation criteria, and a detailed format for proposals. NextFlex projects do not call for performers to deliver a prototype device, but rather, to develop capabilities that close gaps.

Members form teams to respond to the project call with a proposal. NextFlex holds Teaming Events (NextFlex 2021b) where members can pitch their proposal ideas and capabilities to other NextFlex members who are looking to collaborate. Each company can pitch only one proposal idea. Each presenter gets one minute and one slide for their pitch. The teams form, and develop proposals that they submit in response to the project call.

The Technical Council, member volunteers, NextFlex staff, and government subject matter experts (SME) review the submitted proposals. Reviewers evaluate the proposals, score each proposal based on the published evaluation criteria, and provide comments.

NextFlex compiles and analyzes the reviews, and summarizes the comments for the NextFlex Technical Council.

The Technical Council recommends the proposals addressing NextFlex-Funded Topics to the Governing Council for funding. The Governing Council votes to select the projects for award negotiation and funding. Agency-Funded Topics proposals go through a similar review process. The DoD agencies, however, select and fund the performers. NextFlex, however, executes the contracts with the performers.

NextFlex underwrites up to 50 percent of the costs of a project. The teams provide the rest as cost-share. Cost share can include labor, materials, use of equipment, and travel. The project cost, however, may not include a profit or fee. The cost-share requirement applies to the entire team. Individual team members can contribute less than 50 percent, but the team as a whole must contribute over 50 percent. This allows larger, better-financed companies to shoulder the funding burden for smaller, less financially capable companies.

All recipients of NextFlex funding must be members. This requirement applies to every member of the project team. Companies supplying standard commercial off-the-shelf (COTS) components to team members, however, are not required to be NextFlex members.

At the end of the project, the performers deliver the project reports. Teams deliver the NextFlex-Funded Topic reports to NextFlex. It publishes the project reports on the NextFlex Member Portal and includes them in quarterly update webinars to the members. Teams deliver Agency-Funded Topic reports to the funding agency. The agency, at its discretion, may share them with NextFlex members.

Intellectual Property

The NextFlex IP policy establishes the rules for IP generated during a NextFlex-funded project. (NextFlex n.d.k) Every member that joins NextFlex agrees to the same IP policy in the Participation Agreement. (US Legal Forms n.d.)

Ownership follows invention. If a member creates IP during a NextFlex-funded project, that member gets the right to keep ownership of it. Because the U.S. Government partially funds NextFlex projects, however, the U.S. Government receives a Government Purpose license to that IP.

Most NextFlex members[30] receive an internal evaluation and R&D license for project-generated IP. Should a member wish to commercialize a product based on that IP, however, they must negotiate a license with the IP owner. NextFlex policy provides that such a license must be available on reasonable and non-discriminatory terms. If background IP would block a member-licensee's commercial use of project IP, the license

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[30] See Tables 1 and 2 for member types that do not get an IP license.

must address such blocking of the IP. Tier 3 academic and non-profit members and corporate observers do not receive an R&D IP license.

Members always retain ownership of their own background IP. Members are not required to provide background IP simply because they joined NextFlex. If background IP is necessary to practice project-generated IP, the owner of the background IP cannot use it to block another member from practicing project generated IP. The background IP owner must provide a license on reasonable and non-discriminatory terms. A member may voluntarily contribute their background IP to a project.

Other Protections

NextFlex IP Policy also sets the standards for confidentiality and protection of information. The IP Policy confidentiality provisions call for a no less than reasonable standard of care when dealing with confidential and proprietary information, require appropriate document markings, and written documentation of oral disclosure. It has standard clauses that exclude publicly available information from consideration as confidential or proprietary.

NextFlex has established a privacy policy for visitors to their websites, which sets out how they treat the visitors' personal information. (NextFlex 2017) The policy describes the information that NextFlex collects, how it uses the information, and how it shares it. NextFlex asserts that it takes reasonable steps consistent with industry practice to protect the visitors' personal information from loss, misuse, unauthorized access, disclosure, alteration, or destruction.

NextFlex does not hold a facility clearance. It performs all work at the unclassified level. The NextFlex fabrication facility in San Jose, however, complies with International Traffic in Arms Regulations (ITAR) (Businesswire 2019) for military electronics, materials, and guidance equipment manufacturing. It also complies with the Food and Drug Administration's (FDA) medical device manufacturing Quality Systems Regulations (QSR) for good manufacturing practices. (FDA 2020)

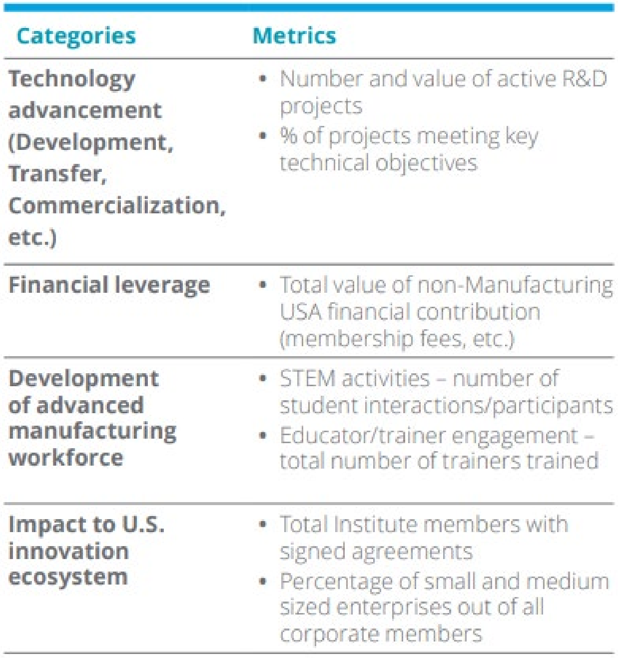
Evaluation and Outcomes

Metrics

Manufacturing USA commissioned Deloitte Consulting, LLP (Deloitte) to conduct a third-party review and evaluation of the Manufacturing Innovation Institute Program. (Deloitte 2017) The study focused on the overall Program, and did not address the detailed operations of any individual Institute. The Institutes and their members, however, provided perspectives and information to assist in developing the Program-level analysis.

The scale and complexity of the Manufacturing USA's goal of establishing America as a global leader in manufacturing make developing metrics that are meaningful across all Institutes challenging. Deloitte put considerable effort into developing appropriate evaluation strategies. Table K-4 shows the metrics that the Program, Institutes, and the governing agencies developed to measure progress.

Table K-4: Metrics that Manufacturing USA has in place to evaluate the Manufacturing Innovation Institutes (Deloitte 2017, 60)



Categories	Metrics
Technology advancement (Development, Transfer, Commercialization, etc.)	• Number and value of active R&D projects • % of projects meeting key technical objectives
Financial leverage	• Total value of non-Manufacturing USA financial contribution (membership fees, etc.)
Development of advanced manufacturing workforce	• STEM activities – number of student interactions/participants • Educator/trainer engagement – total number of trainers trained
Impact to U.S. innovation ecosystem	• Total Institute members with signed agreements • Percentage of small and medium sized enterprises out of all corporate members

Outcomes

NextFlex has accumulated a significant portfolio of success stories. This is a small sample of examples:

1. Translated electronic designs based on Arduino® products from standard printed circuit boards (PCB) to printed flex circuits;
2. Helped Boeing develop a process to print antenna elements and a microstrip feed networks on flexible hybrid substrates without vertical interconnect access. This greatly reduced fabrication time and costs;
3. Helped NASA develop a next-generation wearable flexible sensor array for astronaut crew health monitoring;
4. Developed a next generation flexible conformal armband capable of monitoring volatile organic compound concentrations, oxygen levels, temperature, and humidity for ensuring worker safety in confined spaces with dangerous vapors;

5. Provided Profusa with expertise in flexible hybrid electronics, engineering, materials science, and optics design work and design criteria to develop smaller, flexible tissue sensors. NextFlex then fabricated over 1000 wearable units at its facility; and
6. Helped GE partition the design for a wearable electrocardiogram between FHE and printed sensor boards. The design now includes a device that is able to bend and move with the body while monitoring internal vital signs—critical to making a wearable monitor that patients can wear all day.

NextFlex has put in place a successful workforce training program targeting different segments of the workforce. FlexFactor (NextFlex n.d.l) targets students still in high school under the premise that if they do not develop interests early, students will not take courses that will put them on track to pursue careers in technology and manufacturing. FlexFactor is a four-week program that introduces high school students to technology and manufacturing. As part of the course, the students must work collaboratively in groups of four to five on a design project. At the end of the four weeks, they have a Shark Tank like competition.

Over 6,000 high-school students have cycled through FlexFactor. NextFlex is now expanding the program to include Community College students.

Flex2Future work-based learning program targets the working adults. It makes it easy for colleges and companies to coordinate internships, apprenticeships, and similar opportunities. NextFlex developed the program in partnership with community colleges to help them incorporate cutting-edge learning into advanced manufacturing programs. Work-based learning allows colleges to incorporate resources that are virtually impossible for colleges to provide on their own. Students train on industrial equipment, work with professionals familiar with cutting-edge materials and business processes, and develop communication and planning skills.

FlexPro is multi-day training program is designed to help working professionals develop FHE awareness and knowledge. Attendees participate in hands-on and group learning experiences and return to their work with an awareness of how FHE can create value for their product designs.

NextFlex' workforce training programs have been so successful that it now has accumulated $8M in funding from multiple sources, and has become self-sufficient. Eight of the manufacturing institutes have asked NextFlex to help them develop a similar workforce development program.

Lessons Learned

Note: Based on the study team's analysis of information.

DoD’s use of a cooperative agreement provided a flexible umbrella for specific task orders, and the opportunity for PPP to grow without limits to cost-shared funding.

The government has a number of vehicles for funding PPPs, contracts, grants and cooperative agreements. Cooperative Agreements, however, can be very flexible, and allow NextFlex to accumulate cost share that is more than the government’s contribution.

A PPP must grow and change as technology and markets evolve or risk becoming irrelevant.

NextFlex grew out of the U. S. Display Consortium (USDC). DARPA established the USDC to support its efforts in flat panel display technology. When most flat panel manufacturing migrated to Asia, however, USDC had to change its mission and focus to stay relevant. USDC broadened its mission to serve the common interests of the display industry and the flexible hybrid electronics industry, which overlapped in certain areas. It changed its name to FlexTech Alliance and promoted collaboration within industry, academia, and government to identify and resolve critical technical challenges of FHE. The FlexTech Alliance submitted the proposal and DoD, and the Manufacturing Technology Program selected the FlexTech Alliance Inc., a 501(c)(6) organization, to manage NextFlex.

Transparency and structuring projects with participation from multiple member companies helped build trust.

NextFlex engages the working groups in the project definition phase. This develops trust, and ensures that the projects closely match members’ needs. The transparency encourages members to participate in projects.

Highlighting successes builds awareness of the PPP’s value proposition, leading to more partners following suit.

NextFlex highlights successful projects in press releases. (NextFlex 2021b, 2021c, 2022) This makes members aware of the value that NextFlex generates, and at the same time publicizes the successes to the wider community. As the wider manufacturing community becomes more aware of NextFlex’s value proposition, it becomes easier to attract new members.

Effective governance and operations appropriately balances structure, which can constrain members, with flexibility, which can hinder focus or provide insufficient direction.

A rigid governance approach constrains members and provides leadership with tools to manage the organization. If it is too rigid, however, it can constrain the members and not focus resources on areas with the most need or impact. Too much flexibility, alternatively, may lead to lack of focus and hinder progress. The PPP must find an approach that balances structure and flexibility.

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Appendix L.
Case Study—Semiconductor Manufacturing Technology (SEMATECH)

Note: For all case studies, information is based on interviews unless otherwise cited. Lessons learned are the study team's own analysis.

Table L-1. Summary of SEMATECH

Goal(s)	Surpass Japan as a leader of semiconductor manufacturing by addressing materials supply chain and equipment issues and establishing industry best practices
Origins	In the 1980s, U.S. semiconductor equipment suppliers' market share was declining rapidly because of competition with Japanese companies, leading industry leaders to raise concerns with Congress. Congress decided to fund SEMATECH based on the concern that the U.S. falling behind on semiconductor leadership is a national security issue.
Partners and Roles	**Federal:** DoD (DARPA) contributed half of SEMATECH's funding and played an active role in funding and strategy 1987–1996 **Private:** 14 original corporate members, mainly large and midsize companies; added international partners to membership in 1998 **Academia:** Partnered with universities and national labs to establish centers of excellence **International:** In 1996, SEMATECH voted to end USG funding and become an international consortium. It added 5 international companies to its membership in 1998. **State and Local:** The State of Texas and later New York provided funding, land, and incentives to SEMATECH
Governance	**Board of Directors:** One representative from each member company (typically the CEO) that determined high-level direction **Executive Technical Boards**: Member company executives (each company has one vote) that provided advice on tech strategy **Focused Advisory Boards:** Member company managers that provided technical advice in specific areas of interest, company voting power based on contribution amount **Project Advisory Boards:** Member company representatives that communicated specific project needs along with feedback, voting power based on contribution amount
Funding	**Federal:** DoD contributed approximately 50 percent of SEMATECH's starting budget of $200 million per year 1987–1996 **Private:** 14 original corporate members, mainly large and midsize companies; added international partners to membership in 1998. Members paid annual

	dues ranging from \$1–\$15 million, depending on their revenues, with an approximate yearly total of \$100 million **State and Local:** The State of Texas provided funding for its first facility (\$40 million grant) and later a \$40 million loan in 2004. The State of New York provided ~\$300 million for SEMATECH's 2010 move to NY through SUNY Polytechnic
Operations	**Years:** 1987–2015, with three distinct eras/goals: 1987–1996, national consortium with USG funding and involvement; 1996–2010, international consortium; 2010–2015, transition to SUNY Albany and dissolution **Infrastructure:** Fab and headquarters with clean room in Texas **Staff:** Assignee model with top talent sent from member companies In its first chapter, SEMATECH had approximately 500 full-time employees and 300 others rotating on two-year assignments. At its height after including international companies, SEMATECH had approximately 700 employees. There were approximately 50–100 employees at SUNY Poly. **Accomplishing Work:** SEMATECH conducted research (generally at TRL levels 4–7) at its headquarters and centers of excellence which developed an advanced computer chip or silicon integrated circuit, along with flexible, automated tools, processes, and equipment by convening industry experts
IP	SEMATECH avoided IP conflicts among members by focusing on pre-competitive research. SEMATECH maintained ownership over all patents derived from SEMATECH-funded work that it then licensed out to member companies who held exclusive rights for a period of two years. SEMATECH employed its own attorneys that managed patent applications, patent infringement cases and other legal issues.
Other Protections	During the first chapter, DoD had more strict security requirements. After transitioning away from DoD funding and becoming an international consortium, SEMATECH allowed an international workforce and more relaxed security arrangements
Evaluation and Outcomes	There is a general consensus that SEMATECH played a vital role in the United States regaining world semiconductor market share. The DRAMs produced during the first chapter were functional and demonstrated the viability of both the Fab process and the wafer material and tool sets used. SEMATECH has been used as a model for other industry consortia.
Lessons Learned	SEMATECH had strong leadership and participation from industry members who were concerned about falling behind Japan. SEMATECH focused on pre-competitive R&D to stabilize the supply chain and set industry standards for U.S. semiconductor manufacturers avoided IP conflicts and encouraged collaboration. SEMATECH's consensus-based decision-making model improved member satisfaction. After meeting its initial goal, SEMATECH did not realign around a clear and compelling mission.

Goals

The high-level goal of SEMATECH was to stop and then reverse the loss of U.S. semiconductor manufacturing leadership to Japan by addressing manufacturing and supply chain issues for the domestic industry (Hof 2011). SEMATECH had an early objective of enabling the U.S. semiconductor industry to eclipse Japan's semiconductor industry by demonstrating that SEMATECH could manufacture state-of-the-art semiconductor devices using only U.S. equipment (GAO 1992).

SEMATECH wanted to strengthen the U.S. semiconductor industry by providing a forum for competitors to address industry issues collaboratively, accelerate technology solutions, and determine the future direction of the industry (U.S. Department of the Treasury 2013). While SEMATECH was initially formed to strengthen the U.S. industry, it opened its membership to international companies in 1998 and refocused on addressing issues for the global semiconductor industry.

In 2010, SEMATECH transitioned from Austin, TX to the SUNY Polytechnic Institute in Albany, New York. Until its sunset in 2015, SEMATECH worked toward a new goal of creating a Photovoltaic Manufacturing Consortium funded by the industry, the Department of Energy, and the State of New York (Hof 2011).

Origins

SEMATECH's history can be summarized in 3 chapters. The first spans its creation as a consortium in 1987, with both a fabrication facility ("Fab") and its headquarters in Austin, Texas, to 1996, when it ceased receiving Federal funding in 1996. In the 1980s, U.S. semiconductor equipment suppliers' market share was declining rapidly because of formidable competition from Japanese companies, who were producing higher quality devices than U.S. suppliers. Although the industry preferred to limit the U.S. government's involvement to a customer role, industry leaders had growing concerns about Japan's leadership and began sounding the alarm to Congress (NRC 2003). Meanwhile, the regulatory climate in the U.S. was becoming more favorable for consortia. For example; the National Cooperative Research Act of 1984 (P.L. 980-462) amended anti-trust law and allowed consortia such as SEMATECH to be formed, and the Bayh-Dole Act of 1980 simplified the process for research groups to obtain intellectual property rights to federally funded research, catalyzed research collaborations such as SEMATECH (Mowery et al. 2004).

These concerns were translated into action in 1987, when a Defense Science Board Task Force released a report on the diminishing competitiveness of the U.S. integrated circuit (IC) industry, which argued that it was a national security problem that the government needed to address, and recommended establishing an industry/government consortium. Although the Reagan administration initially opposed an industry/government consortium, Congress was concerned that the U.S. IC manufacturing industry would fall further behind Japan without intervention and approved a bill to authorize funding for SEMATECH (P.L.100-180) (Slusarczuk and Van Atta 2012).

The second chapter began in 1996 when SEMATECH established an international program to transition the wafer size used in manufacturing to 300mm (12”) (Ham et al. 1998). In 1998, after the end of USG funding, SEMATECH became an international consortium, with significant foreign dues-paying membership (Dorsch 1999). The third chapter and final chapter began in 2010, when SEMATECH moved from Austin, TX, to Albany, N.Y., and ended with its sunset in 2015, when its remaining staff and resources were absorbed into the College for Nanoscale Science and Engineering (CNSE) at the State University of New York’s Albany Campus (Rulison 2010).

Partners and Roles

Fourteen original corporate members of SEMATECH, plus DARPA, represented the USG/DoD during the first chapter (DoD 1997). The corporations ranged in size from large companies like IBM and Hewlett-Packard, to a number of then midsize companies such as Intel, AMD and Micron Technology. While largely effective, the corporate dues structure may have resulted in the underrepresentation of smaller companies in SEMATECH membership (Byron 1993). In 1996, as the industry and broader economy were globalizing, SEMATECH decided to end Federal funding and opened its membership to international companies in 1998 (Hof 2011). SEMATECH’s membership increased and decreased over time; while they started with 14 companies, they had only 8 in 2003. SEMATECH’s waning membership was largely due to consolidation and companies exiting the IC industry. For example, although AT&T was a founding member, it decided to exit silicon and focus on telecommunications.

During SEMATECH’s first chapter when DARPA/DoD was a partner, although DoD provided 50 percent of the funding for the consortium, DoD had minimal input in the planning and activities of SEMATECH (Slusarczuk and Van Atta 2012). These statutory limitations created some tension between DARPA and member companies; because DARPA was a non-voting member on the Board of Directors, SEMATECH leadership could act independently of DARPA preferences for or against projects. There were also some conflicting interests at play: DARPA PMs were sometimes interested in projects with further out horizons than industry members were interested in. Despite the limited role and at times conflicting interests, this was not a one-sided partnership. SEMATECH recognized the importance of the government role, and made efforts to keep the partnership strong, securing funding and keeping DARPA appraised of the strategic plan for the program. Ultimately, the shared mission to get ahead of Japan and secure leadership of the IC industry united the government and industry during SEMATECH’s first chapter.

While SEMATECH was primarily an industry-government consortium, and later exclusively an industry consortium, it also had partnerships with universities and State and local government. SEMATECH partnered with universities and national labs to establish centers of excellence that were administered by the Semiconductor Research Corporation

(SRC). SEMATECH also worked in partnership and shared a campus with The University of Texas at Austin and SUNY Polytechnic. While SEMATECH's State and local partners in Texas and New York were primarily funding partners, the impact of SEMATECH's presence in Austin and Albany justified the expense. SEMATECH has been considered a crucial element of Austin's development as a tech hub, and its presence in Austin has been credited with drawing high-tech investment and compelling companies including Applied Materials, Samsung, and Motorola to build plants in Austin (Copelin 2012). Likewise, the State of New York justified its efforts to outbid Texas by arguments that SEMATECH's prestige and capability would strengthen SUNY Polytechnic and benefit the New York economy (Copelin 2012).

Governance

SEMATECH was owned and governed by its members (U.S. Department of the Treasury 2013). Because SEMATECH governed by consensus, there was significant negotiation and relationship building behind-the-scenes. SEMATECH had a Board of Directors, composed of a representative from each member company (typically the CEO), that determined high-level direction. SEMATECH's CEO was also a voting member of the Board of Directors, but the chairman of the board of directors is not allowed to vote (U.S. Department of the Treasury 2013).

In addition, executive technical boards of member company executives experienced in tech transfer provided advice on tech strategy, focused advisory boards of member company managers provided technical advice in specific areas of interest, and project advisory boards of member company representatives communicated specific project needs along with feedback on SEMATECH's programmatic activities. On the Board of Directors and executive technical advisory board, each member company had one vote. On the focused and project advisory boards, a company's voting power was based on its membership dues. During SEMATECH's first chapter, DARPA had a non-voting role on the Board of Directors. In its third chapter, the research foundation of the Colleges of Nanoscale Science and Engineering (CNSE) and Fuller Road Management Corporation (FRMC) (representing SUNY Polytechnic) each had a representative on the Board of Directors.

Funding

In SEMATECH's first chapter, the starting budget was $200 million with $100 million coming from the DoD and the remaining $100 million from individual members (Byron 1993). The State of Texas provided a $40 million grant for its first facility, and later a $40 million loan in 2004. SEMATECH established an arrangement where several companies invested a combined total of $100 million per year and the Federal government matched that amount. Between 1988–1996, Congress appropriated a total of approximately

$870 million to SEMATECH through DARPA (PLATZER et al. 2020). In 1994, the Board of Directors voted to end DARPA's contribution and pivot to being entirely dues-funded, which took effect in 1996. (SEMATECH n.d.) Members contributed yearly, and could leave after giving two years notice (Irwin & Klenow 1995). Member contributions ranged from $1 million and were capped at $15 million. The amount each member contributed was equal to 1% of its annual semiconductor sales (Byron 1993).

As the U.S. IC industry began to regain leadership in the mid-1990s SEMATECH decided to stop seeking federal funding and members increased their contributions to partially fill the gap (Hof 2011). While this decision was partially driven by industry member desires to operate independently from the government, it was primarily because the industry was becoming increasingly global, and open to working with international partners and suppliers (Hof 2011). In 1998, five foreign firms (Hyundai Electronics, Phillips, SGS-Thompson, Siemens AG, and Taiwan Semiconductor Manufacturing) joined SEMATECH, forming a subsidiary called International SEMATECH.

Although SEMATECH had a membership-driven business model for its first two chapters, SEMATECH pivoted to a project-driven business model when it relocated to SUNY Polytechnic. This change meant that instead of members paying dues and directing what it worked on, members could elect to sign-up and gain IP access to specific projects (LaPedus 2015). SUNY Polytechnic was a partner between 2010–2015, and provided ~$300M for SEMATECH's move to New York through SUNY Polytechnic.

Operations

SEMATECH's operations consisted of identifying process and supply chain issues, determining what technologies should be pursued to address these issues, and conducting research and development at the main SEMATECH campus or at its centers of excellence. SEMATECH leveraged technical experts from their rotational assignee program and other industry to determine the right technologies to invest in to support their objectives (Hof 2011). Along with crowd-sourced decision making, SEMATECH made equipment purchase decisions by evaluating cost on the basis of purchase price, operating costs, wafer yields, and other factors (GAO 1992). SEMATECH had programs that focused on improving relationships between manufacturers and their equipment and material suppliers and developing industry wide standards for semiconductor manufacturing equipment (GAO 1992).

SEMATECH's staff included its own employees and assignees from member companies that joined SEMATECH on rotations, providing useful technical expertise and industry perspectives. When the assignees returned to their companies, they could take the initiative to push the technologies researched at SEMATECH into the design and manufacturing process (Hof 2011). In its first chapter, SEMATECH had approximately 500 full-time employees and 300 others rotating on two-year assignments. At its height after including international companies, SEMATECH had approximately 700 employees, and at its lowest staff numbers there were approximately 50–100 employees at SUNY Poly.

Intellectual Property

SEMATECH maintained ownership over all patents resulting from SEMATECH-funded work and licensed IP out to member companies who held exclusive rights for a period of two years (Irwin and Klenow 1996). SEMATECH chose to avoid conflicts of interest over IP rights and focus on sharing precompetitive data, creating a forum for communication among industry competitors (GAO 1992). SEMATECH's decision to focus on pre-competitive research to address issues with tools, metrology, and equipment reduced IP issues. That said, SEMATECH had a relatively aggressive IP posture for the research it funded: it claimed IP ownership for IP produced at the SEMATECH campus and its centers of excellence.

Other Protections

In the first chapter of SEMATECH, some issues arose with DoD's desire for access to the leading technology security requirements, with employees having security clearance requirements. After transitioning to being an international consortium, SEMATECH's security arrangements were more relaxed and allowed for an international workforce.

Evaluation and Outcomes

SEMATECH was formed because the U.S. was steadily losing ground to Japan in both semiconductor market share and semiconductor manufacturing equipment sales. Both of these trends were reversed in 1991, and the U.S. eventually gained leadership in both (NRC 2003). There is a general consensus that SEMATECH played a vital, and perhaps essential, role in this turnaround (NRC 2003). Considering that there were also trade policy changes and tariffs enacted during this time period, it is not clear how much of the turnaround is attributable to SEMATECH alone (GAO 1992).

SEMATECH also achieved its original objective of demonstrating the capability to manufacture state-of-the-art semiconductors using only U.S. equipment (GAO 1992). Several member companies increased their purchases of U.S. equipment (GAO 1992). Although it is difficult to quantify the exact benefits of SEMATECH's efforts to address supply chain issues and improving relationships between manufacturers and suppliers, by realigning suppliers with the technical requirements and strategic needs of manufacturers, SEMATECH was able to accelerate innovation and reduce manufacturing costs (GAO 1992).

Another notable outcome is the use of SEMATECH as a model for other consortia. SEMATECH has become a model for how industry and government can work together to restore manufacturing industries, and its design has inspired initiatives such as the National Alliance for Advanced Transportation Battery Cell Manufacture and Department of Energy's SunShot Initiative (Hof 2011). SEMATECH is also considered a model for successfully transitioning from 50% government funding to being self-sustaining, and its timeframe of transitioning away from government funding has been replicated in other PPPs (to variable effect).

Lessons Learned

Note: Based on the study team's analysis of information.

SEMATECH's long history has had many highs and lows. At its best, SEMATECH had clear incentives for participation, technology focus and technical goals, and favorable IP arrangements (NRC 2003). If SEMATECH had ended in its first chapter, it would be remembered as a model for government/industry partnership and the ability to work across sectors to save an industry. Over time, as the industry became more consolidated, changed technology focus, and embraced foreign foundries, SEMATECH became less relevant, it lost a clear mission, and its business model could not adapt.

SEMATECH had strong leadership and participation from industry members who were concerned about falling behind Japan.

In the beginning of SEMATECH, strong leadership, participation of 80% of the industry, and a sense of crisis brought a critical mass of partners and resources to the table. SEMATECH's founding CEO, Robert Noyce, was a widely respected industry leader who cofounded Intel and led the Semiconductor Industry Association. Noyce was pivotal to bringing other industry leaders to the table, and encouraged innovative thinking (Hof 2011). Because SEMATECH's member companies represented around 80 percent of the industry, it was able to successfully establish standards for the industry (Government Accountability Office 1992). This could also lead to conflict: a small but vocal minority accused SEMATECH of excluding small companies thereby denying access to technology SEMATECH developed, creating a competitive advantage (Platzer et al. 2020). Finally, these industry competitors were motivated by crisis to work together and surpass Japan, advocating for SEMATECH to Congress and fostering a culture of innovation (Hof 2011).

SEMATECH focused on pre-competitive R&D to stabilize the supply chain and set industry standards for U.S. semiconductor manufacturers avoided IP conflicts and encouraged collaboration.

While the overall sense of urgency was essential to bringing competitors to work together, SEMATECH's decision to focus on stabilizing the supply chain (tools, metrology, and materials) that the US manufacturers depended on rather than trying to share product IP among members allowed for identification of common interests and collaboration among competitors. SEMATECH's unique role as a consortium allowed it to establish industry standards for equipment and software suppliers, something that no semiconductor company could do alone.

SEMATECH's consensus-based decision-making model improved member satisfaction.

Another notable element of SEMATECH's model was its decision-making process. SEMATECH used consensus-based decision making which required continuous bilateral negotiation and relationship building behind-the-scenes. While this process could be time consuming, it also contributed to member satisfaction. Because SEMATECH's member size ranged from mid-size companies to behemoths like Intel, it was important that each member felt like their voice was heard.

After meeting its initial goal, SEMATECH did not realign around a clear and compelling mission.

In SEMATECH's first chapter, it had a clear and compelling mission: beat Japan. After SEMATECH's initial goals were met, it was hard to hold members together when the mission becomes less clear. While it could be argued that SEMATECH should have sunsetted after it met its initial goals, there were other topics of interest and reasons for it to continue. Ultimately, SEMATECH did not have a necessary reset to think about how its model and goals should change, and how its timeline should be adapted. While some PPPs are developed to exist in perpetuity, SEMATECH did not have a plan to continue evolving, or a clear defining mission.

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Appendix M.
Case Study—Semiconductor Research Corporation (SRC) Programs

Note: For all case studies, information is based on interviews unless otherwise cited. Lessons learned are the study team's own analysis.

Table M-1. Summary of SRC Programs

Goal(s)	**NRI evolving into nCORE**: Discover a new logic switch to replace CMOS and then enable novel computing paradigms via fundamental research at the material and device level, very long term. **JUMP:** Conduct multi-disciplinary, collaborative research that aims to disrupt microelectronics research and attach post-Moore's scaling, long term.
Origins	Conduct precompetitive research with shared IP. Research was too costly and uncertain for any member to fund on its own. SRC provided an opportunity to fund research together, with individual members free to commercialize the results. Also, members are able to higher talent from the universities performing the research.
Partners and Roles	**Federal:** DARPA for JUMP. NSF and NIST for NRI/nCORE. Provided funding (force multiplier for industry funds). **Private:** Analog Devices, Inc., Arm Limited, EMD Electronics (a Merck KGaA affiliate), IBM Corporation, Intel Corporation, Lockheed Martin Corporation, Micron Technology, Inc., Northrop Grumman Corporation, Raytheon Technologies, Samsung Electronics Co., Ltd., SK Hynix Inc., Taiwan Semiconductor Manufacturing Company Limited **Others:** U.S. universities. NRI had State and local partners in TX, IN, CA, and NY. Universities (as well as State governments for NRI) provided the people to conduct the research.
Governance	Each program has a Science Advisory Board (SAB) with representatives from member companies and government. SAB determines the research agenda, guides research approach, and selects research performers. Each program has a Governing Council (GC) that makes fiscal decisions and has final sign-off. SRC is a 501c(6) not for profit corporation. It has a Board of Directors, corporate officers, and other employees to manage the work carried out under its programs. NRI/nCORE and JUMP SAB and GC are chaired by an SRC employee.
Funding	**JUMP:** ~\$200M total, with ~\$80M (40%) from DARPA, ~\$120M (60%) from industry **NRI:** ~\$20–25M/year, with ~\$15M (60%) from States, ~\$6M (25%) from industry, ~\$3M (10%) from NIST, ~\$1M (5%) from NSF supplements for existing centers; Joint NSF-SRC solicitation Nanoelectronics for 2020 and Beyond provided \$18M from NSF and \$2M from NRI in 2011, Joint NSF-SRC solicitation Energy-Efficient Computing: from Devices to Architectures (E2CDA) for \$4M in 2016, and \$6M in 2017

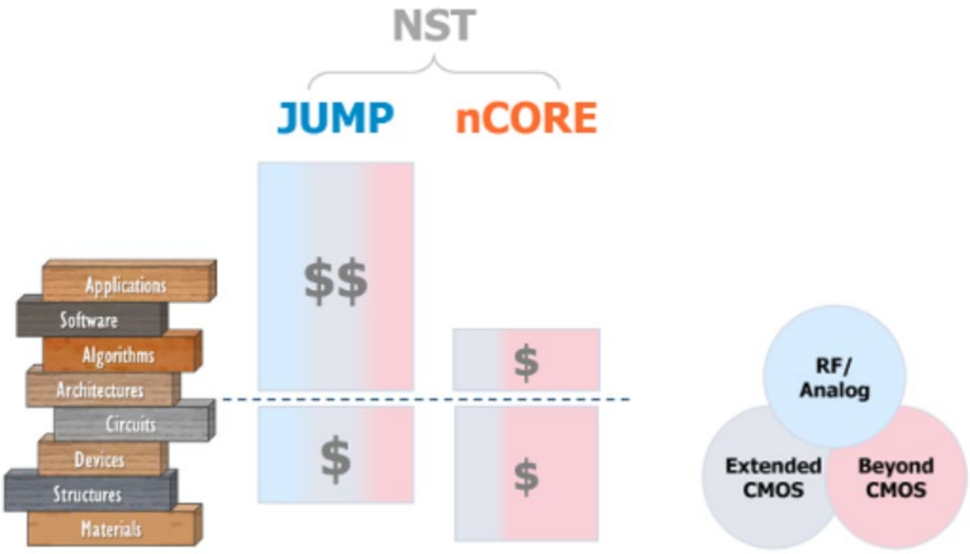
	nCORE: In 2020, ~$13M total, with ~$4M (30%) from NSF, ~$4M (30%) from NIST and ~$5M (40%) from industry
Operations	**Years:** SRC was established in 1982. NRI launched in 2006 and lasted until 2018. Both nCORE and JUMP began in 2018 and are scheduled to last until 2023. SRC programs typically last for five years at which point, depending on the research results, they may be extended or they may evolve into something else. **Accomplishing Work:** Research partially funded by NIST or DARPA is carried out in university-based centers, selected competitively by SRC through the SAB. NRI had 5 centers, nCORE has 3 centers, and JUMP has 6 centers. Industry liaisons (assignees for NRI) After 2.5 years into a research program, the SAB conducts a six-month mid-program review. As a result, the centers may rebalance as much as 20% of the remaining funding and the SAB may rebalance up to 10% of the remaining funds. Research partially funded by NSF is carried out in university-based centers established by NSF. NSF gets input from companies on topics for funding solicitations, but essentially NSF runs its normal peer review selection process (maybe 1 NRI/nCORE industry person involved in the panel) to choose projects. Then SRC would decide to add to the NSF funding of those same projects. **TRL:** TRL 1–2 (Basic research), precompetitive, high risk, disruptive technologies, long term (10–20 year) impact.
IP	IP available to all members involved in funding the project. Universities own the IP rights. All industry partners have non-exclusive royalty free (NERF) licensing agreements available to all of the patents developed.
Other Protections	Not applicable
Evaluation and Outcomes	SRC keeps track of total research dollars, number of research projects, number of universities involved, number of students involved, number of faculty involved, publications, patent applications and patents. In its 40 years of operation, SRC has achieved the following: Funded over $2 billion of research; Supported over 12,000 graduate students to strengthen the semiconductor workforce; and Provided over 700 patents to member companies.
Lessons Learned	The uncertainty around high-risk high reward research goals can make it difficult to select projects and evaluate outcomes. Benchmarking technology needs to be included in research processes from the beginning. Low industry member engagement can lead to research that does not fit the needs of industry, but using an assignee model can encourage engagement. It can be challenging for competing companies to coalesce around common goals. Strong leadership is important. A disconnect can occur between industry-funded and federally-funded PPP programs. SRC's long history (operating partnerships over many decades) has allowed them to refine their governance and operational model over many iterations of programs. Clear IP terms are necessary for maintaining trust for collaborative basic research.

Goals

This case study focuses on three public private partnerships (one from the past and two others currently within the SRC umbrella)—Nanoelectronics Research Initiative

(NRI), nanoelectronics Computing Research (nCORE), and Joint University Microelectronics Program (JUMP). All of these PPPs were engaged in basic precompetitive research at TRLs 1–2. The research efforts focused on high risk, disruptive technologies with long term (10–20 year) impacts. The goal of the Semiconductor Research Corporation (SRC) is to bring together companies to leverage their pooled funding to sponsor precompetitive research that was generally too expensive for a single company to finance to advance the field of microelectronics. SRC has operated a number of specific research initiatives each with a particular research emphasis.

The technical goal of NRI, which is no longer in operation, was simply stated to discover a new logic switch to replace CMOS by 2020 (Welser 2009). The technical goals for JUMP and nCORE (as illustrated in Figure 1) are broader: to conduct multidisciplinary, collaborative, fundamental research on the materials and device level (nCORE) and at the architecture and systems level (JUMP) (SRC n.d.). All three programs sought to fund disruptive high risk, high reward research that would transform the microelectronics industry in 5–10 years for JUMP or 10–20 years for NRI and nCORE.



Source: Reproduced from SRC (n.d.).

Figure M-1. Schematic of the technical focus of nCORE and JUMP

The NRI, unlike nCORE or JUMP, had an exclusively domestic focus (only U.S. companies could participate). NRI aimed to bolster the domestic capacity in microelectronics R&D such that the U.S. would be the first country to develop a novel logic switch (Logar et al. 2014). When NRI ended, and nCORE and JUMP began, international commercial partners joined the programs and the domestic only focus of the program was discontinued. For all three programs, only U.S. universities are eligible to participate.

All three SRC PPPs served the goals of workforce development by funding graduate students' research which created a hiring pipeline for the partners. SRC-funded graduate students have frequent opportunities to interact and form relationships with industry sponsors, as well as access to networking, employment, internship opportunities through SRC-sponsored activities, such as the TECHCON conference targeted solely on SRC-funded research. These opportunities help graduate students better understand industry needs and build industry connections, which can help their career development.

NRI goals did not change over the course of the program although the research approach evolved as a function of prior research results. NRI also did not meet its core technical goal of discovering a new logic switch to replace CMOS, though it led to a number of other technical achievements. nCORE and JUMP goals are also not expected to change. Both of these programs are expected to evolve after five years into new programs with corresponding changes to the goals.

Origins

SRC was formed in 1982 as an independent subsidiary of the Semiconductor Industry Association (SIA) in response to declining American leadership in semiconductors (SRC n.d.a). SRC is in itself an industry-government-academia public private partnership (PPP) with membership from over 20 semiconductor industry companies, three government agencies and more than 100 universities (SRC n.d.b).

SRC's original research program, now known as the Global Research Collaboration (GRC), aimed to fund pre-competitive research aligned with the International Technical Roadmap for Semiconductors (ITRS) on the three-year time horizon. GRC research was primarily funded by industry members, with some government contributions too (Logar et al. 2014).

In 1997, SRC formed the Microelectronics Advanced Research Corporation (MARCO), a subsidiary research organization, which launched and managed the Focus Center Research Program (FCRP). The FCRP was a PPP between industry members and the Department of Defense, largely through DARPA, to fund multi-university research on an eight-year time horizon (Logar et al. 2014; SRC n.d.c).

Beginning in 2001, SIA began to explore the strategic research needs of "post CMOS" or "beyond Moore's law" microelectronics. The National Nanotechnology Initiative (NNI) motivated this exploration by funding large amounts of new research in nanotechnology (Khan 2015). Initially, SIA considered a proposal to create an "industrial research institute," which would be staffed by industry researchers and visiting academics in the FCRP community, and funded at ~$600 million per year (mostly through NNI) (Khan

2015). Instead, SIA chose to go with the NRI, using the FRCP's multi-center university model. While other SRC programs were largely industry funded, there was a hope that NRI would have a 90-10 government-industry funding ratio (Khan 2015). The NRI was launched in 2006 as a partnership of SRC with NSF and with NIST (Chen 2016). The NRI research centers were re-competed in 2013, with this second phase sometimes referred to as NRI 2.0 (SRC 2013).

In 2013, the sixth phase of FCRP, more commonly known as STARnet, was established to fund research further up the "stack" (Figure M-2) than earlier phases of FCRP or NRI (SRC n.d.d). Although NRI and STARnet operated largely independently, there was collaboration around benchmarking efforts (Chen 2017). Both STARnet and NRI ended in ~2017.

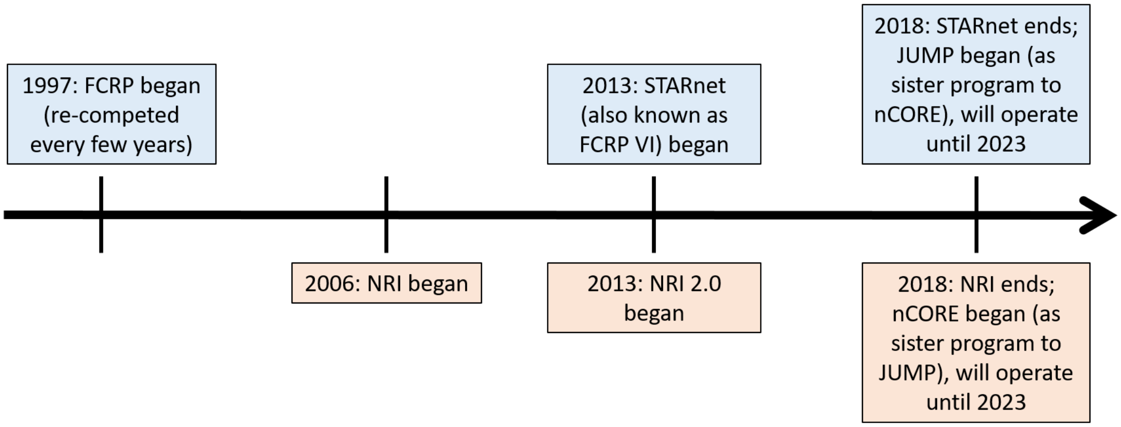


Figure M-2. Timeline of the evolution of FCRP to STARnet to JUMP (top, blue) and evolution of NRI to nCORE (bottom, red).

In 2018, SRC launched the New Science Team (NST), which was comprised of two specific programs, nCORE and JUMP as "sister programs." nCORE was intended to be the next iteration of NRI and JUMP as the next iteration of STARNet. Both nCORE and JUMP will operate until 2023, when it is presumed that a new iteration of both programs will launch. Figure M-2 provides a timeline of the evolution of SRC programs.

Partners and Roles

Across all its programs, SRC as a whole has member companies that include foundries, integrated design manufacturers, analog companies, equipment and materials suppliers, integrators and IP managers (Chen 2020). SRC also has strategic partnerships with organizations like SEMATECH, SEMI and SIA (SRC 2009).

Across all three PPPs (NRI, nCORE and JUMP), there is at least one Federal partner, a collection of industry partners and many university partners. For NRI, there was also State and local government involvement. The commercial industry partners for all three programs represented a subset of SRC members that chose to buy-in to these additional programs by paying additional dues.

The details of how members exerted influence over the research agenda is further explained in the Governance section.

Industry

NRI had six-member companies, AMD, Freescale, IBM Corporation, Intel Corporation, Micron Technology, Inc., and Texas Instruments (TI). The first three NRI centers were established without an open competition. Instead, these initial centers were chosen from a pool of universities where companies already had contacts, with priority to universities willing to try out the multi-disciplinary research center model that NRI was pursuing. Additionally, because regional spillover was a goal of NRI, the first three centers were awarded to universities and states that were prepared to invest financially. As a result, the first three centers were formed in NY, CA and TX, partially due to IBM, Intel and TI each approaching local university professors to form a center in or near the firm's home state (Khan 2015). All the NRI member companies were well-established integrated device manufacturers that designed and manufactured their own products (Khan 2015). Though the NRI member companies were direct competitors, they had a history of collaborating through other programs at SRC and in SEMATECH, so there was little tension about their coming together to jointly fund pre-competitive research through NRI.

During the transition from NRI and STARnet to nCORE and JUMP, SRC decided that both programs should have the same set of 12-member companies: Analog Devices, Inc., Arm Limited, EMD Electronics (a Merck KGaA affiliate), IBM Corporation, Intel Corporation, Lockheed Martin Corporation, Micron Technology, Inc., Northrop Grumman Corporation, Raytheon Technologies, Samsung Electronics Co., Ltd., SK hynix Inc., Taiwan Semiconductor Manufacturing Company Limited (SRC n.d.d).

The member companies participating in nCORE and JUMP differ from those in NRI in the type of companies taking part (Table M-2). While NRI was composed of IDMs, nCORE and JUMP include IDMs as well as three defense contractors, one large foundries, one fabless design firm and one semiconductors materials producer. The member companies for STARnet were Global Foundries, IBM Corporation, Intel Corporation, Micron Technology, Inc., Raytheon Company, Texas Instruments Incorporated and United Technologies (SRC 2015). Another big shift in the transition to nCORE and JUMP was the inclusion of five international companies, such as Samsung, SK Hynix and TSMC. SRC believed that given the influence of these large international companies on the industry engaging them in SRC programs would be beneficial. An added challenge was knowing the best way to interface with the researchers and other members because these firms were not previously associated with SRC before joining JUMP and nCORE.

Table M-2. nCORE/JUMP Member Companies and Microelectronics Company Types

nCORE/JUMP Member Company	Company Type
Analog Devices, Inc.	IDM (analog, digital)
Arm Limited ┼	Fabless design firm
EMD Electronics (a Merck KGaA affiliate) ┼	Semiconductor materials producer
IBM Corporation *	(not sure how to categorize now)
Intel Corporation *	IDM (digital)
Lockheed Martin Corporation	Defense contractor
Micron Technology, Inc *	IDM (memory)
Northrop Grumman Corporation	Defense contractor
Raytheon Technologies	Defense contractor
Samsung Electronics Co., Ltd. ┼	IDM (memory, digital)
SK hynix Inc. ┼	IDM (memory)
Taiwan Semiconductor Manufacturing Company Limited ┼	Foundry

* indicates that the member company was also a member of NRI.

┼ indicates that the company is foreign owned.

The primary roles for the industry partners are to provide technical direction and funding for the research. The value proposition for companies in these SRC programs was largely that participation gives them early access to the newest R&D in the field, and non-exclusive royalty free licensing of any patents that came out of the research from these programs. Companies also had access to world leading professors where they could build relationships and ask questions. Finally, companies are able to recruit from the pool of PhD students working on research funded by these programs.

Federal

The Federal partner for JUMP is DARPA, while the Federal partners for NRI and nCORE are both NSF and NIST. The primary role of the Federal partners is to fund the research, although each Federal agency also contributes to differing degrees to the research agenda (discussed further in the operational model section below.) The goals of these SRC programs align with missions to support high risk high reward research for DARPA, and fundamental research or precompetitive R&D driven by industry needs in the case of NSF and NIST, respectively.

University

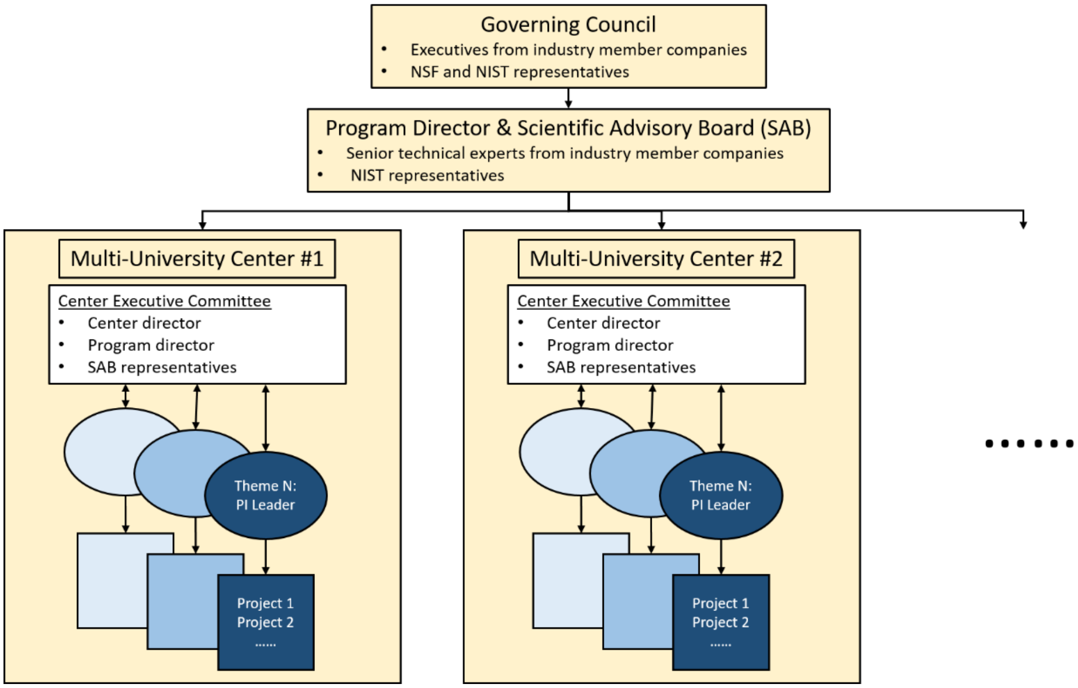
Universities were involved in all of these SRC programs as the performers who were funded to conduct the research. The value proposition for universities is the influx of research funding on impactful topics.

State and local government

NRI was the only program (of these three) with State and local government partners. The initial NRI-funded centers were intentionally geographically distributed across the United States, with one center in the East, one in the West, one in the South and one in the Midwest. For the initial four NRI centers, for which there was not a formal solicitation and competition, there was a requirement that the center obtain State or local government funding for the NRI center. The specific amounts of the funding contribution varied by center. The value proposition for State and local governments was related to the perceived local economic growth that may arise as spillover from the NRI-funded centers. For some centers that were located in geographic areas without an existing microelectronics ecosystem, the expectations of economic growth due to an NRI center may have been overly optimistic, however, some spinoffs have formed in the local vicinity of the center. When NRI ended and nCORE and JUMP began, a decision was made to not pursue State and local government funding for those programs.

Governance

Both JUMP and the NIST-funded portion of nCORE have similar governance structures. The NIST-funded portion of NRI was similar (Figure M-3), though the names for the entities differed. Each program has a program manager (on the SRC staff), as well as a governing council and a science advisory board (SAB). During NRI, the SAB was called the technical program group (TPG). The SAB (one for each program) is comprised of technical experts from the industry companies (two per company) and Federal government members. The SAB is responsible for setting the technical direction of the program.



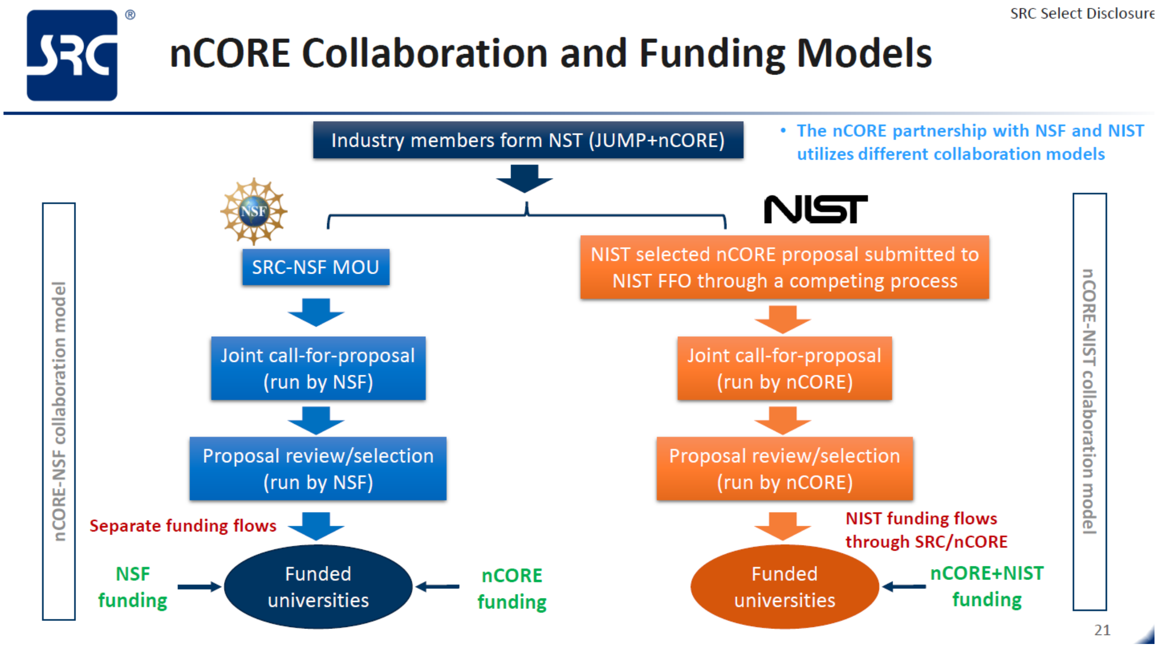
Note: The figure shows a governing council and scientific advisory board (called a technical program group in NRI). Within each NRI funded multi-university center, there were multiple research themes, each of which had multiple research projects. Industry assignees interacted both at the center management, theme and project level, while NIST researchers mostly interacted at the project level. Adapted from Chen (2020).

Figure M-3. Illustration of the generalized governance structure of the NIST-funded portion of nCORE and NRI, and JUMP

For JUMP and the NIST-funded portions of nCORE and NRI, the program's solicitation and selection processes are managed entirely by the respective program's governing bodies (Figure M-4, right hand side). SAB members deliberate to identify the new focus areas for a program solicitation. The governing council, which is made up of high-level representatives from companies, have final sign off on the program solicitations. Proposals for new multi-university research centers are reviewed and selected by the SAB, before getting approved by the governing council. Once centers were selected, the center directors work closely with the SAB on the technical scope and direction of each center.

A unique role for the JUMP SAB is a "mid-term realignment", which allows for course corrections in the direction of the research. After 2.5 years, the JUMP SAB initiates a six-month mid-program review. As a result, each JUMP center may rebalance as much as 20% of the remaining funding and the SAB may rebalance up to 10% of the remaining funds. nCORE does not have a similar mid-term realignment as its research center are much smaller than the JUMP centers and targeting a 20 percent change of personnel or research scope could be too disruptive to a small center.

Although research goals for the NSF-funded portion of NRI and nCORE were developed jointly between SRC and NSF, the projects were selected through NSF's typical peer review process (Figure M-4, left hand side). After NSF's review panel, which may have up to one industry member on it, recommended which projects NSF should fund, then the governing council was offered the opportunity to decide to fund those projects and at what level. This alternate method of selecting research proposals was an important mechanism for expanding the breadth of research topics covered, an important undertaking given the uncertainty of what a "post-CMOS" logic switch might be (Khan 2015).



SRC Select Disclosure

nCORE Collaboration and Funding Models

Industry members form NST (JUMP+nCORE)

- The nCORE partnership with NSF and NIST utilizes different collaboration models

nCORE-NSF collaboration model

SRC-NSF MOU

Joint call-for-proposal (run by NSF)

Proposal review/selection (run by NSF)

Separate funding flows

NSF funding

Funded universities

nCORE funding

nCORE-NIST collaboration model

NIST selected nCORE proposal submitted to NIST FFO through a competing process

Joint call-for-proposal (run by nCORE)

Proposal review/selection (run by nCORE)

NIST funding flows through SRC/nCORE

Funded universities

nCORE+NIST funding

Source: Reproduced from Chen (2020).

Note: The NIST-funded portion of nCORE (depicted here on the right-hand side) is similar to the process for the NIST-funded portion of NRI and for JUMP. The NSF-funded portion of nCORE (depicted here on the left-hand side) is similar to the process used by the NSF-funded portion of NRI.

Figure M-4. Illustration of the different collaboration mechanisms for program solicitations and selections used by SRC programs.

Funding

SRC revenue comes from multiple sources including member fees, investments that SRC makes on its assets, fellowships, management fees, and grants (ordered approximately by magnitude) (SRC 2019). Subject to certain limitations, membership fees (as by far the largest component of revenue) are in some cases based on a percentage of revenue attributable to semiconductor sales, use or manufacture. Membership fees may also be negotiated (SRC 2019). A company becomes an SRC member by becoming a member of one or more of its programs, such as GRC, FCRP, STARnet, NRI, nCORE or JUMP.

The scope of nCORE and JUMP research is limited by the amount of funding allocated to them. The funding allocated to them may be impacted by any required ratio of government funding to industry funding. Therefore, a close relationship is necessary between the governance and operations model and the business model.

For NRI, the many funders of research included NIST, NSF, member companies, State and local governments and university contributions. In the beginning of NRI (from 2007–2012), NIST provided $2.75 million per year to NRI. During this time, NRI member companies paid ~$1 million per year each in dues, which was split across the NIST-funded centers and NSF-funded projects (Khan 2015). Specific NRI member companies also provided additional contributions in a specific NRI center co-located in their home state, so INDEX, SWAN and WIN, each received direct support from IBM, TI and Intel, respectively. MIND, which was formed slightly later in 2008, received no direct member company support (Khan 2015). As mentioned above, the initial four NRI centers were selected in part because their universities and State or local governments had agreed to commit substantial funding (Khan 2015). The level of State and local government cost share for NRI centers ranged from a few million dollars to tens of millions of dollars, though some of this may not have exclusively supported NRI research, but rather been used to fund new microelectronics facilities and infrastructure (Khan 2015). The universities also provided a cost share at varying levels, mostly in the form of additional support for personnel. For the second phase of NRI (beginning in 2013), NIST provided $2.6 million per year for up to five years, matched by $2.4 million per year from NRI member companies (NIST 2013).

The NSF contributions to NRI varied in their nature and magnitude. One mechanism for funding was a Dear Colleague Letter about NSF-NRI supplements to these existing NSF centers, such as Nanoscale Science and Engineering Centers (NSECs), Nanoscale Interdisciplinary Research Teams (NIRTs), and Materials Research Science and Engineering Centers (MRSECs). These supplements, which were funded yearly from 2005–2010, provided $1 million of NSF funds matched with $1 million of NRI funds. (NSF 2010). In 2010, NSF announced the nanoelectronics for 2020 and Beyond (NEB2020), which provided $20 million to 10–15 interdisciplinary research teams. For NEB2020, NSF funded $18 million and NRI funded $2 million (NSF 2010b).

Total funding for nCORE over five years is approximately $44 million. Of this total, NIST contributes ~$13.5 million, NSF ~$12 million, SRC member companies ~$16.5 million and university cost share ~$7.6 million. Funding for nCORE fluctuates from year to year based on the different durations of some of the programs involved. The funding ratios for nCORE are fixed at NSF:SRC at 2:1 and NIST:SRC at 3:1. The NSF funds support the projects of individual PIs as well as center-based projects through two solicitations (NSF 2016; NSF 2017).

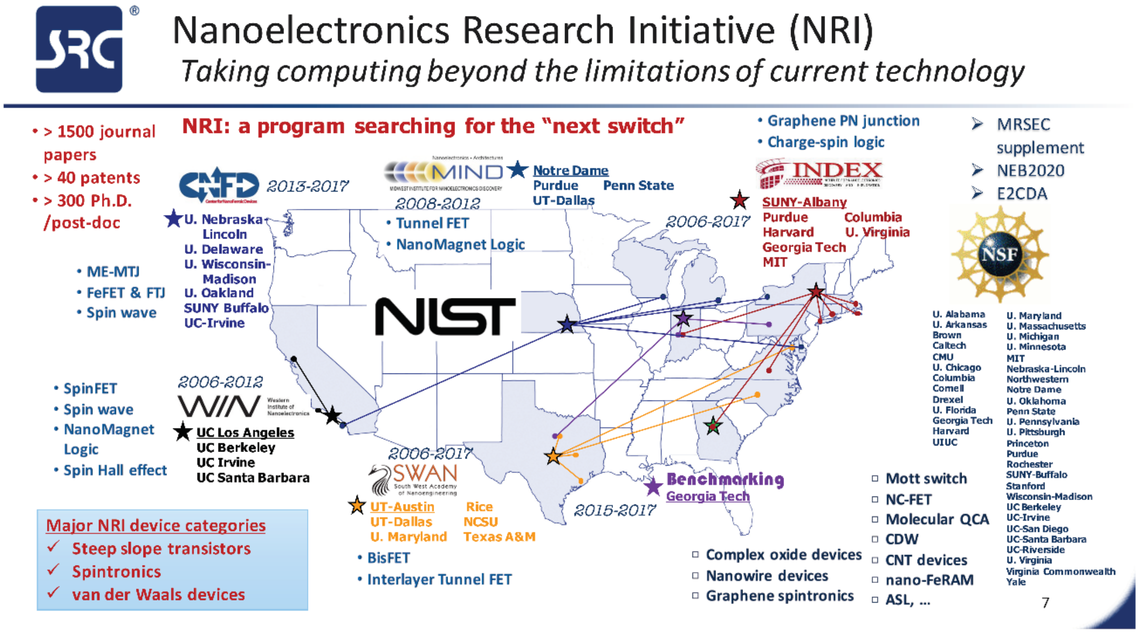
Total funding for JUMP is $200 million over the five years of the program. Each of the six JUMP centers has a unique funding level, ranging from $33 million to $49 million. (Chen 2020). Approximately 40 percent of this funding is provided by DARPA, with the remainder funded by member companies (DARPA 2018). There is an additional $2 million per year that DARPA PMs allocate to special projects within JUMP centers (Chen 2020).

Operations

SRC is a 501(c)6 not-for-profit organization. It has its own Board of Directors and staff that carries out the management functions necessary to conduct corporate operations and the research program.

SRC established an independent subsidiary organization to manage each of its PPPs. For NRI, this entity was the Nano Electronics Research Corporation (NERC), for STARnet the entity was Microelectronics Advanced Corporation (MARCO), and for nCORE and JUMP it is "SRCco". From our understanding, the role of this independent subsidiary is to serve as the unique legal entity through which funds flow for each specific SRC PPP. nCORE and JUMP are sister programs with the same member companies, and thus can be managed by the same entity.

All the research funded by these SRC programs is performed by university researchers. Specifically, NRI, nCORE and JUMP all fund multidisciplinary, and often multi-university research centers, each focusing on a particular theme (Figure M-5). Each center is led by a director, usually a university professor, who is responsible for unifying the dozens of PIs and PhD students around the vision for the research center and as an important connector to the industry members. In the case of NRI, the first set of center directors had a long history of working with SRC or in industry labs, including at some of the member companies, giving them a good understanding of both the academic and industry worlds (Khan 2015).



Nanoelectronics Research Initiative (NRI)

Taking computing beyond the limitations of current technology

- > 1500 journal papers
- > 40 patents
- > 300 Ph.D. /post-doc

NRI: a program searching for the "next switch"

CNFD 2013-2017
★U. Nebraska-Lincoln
U. Delaware
U. Wisconsin-Madison
U. Oakland
SUNY Buffalo
UC-Irvine

- ME-MTJ
- FeFET & FTJ
- Spin wave

MIND 2008-2012
★Notre Dame
Purdue
Penn State
UT-Dallas

- Tunnel FET
- NanoMagnet Logic

INDEX 2006-2017
★SUNY-Albany
Purdue
Columbia
Harvard
U. Virginia
Georgia Tech
MIT

- Graphene PN junction
- Charge-spin logic

WIN 2006-2012
★UC Los Angeles
UC Berkeley
UC Irvine
UC Santa Barbara

- SpinFET
- Spin wave
- NanoMagnet Logic
- Spin Hall effect

SWAN 2006-2017
★UT-Austin
Rice
UT-Dallas
NCSU
U. Maryland
Texas A&M

- BisFET
- Interlayer Tunnel FET

★Benchmarking
Georgia Tech
2015-2017

Major NRI device categories
✓ Steep slope transistors
✓ Spintronics
✓ van der Waals devices

☐ Complex oxide devices
☐ Nanowire devices
☐ Graphene spintronics
☐ Mott switch
☐ NC-FET
☐ Molecular QCA
☐ CDW
☐ CNT devices
☐ nano-FeRAM
☐ ASL, …

➢ MRSEC supplement
➢ NEB2020
➢ E2CDA

U. Alabama
U. Arkansas
Brown
Caltech
CMU
U. Chicago
Columbia
Cornell
Drexel
U. Florida
Georgia Tech
Harvard
UIUC
U. Maryland
U. Massachusetts
U. Michigan
U. Minnesota
MIT
Nebraska-Lincoln
Northwestern
Notre Dame
U. Oklahoma
Penn State
U. Pennsylvania
U. Pittsburgh
Princeton
Purdue
Rochester
SUNY-Buffalo
Stanford
Wisconsin-Madison
UC Berkeley
UC-Irvine
UC-San Diego
UC-Santa Barbara
UC-Riverside
U. Virginia
Virginia Commonwealth
Yale

7

Source: Reproduced from Chen (2017).

Note: On the right hand side is a list of all of the universities who participated in the NSF-funded portion of NRI. The top left corner contains a few key metrics of the NRI.

Figure M-5. Illustration of NIST-funded NRI research centers, which universities were members, the years over which each was operational, and their main research focus.

During NRI, an industry "assignee" was used to integrate representatives from member companies into university labs. These assignees were supposed to be onsite for 100% of their time with the university researchers, contributing to the direction and completion of the research. This assignee model was reported to have increased the level of member company engagement in the program. The level of engagement of each industry assignee varied, with some assignees spending only a portion of time visiting NRI centers to discuss research progress and other assignees working alongside researchers in the lab and taking a central role in advising students. When nCORE and JUMP started, there was a decision to end the "assignee" model, instead having industry liaisons who can engage at will with any research group. Member firms received a rebate toward their annual NRI dues for placing assignees in NRI centers, while there is no financial compensation from SRC an industry liaison (Khan 2015). With double the number of member companies in nCORE and JUMP as in NRI, it could have been too expensive for SRC to continue to fund assignees while also funding the JUMP and nCORE research centers at the desired levels.

Using industry assignees versus industry liaisons represents two different engagement models for industry involvement in the research. Both academic researchers and assignees seemed to think the assignee model was effective at moving the research forward in productive directions (Khan 2015). Based on STPI's interpretation of our discussions with interviewees, it does not seem the companies achieved a significant benefit in using the assignee model. If companies had found using assignees to be enough of a value add, they likely would have spent their own money on the equivalent, but as far as we know, no nCORE or JUMP companies did so. During NRI, SRC essentially had less money to fund research because it was instead subsidizing industry assignees. Another possible explanation is at the outset of NRI, companies believed the basic research on “Beyond CMOS” being conducted in the NRI centers was closer to becoming applied research that could be moved in house than it was. By the end of NRI, companies perhaps had a more realistic expectation about the timeline for technology commercialization for the nCORE research, and therefore, the companies saw less value in justifying spending their own funds on an employee’s time as an assignee.

One additional aspect of conducting the research to highlight is the collaboration between university researchers and NIST scientists. In NRI, there was some collaboration and leveraging of NIST facilities or capabilities by NRI-funded researchers, but such collaboration was more of an ad hoc decision by NIST researchers. In starting up nCORE, NIST sought to increase the involvement of NIST researchers in the nCORE research projects. The main mechanism for increased engagement is through funding postdoctoral researchers from nCORE centers to perform work at NIST labs and collaborate directly with NIST researchers.

Accomplishing Work

Each of the SRC programs discussed in this case study had a different technical focus and different timelines until expected commercialization. SRC’s original and longest running program, the Global Research Collaboration Program (GRC), funds research that is expected to be 3–7 years from commercialization. STARnet and JUMP, too, target basic research that is expected to be 3–7 years from commercialization. NRI was the first SRC program to target a longer time horizon, focusing on technology that was likely closer to 10 years away from commercialization. nCORE, too, has focused on technologies that are expected to be 10 years away from commercialization.

While many people we spoke to described all of the research activities funded by these programs as basic research, some others felt that because the research is application-driven by design, that it is not truly basic research that is exploratory. Some felt that for a challenge like discovering a competitive beyond-CMOS technology, broad, large-scale investments in nanotechnology were more likely to yield success than the approach taken by NRI.

The specific technical focuses of each PPP are described below.

NRI

NRI'S technical program focused on finding the next devices and circuit architectures to move computing beyond current limitations. Since its inception, NRI has supported 128 research themes across microelectronics technologies (SRC n.d.h).

The Center for NanoFerroic Devices (CNFD) was co-funded by NIST and based at the University of Nebraska-Lincoln. CNFD focused on research on magnetoelectric, ferroelectric, and spin wave devices (SRC n.d.h).

The Institute for Nanoelectronics Discovery and Exploration (INDEX) was co-funded with NIST and based at the College of Nanoscale Science and Engineering, University at Albany SUNY. INDEX worked on spin and graphene p-n junction logic device research (SRC n.d.h).

The South West Academy of Nanoelectronics (SWAN) was co-funded with NIST and based at the Microelectronics Research Center, University of Texas at Austin. SWAN worked on graphene-based Bilayer Pseudospin Field Effect Transistor (BiSFETs) and other emerging technologies to improve computing speed and energy efficiency (SRC n.d.h).

NRI and NSF co-funded the Energy Efficient Computing: from Devices to Architecture Program, six collaborative research efforts across the U.S., which focused on improving the energy efficiency of next generation computing (SRC n.d.h).

The Benchmarking Center was based at the Georgia Institute of Technology, and focused on improving current benchmarking methodology, evaluating the performance of NRI and STARnet devices in the established benchmark circuits, and developing benchmarks for emerging device concepts (SRC n.d.h).

nCORE

The technical program of the NIST-funded nCORE centers is described as a vertically integrated and holistic approach to research into new computing and storage paradigms beyond CMOS. There are five research vectors for nCORE: 1) basic material, device and interconnect research, 2) novel computing and storage paradigms, 3) advanced manufacturing, 4) characterization, test, metrology, standards, and 5) simulations and modeling (Chen 2020).

Currently three multi-university nCORE centers are in place, each of which address somewhere between one and five of these research vectors.

The NEW materials for LogIc, Memory and InTerconnectS (NEW LIMITS) center is led by Purdue University. NEW LIMITS is a vertically integrated center that is working on research addressing all five nCORE research vectors. The NEW LIMITS center has a focus on 2D materials, devices and technologies (SRC n.d.h)

The Spintronic Materials for Advanced Information Technologies (SMART) center is led by University of Minnesota. SMART is focused on advanced spintronic materials research though its research portfolio overlaps with all five of the nCORE research vectors.

The Innovative Materials and Processes for Accelerated Computer Technologies (IMPACT) center is led by Stanford University. IMPACT is focused on new materials for scaled, reconfigurable and mm-wave interconnects, and materials for storage class and neuromorphic memory. The IMPACT center combines computational modeling with synergistic experimentation.

The NSF-funded portion of nCORE funded ~10 awards, some to individual PIs and some to collaborative multi-university teams, to focus on improving the energy efficiency of computing. There are two research focuses: 1) disruptive system architectures, circuit microarchitectures and attendant device and interconnect technology and 2) revolutionary device concepts and associated circuits and architectures (SRC n.d.h).

JUMP

Six multi-university JUMP centers exist. Four of the JUMP centers were described as “Vertical Applications Centers,” each focusing on a particular grand challenge. Two of the JUMP centers were “Horizontal Disciplinary Centers” that were focused on benchmarking that would be cross-cutting to the other four centers (Chen 2020). Table M-3 provides a summary of information about the six JUMP centers, their technical focus, lead university and funding levels.

Table M-3. Summary of information about JUMP centers, their technical focus, lead university and funding levels.

Center Acronym	Center Full Name	Vertical Application (V) or Horizontal Disciplinary (H) Center	Technical Focus	Lead University	Funding Level (over Five Years)
ADA	Applications Driving Architectures Center	H	Advanced Architecture and Algorithms	University of Michigan	$33M
ASCENT	Applications and Systems driven Center for Energy-Efficient Integrated NanoTechnologies	H	Advanced Devices, Packaging and Materials	University of Notre Dame	$49M
ComSenTer	Center for Converged TeraHertz Communications and Sensing	V	RF to Terahertz Sensors and Communication Systems	University of California Santa Barbara	$39M
CONIX	Computing on Network Infrastructure for Pervasive Perception, Cognition, and Action	V	Distributed Computing and Networking	Carnegie Mellon University	$38M
C-BRIC	Center for Brain-inspired Computing Enabling Autonomous Intelligence	V	Cognitive Computing	Purdue University	$38M
CRISP	Center for Research on Intelligent Storage and Processing-in-memory	V	Intelligent Memory and Storage	University of Virginia	$43M

Source: Information from Chen (2020).

Workforce and Training Programs

NRI, nCORE and JUMP all contribute broadly to the strength of the semiconductor industry workforce by funding microelectronics related research at universities in which students participate. These SRC-funded graduate students are able to form relationships with industry companies, which can lead to internship or employment opportunities.

Specific to JUMP is the JUMP Undergraduate Research Initiative (URI), which selects U.S. citizen students to participate in a structured undergraduate research experience with PhD student mentorship. Through this academic-year long program, undergraduate students learn about career opportunities with JUMP member companies and about the benefits of earning an advanced degree related to microelectronics.

Intellectual Property

All NRI, nCORE, and JUMP research is precompetitive. However, a number of important considerations are still around IP.

Despite decades of experience operating research programs, SRC's long-standing and established IP policies for prior research programs were not suitable for NRI. When NRI was forming, its focus on such far future, basic research and its use of the industry assignee model both contributed to disagreements about hypothetical patent rights and their future value (Khan 2015). In some cases, these disagreements delayed the arrival of industry assignees (Khan 2015).

The IP agreement ultimately reached for NRI was that universities fully own the IP rights. All industry partners have non-exclusive royalty free (NERF) licensing agreements available to all of the patents developed. "The SRC Contracts & IP (CIP) office implements and manages all formal agreements supporting SRC-sponsored research projects while ensuring SRC and its Members and Participants have the freedom to practice the results of the sponsored research" (SRC n.d.f). In addition to the CIP office staff that specialize in contracts and IP, the SRC program managers, administrators, finance and legal teams all play a role in monitoring for potential violations.

Over the course of NRI, another IP-related issue arose around "background IP," also called "blocking IP," which is university-owned IP that was developed prior to NRI, but which was used to develop new IP during NRI. The concern raised was that the IP associated with new research that depends on prior IP cannot be automatically shared with all industry members in the same way. During NRI, the NSF-SRC funding solicitations all contained language requiring the disclosure of blocking IP. The solicitation states: "All proposals must include a statement disclosing any background intellectual property (IP) known to the proposer that is expected to block the freedom to practice the results of the proposed research. Whereas SRC is entitled to a royalty-free, non-exclusive license only to practice any IP that directly results from activities funded by NSF/SRC joint funding, SRC must resolve issues regarding blocking IP prior to awarding an SRC contract. For example, SRC may negotiate a license to blocking IP. NSF funding will not be contingent upon resolution of any blocking IP, and funding by SRC or NSF will not create an obligation for the other organization to provide funds" (NSF 2016).

In general, these terms were satisfactory, but SRC and industry members felt real or perceived risks that companies could be sued for developing technology based on undisclosed blocking IP. Therefore, around the beginning of nCORE, SRC pursued stronger IP protections for the companies that would have required all relevant background IP upon which new nCORE-funded research was built to also be made available under NERF licensing terms to member companies. These terms were not satisfactory to the universities nor to NSF, and this disagreement led to a delay in new NSF funding for nCORE. It seems that the resolution will be to revert to the prior IP arrangement, though new research projects with blocking IP that cannot be made available to all participants might be less likely to be selected for nCORE funding.

Other Protections

We do not believe SRC plays a large role in maintaining or overseeing the security practices at universities. All new IP generated under NRI, nCORE and JUMP was shared, as the research was precompetitive. Standard academic practices for handling the associated data were followed by the university researchers generating this IP. Research content generated by the PPP is accessible only by eligible users via the SRC website. For research collaborations between university and NIST researchers, those two parties made their own security arrangements without the involvement of SRC.

Evaluation and Outcomes

The research conducted under SRC programs is evaluated by annual reports and reviews, and mid-program evaluations. Additionally, SRC has developed key performance indicators that it has integrated into JUMP and nCORE (Table M-4).

Table M-4. Key Performance Indicators for nCORE and JUMP

Key Performance Indicators for nCORE and JUMP
• Demonstrate Viability • Set a New Direction • Technology Transfers • Transfer from Member to Academia or Start-up • Full-time Hire into Member Company • Identified Showstopper or Mitigation of High Risk • Member Awareness/Collaborations

Key Performance Indicators for nCORE and JUMP

- Cross-Task Awareness/Collaborations
- Ecosystem Development
- Intern Hire into Member
- Students
- Policy Making/Standards
- Patents
- Publications
- Industry Partner Alliance or Investment

By most measures, NRI has been a successful PPP and nCORE and JUMP are moving in a similar direction. Although NRI did not achieve its narrowly defined technical goal, the high caliber research projects conducted contributed to a better understanding of the semiconductor field. Some research led to changes in research goals and approaches when certain hypotheses were found to be nonproductive or infeasible. Such results are valuable. Some of the research projects have been transitioned to commercial applications.

As far as technical metrics are concerned, during the first phase of NRI, the need for benchmarking of alternate logic switch technologies against CMOS was identified. In 2009, the first benchmarking program under NRI began, and later a NRI center focused on benchmarking technologies was later created out of Georgia Tech (Khan 2015).

The NRI benchmarking program developed a uniform methodology to quantitatively evaluate the beyond-CMOS devices researched in the NRI program. These beyond-CMOS devices were used to design common logic gates (e.g.., inverter, NAND-gate, Adder) and the performance of these gates/devices were evaluated using a common set of metrics (i.e. delay, power, area, etc.), which are the same metrics used to evaluate CMOS performance. The benchmarking work didn't invent new metrics, but developed a uniform methodology to evaluate beyond-CMOS devices. The concept and methodology of beyond-CMOS device benchmarking have been adopted by many SRC-funded researchers. There are follow-on benchmarking projects in both nCORE and JUMP.

In its 40 years of operation, SRC has achieved the following:

- Funded over $2 billion of research;
- Supported over 12,000 graduate students to strengthen the semiconductor workforce;
- Provided over 700 patents to member companies.

Since inception, NRI has funded the following (SRC n.d.g):

- 63 universities (758 students, 332, faculty researchers)

- 144 industry liaison personnel
- 4,004 research publications
- 70 patent applications and 28 patents granted

Since inception, nCORE has funded the following (SRC n.d.h):

- 30 universities (227 students, 91 faculty researchers)
- 184 industry liaison personnel
- 1,006 research publications
- 29 patent applications

Since inception, JUMP has funded the following (SRC n.d. i)

- 35 universities (1,307 students, 169 faculty researchers)
- 453 industry liaison personnel
- 4,068 research publications
- 67 patent applications and 5 patents granted

Lessons Learned

Note: Based on the study team's analysis of information.

The uncertainty around high-risk high reward research goals can make it difficult to select projects and evaluate outcomes.

Especially at the beginning of NRI, determining to frame the high-risk high reward research goals in a productive way was challenging. For NRI, a large amount of uncertainty arose about the direction of the research to discover a replacement to the CMOS logic switch. This uncertainty sometimes made prioritizing research projects difficult or as well as determining whether goals were being met.

Benchmarking technology needs to be included in research processes from the beginning.

The benchmarking metrics were developed during the first portion of NRI and during STARnet, but were critical in evaluating the competitiveness of CMOS replacement technologies. Benchmarking has been included from the start of nCORE and JUMP to help prioritize research direction. A related lesson learned is that is a good idea to reevaluate goals every 5 years, which didn't happen after the first 5 years of NRI.

Low industry member engagement can lead to research that does not fit the needs of industry, but using an assignee model can encourage engagement.

A varying degree of industry member engagement takes place among the companies involved. Lower member engagement may lead to research less likely to be adopted into industry. The assignee model (used during NRI) may have helped with this, but it was not used for nCORE and JUMP. These partnerships need the "right" industry representatives involved, ones who are engaged with the research and are able to think about the long-term vision for the field.

It can be challenging for competing companies to coalesce around common goals.

It can be challenging for industry and academia to effectively communicate and to be on the same page about research direction. Two such examples are provided here. In the early phase of NRI, academics had trouble grasping that the member companies in fact wanted research outputs that were not field effect transistors, because they assumed that the companies wanted research that would be more immediately applicable (Khan 2015). Later on in NRI and into nCORE, some academics did not like the benchmarking metrics used to evaluate technologies, as these metrics sometimes directed the research away from topics of interest for basic research.

Strong leadership is important.

SRC depends on effective leadership, program directors, and university center directors. These leaders need to be able to build mutual trust among competitor companies and open exchange between industry and academia.

A disconnect can occur between industry-funded and Federally-funded PPP programs.

Some companies did not experience much value in the NSF-funded portion of NRI and nCORE, as they see NSF's goals as disconnected from their industry goals. For the NIST-funded portions of NRI and nCORE and the DARPA-funded JUMP, the process of setting the research direction is more collaborative between industry and government, leaning towards a more industry-lead definition of the research goals.

SRC's long history (operating partnerships over many decades) has allowed them to refine their governance and operational model over many iterations of programs.

The governance model has well-defined roles for industry and government in decision-making bodies. These roles vary across NRI, nCORE and JUMP, but all seem to work reasonably well. SRC's operational model evolved to discontinue use of industry assignees in favor of industry liaisons. In nCORE, reduced the number of centers and PIs funded to be able to capture a larger share of each professor's time, funding multiple students per professor.

Clear IP terms are necessary for maintaining trust for collaborative basic research.

When NRI was forming, its focus on such far future, basic research and its use of the industry assignee model both contributed to disagreements about hypothetical patent rights and their future value. These disagreements stalled progress at the beginning of NRI. Later when nCORE was beginning, a new IP disagreement emerged about whether "background IP" should be also be provided to the industry members with NERF license terms, with the industry members in favor of this change, and universities and NSF opposing it. Ultimately, it appears the IP arrangement will remain unchanged, but some trust has been lost and progress was stalled on the NSF-funded portion of nCORE.

An understanding of and clear initial IP ownership among partners is critical; changing IP terms after formation can stall progress.

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Appendix N.
Other Private Sector Engagement Models

The study team identified other private sector engagement models related to the scope of this study. The study team categorized these models as coordination units, Federal open research infrastructures, innovation ecosystem and innovation continuum support, place-based networks, research parks and innovation hubs, and venture capital arms. Table N-1 provides a brief description of the model, why it was of interest for this study, including the use of relevant Federal authorities, as applicable.

Table N-1. Brief Descriptions of Other Private Sector Engagement Models

Model	Brief Description	Why of Interest
	Coordination Units	
National Nanotechnology Initiative (NNI), National Nanotechnology Coordination Office (NNCO)	NNI launched in 1999, now involves 20 departments and independent agencies Coordination of Federal support for nanotechnology R&D across academic, government, and industry laboratories (NNI n.d.) NSF's National Nanotechnology Coordinating Infrastructure (NNCI) establishes a network of user facilities, other shared infrastructure coordinated across Department of Energy (DOE), NIST, and the National Institutes of Health (NNCI n.d.) Joint funding provided through a memorandum of understanding	Interagency coordination in the development of frameworks for shared goals, priorities, and strategies Dedicated staff in coordination office Network of shared user research facilities coordinated by consortia of universities Relevant authorities: Grants, Cooperatives Agreements, NNI and NNCO later became law in 2003 through the 21st Century Nanotechnology Research and Development Act (P.L. 108–153)

Model	Brief Description	Why of Interest
COVID-19 High-Performance Computing Consortium (HPCC)	Announced in March 2020 to provide access to the HPC capabilities across sectors to advance COVID-19 research (COVID-19 HPCC n.d.) Led by the White House Office of Science and Technology Policy (OSTP), the Department of Energy (DOE), and IBM By May 2020, included 38 members from the largest industry players in the computing and high-technology sector—Amazon, Dell, Google, Intel, NVIDIA, and Hewlett Packard—top tier academic research institutions and computing facilities—MIT, Carnegie Mellon University—the Ohio Supercomputer Center; seven DOE National Laboratories, and several HPC computing centers funded by NSF and the National Aeronautics and Space Administration (NASA)	Brings together Federal Government, industry, and academic researchers Governance via a Board and Committees Brokers access to existing infrastructure Open shared R&D and IP model (via publications) Relatively fast establishment to address pandemic response Serving as a model for continued engagement post-pandemic Relevant authority: Established with no special Federal authorities
Federal Open Research Infrastructures		
DoD Army Research Laboratory (ARL) Open Campus	Initiative launched in 2014 to strengthen the science and technology ecosystem through R&D collaborations with ARL and visiting scientists at collaborating institutions (ARL n.d.) Various centers designated as part of Open Campus infrastructure Campus expanded to multiple sites across the United States and internationally (Leonard 2018)	Implementation of a new business model focused on ARL workforce exchange and visiting scientists Access to ARL facilities, shared facilities with collaborating institutions Relevant authorities: CRADAs, Education Partnership Agreements, Enhanced Use Lease
DOE Livermore Valley Open Campus (LVOC)	Joint effort launched in 2011 between Sandia National Laboratories and the Lawrence Livermore National Laboratory (SNL n.d.) 110-acre campus, with recent expansion of new facilities outside LLNL's security fence (LLNL 2019)	Shared infrastructure, with continued expansion since its launch Location sited outside the security fence for ease of access Relevant authority: CRADAs and other collaborative or user facility agreements
DOE User Facilities	Research facilities designated by DOE across DOE's National Labs Aimed at providing access to infrastructure, equipment, tools, and National lab researchers to research communities across academia and industry	National Labs serve as stewards of the infrastructure, long-term investments Flexible IP models, shared or proprietary

Model	Brief Description	Why of Interest
	Differing models, some provide access for free if sharing IP (via publications), proprietary R&D conducted at cost; others only offer access for non-proprietary R&D	Relevant authority: Established with no special Federal authorities: CRADAs and other collaborative or user facility agreements
Innovation Ecosystem and Innovation Continuum Support		
Defense Electronic Consortium (DEC)	Consortium established in 2021 by DoD and led by the US Partnership for Assured Electronics, an association of industry and academic members (DEC n.d.) Goals focus on strengthening the economic and force posture of the defense electronics industrial base, targeting component manufacturers and tool and equipment providers	Leveraging of association members towards consortium goals Integration of large, medium, and small businesses Relevant authority: Other Transaction Authority
DoD NavalX TechBridges	Established by the Office of Naval Research, the NavalX TechBridges Focuses activities on increasing collaboration with industry and academia by targeting local sites across the United States, expanded into the United Kingdom in 2020 (Eckstein 2020)	Aimed at creating a network of networks and linking innovation units across DoD Industry, including small business, engagement Relevant authorities: Established as DoD offices, PIAs used to engage with innovation ecosystem builders
DOE Lawrence Berkeley National Laboratory (LBNL) Cyclotron Road	Established in 2015 as a program to support entrepreneurial scientists through a fellowship program for up to 2 years (LBNL n.d.) Partnership with non-profit for curriculum design Participants include individuals, teams, and small businesses in pre-commercial stage	Entrepreneurial R&D training Dedicated space, access to infrastructure and tools, lab experts, and seed funding Relevant authority: Established with no special Federal authorities
Foundation for the NIH (FNIH)	Established in 1990 as a non-profit to partner with the NIH and private funders to accept gifts, grants, and other donations Supports R&D programs, including clinical trials and data sharing; education and training; and educational events, among others Board of Directors comprised of industry, including foundations and private capital investors, academia, and leadership from the NIH and the Food and Drug Administration (FNIH n.d.a) Raised $80 for every $1 of NIH funding (FNIH n.d.b)	Allows for raising of private funds for R&D aligned with NIH's mission Governance includes a multi-sector Board Relevant authority: Public Law 101–613, 42 U.S. Code § 290b

Model	Brief Description	Why of Interest
MilTech	Established in 1990 as a partnership intermediary, provides tech scouting, market research, design and prototyping services, and design and manufacturing expertise for DoD Leverages the Manufacturing Extension Partnership (MEP) network for prototyping infrastructure and expertise as well as to scout for small-business capabilities (MSU n.d.)	Leverages infrastructure across MEPs In-house expertise and staff supporting R&D and prototyping Engagement with small businesses Relevant authority: Partnership Intermediary Agreement under 15 U.S.C. § 3715 or 10 U.S.C. § 2368, Grants, Contracts, and other funding vehicles from DoD
NSF I-Corps	Created in 2011 to provide experiential learning and support the translation of discoveries to the marketplace Funds 99 sites across the United States supported by 9 established “nodes” (VentureWell n.d.a) National Innovation Network provides participants with information about resources available (VentureWell n.d.b)	Focuses on education, infrastructure, and R&D Network of sites, distributed training model Model expanded to other agencies for Federal and non-Federal researchers Relevant authority: Grants, Later became law through the American Innovation and Competitiveness Act (P.L. 114-329, Sec. 601)
U.S. Small Business Administration (SBA), Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR)	SBIR provides funding for entrepreneurs and small businesses from concept to prototype development (SBA 2020) STTR provides funding for small businesses to formally collaborate with research institutions; fostering technology transfer through cooperative R&D	Start-up and small business funding Cross-sector partnerships through STTR Tiered program design Relevant authority: 15 U.S.C. §638
Place-Based Networks		
Fraunhofer Institutes	Conduct applied research with the express aim of enhancing the innovative capacity of German industry R&D addresses topics identified top-down by an Executive Board (Fraunhofer n.d.) Range of sites across Germany with specialized technology focus	Top-down governance structure, informed by technical bodies Network of sites as focused research centers Relevant authority: Not applicable

Model	Brief Description	Why of Interest
Manufacturing USA Institutes and Manufacturing Extension Partnerships (MEPs)	16 Institutes serve as focused research sites with specialized technology focus to accelerate advanced manufacturing R&D (Manufacturing USA n.d.b) Institutes establish partnerships with educational organizations to provide education and training programs via workshops, courses, internships, and apprenticeships (Manufacturing USA n.d.a) MEPs serve as a network of centers in each of the 50 States to provide a range of resources, including product design and development services, market research support, technology scouting, and other support for business growth (NIST 2019)	Network of sites as focused research centers Formal education program Provides access to expertise and infrastructure Funding provided across multiple agencies Small business resources Relevant authority: Cooperative agreements, Network for Manufacturing Revitalize American Manufacturing and Innovation Act of 2014 as Title VII of Division B of the Consolidated and Further Continuing Appropriations Act, 2015 (P.L. 113-235),15 USC 278k
NSF Engineering Research Centers	Relatively large and long-term awards for varied sites / centers across the United States (up to 10 years with renewal) University-based, staffing from academic faculty, including doctoral-level scientists and engineers Engagement of academic and industry partners to guide R&D Education and workforce programs, including K–12 outreach Examples of self-sustained centers after 10 years (e.g., Center for Biofilm Engineering at Montana State University (MSU 2020)	Bottom-up, hands-off NSF governance Focus on academic-led centers with industry engagement as R&D collaborators Educational and technology transfer goals, in addition to R&D (Lal et al. 2007) Self-sufficiency as a possible outcome Relevant authority: Cooperative agreements
Research Parks and Innovation Hubs		
Department of Homeland Security National Bio and Agro-Defense Facility—Manhattan, Kansas	In 2005, DHS begins a solicitation process for the conceptual design and award of NBAF to address a capability in agro-terrorism Launched a national competition and a site selection process using criteria based on General Services Administration (GSA) practice (GSA n.d.) Winning proposal from consortium in Kansas of academic, industry, State and local governments to provide land and funding (over $300 million and in-kind contributions)	Open national competition for site selection State and local government matched funding and in-kind contributions for infrastructure development Relevant authorities: Grants, Contracts, DHS Directive 112-02 Rev. 00, “Gifts to the Department of Homeland Security”

Model	Brief Description	Why of Interest
DoD Air Force Falcon Hill Aerospace Research Park - Hill AFB, Utah	Partnership with private sector to develop 550 acres of commercial and non-commercial property within and outside of the security fence of the base, Air Force received in-kind considerations Utah Science Technology and Research Innovation Center, a 21,000 sq. ft. facility, built as a technology incubator	New infrastructure development Attraction and co-location of businesses, current and potential R&D collaborators <u>Relevant authority</u>: Enhanced Use Lease
NASA Research Park - Ames, Moffett Field, California	Partnership established in 2014 with Planetary Ventures (a Google subsidiary) to develop 42 acres via an enhanced use lease Cost-savings to NASA for operations and maintenance estimated at $6.3 million annually (NASA 2014) 1.2 million square feet of R&D facilities and office space to develop space exploration and robotics technologies	New infrastructure development Co-location of industry to support agency mission and collaborative R&D Leases provide source of revenue and savings <u>Relevant authority</u>: Enhanced Use Lease
National Interagency Confederation for Biological Research (NICBR)/National Interagency Biodefense Campus (NIBC)—Fort Detrick, Maryland	After the events of 9/11 and the subsequent anthrax attacks, several agencies began coordinating biodefense research and co-located research facilities at the NBIC Around 2002, established the NICBR as a loose confederation of research organizations (Peña et al. 2014) Partners evolved over time, including National Cancer Institute (NCI), National Institute of Allergy and Infectious Diseases, U.S. Army Medical Research and Materiel Command, U.S. Department of Agriculture (USDA), DHS, Centers for Disease Control and Prevention, Naval Medical Research Center, and Food and Drug Administration Joint investment in a Central Utility Plant to accommodate growing campus, costs for the mortgage, development, and operations of the facility shared among users	Interagency pooling of resources Growth of partnership led to new infrastructure needs Governance with working groups Shared research and joint-infrastructure investments to address limitations from individual agency Congressional appropriations <u>Relevant authority</u>: Enhanced Use Lease
SUNY Polytechnic NanoTech Campus–Albany, New York	State government funding promoted infrastructure expansion and to incented companies to move to the SUNY campus Location of various PPPs including SEMATECH and AIM Photonics, a Manufacturing USA Institute	New infrastructure development State government funding <u>Relevant authorities</u>: Grants, Cooperative Agreements, Contracts, and other Federal funding provided to support R&D and new infrastructure

Model	Brief Description	Why of Interest
	Venture Capital Arms	
Department of Health and Human Services, Biomedical Advanced Research and Development Authority (BARDA) DRIVe	Announced in 2020 as an initiative to partner with a non-profit and use venture capital methods and practices to address pandemic preparedness (BARDA 2020) Equity financing and management of an investment portfolio Governance includes a Joint Oversight Committee with BARDA personnel involved in decision making of focus technology areas	Investment in start-ups and small businesses BARDA provides oversight and approval of strategic directions Relevant authority: 21st Century Cures Act (P.L. 114-255)
DoD Air Force AFVentures	Operates SBIR and STTR programs as open topic solicitations (AFWERX 2020) Phase 1: provides seed funding; Phase II: encourages third-party match, Phase 3: requires 1:1:2 DoD program-SBIR-private matching (AFWERX n.d.)	Venture capital cost-share Tiered program designed to allocate risks across investors, including DoD Relevant authority: Grants, Contracts or other for follow-on funding
InQTel	Established in 1990 as a non-profit venture arm for the Intelligence Community Programs support translation of federally funded and identification of technology solutions to meet U.S. Government capabilities (InQTel n.d.) Invests directly in promising start-ups and technologies Profits are reinvested back into its programs, funding allocations supported by Board of Director decision-making (Reinert 2013)	Commercialization of federally funded R&D Market scouting role and investment in start-ups Relevant authority: Established with no special Federal authorities

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Appendix O.
Mapping of PPP Goals

The study team mapped each of the 8 case study PPPs to respective goals to inform the development of major goals relevant to framing the options for a new microelectronics PPP.

Table O-5. Mapping of Goals for 8 PPP Cases

PPP Goal/Description	AIM	BRIDG	IMEC	MOSIS	MX	NEXTFLEX	SEMATECH	SRC-JUMP	SRC-NRI	SRC-nCORE
Scientific and technological progress (general technical goal)	0	3	1	1	2/3	0	2	1	2	1
Scientific and technological progress (specific technical goal)	0	2	2	3	3	0	2	2	1	2
Increased technology transfer / maturation / development (increasing TRL/MRL); lab to prototyping or prototyping to demonstration	1	1	2	1	2	1	3	3	3	3
Breakthrough, high-risk / high-reward advances in ME	2	1	2	3	3	1	3	1	1	1
Organized strategic and market direction/roadmap for technology and participants	0	1	2	0	0	1	1	1	1	1
Development of new or strengthened markets for technologies of interest to partners	1	3	2	1	0	1	2	2	2	2

PPP Goal/Description	AIM	BRIDG	IMEC	MOSIS	MX	NEXTFLEX	SEMATECH	SRC-JUMP	SRC-NRI	SRC-nCORE
Increased market readiness: spin-offs, commercialization, VC funding	1	3	2	0	0	1	0	3	3	3
Collaboration / communication among industry competitors	1	2	2	0	0	1	1	1	1	1
Strengthened domestic innovation ecosystems, including U.S. supply chains	1	2	1	3	0	1	1	2	1	2
Strengthened domestic industries	1	1	1	1	3	1	1	2	1	2
Increased U.S. market share for technologies of interest	2	2	3	3	0	1	1	2	1	2
Ensuring U.S./USG has domestic ME prototyping / access to state-of-the-art manufacturing capabilities	1	1	0	1	1	1	3	0	0	0
Ensuring the U.S. DIB/industry has affordable access to (state-of-the-art) ME design and manufacturing technologies	2	1	0	1	3	1	3	1	2	2
Cadre of skilled workers to support the industry	2	1	1	1	0	1	0	1	1	1
U.S. economic and productivity gains	2	3	1	3	0	2	3	3	3	3
Enhanced national security	0	1	0	3	0	0	3	3	3	3

“0”—the goal does not apply to the PPP; “1”—the goal is a primary goal of your PPP e.g., specific formalized programs and activities are established to support that specified goal; “2”—the goal is a secondary objective or a minor part of the PPP’s activities; “3”—the goal is not directly attributable to but is an outcome that was achieved indirectly due to the PPP’s activities

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Abbreviations

AECA	Arms Export Control Act
AIM	American Institute for Manufacturing
AIT	Advanced Information Technologies
AMLCD	active matrix liquid crystal displays
APS	American Physical Society
ARPA-E	Advanced Research Projects Agency–Energy
ATI	Advanced Technology International
ATP	Advanced Technology Program
BiSFETS	Bilayer PseudoSpin Field Effect Transistor
BRIDG	Bridging the Innovation Development Gap
CAMM	Center for Advanced Microelectronics Manufacturing
CHIPS	Creating Helpful Incentives to Produce Semiconductors
CMU	Carnegie Mellon University
CNRI	Corporation for National Research Initiatives
COTS	commercial off-the-shelf
CU	Columbia University
CRADA	Cooperative Research and Development Agreement
CRS	Congressional Research Service
DARPA	Defense Advanced Research Projects Agency
DC	Deloitte Consulting LLP
DIB	defense industrial base
DMEA	Defense Microelectronics Activity
DOC	Department of Commerce
DoD	Department of Defense
DOE	Department of Energy
DSB	Defense Science Board
EAA	Export Administration Act
EL	electroluminescent display
EPDA	electronic-photonic design automation
EPRI	Electric Power Research Institute
ERI	Electronics Resurgence Initiative
EUV	extreme ultra-violet
Fab	fabrication facility
FCRP	Focus Center Research Program
FDA	Food and Drug Administration
FHE	Flexible Hybrid Electronics
FY	fiscal year
GAO	Government Accountability Office
GRC	Global Research Collaboration
IC	integrated circuits

ICAMR	International Consortium of Manufacturing Research
ICT	inline control and test
IDA	Institute for Defense Analyses
IMEC	Inter-University Micro Electronics Centre
IMPACT	Innovative Materials and Processes for Accelerated Computer Technologies
INDEX	Institute for Nanoelectronics Discovery and Exploration
IP	intellectual property
IPS	IEEE Photonics Society
IPTO	Information Processing Office
ISI	USC Information Services Institute
ISWA	International Solid Waste Association
ITAR	International Traffic in Arms Regulations
ITRS	International Technical Roadmap for Semiconductors
ITU	International Telecommunication Union
JUMP	Joint University Microelectronics Program
KTMA	Key Technology Manufacturing Area
LEAP	Laboratory for Education and Application Prototypes
LIA	Laser Institute of America
LIDAR	light detection and ranging
MANTECH	Manufacturing Technology
MARCO	Microelectronics Advanced Research Corporation
MCNC	Microelectronics Center of North Carolina
MEMS	microelectronic mechanical systems
MEP	Manufacturing Extension Partnership
MIIP	Manufacturing Innovation Institute Program
MIT	Massachusetts Institute of Technology
MOSIS	Metal Oxide Silicon Implementation System
MPW	multi-project wafer
MRL	manufacturing readiness level
MRSECs	Materials Research Science and Engineering Centers
MSSF	Multilateral Semiconductors Security Fund
MUMPS	Multi-User MEMS Process Sequence
MX	MEMS and Nanotechology Exchange
NAS	National Academy of Sciences
nCORE	nanoelectronic Computing Research
NDAA	National Defense Authorization Act
NDIAETI	National Defense Industrial Association Emerging Technologies Institute
NERF	non-exclusive royalty free
NIBC	National Interagency Biodefense Campus
NICBR	National Interagency Confederation for Biological Research
NIRTs	Nanoscale Interdisciplinary Research Teams
NIST	National Institute of Standards and Technology
NNCI	National Nanotechnology Coordinated Infrastructure

NNI	National Nanotechnology Initiative
NPI	National Photonics Initiative
NRC	National Research Council
NRI	Nanotechnology Research Initiative
NSECs	Nanoscale Science and Engineering Centers
NSET	Nanoscale Science, Engineering and Technology
NSF	National Science Foundation
NSMR	National Strategy on Microelectronics Research
NST	New Science Team
NSTC	National Science and Technology Center
OIDA	Optoelectronic Industry Development Association
OSA	Optical Society of America
OSTP	Office of Science and Technology Policy
OTA	Other Transaction Authority
OTs	Other Transactions
PCAST	President's Council of Advisors on Science and Technology
PCB	printed circuit board
PDK	process design kit
PIA	Partnership Intermediary Agreement
PIC	photonic integrated circuits
PII	personally identifiable information
PIPS	Potomac Institute for Policy Studies
PPP	public-private partnership
PUF	physically uncloneable function
PTO	U.S. Patent and Trademark Office
PVMC	Photovoltaic Manufacturing Consortium
PWC	PricewaterhouseCoopers
QEDC	Quantum Economic Development Consortium
QSR	Quality Systems Regulations
R&D	research and development
R2R	roll-to-roll
RAMI	Reinvesting in American Manufacturing Innovation
RF	radio frequency
RIT	Rochester Institute of Technology
S&T	science and technology
SBIR	Small Business Innovation Research Program
SEMATECH	Semiconductor Manufacturing Technology
SITRI	Shanghai Industrial Technology Research Institute
SMART	Spintronic Materials for Advanced Information Technologies
SME	subject matter experts
SPAWAR	Space and Naval Warfare Systems Command
SRC	Semiconductor Research Corporation
STARnet	StarNet Communications Corporation
STPI	Science and Technology Policy Institute

SUNY	State University of New York
SWAN	South West Academy of Nanoelectronics
TAP	test, assembly, and packaging
TFFATI	Tekes Finnish Funding Agency for Technology and Innovation
TIA	Technology Investment Agreement
TRB	Technical Review Board
TRL	technology readiness level
TSMC	Taiwan Semiconductor Manufacturing Corp.
TWG	Technical Working Group
UA	University of Albany
UCF	University of Central Florida
UCSB	University of California at Santa Barbara
UNITAR	United Nations Institute for Training and Research
UNU	United Nations University
UR	University of Rochester
USCAR	United States Council for Automotive Research
USDC	U.S. Display Consortium
USICA	U.S. Innovation and Competition Act
USPAE	U.S. Partnership for Assured Electronics
VLSI	very large scale integration
WSJ	Wall Street Journal

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14. ABSTRACT
The Department of Defense's (DoD) Defense Advanced Research Projects Agency (DARPA) has supported research and development (R&D) in microelectronics for many decades. DARPA is interested in ways to improve engagement with and support the microelectronics industry, potentially through establishing a public-private partnership (PPP) to advance R&D and technology development goals. To support these interests, DARPA requested the IDA Science and Technology Policy Institute (STPI) identify and analyze prior and ongoing PPPs to inform their efforts to establish a new PPP. DARPA anticipates a new PPP could advance microelectronics R&D and technology development potentially by supporting infrastructure to meet prototyping needs across the industry. Specifically, the study team set out to identify lessons learned related to the design and implementation of past and ongoing PPPs and develop options for structuring a new PPP, and propose options for a new microelectronics PPP for DARPA to consider.

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