Applied Science & Technology Research Organization of America

GUAM ADDITIVE MANUFACTURING AND MATERIALS ACCELERATOR

Implementation Plan for GAMMA Technology & Education Center

Developed for the Government of Guam and
Bureau of Statistics & Planning

Phase II, Deliverable 7

June 2024



Implementing a Guam Advanced Materials & Manufacturing Accelerator, Phase II Report

Deliverable 7

June 2024

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ASTRO America. RADM Scott Pappano (PEO SSBN) and Hon. Lou Leon Guerrero (Governor of Guam).
SME. Photo gallery of 2023 RAPID + TCT meeting.
NASA. Wire Arc Directed Energy Deposition photo. Presentation to 2020 ASTM ICAM meeting.
University of Guam
ASTRO America. Meeting among ASTRO, Guam Economic Development Authority and Governor staff.

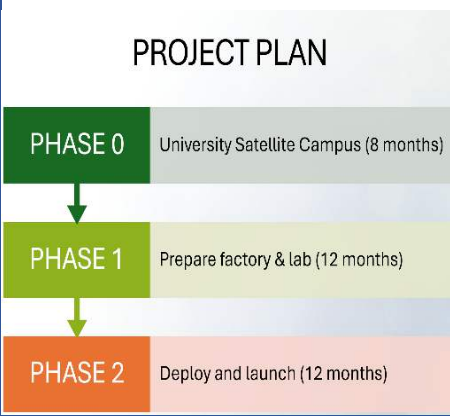
"MEMO IN BRIEF"

WHAT THIS REPORT IS ABOUT

For over a year, ASTRO America explored use of Additive Manufacturing (AM) in Guam. Our first report analyzed its feasibility. This second report recommends establishing a Guam Additive Materials & Manufacturing Accelerator (GAMMA).

KEY FINDINGS IN THIS REPORT:

- Partnership with the submarine industrial base offers an immediate pathway to a sustainable manufacturing sector.
- Mainland U.S. universities can accelerate institution-building with a credentialed satellite campus in Guam.
- Major academic, business, and government parties across the U.S. stand ready to help GAMMA's initiation.
- A practical strategy to build GAMMA entails:



Plan for the Guam Additive Materials & Manufacturing Accelerator – PROJECT "GAMMA"

For over a year, ASTRO America has undertaken a feasibility study of the use of Additive Manufacturing (AM) in Guam. The completion of Phase II culminates in an Implementation Plan to build a center with three pillars: workforce development and education; manufactured part-testing; and business incubation.

As a part of Phase II, ASTRO helped the Government of Guam and U.S. Program Executive Office - Strategic Submarines devise a joint project plan for initiating GAMMA's development.

This effort begins by building a Guam-based satellite campus of a leading U.S. AM university. It brings sophisticated training on-island and establishes the sole industrial part inspection laboratory for thousands of miles. In so doing, it has the potential of transforming Guam's economy, enabling on-demand part production and validation for key industries.

Figure 1. Honorable Lou Leon Guerrero, Governor of Guam, and RADM Scott Pappano, program executive officer, strategic submarines

Making GAMMA a reality requires partnerships with mainland U.S. educational institutions and companies for investment, technology, and expertise. It entails involvement by Guam infrastructure including airport and port authorities, as well as commercial entities. Utilizing local talent, Guam Economic Development Authority and University of Guam are also key participants in setup and operation of GAMMA.

The enclosed implementation plan charts a course along the three aforementioned pillars to implement GAMMA, over five years, in concert with key public and private sector partners.

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1.0 EXECUTIVE SUMMARY

The Applied Science & Technology Research Organization of America (ASTRO America) is pleased to provide its second major report to the Government of Guam, now at the behest of Guam's Bureau of Statistics and Plans (BSP), building off a feasibility analysis commissioned by the Guam Economic Development Authority (GEDA) in 2022-2023.

This deliverable constitutes the latest stage of an initiative launched nearly three years ago by Governor Lourdes A. Leon Guerrero, after considering the potential economic impact of additive manufacturing in Guam. Initially, GEDA had directed ASTRO to organize a study and technology summit to determine potential of developing 3D printing on-island to address Guam's economic development and key military needs. The resulting "Phase I" report provided important analysis upon which to base a plan for an education and technology center that could generate new opportunities for economic growth, entrepreneurship, and jobs in Guam.[1]

By serving a dual role as both a production powerhouse and an educational hub, the GAMMA center will offer advanced technical education and well-paying, sustainable job opportunities to the local community, thus elevating the economic landscape and providing new career paths for Guamanians.

In that initial report, it was concluded that the building blocks exist to establish an advanced manufacturing economy in Guam, if sustained by key federal, academic, and industry partnerships. Accordingly, this year, we completed the following detailed plan, as "Phase II," including a practical strategy for creating the Guam Additive Materials and Manufacturing Accelerator (GAMMA) facility. This state-of-the-art center will be dedicated to advancements in additive manufacturing on-island, becoming in the short term an essential resource for submarine-building technology and workforce development.

Having collaborated on this plan with the Government of Guam and the U.S. Navy's Program Executive Office for Strategic Submarines (PEO SSBN), ASTRO believes such a partnership will kickstart GAMMA with a built-in constituency to support its organization and satisfy currently unmet submarine part-sourcing needs in the Indo-Pacific region.

At the outset, the U.S. Navy will serve as the primary customer and funding source for GAMMA, which will encompass comprehensive facilities for workforce training and education, naval ships' part testing and evaluation, as well as prototyping and supply chain maturation. Resulting infrastructure will provide high-caliber training and cutting-edge production capabilities on-island that, over the long term, may also be applied to a broad range of commercial (non-Naval) industries across the Indo-Pacific.

In so doing, GAMMA will support the Guam government's economic diversification goals, and ultimately extend beyond traditional military markets, leveraging its advanced manufacturing capabilities to penetrate adjacent sectors, including maintenance, repair, and overhaul (MRO) in aerospace, general industrial fields such as heavy equipment and machinery, tooling and fixturing, and automotive

[1] ASTRO America. Baseline Additive Manufacturing Readiness. Developed for the Guam Economic Development Authority. April 2023.

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replacement parts. This expansion will not only enhance the center's offerings but also contribute significantly to expanding Guam's economic reach beyond its borders into Indo-Pacific export markets.

However, the cornerstone of this initiative remains the creation of a satellite campus in Guam, in partnership with the University of Guam and a mainland U.S. university renowned for its leadership in manufacturing education and technical research. This strategic development introduces cutting-edge training opportunities to the region, supplemented by the sole industrial part-inspection laboratory within thousands of miles. Thus education will need to support part-inspection training to build major advanced manufacturing enterprises, ensuring that each component produced on-island adheres to the established quality standards. By enabling on-site production and immediate validation of parts for both Defense and key commercial sectors, this project is poised to reshape Guam's economic horizon.

Indeed, GAMMA could eventually serve a dual role as both a production center and educational hub, offering advanced technical training and well-paying, sustainable job opportunities to the local community. This initiative thus promises to transform Guam into a strategic, resilient, and economically diverse hub, making it an essential technological and industrial node in the Indo-Pacific region.

A 5-Year Strategy and Implementation Plan

This implementation plan outlines a five-year, three phase, public/private collaboration. ASTRO developed this concept with PEO SSBN and Guam's government.

Figure 2: Accelerated Training in Defense Manufacturing in Danville, VA, a model for GAMMA

Phase 0: Planning and Design

This phase entails preliminary planning and sets the stage for a satellite campus of a mainland U.S. institution with reputable advanced manufacturing credentials on the grounds of the University of Guam. Such an effort will provide accredited mechanical engineering education/training and establish the only industrial-scale production test and evaluation center for thousands of miles. ASTRO's partners will consider multiple models upon which to base the GAMMA design, including Virginia-based Accelerated Training in Defense Manufacturing (ATDM), sponsored by the U.S. Navy; and the Alliance for the Development of Additive Processing Technologies (ADAPT) at the Colorado School of Mines.

Phase 0 entails:

- **Planning and Finalizing Satellite Campus** agreements including site, architecture, business model, governance agreements, and functionalities.
- **Design and Requirements Building** for technical aspects of GAMMA facility.
- **Understanding Capabilities Required for the Testing & Evaluation and Prototyping Lab** to meet shipbuilding and submarine industrial requirements.
- **Establishing Buy-in** from key submarine industrial base stakeholders, such as:
    - Shipbuilders - General Dynamics – Electric Boat (GD-EB), Huntington Ingalls – Newport News Shipbuilding (HII-NNS), Austal, BAE Systems
    - Operators - Submarine Squadron 15

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- Navy Organic Industrial Base - Pearl Harbor Naval Shipyard Guam Detachment, Naval Sea Systems Command Chief Technology Office (NAVSEA 05T) technical warrant officers.

Phase I: Design, Procurement, Integration, and Launch of Initial Containerized/Modular Factory
In this phase, we propose launching the satellite campus and providing interim capability of the Testing & Evaluation laboratory via the first of three containerized, modular factories built on the mainland and deployed to Guam – a first for the region.

Styled as shipping containers with electrical power, these modules contain complete additive manufacturing systems and will be designed, integrated, and staged for transport near the Colorado School of Mines, home to one of the U.S.' leading additive manufacturing engineering research/ education programs. Initial proximity to such an institution will enable teams to consult expert practitioners intensively, as they procure, configure and integrate technology into the modules. Additionally, the preliminary staging in the mainland U.S. will also afford policy and submarine industrial base experts access to modules, allowing them to contribute hands-on perspectives on implementation.

Overall, Phase I prioritizes rapid deployment to quickly establish advanced manufacturing capabilities. This setup not only facilitates swift implementation but also supports the integration of design, production, and inspection processes. Once operational, the modules will be deployed to Guam, adjacent to the newly launched satellite campus designed in Phase 0, thereby enhancing local capabilities while a permanent facility is being constructed. Experts from mainland U.S. higher education institutions and other leading technical experts will collaborate with Guam authorities to deploy the modular factory and begin construction of a permanent GAMMA facility.

To demonstrate industry need and applicability, Navy officials and the submarine industrial base will collaborate with participants from the GAMMA project—including Guam institutions, mainland U.S. higher education entities, and technical experts—to engage in practical use-case projects.

Figure 3. Example of modular platforms designed for complex production operations. Courtesy: Kratos

Successful development and validation of prototype parts that meet the specific needs of the Navy will affirm the GAMMA project's effectiveness and lay the groundwork for its subsequent phase. Determining the most appropriate AM, post-processing, and testing equipment for such activity will be based on Navy and industrial base input. However, recent use of AM to build key ship components may well inform these decisions, as discussed later in this report. For example, wire arc additive manufacturing (WAAM) shows promise for shipbuilders due to its large scale, speed, and material range, whether building a 400lb hinge or eight-foot-long pressure vessel. Other technologies, such as laser powder bed fusion (LPBF) hold promise for making intricate structures such as heat exchangers or impellers but may prove challenging to implement initially due to its complex operational parameters and material-handling and processing requirements.

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Phase II: Expansion and Enhancement
Once technology types have been determined, installed, and shipped via temporary factory modules, the next phase will be focused on enhancing the satellite campus educational experience and accelerating the testing and evaluation lab development. Phase II will thus integrate two additional containerized modular factories, thereby expanding on-island operations. These additional modules will integrate learning from Phase I and expand capability and production capacity to fulfill the needs of both U.S. and Allied submarine industrial base stakeholders, including potential participants within key Australian and U.K. naval supply chains.

The importance of establishing a testing and evaluation laboratory cannot be overemphasized. Without a sophisticated means for validating parts produced for ships or aircraft, any essential components produced on-island will be barred from being inserted immediately into highly regulated supply chains such as defense, shipbuilding or aerospace. To overcome this challenge, the Navy has indicated they will support development of these capabilities to enable highly sought-after testing and evaluation processes. However, onboarding this capability requires considerable technology and training.

Local Impact and Engagement

GAMMA will be developed to meet Navy part manufacturing needs in Guam, based on consistent input from prospective end-users of part-production services and workforce development. In the course of the aforementioned phases, GAMMA will host U.S. and Allied Navy authorities, shipbuilders, and equipment producers to ensure its appropriate development. Additionally, the implementation team will also ensure strong integration of Guam-based stakeholders, ranging from local government agencies and educational institutions to private companies and relevant industry organizations.

Ultimately, GAMMA represents a crucial partnership among both mainland U.S. and Guam organizations, working collaboratively to advance common economic and national security goals. Guam Economic Development Authority is expected to play a leadership role in coordinating local agencies and sponsoring the building construction necessary to host GAMMA’s permanent site. The University of Guam and Guam Community College will work with mainland U.S. academia to establish and operate a credentialed satellite campus for mechanical engineering programs and degrees as well as support certified skills training in prototyping, production, testing, and evaluation capabilities. Guam’s infrastructure leaders including airport and port authority officials will further work with GAMMA personnel to afford safe and efficient supply chain operations (e.g. shipment of capital equipment, regular import of consumables such as material feedstock, and export of AM-produced parts – as appropriate).

Once operational, this coordinated public-private partnership will establish an unprecedented pipeline of manufacturing talent in Guam, creating scores of highly skilled jobs, new business opportunities, and a reliable conduit for important goods/services for U.S. and Allied military forces. In summary, the GAMMA initiative represents a strategic, forward-looking investment that will deliver significant economic, educational, and technological benefits to Guam and beyond. Its establishment marks a major step in strengthening Guam's position in global manufacturing, securing its economic future, and providing valuable opportunities for its residents. This center is poised to become a hub for innovation and economic prosperity in the region.

1.1. Deliverables for this Study

Over a year-long period, ASTRO America has been undertaking the Guam Additive Manufacturing (AM) Feasibility Study. The purpose of the study is to conduct a comprehensive analysis to determine viability of a local AM industry in Guam. This report constitutes the final deliverable of this two-phased study.

1.2. Expected Outputs of this Study

Working with Guam's Bureau for Statistics and Plans set the stage for implementing a Guam Additive Manufacturing & Materials Accelerator, including: (1) Analysis of potential regional demand for Guam-based additive manufacturing, (2) Assessment of supply chain requirements, and (3) Executable solutions for corresponding workforce development and long-term sustainable growth.

Expected Outcomes: Project outcome will (1) confirm assumptions related to requirements for a Guam-based advanced materials and manufacturing accelerator facility; 2) discern the value proposition and long-term economic viability of such a center; and 3) develop an executable plan to establish workforce development, testing, evaluation, prototyping and production capabilities, and a strategy for long-term growth and sustainability.

1.3 Milestones and Timelines of this Study

This table details deliverables for this study, as directed by the Bureau of Statistics and Programs:

Phase 2 – Deliverable 001 (Month 1)	**Kick off Meeting and Preparation** 1. Presentation on assembled team 2. Detailed program plan and calendar 3. Meeting minutes 4. Implementation plan for input/feedback
Phase 2 – Deliverable 002 (Month 2)	**Pilot Concept** 5. Identify factors in determining total addressable market for additive manufacturing 6. Define range of production capabilities/capacity of a potential Guam Additive Materials & Manufacturing Accelerator (GAMMA) 7. Align gap analysis from Baseline Report on Additive Manufacturing Readiness to GAMMA requirements

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Phase 2 – Deliverable 003 (Month 2)	**Pre-Workshop Engagement** 8. Communication with participants, speakers, and facilitators 9. Workshop agenda preparation 10. Commercial/civil and Defense industrial base: a. aviation (engine & airframe); space; shipbuilding; automotive b. energy, medical device c. other (industrial, building) 11. Department of Defense/INDOPACOM 12. Additive equipment manufacturers, material providers, service providers 13. Higher education institutions
Phase 2 – Deliverable 004 (Month 3)	**CONUS Workshop** 14. Total addressable market 15. Continued (e-h) above and analysis 16. Feasibility of CONUS college/university partnerships/rotations 17. Strawman conclusions 18. Agenda/breakout; use case identified 19. CONUS workshop conclusions
Phase 2 – Deliverable 005 (Month 4)	**Post-Workshop Conclusions, Economic Viability/Policy** 20. Viable capacity (including workforce) vs. total addressable (including DOD) 21. Supply chain risks and mitigation 22. Short- and long-term workforce development/education solutions 23. Use case identification/conclusions
Phase 2 – Deliverables 006 (Month 5)	**Use Cases and Implementation Plan** 24. Use case: value proposition evaluated 25. Implementation plan
Phase 2 – Deliverable 007 (Month 6)	**Conclusion** 26. Final Report 27. Follow-on Proposal/Initiatives 28. Communication strategy

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2.0 Introduction & Program Overview

2.1 Background

While the Phase I report of this project, sponsored by the Guam Economic Development Authority (GEDA),[2] established that Guam possesses baseline building blocks for additive manufacturing readiness, Phase II was conducted to:

- analyze areas of demand for parts manufactured using additive manufacturing (AM),
- assess supply chain requirements for developing this capability, and,
- develop a viable implementation plan for workforce development and sustainable growth for the island.

The aim is to drive investment into an industrial base on Guam that will serve as a new economic engine for the island, as well as for U.S. Department of Defense (DoD) activities in the region.

Accordingly, ASTRO America recommends establishing a "Guam Additive Materials and Manufacturing Accelerator" (GAMMA), to develop technological capabilities, grow workforce skills to support local fabrication, and relieve the island of reliance on already strained foreign and offshore supply chains. In addition, by addressing burgeoning demand across the Indo-Pacific region for on-demand part production and validation-testing, it has the potential to build entrepreneurship opportunities for the population of Guam. Such an effort squarely aligns with the local government's goals to diversify on-island economic output, reduce reliance on imported parts and products, and raise workforce wages.

Figure 4. University of Guam, site of GAMMA and potential satellite campus

GAMMA consists of three pillars: 1) workforce development and education; 2) a lab-to-market testing and qualification facility; 3) an AM Marketplace/Incubator to host 3D printing businesses that can service on-island industries. Each of these components requires location of personnel and assets from mainland U.S. entities. Catalyzing such investment will also require financial and development support from the Government of Guam. Ultimately, such collaboration will contribute to effective maturation of a new industry in the Indo-Pacific region, based in Guam. To help formulate a plan that would address these requirements, ASTRO America formed a research team composed of experts in AM from industry, academia and public-private partnerships. Those experts engaged potential industry and defense partners for the project, identified realistic funding sources, and established solutions for workforce training and education at every level, as it pertains to bringing sustainable AM to the island.

[2] ASTRO America. Guam Additive manufacturing and Materials Accelerator Baseline Additive Manufacturing Readiness Report, published for the Guam Economic Development Authority. May 2023.

2.2 Research Approach (Phase I Study vs. Phase II Study)

The previous Phase I report commissioned by GEDA discussed the components of a sustainable AM ecosystem in Guam, comprised of key stakeholders, such as (1) equipment manufacturers, (2) businesses that 3D print parts, (3) industry and government end-users with 3D product demand, (4) sophisticated test/evaluation capabilities to validate AM-produced parts for these end-users, (5) educational institutions with specialized AM training to staff these on-island capabilities, and (6) port/infrastructure from which to import equipment consumables. However, before developing a plan for integrating these elements into an on-island ecosystem, researchers first needed to understand adaptability of Guam's existing capabilities and institutions.

In Phase I, ASTRO thus undertook extensive communication <u>within Guam</u>, with representatives of civil society among local government, colleges, industry, and port/airport authorities, as well as major U.S. military units based in Guam. These efforts culminated in a workshop on the feasibility of an additive manufacturing sector on-island. Among those participating, the University of Guam, U.S. Navy, as well as the shipbuilding and repair community, emerged as the most interested and immediately ready parties, with the most short-term potential benefit from GAMMA.

At the conclusion of Phase I, the research team and GEDA agreed to base a subsequent GAMMA plan on the aforementioned <u>three pillars</u>: 1) workforce development and education; 2) lab-to-market testing and qualification; 3) AM Marketplace/ Incubator to host 3D printing businesses.

In Phase II, the ASTRO America team conducted outreach <u>off-island</u> to determine the viability of attracting new investment, economic development, and educational opportunities to Guam to fulfill this vision. Our research resulted in a series of meetings and workshops focused on practical approaches to implementing GAMMA's three pillars. In so doing, the team received considerable input into a multi-staged implementation plan that will eventually lead to long term economic development, aligned with the Government of Guam's economic diversification strategy. While ASTRO remained in direct communication with senior decision-makers in the Guam government, we also extended a broad reach across multiple parts of the U.S. business, academia, and federal government (particularly the U.S. Navy). ASTRO then calibrated its plan to account for partners' varying potential levels of commitment.

2.2.1 External Engagement

ASTRO interfaced with different parts of the manufacturing/innovation community for purposes of supporting this report's research; these engagements can be broken into four categories: submarine industrial base (SIB) including U.S., Australia, and U.K. supply chains; non-submarine Defense sectors, including missile defense and other on-island stakeholders; commercial markets, including aerospace and automotive parts suppliers and repair services; and companies/agencies seeking industrial part validation/inspection. The matrix below illustrates these short and mid-term market prospects.

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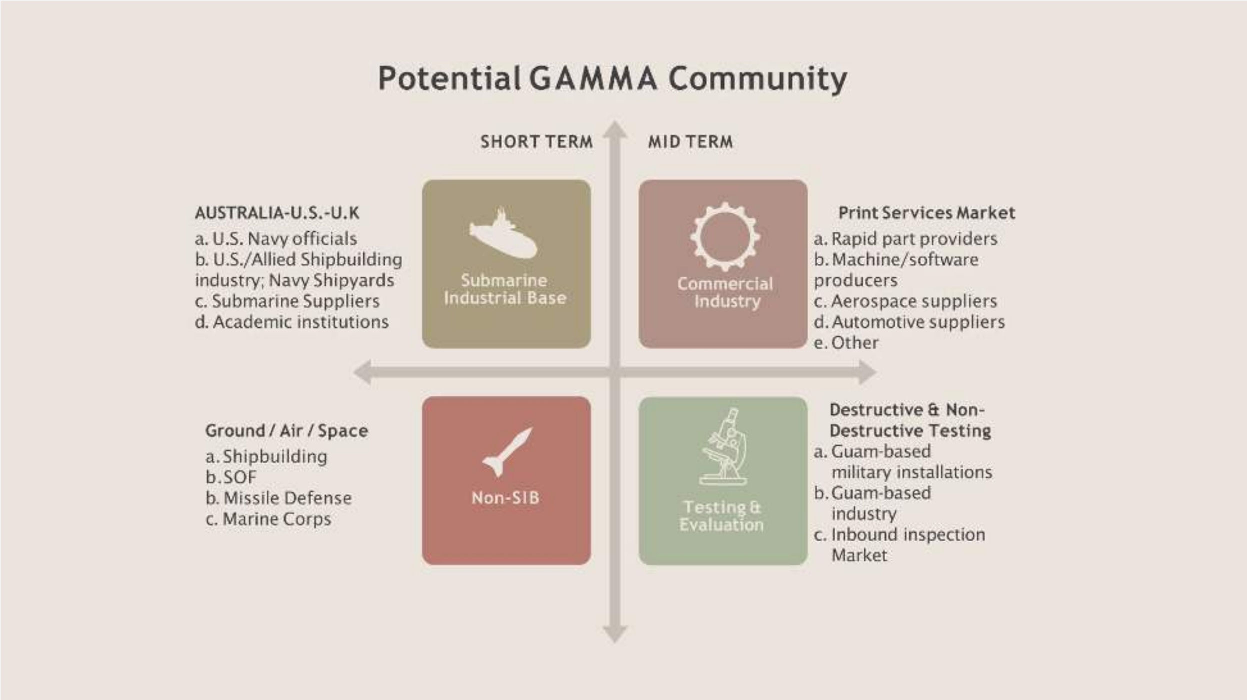

Figure 5. Prospective stakeholders in a GAMMA center

The U.S. Navy, it was concluded, had the most urgent need for on-demand parts development in Guam to support the submarine industrial base—leading to a dialog with the Program Executive Office, Strategic Submarines (PEO-SSBN). This engagement led to substantial collection of market data and information on prospective seed investment into GAMMA and the formulation of a project plan to establish capabilities in Guam with a particular emphasis on pillars 1 and 2.

2.2.2 Submarine Industrial Base

Substantial preparatory work has been undertaken to facilitate collaboration between the Governor of Guam and PEO SSBN. In this endeavor, ASTRO received support from PEO SSBN Program Integrator, Blue Forge Alliance—a nonprofit organization— to understand the structure and objectives behind the workforce development and the U.S. Navy Additive Manufacturing Center-of-Excellence (CoE) established in Danville, Virginia. The adjacent training facility, known as Accelerated Training in Defense Manufacturing (ATDM), is focused on developing manufacturing skills and technology to support the Submarine Industrial Base. It now serves as a benchmark for similar initiatives throughout the U.S., including the GAMMA project.

Recognizing Guam's strategic significance and the U.S. Navy's expanding partnerships in submarine construction with allied forces, PEO SSBN has shown interest in exploring the GAMMA vision. This culminated in a virtual meeting on July 17, 2023, between Governor Lourdes A. Leon Guerrero and U.S. Navy Rear Admiral Scott Pappano, Program Executive Officer, Strategic Submarines, along with their respective staffs and ASTRO personnel. Both Governor Leon Guerrero and RADM Pappano expressed an interest in collaborating to promote the adoption of additive manufacturing, aiming to enhance the submarine industrial base. While RADM Pappano primarily oversees the procurement of the Navy's strategic submarines (SSBN), his role also extends to implementing policies that support the sustainability of supply chains for both U.S. SSBN and attack (SSN) submarines. Additionally, he contributes to federal policy on the Australia-UK-US (AUKUS) agreement to foster continued cooperation in establishing an interoperable, coordinated submarine fleet across the Indo-Pacific region.

Both parties agreed to continue discussion in furtherance of addressing common objectives and supporting the GAMMA concept. From Guam's perspective, the project would establish a new engine for economic development and higher education on-island.

The GAMMA project would also require engagement with other parts of the Navy, including Naval Sea Systems Command's Chief Technology Office (NAVSEA 05T) which, together with private shipbuilders, sets policies for qualifying AM-produced parts that will be acceptable for submarine usage. ASTRO's prior analysis of NAVSEA's relevant policies and feedback from key shipbuilders has contributed to development of a project plan, announced by both the SSBN program executive office (PEO) and Guam government. In October 2023, ASTRO executives met at U.S. Naval Sea Systems Command headquarters with PEO SSBN's executive director who reports to RADM Pappano at the Washington Navy Yard. At this meeting, participants further elaborated on their organizations' respective goals working toward an in-person "principals" meeting (to include RADM Pappano and Governor Leon Guerrero) to affirm a multi-year, multi-phased project plan in Q1 of 2024.

A pivotal part of this plan included establishing a Guam satellite campus of the Colorado School of Mines (Mines)— considered a national leader in higher education and research in additive manufacturing. Subsequent discussions with Mines included a critical meeting in November 2023, with leaders from both its Research and Technology Transfer office and Global Initiatives and Business Development office to determine how they might support this effort's potential implementation.

Ultimately, the framework of the GAMMA project plan, as elaborated in Section 3.4 was formulated and then announced at an in-person meeting between Governor Leon Guerrero and RADM Pappano in Washington, DC February 23, 2024.[3]

2.2.3 Broad Commercial Manufacturing Sector

Separately, in May 2023, ASTRO staff accompanied the Chairman of the Guam Economic Development Authority (GEDA) to the Rapid + TCT additive manufacturing industry trade show— the nation's largest forum exclusively focused on 3D printing technology. At this event, the team organized workshops and in-person meetings to gather analysis and feedback on the GAMMA concept from members of industry, government, and academia. These discussions stimulated ASTRO's research on the total addressable market, and suitable paths for workforce training and education.

These meetings featured key submarine industrial base stakeholders, ranging from Shipbuilder Huntington Ingalls-Newport News Shipbuilding to qualified shipbuilding 3D printed part-producer Sintavia. It also included a multitude of additive manufacturing technology, materials, and software vendors and researchers as well as a broader set of non-Navy-oriented industry representatives.

Participants from both government and industry expressed strong support for forming a public-private partnership utilizing federal resources to catalyze the development of GAMMA and meet the high demand for replacement parts across various economic sectors. Throughout the discussions, it was

[3] "ASTRO America Announces Details of Next Steps in 3D Printing Plan for Guam." 3Dprint.com. February 24, 2024

unanimously agreed that stakeholders—including the Government of Guam, private industry, and academic institutions—would collaboratively share the costs associated with development and ongoing operations to ensure the long-term sustainability of the initiative.

As a result of the workshop, ASTRO concluded that prominent mainland U.S.-based companies were prepared to support the development of the third pillar, an **AM Marketplace Incubator**. This enthusiasm was particularly fueled by the second pillar, a **testing and evaluation** center, which would validate quality of parts produced. During the RAPID meetings, a diverse range of organizations, including major AM players such as Boeing, John Deere, Siemens, Divergent, HP, EOS, and 3D Systems, along with the Society of Manufacturing Engineers (SME) and the Additive Manufacturing Green Trade Association (AMGTA), expressed their market interest and willingness to support future GAMMA activities including participating in federally backed consortia such as an Economic Development Administration "Tech Hub" or U.S. Department of Agriculture Rural Innovation Stronger Economy grant.

Companies and organizations who engaged ASTRO and GEDA during and after the RAPID + TCT 2023.

Figure 6. RAPID + TCT conference in Chicago, IL, May 2-4, 2023. The largest AM trade show in the U.S., with 6,000 attendees and 400 exhibits.

3D Systems	Impossible Objects
AM Green Trade Association	Ingersoll Machine Tools
America Makes	John Deere
Big Metal Additive	MELD Manufacturing
Boeing	Naval Post Graduate School
Capital Park Partners	Northrop Grumman
Direct Dimensions	Siemens Energy
Divergent Technologies	Siemens Software
EOS	Sintavia
Ford Motor Company	SME
GE Additive	US Army
General Motors	US Navy
Huntington Ingalls Industries - Newport News	

Building on this momentum, ASTRO crafted consortium proposals that included a mix of mainland U.S. companies and local Guam businesses in sectors such as ship repair, automotive, and military base services. Siemens proposed its new DiMAX software platform as a solution for mainland U.S. companies to seamlessly transmit part designs to pre-approved manufacturing facilities in Guam, facilitating the production of validated components. Additionally, contributions from other parts developers, machine manufacturers, and end-users provided crucial data supporting the total addressable market analysis, detailed in Appendix 1. This collective input underscores the robust commercial potential and strategic alignment of the AM Marketplace incubator initiative.

3.0 Recommended Implementation Plan

3.1. The Three Pillars of GAMMA

The GAMMA concept consists of three pillars: 1) Education and Workforce Development; 2) Testing & Evaluation Lab; 3) AM Marketplace/Incubator

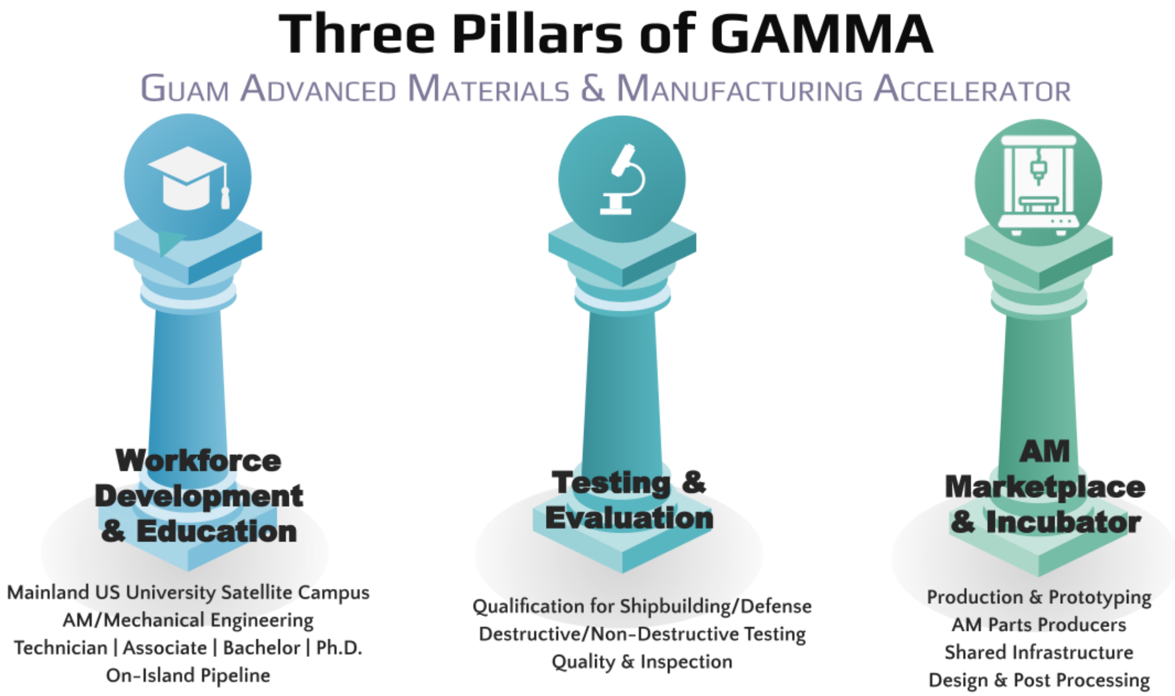

Figure 7. GAMMA's Three Pillars

3.1.1. PILLAR 1: Workforce Development & Education

Guam does not currently have a cadre of experienced additive manufacturing technicians, designers, material scientists, metallurgists or process engineers. To establish educational opportunities in advanced manufacturing, this project will establish mechanical engineering education and training to ensure access to essential skills in design, simulation, additive manufacturing, materials science, machining, and quality testing. These competencies are critical for establishing a robust advanced manufacturing center envisioned for the Guam Additive Materials and Manufacturing Accelerator (GAMMA).

GAMMA will transform Guam into a vibrant industry hub through a strategic partnership with mainland U.S. institutions, including the Colorado School of Mines (Mines). This collaboration will introduce a satellite campus at the University of Guam, allowing students to enroll in UOG or Guam Community College's existing classes in the first two years, followed by specialized advanced education from Mines delivered on the island via rotating/visiting faculty as well as other Guam-based faculty and e-learning.

Conferring universally recognized degrees or certification in mechanical engineering requires affirmation by the Accreditation Board for Engineering and Technology (ABET), a highly time-consuming and costly process. Conversely, relying on Mines and/or other mainland U.S. institutions for requisite coursework not only ensures baseline accreditation but – more importantly—affords Guam-based students access to

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best-in-class education and research capabilities.[4] As will be explored later, the GAMMA approach differs from other partnerships since it will not necessarily take students off-island nor confine participating students to a government job upon graduation.

3.1.2. PILLAR 2: Testing & Evaluation Laboratory

GAMMA's testing and evaluation lab in Guam for additive manufacturing would not only enhance manufacturing capabilities and performance, but also position Guam as a unique hub in the region. Robust testing protocol is critical for validating AM part production, qualifying processes, and ultimately achieving certification of parts for specific supply chains. This involves materials testing, comprehensive statistical data analysis, and standardized processes, conducted in close collaboration with stakeholders.

The presence of such a facility on Guam would be instrumental in securing full acceptance from key end-users, particularly in Naval Sea Systems (NAVSEA) and other highly regulated sectors. By ensuring that parts rigorously meet design specifications and fulfill all required standards, the testing and evaluation process confirms that components are fit for purpose and also assures their reliability and safety for use in critical applications. This strategic element would make Guam an essential link in global supply chains, especially in serving and supporting operations in the vast Asia-Pacific region.

3.1.3. PILLAR 3: Additive Manufacturing Marketplace & Business Incubator

Establishing a state-of-the-art production facility on Guam is pivotal for enhancing on-island supply chains and creating a distributed manufacturing network with Additive Manufacturing at its core, supporting design and simulation, machining, and post processing. This facility will function both as a business incubator, attracting established companies and local startups, and as a specialized center with dedicated spaces for prototyping, tooling, and part replacement.

Initially focusing on the needs of PEO SSBN, this facility will enable rapid on-demand production of high-quality components. Such an effort will help address the PEO's recently announced goal of utilizing metal AM as a means to reduce scheduled parts supply time by 80%.[5] In so doing, GAMMA will enhance operational readiness and reduce maintenance downtime, ensuring that vessels are fit for deployment with minimal delays. By localizing critical manufacturing capabilities, the Navy benefits from enhanced logistical efficiency and improved turnaround times for parts and repairs, reinforcing Guam's strategic importance as a key hub in the Pacific for naval operations. The GAMMA plan thus calls for space and infrastructure to be allocated for mainland U.S. based parts producers to locate personnel and equipment. Moreover, Guam-based entrepreneurs will be able to partner with these other experienced manufacturers to build up new commercial enterprises in support of the submarine industrial base.

Looking to the future, this facility is also poised to serve broader needs across the Indo-Pacific region, supporting industries such as aerospace, industrial manufacturing, commercial shipping, heavy equipment, and automotive. This will include MRO (Maintenance, Repair, and Overhaul) and the production of replacement parts. Such diversification will not only enhance the economic footprint of Guam but also ensure that the facility remains a versatile and critical asset in the regional supply chain.

3.1.4 The Case for AM Illustrated by Wire-Arc Additive Manufacturing

Production of metal parts is traditionally done via forging, casting, cutting, bending, welding and machining. Some of these methods can benefit from economies of scale of mass-manufacturing, such as

[4] For example, *Niche* consistently ranks Mines in top 30 colleges; *Money Magazine* ranks it #3 among U.S. engineering colleges.

[5] Magnuson, Stew. "Navy Must Go All in on Additive Manufacturing," *National Defense.* March 2023

die casting and metal injection molding. Others can be highly manual including metal bending and cutting as well as joining/assembly. In contrast Metal AM is mostly automated and faster than these traditional methods, especially where tooling is required. AM allows users to bypass weeks, if not months of tooling production, and offers effective ways to avoid potential errors of manual assembly.

Metal AM, however, has not typically been cost-competitive versus these traditional methods. In certain situations, though, improvements in cost models are making the technology more viable. Given fewer process requirements, it also may lend itself to installation in a remote location such as Guam to support low volume high-mix part-production.

In a study published by the academic Multidisciplinary Digital Publishing Institute (MDPI) journal, a metal part created using both wire arc additive manufacturing (WAAM) with integrated machining, was compared to the same part made through machining.[6] Machining is a subtractive process where the part is cut or ground out of a block of material, whereas metal AM builds the part from scratch. The WAAM process uses an electric arc as the heat source and a solid wire as the feedstock material. Machining develops more scrap while WAAM builds an imprecise shape that needs some final machining for accuracy and finish.

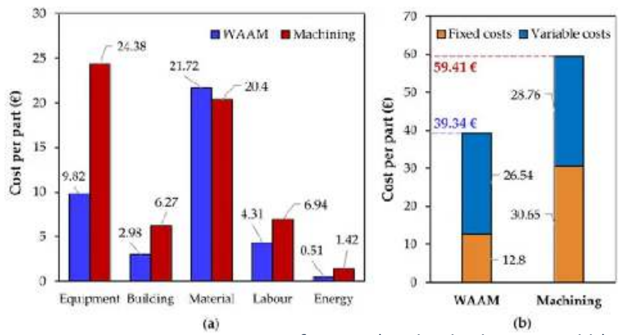

Figure 8. MDPI Comparison of costs a) Individual costs and b) Total costs.

Results found that while the cost of WAAM materials was greater per part, the cost of capital equipment for machining was more than two times greater than WAAM for the desired production levels in the study. Since there are no true economies of scale in either process, the per-part cost was found to be €39.34 (~$43.04) for WAAM and €59.41 (~$64.02) from machining. Note, however, that other studies have found WAAM to be double the cost of machining which suggests that cost savings are dependent on the part design, material and machines in use.[7]

Nonetheless, this data provides some justification for further considering additive manufacturing for use in Guam for the Navy. Thus, to illustrate GAMMA's practical impact, ASTRO examined a couple of cases where just one technology – WAAM has addressed maritime platforms' lead-time and cost challenges, and could potentially help meet the submarine industrial base's needs in a remote Indo-Pacific location. In particular, WAAM has potential to be an alternative to metal castings in order to address naval supply chain bottlenecks and accelerate lead time for otherwise hard-to-source parts.

In fact, according to researchers at the U.S. Naval Warfare Center Carderock Division, additively manufactured nickel aluminum bronze alloys have improved properties compared to cast material, due in part to the difference in microstructure. "At moderate cooling rates such as those associated with arc-based processing, the microstructure … become more refined with increasing cooling rate. This leads to

[6] "Economic and Environmental Potential for Wire-arc Additive Manufacturing." MDPI, April 2022.

[7] "Modelling of Wire Arc Additive Manufactured Product Cost". Procedia Computer Science. Elsevier. 2022

an improvement in the tensile properties of wire-arc direct energy deposited NAB, with >17% increase in yield strength and >90% increase in ductility when compared to cast material." [8]

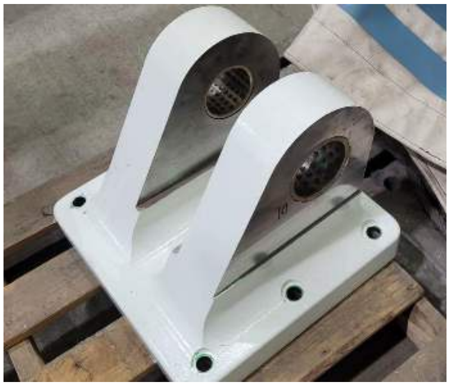
Figure 9. 3D printed hinge for reactor doors

3.1.4.1 Bulkhead Reactor Compartment Door. Huntington Ingalls **-** Newport News Shipbuilding is one of two major U.S. submarine manufacturers and the only prime builder of U.S. aircraft carriers. This company recently employed the WAAM process to create a 400-lb hinge for a reactor compartment door for the USS Enterprise— while applied to an aircraft carrier, the process remains relevant to comparable submarine components as well.

The hinge was created using Lincoln Electric's Sculptprint Production 1500 platform, a WAAM system that is known for making large, robust metal parts for heavy industry. It took two weeks to 3D print followed by several weeks of post processing– resulting in a total of ten weeks to progress from a 3D computer aided design (CAD) data-file to production and qualification.

In contrast, to build the part conventionally would have required a casting process that might take between 12-18 months to produce similar structures.

3.1.4.2 Panama Chocks. Keppel Technology & Innovation (KTI) in partnership with AML3D recently received a verification certification from DNV, an independent energy expert and assurance provider for its 3D printed deck mounted type Panama Chock.[9] It is currently regarded as the largest 3D printed shipboard fitting ever to be produced, delivering faster time to production and significantly improved strength to weight ratios than its traditionally-produced alternative.[10]

The 1,450 kg Panama Chock was designed and produced to meet international standards and KTI's project-specific material specification. Material yield strength was twice that of the original cast material and was produced with acceptable internal soundness that was confirmed by various nondestructive testing and evaluation methods. The part was then proof-load tested to 20% higher load than its design working load. Ultimately, this example has shown that large scale additively manufactured parts can have superior qualities to their traditional counterparts.

While other examples exist that directly relate to U.S. naval industrial base requirements, publicly releasable data on such 3D printed cases' lead time, cost, and performance effectiveness is limited. Indeed, in 2018, the U.S. Naval Sea Systems Command (NAVSEA) approved the first 3D printed part, a prototype drain strainer orifice assembly for ship-board installation. This part enables drainage and the

[8] Orzolek, Sean M. et al. "Nickel-Aluminum Bronze (NAB) Review: Additive Manufacturing and Weldability." Naval Surface Warfare Center - Carderock Division. *Platform Integrity Department Technical Report.* June 2021

[9] The Panama chock is a type of ship's mooring/towing fitting to lead the mooring or towing rope from a ship's inboard to outboard. The Panama chocks are normally adopted for ships passing through the Panama Canal.

[10] Press Release. "Keppel receives DNV verification certificate for the world's largest 3D printed shipboard fitting." DNV Oil & Gas News. September 2021

removal of water from a steam line while in use. The metal 3D printed prototype passed functional and environmental testing, which involved the evaluation of material, welding, shock, vibration, hydrostatic, and operational steam.

While preliminary evaluation involved traditional mechanical testing to identify requirements and acceptance criteria, further analysis and inspection of such parts has been ongoing to expand prospective application of additive manufacturing in Navy shipbuilding. Needless to say, the Naval Sea Systems Command determined that this part's production marked a critical development in illustrating additive's potential to reduce lead-times and bring just-in-time production to the fleet.

Figure 10. 3D printed part approved by the U.S. Navy

3.2. GAMMA Facility Design

3.2.1. An Innovative Advanced Manufacturing, Testing, and Learning Lab

Ensuring the GAMMA center becomes a state-of-the-art facility will require integrating a suite of advanced manufacturing technologies and educational services to foster innovation, component qualification, and workforce development.

GAMMA will co-locate design, production, testing/qualification, and education/training activities in a synergistic facility. This brings several advantages to the production process:

- Multiple technologies co-exist, providing a comprehensive solution set to engineering, design, production, part replacement and testing.
- Provides a broader view of the entire manufacturing process from design to test – increasing quality by feeding as-built data into the design and manufacturing process.
- AM removes many fabrication constraints so the design can be optimized earlier in qualification and production process.
- The proximity of test facilities to the design and manufacturing activities may enable parts to be modified, tested, and qualified more quickly.

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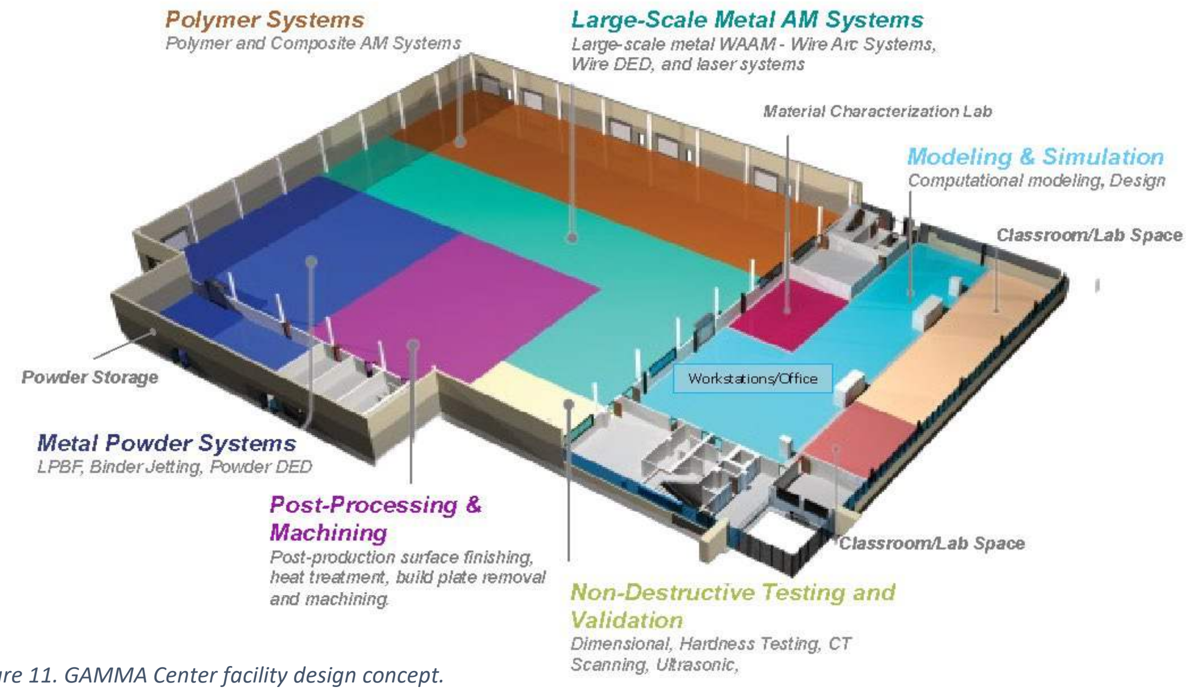

Figure 11. GAMMA Center facility design concept.

The above figure illustrates a notional facility to allow for both part production/prototyping and experiential learning. Different elements are co-located under one roof, allowing for an interplay among different stages of production as well as hands-on learning for students and interns alike.

3.2.1.1. Key technologies for the center include:

Design, Modeling, and Simulation: Foundational technologies that enable the creation of detailed digital models and simulations in order to predict how a product will perform in the part production process. With dozens of different machine settings, engineers increasingly use software to adapt part designs (previously built for traditional manufacturing) for optimal positioning, orientation, and geometric parameters to ensure an effective part build. This element is meant to reduce numbers of physical prototypes during iterative processes, speeding up development, and enhancing design accuracy.

Additive Manufacturing (3D Printing): As detailed in ASTRO America's Phase I study, Additive Manufacturing (AM) is a fundamental pillar of the GAMMA initiative. This technology is a priority for the Navy and industry at large for its broad array of benefits, including design freedom, on-demand manufacturing capabilities, suitability for high-mix and low-volume production, cost efficiency, use of innovative materials, sustainability, and enhanced part replacement opportunities. Above all else, additive's advantage to Guam will be its flexibility to support production in remote locations, converting digital data (transmitted from thousands of miles away) into a format to be printed on-island.

The production facility allows space for a variety of AM technologies and systems which will be selected depending on stated needs of the US Navy and other stakeholders. Wire-arc additive manufacturing

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(WAAM) is a desirable technology for Phase I as it is based upon welding technology and the materials and processes have a wider acceptable range of environmental conditions. Laser Powder Bed Fusion (LPBF), Hybrid, Polymer, Ceramic, and other technologies are also being considered.

Post-Processing: After objects are printed, post-processing technologies such as heat treatment and surface finishing are used to enhance the mechanical properties and aesthetic of the final products. This ensures that components meet stringent functional and visual criteria.

CNC Machining: This technology provides high precision in subtractive manufacturing processes, where material is removed to shape parts. CNC machining complements additive manufacturing by refining and detailing parts to exact specifications. Additional 5-axis CNC machines are necessary to ensure surface integrity of critical parts.

3D Imaging and Metrology: The science of measurement plays a critical role in ensuring components meet stringent quality standards. Advanced techniques like 3D imaging provide opportunities for reverse engineering of obsolescent parts and ensure that every component is manufactured to precise dimensions and tolerances.

Metallurgy/Metallography: In an advanced manufacturing context, metallurgy is crucial for selecting optimal materials for specific applications and for developing new materials. Metallography studies the physical structure and components of metals, typically using microscopy to observe the microstructure of metallic alloys. This is crucial in understanding the properties, performance, and behavior of metals under different conditions.

Non-Destructive and Destructive Testing: Non-destructive testing (NDT) methods, such as ultrasonic, CT, and X-ray imaging, allow for the inspection of materials and components without damage, ensuring their integrity and safety in use. Destructive testing provides invaluable data on material properties under extreme conditions.

Welding and Other Post-Processing Technologies: Joining of components via welding is vital in many operations – especially for shipbuilding. Other technologies, such as laser cutting, metal forming, and grinding provide additional capabilities. The post-processing (machining, welding, and heat treatment) areas provide basic machine shop services, including wire electro-discharge machines (EDM) to remove parts produced by AM from the build plates. Most as-built components undergo hot isostatic pressing to reduce the porosity within components and subsequent heat treatments to reduce residual stresses, regularize the grain structure, and form secondary phases providing strength to the material.

Any powder-based additive manufacturing systems (often involving laser fusion) will need feedstock to be in a closed system to prevent the possibility of powder contamination, environmental issues, and safety. In the event of widespread metal powder production, a closed powder handling system should be considered to provide maximum capability and safety without extensive personal protective equipment. The facility would also provide ample space for design and production engineers at computer workstations. This facility would ideally be connected to the testing facility although contained to reduce noise and powder contamination, and to utilize common resources such as utilities, washrooms, etc.

3.2.1.2. An Integrated Approach

The integration of these advanced technologies enables a comprehensive approach to the product lifecycle—from initial concept through production to final testing. In the educational context, the center serves as a living lab where students and professionals gain hands-on experience with cutting-edge technologies, bridging the gap between theoretical learning and practical application. This synergistic environment not only drives innovation in product development but also cultivates a skilled workforce adept in multiple facets of advanced manufacturing. The laboratory will be accessible to key stakeholders across the U.S. Navy, as well as important elements of the submarine industrial base—regularly helping to hone supply chain-relevant priorities, methodology and requirements. Similar to the Colorado School of Mines' 2Alliance for the Development of Additive Processing Technologies (ADAPT), the center will eventually benefit from continuous guidance from an advisory committee, with representatives of key equipment manufacturers, shipbuilders, and Naval Sea Systems Command, military operators, and Guam-based agencies/interests. This input will be important to ensure that the center remains relevant to both Government and industry needs throughout its operation.

By offering training, education, and access to this wide array of technologies, the center not only propels local manufacturing forward but also establishes a benchmark for modern manufacturing education and practice. This holistic model ensures that products are built, thoroughly tested, and qualified.

The prospect of this center, which will host workforce development, qualification, testing and production capabilities, assumes a contribution by the Government of Guam $7-$10 million for facility design, development, and construction, perhaps as an effort led by the Guam Economic Development Authority, in coordination with the University of Guam and other relevant agencies.

3.2.2. Testing & Evaluation Lab

3.2.2.1. Qualified Part Acceptance Needs and Requirements

In order for any additive manufacturing process to be acceptable for production of essential aerospace or critical shipboard applications, it must meet rigorous qualification standards. This typically consists of demonstrating that the process produces parts that can achieve specific material and mechanical properties and can be repeatable and reproducible. Process repeatability means being able to produce parts that meet the property requirements over and over again with a tight distribution curve in the same machine, while reproducibility implies getting the same properties and property distribution between different machines and machine operators. Both aspects are critical to meeting process qualification standards.

Demonstration of consistent material properties is typically achieved using a statistical-based approach[11] that is rooted in extensive mechanical testing, requiring hundreds or even thousands of tests for each material property being measured. For aerospace applications, it is typical to use the notion of "design allowables" when referring to material property values required for a certain application. Designers use "A-Basis" and "B-Basis" allowables when specifying minimum property values. These terms refer to the spread in the data distribution curve: B-Basis requires that at least 90% of the data equals or exceeds the specified value with 95% confidence, while A-Basis requires that at least 99% of the data equals or exceeds the specified value with 95% confidence. Extremely consistent property data is required to meet or exceed these specifications, hence the need for a qualified process that has been validated via extensive mechanical testing.

[11] S.P. Moylan et al, "Qualification for Additive Manufacturing Materials, Processes, and Parts," NIST, Jan 27, 2020.

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Other types of approaches can also be used for process qualification once the manufacturing process is well established. For slight changes to a qualified manufacturing process, equivalence-based qualification can be used to demonstrate that the new slightly changed process is equivalent to the existing process. Equivalence-based qualification often requires only moderate testing. A newer type of process qualification that is gaining traction is known as model-based qualification. This approach uses extensive computational modeling to predict material properties, which need to be verified to confirm the validity of the models. This approach often requires minimal testing compared to the other approaches and is still not accepted by most of the aerospace community.

Once a part is manufactured using a qualified process, there are additional requirements in order to certify that the part is acceptable for use in the intended application. Some of these requirements include mechanical testing of specimens that have been fabricated alongside the actual part (often referred to as “witness coupons”), non-destructive evaluation (NDE) of the part to validate internal integrity, chemical analysis of the metal powder or other metal feedstock, and extensive reporting on all aspects of the part certification process. Many of these additional requirements are described in more detail in the following paragraphs.

In some cases, tools to verify part properties and performance are required to determine microstructure of the material and classification/quantification of defects within the deposited structure. Metallurgical analysis requires a variety of tools– from hand tools for extracting small samples of material to automated tools for sample preparation. For destructive testing, a typical process flow is:

1. Extraction of small samples from the overall part using band saw or abrasive cutoff saw.
2. Mounting the sample into a small puck using a mounting media such as epoxy. This allows the sample to be easily handled and further processed.
3. Grind and polish the sample using rotating discs with abrasive/polishing pads. This can be done manually (with automated polishing discs) or in a fully automated process where the mounted samples are loaded into a holder and a preprogrammed process is used.
4. Etch the samples to reveal microstructure using appropriate acid/basic etchants. For many materials this is a simple mixture of dilute acids that can be handled in standard fume hood. Other materials may need more complex electrochemical etchants which require dedicated equipment including a power supply and chemical bath.
5. Conduct microscopic analysis using an appropriate microscope which usually includes an integrated digital camera for record keeping.

The process above provides a microstructural record of a sample of material from the part. Often, it is necessary to test the mechanical performance of the material as well. This involves extracting a test sample of material from the part (or building a witness coupon along with the part) and performing a mechanical test on that sample. These tests span many different configurations and are capable of extracting static tensile strength, dynamic fatigue, and other key properties. Post testing, fractography can be done on the samples using a stereomicroscope to get a visual picture of the fracture surface. For both polished/etched samples and fracture surfaces, detailed analysis using electron microscopy is useful though not required. While some large companies have their own electron microscopes, many companies outsource this to qualified test labs or partner with capable universities.

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Chemical analysis is useful for checking that the material conforms to the desired specification for the alloy being fabricated. Varying levels of accuracy are possible across the relevant test methods available. Properly equipped electron microscopes can provide a qualitative assessment of composition. Handheld x-ray fluorescence devices can also be used to broadly characterize an alloy. For highly detailed analysis (at the parts per million level), spectroscopic techniques are often required. The complexity of these techniques requires specialized operators and are usually done at certified test labs or universities.

For parts that are to be put into service and cannot be destructively tested, a nondestructive evaluation (NDE) method must be used. This can include standard industrial radiography, ultrasonic testing, eddy current testing, dye penetrant, and computed tomography. Due to the complex designs often associated with AM parts, x-ray computed tomography (CT) has become the most popular method for NDE of critical parts. Industrial CT systems can rival AM equipment in terms of cost, floor space, and utilities requirements and is often outsourced at a certified facility.

3.2.2.1. The Importance of Testing and Validation

For critical maritime or other high-risk applications, all parts, regardless of methodology used, are subject to meeting certain qualification requirements as defined by the Prime contractor or DoD entity (e.g. tensile strength or elongation). Additively manufactured parts are sometimes subject to higher standards than traditional manufacturing since properties are less known or understood. Thus testing of parts remains a major hurdle to overcome.

3.2.2.2. Metrology, Inspection and Test

Inspection of parts is a requirement to ensure that all parts are within tolerances and free of defects. Measurements can be made manually with calipers or using coordinate measurement machines and laser devices. For metal parts there is an increasing use of CT scanners to ensure parts do not have internal defects. Also, very common with metal parts is the use of witness coupons in the build, which may undergo characterization or testing to verify proper microstructure and material properties.

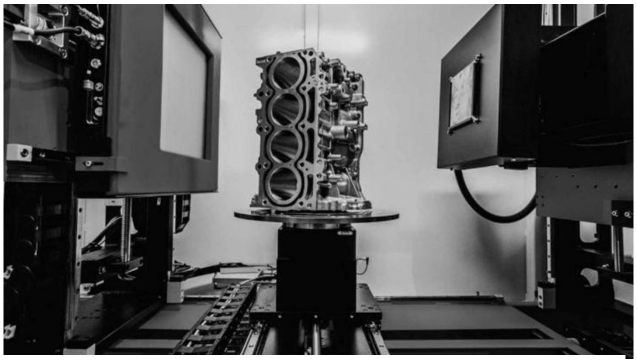

Figure 12. X-Ray inspection of an engine block. Courtesy: Quality Magazine. 2022

Tomography is necessary for characterizing defects, such as lack of fusion bonding, porosity, keyholing, and non-metallic inclusions AM-made parts, which can have a deleterious effect on the properties.

Scanning electron microscopy (SEM) offers the highest resolution to view defects and microstructure of powders or builds/parts produced via AM.

3.2.2.3. Metallurgy and Material Characterization

The quality of the final builds and reliability of the finished parts are directly tied to the quality of the powders used. Therefore, inspection of the metallurgy and geometry of the powders need to be conducted to qualify the use of these powders within the overall workflow.

Conventional bulk and shear properties' assessment of flow are critical for AM builds and needs automated measurements that are repeatable and accurate. Lastly, to qualify materials for use in applications, compositional standards limit elemental quantities of nitrogen, oxygen, and hydrogen,

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which can react to form damaging intermetallic oxide or carbide particles that are known to be probable sites for damage nucleation within structural parts.

3.2.2.4. Mechanical Testing

Materials requirements for submarine applications represent the epitome of reliability within extreme environments. To assess whether the produced materials and components meet these requirements, mechanical testing equipment is required to ensure performance, and validate any simulation activities, including tension, compression, flexure, fracture toughness, fatigue, damage tolerance, and creep.

Overall, the center will be required to follow Naval Sea System Command direction in developing and validating additively manufactured parts. Since 2018, NAVSEA has been issuing AM guidance, with technical authority products ranging from guidelines for use of polymeric materials aboard ship (released August 2018) to a Powder Bed Fusion Technical Publication (first issued January 2020)[12] and Directed Energy Deposition Technical Publication -- including WAAM guidelines (first issued May 2021).[13] According to the Navy's technical warrant holders, these activities have led to considerable lessons learned, including the need to balance systemic risks (providing some direction to AM users for consistency/reliability and safety) with application risks (ensuring production processes have relevance to actual Navy usage to drive appropriate AM adoption).

3.2.3. Workforce Development and Education

3.2.3.1. Satellite Campus

The Navy will further provide guidance in development of AM-relevant workforce development requirements to ensure appropriate skill-levels needed to comply with the aforementioned NAVSEA guidance. The GAMMA team plans to offer two years of coursework at UOG or Guam Community College (GCC), followed by two years of education from a CONUS-based university, such as the Colorado School of Mines, delivered on-island. This approach will utilize existing workforce training networks and technical expertise, and will be tailored to meet market needs, required competencies, and goals.

Furthermore, Mines and/or other universities will establish a satellite campus on the grounds of UOG under a reciprocity agreement to offer technical certificates and corresponding undergraduate/graduate engineering credentials. Additionally, CONUS-based manufacturing workforce development organizations like SME and ATDM will supply industry-recognized curriculum and training materials to GCC for an accredited Advanced Manufacturing program.

These partnerships are necessary since the University of Guam (UOG) currently lacks an accredited Mechanical Engineering (ME) department. However, a collaboration initiated in October 2022 by UOG, Pearl Harbor Naval Shipyard (PHNSY), and the University of Hawaii (UH) Mānoa illustrates the potential for establishing a multi-party mechanical engineering degree program among government and disparate colleges. This program enables 1-2 students annually to spend two years studying engineering in Guam, followed by two years at UH to complete a Mechanical Engineering degree (2+2 model). After graduation, students have the opportunity for full-time employment with the Navy at PHNSY. Engineers can gain 2-3 years of on-the-job shipyard experience at PHNSY before returning to Guam.

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[12] S9074-A2-GIB-010/AM-PBF, NAVSEA Technical Publication. "Requirements for Metal Powder Bed Fusion Additive Manufacturing." January 21, 2020.

[13] S9074-A4-GIB-010-AM-WIRE DED, NAVSEA Technical Publication. "Requirements for Directed Energy Deposition Additive Manufacturing." May 27, 2021.

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Unlike the UoG/UH program, the Guam Additive Materials and Manufacturing Accelerator (GAMMA) aims to establish an entire industry sector on-island. Such an objective exceeds the UOG/UH exclusive focus on supporting Pearl Harbor Naval Shipyard employment. Given the limited mechanical engineering resources, infrastructure, and workforce in Guam, a crucial component of GAMMA's workforce strategy—beginning in Phase 0—includes deploying to Guam advanced manufacturing and educational expertise from ASTRO, mainland U.S.-based universities, ATDM, and other workforce organizations.

This comprehensive educational framework will involve rotating mainland U.S. faculty and industry experts, and utilizing blended distance learning methods to make top-tier industry and academic expertise accessible on-island – regardless of location. Establishing this satellite campus aims to rapidly build a skilled workforce, streamline certification processes for Guam-based students and faculty, and enable them to operate the GAMMA facility and engage with other manufacturing entities setting up on the island. While qualified faculty and staff might be rotated into Guam on a temporary basis, the emphasis will be on the development of local talent at all skill levels in a variety of disciplines including:

- Machining
- Welding
- Inspection & Measurement
- Facility Management
- Mechanical Testing
- Design for AM
- AM Technician
- Metallurgical testing
- Finishing/polishing
- Project management
- IT/data management
- Cyber security
- Physical Security
- Business Development

Figure 13: Location of University of Guam relative to other points of interest

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3.2.3.2. Trades and Skills Training

Guam Community College and Guam Trades Academy provide critical skills training across various industries and enable access to apprenticeships. Both institutions are nimble and flexible in providing training when there is a stated or recognized need. Guam Community College offers courses up to associate degree level as well as some professional certifications.

Suggested new courses:

- Introduction to Additive Manufacturing (certificate)
- 3D MCAD basics (certificate)
- Design for Additive Manufacturing (certification)
- CNC Machining (certification)
- Measurement and metrology (certification)
- Engineering Project Management (non-construction) (certification & Associates)
- Engineering Materials (certification)
- Mechanical engineering (Associates)
- AM operator(certification)

3.2.4 Rapid Deployment via Containerized Modules

While planning and constructing a new permanent facility, ASTRO will develop integrated, self-contained expeditionary "factories" built as sequential modules addressing various AM technologies, post processing and testing capabilities. GAMMA requires staging a consolidated supply chain, with design-laboratory, industrial additive manufacturing (AM) systems, post-build machining and heat treatment, and advanced inspection processes.

Figure 14. Example of a containerized metal 3D printer and auxiliary equipment deployable to remote locations. Source: SPEE3D

To accelerate time-to-implementation, modules will be engineered near Colorado School of Mines (Mines) within shipping container-style, modular buildings. These containers will be self-sufficient and prepped for connection to external climate control, electrical power, compressed air, and gas sources, meeting relevant environmental health/safety standards. This activity includes planning and simulating integration of design, production, and inspection capabilities effectively. These modules will be transitioned to Guam and configured to ensure cohesive integration into the qualification and testing center. This provides valuable time on-island to develop knowledge and capabilities while a permanent facility is constructed near the Satellite campus.

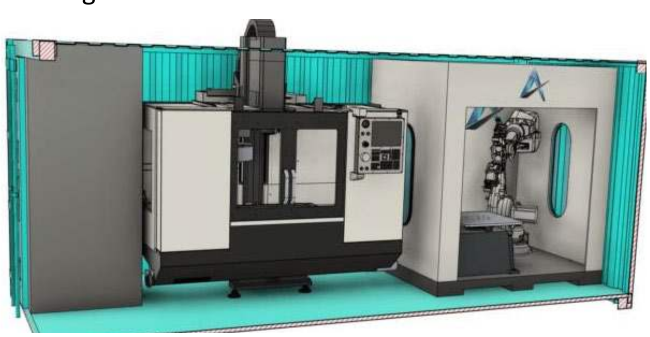

Figure 15: Highlights single 40-foot Connex equipped with portable robotic AM cell, CNC mill, and heat treatment furnace. (Source: ADDiTEC, Fabricating & Metalworking)

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On Guam, the modules will be installed in locations proximal to the University of Guam and the Port of Guam to provide required infrastructure, utilities, and services – and link the production and qualification activities to education and workforce development. The modules will be configured to ensure proper flow and efficiency of manufacturing operations. Facility needs include requisite utilities and power (including backup generators), environmental, load-bearing reinforced concrete, climate control, and other industrial requirements.

First year start-up costs include acquisition of large- and medium-scale metal additive manufacturing systems and non-destructive evaluation (NDE) equipment ranging from X-Ray CT scanners to radiographic testing. Ancillary technologies including machining and welding equipment will be acquired for use. In subsequent years, additional AM/NDE/Manufacturing equipment and technologies will be incorporated as requirements evolve and GAMMA operations mature to provide a full range of MRO capabilities on-island.

Figure 16: External View of 40’ Containerized Production and Test Module with HVAC, loading dock, and utilities. (Source: Giant Containers, Labatt Brewing)

High-bandwidth internet access will be a requirement to enable communication of very large datasets and communication/ collaboration, accompanied with appropriate security measures. Some parts of the facility may be air-gapped for security purposes. IP will be protected from unauthorized use and disclosure. Moreover, the expected manufacturing machines, network and cloud aspects will specifically enable companies’ full control over sharing access to data with relevant collaborators without taking possession of proprietary code and data. This capability will be part of the larger cyber security measures that will be put in place.

3.3. GAMMA Market Approach

3.3.1 US Navy as Primary Customer, Building Commercial Capabilities Over Time

At the outset, the GAMMA Initiative will establish additive manufacturing capabilities on-island focused on US Navy and DoD customers for replacement parts. Such a capability will support functional prototypes, custom tooling and fixtures, part testing/evaluation, new repair process-development, and experiential learning. GAMMA will eventually become a higher education and training hub and a public-private partnership developing a regional industrial base, composed of both defense and private sector business interests— serving both on-island and other Indo-Pacific markets.

In the short term, GAMMA has the potential to address crucial replacement-part challenges that have been plaguing the U.S. Navy for years. Without broad-based on-demand manufacturing available, U.S. Naval Sea Systems Command (NAVSEA) reports that 70-80% of submarine maintenance availabilities have run late, due largely to shortfalls in materiel. Moreover, submarine spare parts budgets have only met 40%-50% of current requirements. As a result, parts are not in inventory when needed by the Navy, leading to significant delays in service.[14]

During fiscal years 2015 through 2020, the Navy spent an average of $2.1 billion per year performing high priority maintenance on submarines, surface ships, and aircraft carriers. Parts and materials shortages have been identified as one of four main challenges, contributing to 2,525 days of maintenance delays from 2015-2020 for 'intermediate maintenance' alone.[15]

These conditions have only compounded part replacement challenges when operating in remote locations such as Guam, where a detachment of the *Pearl Harbor Naval Shipyard & Intermediate Maintenance Facility* (PHNSY & IMF) is being built and Submarine Squadron 15 (CSS-15) operates.

To address these issues, additive manufacturing (AM) has the potential to produce parts on-demand at the point of need, consolidating supply chains, cutting lead times, and significantly reducing logistical footprints. While this technology has been explored for new ship and submarine construction it was not until 2021 that NAVSEA commenced a new strategy to "Operationalize Additive Manufacturing as a Routine Manufacturing Process." This has resulted in the acceleration of production of new and replacement parts driven by the Navy's AM Center of Excellence throughout 2023 and into 2024.[16]

There is potential to revolutionize part replacement with a digital inventory, building spare parts at operational points-of-need to support:

- **Private contractor base**
    - Shipbuilders – Huntington Ingalls/Newport News Shipbuilding, General Dynamics/ Electric Boat, Austal, BAE Systems
    - Cabras Marine (and other Port of Guam users)- Ship fitting, pipefitting, water blasting, deck repair, painting, mechanical services for vessels under 1,000 tons.
    - Submarine Industrial Base (SIB) Suppliers – 350 critical and 12,000+ overall that supply spares to the Navy

[14] Eckstein, Megan. "Submarine fleet needs more spare parts to stem maintenance delays: Less than 30% of submarine maintenance work is completed on time," Defense News. Sept 21, 2022.

[15] Government Accountability Office, GAO Report 22-104510. Navy Ship Maintenance. February 2022.

[16] Retaliatta. "NAVSEA 05TAdditive Manufacturing Program Brief to NRC". NAVSEA 05T. Oct 2023

- **Organic Industrial base and Forward Deployed Units**
    - Submarine Squadron 15 based on Polaris Point in Guam.
    - Pearl Harbor Naval Shipyard (PHNSY) & IMF-Guam Detachment - Expeditionary maintenance and support for ships in the U.S. Indo-Pacific Command Area of Operations, including submarines from Submarine Squadron-15.
    - Ship Repair Facility (SRF-JRMC) – Yokosuka, Japan - ship repair and maintenance of 22 surface ships of the Forward Deployed Naval Forces (FDNF) serving in the U.S. 7th Fleet.

Given these end-users' needs, ASTRO America believes these entities will form the core of an initial end-user community, interested in output from GAMMA and its affiliated consortium. But this demand-base will likely grow to encompass both U.S.-based and Allied military organizations. The Australia-United Kingdom-United States (AUKUS) agreement to furnish submarine technology and know-how among three major submarine forces will provide a strong outlet for potential collaboration in workforce development as well as additive manufacturing technology insertion/validation. Given its strategic location in the region, GAMMA may thus serve as a center for education/technology for tri-lateral collaboration in applying additive manufacturing research and training across three navies.[17]

3.4 Initial Navy-Centric GAMMA Project Plan

3.4.1. GAMMA Timeline

The GAMMA effort is reliant on a combination of public and private funding, the availability of which will dictate the size/scope of the accelerator capability as well as the speed of implementation. This document makes several assumptions based on relevant engagements, assessments, and statements of support with/by prospective participants in the project, including representatives of the US Navy and Government of Guam. Our plan focuses on access to the "best of the best" in additive manufacturing higher education and technology, while also ensuring we achieve objectives in a reasonable timeframe.

[17] For information on AUKUS, see White House Fact Sheet: Implementation of AUKUS. April 05, 2022.

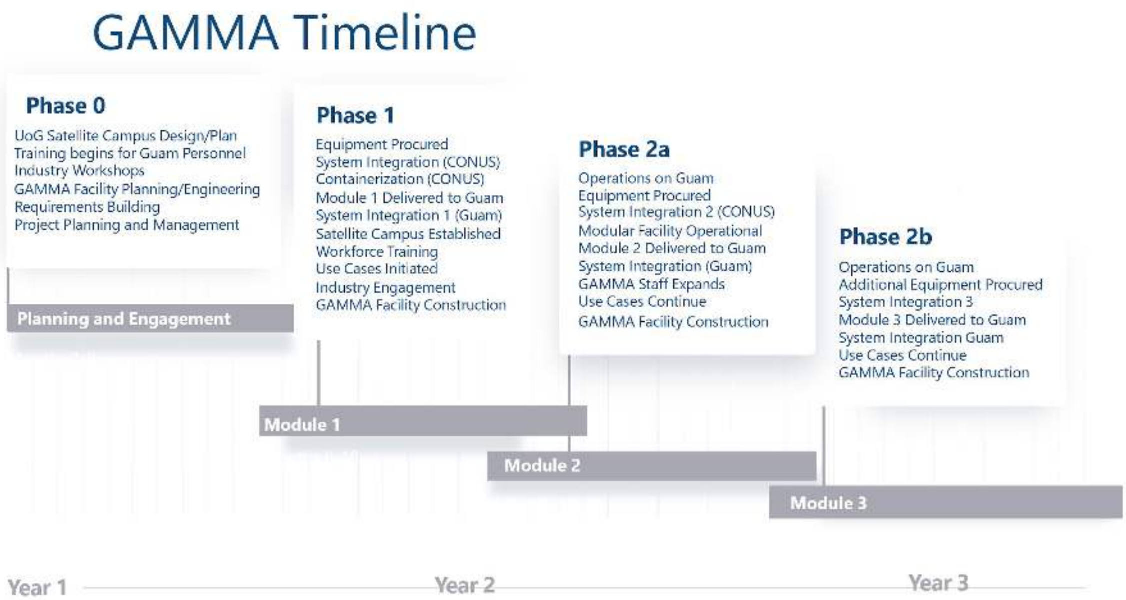


Figure 17. Proposed Phased Timeline for Gamma

3.4.2. Phase 0 - Planning Phase and Establishing a Satellite Campus

Phase 0 (Month 1-8): Planning and Design of GAMMA Center and Campus

Laying the groundwork for this effort will start immediately with conception of a satellite campus at UOG of a mainland U.S. university that is a leader in additive manufacturing research and higher education such as the Alliance for the Development of Additive Processing Technologies (ADAPT) at the Colorado School of Mines (Mines). ASTRO envisions allowing students at local institutions such as the University of Guam (UOG) and Guam Community College (GCC) to undertake two years of studies at their home institutions and then potentially transferring to a Guam-location of a leading mainland U.S. mechanical engineering department. Such an arrangement would require agreements among UOG, GCC, and such off-island institutions, as well as a viable business plan to sustain this capability.

This plan necessitates a market for an industry sector with an AM workforce—which the U.S. Navy indicates is growing, particularly for submarine supply chains (including both American and close U.S. allies'). Thus, ASTRO is pursuing sponsorship by submarine industrial base officials within the Navy to pursue such an approach.

To validate these approaches, ASTRO will seek input and buy-in from stakeholders within the Navy, academia, and shipbuilding industry, as well as local Guam-based organizations including UOG and GCC. ASTRO will undertake further intensive engagement with these parties, with workshops held in Washington, DC, Guam, and even on the campus of appropriate mainland U.S.-based college campuses to review capabilities necessary for building a top-rate additive education/technology center in Guam. Ultimately, the team will need to determine facility design, educational structure, curriculum, and equipment needs for the education campus and the Qualification/Test Lab. This process will also entail finding an appropriate site in Guam and designing the layout/requirements for both temporary (containerized) facilities and a permanent center to house GAMMA.

Visits to the continental U.S. (CONUS) by ASTRO, Mines, GCC, and UOG personnel will include AM lab benchmarking and training at ATDM and Mines on CAD/CAM, AM-related design, build preparation, materials, machine operation, and inspection/qualification. Additionally, Mines will be specifically tasked with articulating a business model that demonstrates a financially sustainable approach to developing/maintaining a satellite campus in Guam. Such a model might contemplate necessary tuition/revenue levels, external support, and resource sharing.

ASTRO will engage industrial planners, machine manufacturers, and engineers to develop high level designs and plans from requirements gathered for the Qualification and Testing Lab and Production area through hosted workshops with key stakeholders including program executive offices for strategic submarines (SSBN) and attack submarines (SSN) as well as Guam-based military units (e.g. Submarine Squadron 15 and Pearl Harbor Naval Ship Yard and Intermediate Ship Repair Facility - Guam Detachment), Naval Sea Systems Command's Chief Technology Office (NAVSEA 05T) , the defense industrial base, AUKUS Stakeholders, UOG, GCC and GEDA. In parallel, this activity will also entail general contractor selection, location scouting, property identification, permitting, utilities, roads, and infrastructure planning for the permanent facility.

Deliverables include campus plan (staffing, curriculum, articulation agreements, financial models, and programs) and final site design for the Qualification and Certification Lab and Production facility.

3.4.3. Phase I – Establishing Manufacturing Capabilities on Guam

Phase I – Months 9-21

Over a 12-month period, the initial phase of this collaborative project lays the foundation for long-term partnerships among Guam, ASTRO America, Mines, BlueForge Alliance (BFA), and the Navy. This phase encompasses four critical elements designed to establish a robust additive manufacturing (AM) capability on Guam:

1. Pre-position: ASTRO America takes the lead in planning, procurement, and staging of innovative self-contained AM 'Modules'. These modules, essentially temporary container-style buildings, are equipped with state-of-the-art additive manufacturing, machining, and inspection technologies. Engineered and staged near the Mines campus, each module is configured within an individual shipping container, complete with pre-set connections for power, air, and gas. Before deployment, the modules undergo rigorous testing and calibration to ensure they meet stringent quality, accuracy, and environmental health and safety standards.

2. Operation: At the Mines campus, ASTRO and Mines personnel will conduct intensive training sessions for University of Guam (UOG) and Navy personnel. Training will cover a wide array of topics including AM-related design, build preparation, materials science, machine operation, and inspection/ qualification techniques, utilizing the equipment installed within the module. Concurrently, a suitable site will be identified and prepared for the temporary placement of the Modules.

3. Transition: After achieving operational readiness, the focus shifts to Guam where trainees along with ASTRO and Mines personnel will oversee the installation and acceptance testing of the containerized modules. This phase also involves strategic planning for future expansions, working closely with Navy stakeholders to test AM and CNC systems, develop requirements documents, create installation plans, identify platforms for equipment installation, and begin using in-situ monitoring and rapid qualification/inspection processes. Development of preliminary Standard Operating Procedures (SOPs) and operator training programs are also critical components of this phase.

4. Permanent Facility Planning: In preparation for a more permanent setup, a general contractor will be engaged to assist with the acquisition, environmental assessment, engineering, and site preparation.

This groundwork is crucial for facilitating the construction of a permanent infrastructure tailored for the needs of an advanced manufacturing center on Guam.

This detailed and phased approach not only ensures the establishment of immediate AM capabilities on Guam but also paves the way for a sustainable, advanced manufacturing ecosystem that can serve the Navy and other industries across the Indo-Pacific region.

5. Industry Use Cases & Technology Development

Engaging industry in technology projects via use cases is essential to advancing AM. Practical, specific, real-world applications help to build technical specifications and reference data for applications. Only via part design, production, testing and studying results can the true viability of AM for MRO be confirmed. The business case – or when it makes sense to utilize AM – will also be defined.

Accordingly, ASTRO will coordinate process and use-case development with a range of relevant stakeholders including shipbuilders, shipyards, submarine industrial base suppliers, manufacturers, technology providers, material experts and appropriate certifying bodies to identify components, systems, and process validation approaches that best represent the areas of highest need (e.g. hard to source or long lead time (LLT) parts) and/or greatest impact of certain applications (Copper-Nickel material development; casting replacements; high-cycle, long lifecycle and/or corrosion prone parts). This will begin to create demand pull for the AM capabilities on Guam.

An 'Industry Day' workshop and written Request for Information (RFI) will be organized to create interest within industry and establish baseline requirements for various technology development projects funded by interested stakeholders. Four use cases per year will involve end-users (prospective AM/Navy customers), including all technical data and analysis, financial data, and overall findings. These activities will take place over 6-8 months per use case – run in parallel and managed by the GAMMA team.

3.4.4. Phase 2 - Scaling to Meet Demand

Phase 2a – Months 22-34. **Phase 2b – Months 34-46**

Cumulatively extending over 12 months, Phase 2 focuses on repeatability, expansion, and continuous improvement. Two additional containerized modules will be engineered, staged and shipped in parallel to establish full-time educational lab, qualification and testing capabilities in Guam.

The focus of this Phase will be on clearly meeting particular U.S. and Allied Navy market needs, based in part on developments in Phase I. Indeed, as the AUKUS relationship further evolves, GAMMA can play a pivotal role in helping train suppliers within both the U.S. and Australian submarine industrial base to support their local and distributed part replacement requirements. Indeed, under AUKUS' Pillar II "Advanced Capability Development," the United States, UK, and Australia are committed to collaborating in supporting both submarine industrial innovation and workforce development. As such, Phase 2 will allow for a new regional hub for training, prototyping, and validating processes to meet essential regional needs for submarine fleets among the three allied Navies.[18]

Upon aligning associated requirements with desired capabilities, the GAMMA team will engage key industry, academic, and partners to set up and apply education and technology solutions for AUKUS-affiliated parties. Doing so will require engaging in multi-faceted development, including--

[18] U.S. Department of Defense. AUKUS Defense Ministers' Joint Statement. April 8, 2024.

1) **Physical Presence**: Modules 2 and 3 will be engineered, staged, built, and shipped in the same method as Phase I, incorporating best practices and continuous improvement. Groundbreaking and construction will begin during this phase for the permanent facility. It is expected that the Guam Economic Development Authority and University of Guam will ensure availability of resources for corresponding sites and facilities to be developed for these purposes.

2) **Talent Pipeline**: The Additive Manufacturing Campus at UOG will regularly host programs to address regional AM requirements and match/grow a corresponding talent pool. These efforts will be jointly undertaken with prospective end-users such as:

   a) **Military:** U.S. Navy; Royal Australian Navy; U.S. Coast Guard

   b) **Academia:** Colorado School of Mines, University of Guam, Guam Community College, as well as possible Australia-based institutions

   c) **Shipbuilding:** Newport News, Electric Boat, Austal, Cabras Marine

   d) **Non-maritime:** Triple J Automotive, DZSP-21, Bella Wing

   e) **Equipment/Tools:** Big Metal Additive, 3D Systems, HP, Siemens, AML3D

   As part of GAMMA coursework and appropriate credentialing, these organizations will participate in apprenticeships and experiential learning at the center to eventually transition recruits to manufacturing employees. Such activity builds off the traditional models of short-term skills "bootcamps" at GCC. Instead, GAMMA will provide a multi-semester environment for students to work with prospective employers in a factory-floor environment over an extended period of time and ensure enduring value from an evolving curriculum, education, and technology center.

   Other GAMMA activities will establish special programs to reach particular population-segments— (e.g. early student pipeline through periodic workshops with K-12 students in their schools and via field trips to GAMMA, with in-school manufacturing demonstrations and internships). Other programs might also support outreach to unemployed and underemployed individuals seeking careers.

   However, the principal outreach function for GAMMA during this phase will be to raise awareness of the test and evaluation laboratory for parts produced on-island and across the region. Given its unique nature—the only such validation capability for thousands of miles (and on U.S. soil) will be deemed considerably valuable to the aerospace/defense community as they seek to rapidly source approved parts into their systems deployed in the Indo-Pacific region.

3) **Personnel**: Direct employment will result in hiring of a numerous (10-15) engineering, management, training, maintenance, and facilities personnel to ensure workforce growth remains commensurate with implementation of additional capabilities.

4) **Business case**: International business models for on-demand production capabilities will be considered in order to sustain operations to service both domestic and trans-shipment markets, leveraging resources prevalent in the additive manufacturing industry, such as ASTM/Wohlers organizations to keep pace with technical, market, and strategic trends in the industry.[19] Such a

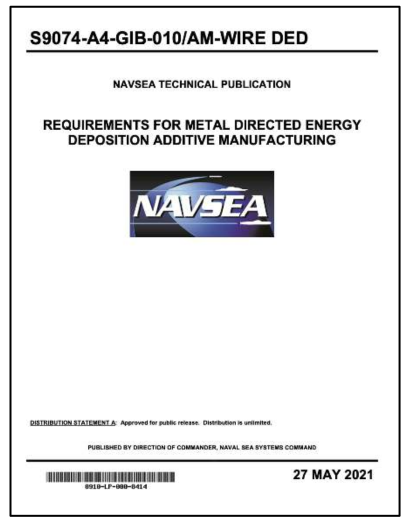
[19] "About Wohlers Associates, powered by ASTM"

dynamic must be employed to track a sufficient demand base to drive technology insertion for qualified part-replacement businesses, aligned with industry standards.

5) **Business Development**: GAMMA outreach will expand to build an active consortium of stakeholders and industry partners to grow the advanced manufacturing ecosystem in Guam.

Additive manufacturing on-island afforded by GAMMA will certainly add valuable productive capabilities to the Indo-Pacific region, but it will also bring other high-value capacity to the Guam economy.

In fact, the importance of establishing a testing and evaluation laboratory on-island cannot be overemphasized. Without a sophisticated means for validating parts produced for ships or aircraft, any essential components produced on-island will be barred from being inserted immediately into highly regulated supply chains such as defense/shipbuilding or aerospace. Indeed, it was this lack of testing/evaluation capabilities on-island that caused the U.S. Air Force to limit prioritization of placing metal AM technology in Guam, as indicated in a telephone interview with ASTRO researchers during Phase I. The Navy's approach, in contrast, appears to support development of these capabilities to meet industrial base needs. In so doing, once in place, Guam may become well-positioned to support highly sought after testing and evaluation processes. However, onboarding this capability requires considerable technology and training. Exact qualification standards for industry are usually considered highly proprietary. Elements that are required and regulated by standards agencies such as the FAA or FDA will be the same, but some differences undoubtedly exist between the qualification process used by different companies.


S9074-A4-GIB-010/AM-WIRE DED

NAVSEA TECHNICAL PUBLICATION

REQUIREMENTS FOR METAL DIRECTED ENERGY DEPOSITION ADDITIVE MANUFACTURING

NAVSEA

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Figure 18. Naval Sea Systems Command (NAVSEA) issued technical publications with guidance on metal additive manufacturing qualification, part verification, and production of metal parts.

The military has been developing standards for qualification of additive manufacturing processes and are publishing detailed descriptions. For example, the Naval Sea Systems Command (NAVSEA) has issued technical publications for two metal additive manufacturing processes (laser powder bed fusion,[20] and wire directed energy deposition)[21] that provide procedure qualification requirements, part verification requirements, and production requirements for fabricating metal parts by each respective process. These documents are very detailed regarding all the procedures required to produce a metal part by additive manufacturing that will be accepted for use.

[20] "Requirements For Metal Powder Bed Fusion Additive Manufacturing," NAVSEA Technical Publication S9074A2-GIB-010/AM-PBF, January 21, 2020.

[21] Requirements For Metal Directed Energy Deposition Additive Manufacturing," NAVSEA Technical Publication S9074-A4-GIB-010/AM-WIRE DED, May 27, 2021.

3.5 Program Integration

3.5.1. The GAMMA Team

ASTRO America	Manages overall program, budget, and schedule. Also, leads coordination of program with Guam Government agencies (GEDA, UOG, GCC), Mines, DoD, and industrial base (DIB) to ensure system/supply chain integration, long term sustainment.
Mines Office of Global Initiatives	Establishes and implements structure of rotating faculty/staff at UOG for a continuous presence with appropriate Ed. resources.
Mines Office of Research & Technology Transition	Works through ADAPT on design/implementation of non-destructive testing AM, machining, and post-process center.[22]
GEDA	Initiates building architectural design and investment into permanent site for new center at UOG.
UOG	Works with: GEDA on new center site, Mines on joint AM certificate program and center requirements; GCC and DIB on training program.
GCC	Implements AM skills training on Guam in coordination with UoG, Mines based on models from ATDM, SME, and others.
ATDM	Provides curriculum, direction and insight for training based on SSBN requirements.
NOMAD	Engineering and System integration – containerization of machinery and equipment for transport to and setup in Guam.
Technology Providers	Serve as vendors to ASTRO, Mines, and UOG in supplying AM machinery, materials, software, and consulting services as needed.

Table 1. Roles and responsibilities of the GAMMA team.

3.5.2. GAMMA Team Management Responsibilities

ASTRO America envisions a partnership with the BlueForge Alliance and other key stakeholders in initially carrying out this project. Below is a list of management functions considered important for the day-to-day execution of a future SSBN-sponsored initiative.

Program Management – Partners will ensure management oversight of cost, schedule, and technical specifications. The team will coordinate with key stakeholders on Guam (GEDA, UoG, GCC, and industry officials) and in CONUS (including technology providers, defense industrial base, organic industrial base (e.g. Naval Shipyards), universities, Naval Sea Systems Command officials, following a systems approach to strategically align programs to overall strategies. This function will oversee effectiveness and

[22] Alliance for the Development of Additive Processing Technologies

efficiency of the strategic value of the program, including systems engineering and test and evaluation processes.

Partners will also complete individual deliverables at the detail level to accomplish program objectives to meet operational needs. Coordination between various entities to ensure project results. Day-to-day management, progress updates and change request management – ensuring strict adherence to schedule and required time for each milestone in the overall requirement.

GAMMA Center Operations Management – Partners will also need to assign personnel to manage business operations to undertake procurement, recruitment, training, accounting, HR, IT, engineering, facilities management, and security, to ensure a high level of efficiency and productivity. Eventually, this function will also establish capabilities to address market needs for DoD and other maritime customers.

System Integration – One individual will be responsible for assuming responsibility over leading technical aspects of the project and understanding interplay of various sub-systems, to deliver functionality for key end-use customers. This person will coordinate with various organizations to provide structure and pathways to achieve program objectives. An experienced engineer, this individual will connect systems in development with established ones to provide customer and program value.

Technology Insertion – The project will also need to develop predictive cost and benefit models related to technology utilization in order to maximize returns on investments, due to the use of AM (in lieu of conventional part orders). It will be important for the GAMMA team to facilitate evaluation of use cases and identify components, materials, and applications where AM will prove most effective. In turn, the team will disseminate findings and business implications of AM technology applications to DoD and other important stakeholders. In commercial applications, the team will identify opportunities on Guam for AM to serve needs for replacement parts and repair. For Naval applications, the team will test and evaluate parts and work with NAVSEA to ensure parts are fit for service, qualify, and implement.

Supply Chain Development and Management – The team will build an advanced manufacturing supply chain to Guam including raw materials procurement, production, quality control, and distribution. With the lack of materials, technology, and workforce on Guam, this is a significant task that will encompass working with suppliers, the educational community, customers and logistics providers in CONUS and Guam.

Quality Management – GAMMA will include a formal quality management system to document processes, procedures, and responsibilities for achieving quality objectives. This function will ensure customer and regulatory requirements are met and continually improved.

Guam Government Liaison – As a trusted partner, ASTRO America will serve as key liaison between key Navy stakeholders and the Office of the Governor of Guam, GEDA, and other Guam-based organizations. As the conduit and convener, ASTRO America will encourage cooperation, exchange information, and facilitate a close working relationship within the stakeholder group and consortia.

Planning and Development. An Integrated Product Team (IPT) will assign part/component manufacturing tasks to GAMMA to be fulfilled first in the temporary modules and later in the permanent facility built in Guam. This IPT will include representatives of academia, industry, and relevant government agencies to ensure appropriate consideration of disparate equities needed for GAMMA's effective sustainment. Follow-on planning for expanded capabilities will be considered annually.

3.5.3. Stakeholders (Initial)

ASTRO will coordinate with these stakeholders relative to requirements, technology needs, demand and capacity utilization, use cases and workforce training, education and recruitment.

PHNSY & IMF Guam Detachment	Expeditionary maintenance and support for ships in the USINDOPACOM AOR, including submarines from CSS-15
AUKUS Stakeholders	Royal Australian Navy and relevant supply chain participants such as Austal and BAE Systems
Yokosuka SRF	Ship repair and maintenance of 22 surface ships of the Forward Deployed Naval Forces (FDNF) serving in the U.S. 7th Fleet
Cabras Marine	Ship fitting, pipefitting, water blasting, deck repair, painting, mechanical services, dry docking services for vessels under 1,000 tons
HII-NNS	Coordinates with ASTRO in developing relevant AM part use cases
GD-Electric Boat	Coordinates with ASTRO in developing relevant AM part use cases
SIB Suppliers	350 critical and 12,000 overall that supply spares and R&O to the Navy

Table 2. Stakeholders

3.5.4. Projected Budget

The plan calls for a rapid deployment approach, utilizing shipping container-style buildings in stages to establish 'boots on the ground' in Guam and initiate operations **prior to a permanent facility being built**. Technology will be installed within the containers, and these containers will serve as interim facilities – fully operational with the intent to have the containers annexed into a permanent facility in time.

The plan notionally costs a rough order of magnitude of **$38,000,000** is required to establish these baseline capabilities in the initial 2-year period. Recurring costs for operations and scale up to meet evolving Navy requirements will total an additional $12,000,000 - $15,000,000 per year over subsequent years, adjusted for inflation.

	Year 1 **Phase 1**	**Year 2** **Phase 2a**	**Year 3** **Phase 2b**	**TOTAL**
Technology & Equipment	$7.7M	$4.2M	$1.2M	$13.1M

Use Cases & Technology Development	$1.5M	$2.5M	$4.0M	$8.0M
Satellite Campus & Workforce Development	$1.2M	$1.6M	$1.6M	$4.4M
Facilities & Operations	$4.25M	$2.5M	$1.2M	$7.95M
Industry & Stakeholder Engagement	$250K	$200K	$200K	$650K
Program Integration	$1.55M	$1.53M	$1.6M	$4.3M
Total:	$16.45M	$12.53M	$9.8M	$38.8M**

Table 3: Notional GAMMA allocations

**In addition to these allocations, it is expected that the Government of Guam will provide baseline resources to establish facilities to house GAMMA's three-pillared configuration on or near the UOG campus, valued at approximately $7-$10 million.

3.6 GAMMA Structure and Requirements

3.5.1. Public/Private Ownership and Management

GAMMA should be configured as an institution-owned and operated facility with involvement of expert non-profit organizations along with a strong Government presence. Organizational structure would follow a lean multi-disciplined professional culture that is team-centric with decision input across all workflow disciplines.

GAMMA will be initially focused on output for the US Navy and other critical DoD activities on the island. Consortium members in related industries will be invited to establish operations within the Incubator and will in-source key resources for their own exclusive use by procuring machines, and employing skilled workforce from within the Guam ecosystem. These companies will share resources and infrastructure at the Incubator (administrative support, facilities, qualification and testing lab) via a shared services agreement.

3.5.2. Information Technology Requirements and Business/Data Management

High-bandwidth internet access will be a requirement for the GAMMA facility to enable communication of very large datasets and any distance learning requirements, accompanied with appropriate security measures. Some parts of the facility can be air-gapped for security purposes when needed.

Managing the technology stack and interoperability of data will be key to the IT strategy for GAMMA – especially to enable Design for Additive Manufacturing (DfAM). General manufacturing software/ systems required include:

- ERP – Enterprise Resource Planning
- MES – Manufacturing Execution System and Workflow Automation Software
- QMS – Quality Management System
- CAD – Computer Aided Design
- M&S – Modeling and Simulation Software

AM-specific software includes segmentation software, topology optimization, data and build prep, and in-situ monitoring/process control software and more. Cyber-Security will comply with relevant requirements of DoD and industry stakeholders.

3.5.3. Facility Construction

Site selection will require requisite power, environmental, reinforced concrete flooring, and other industrial requirements. Access to infrastructure (roads, utilities, etc.) and energy efficiency will be essential in reducing sustainability costs over time.

3.5.4. Infrastructure Requirements for GAMMA Facility

The GAMMA facility indicates areas for equipment for (a) powder storage, removal, and recovery, (b) Metal Powder Systems, (c) Large-scale Metal AM Systems, (d) Polymer/Composite Systems, (e) Non-destructive Testing & Evaluation, (f) Post-processing and Machining, (g) material characterization, (h) Modeling & Simulation, and (i) classroom/lab space. The facility layout is designed to follow a typical AM build sequence. Hence, providing the most efficient layout of the equipment and space, and providing the equipment and facilities necessary for the complete product lifecycle, including design, build, and test. (See Figure 11.)

3.5.5. Utilities

Based on the equipment allocated for the facility and its size, it is estimated that the power required at 100 percent utilization would be approximately 10 MWh annually. In addition, the equipment selected might require access to shop air and water, and the ability to handle inert gasses. Depending on the specific site requirements, the building should provide heating and water chillers. These provisions are not meant for environmental controls but to accommodate usage of factory equipment selected by government and industry stakeholders.

In a tropical environment like Guam, climate control for material properties and performance will be somewhat challenging. Systems may need to go beyond typical HVAC applications into specific temperature and humidity control. Industrial facilities planners and engineers will need to be consulted in designing the appropriate system alongside equipment vendors' factory specifications.

4.0 Attracting a Commercial Base by Building Capabilities

Currently, there is a small market and minimal capabilities on the island of Guam for additive manufacturing that addresses submarine production needs as well as other industry sectors described herein. This strategy is based upon what share of the market – currently in other geographic regions or served by other means – could be captured on Guam by building AM and part-replacement capabilities. It also contemplates potential investment needed to attract companies who would agree to locate on-island and build the market and demand.

Primary market segments include natural offshoots of the naval work such as commercial ship repair. From there, aerospace, energy generation tools and fixtures, automotive replacement parts, and training models are potential growth markets. Preliminary interest from major market leaders was documented in the Total Addressable Market report undertaken as a prior milestone in this study.

- **Commercial base**
    - Aerospace - Boeing, United Airlines, Vietnam Airlines
    - Engine Manufacturers - RTX, GE Aerospace
    - Infrastructure - Guam Port Authority, Guam Power

T&E in Guam allows capability on US soil close to key Asian markets that were previously inaccessible.

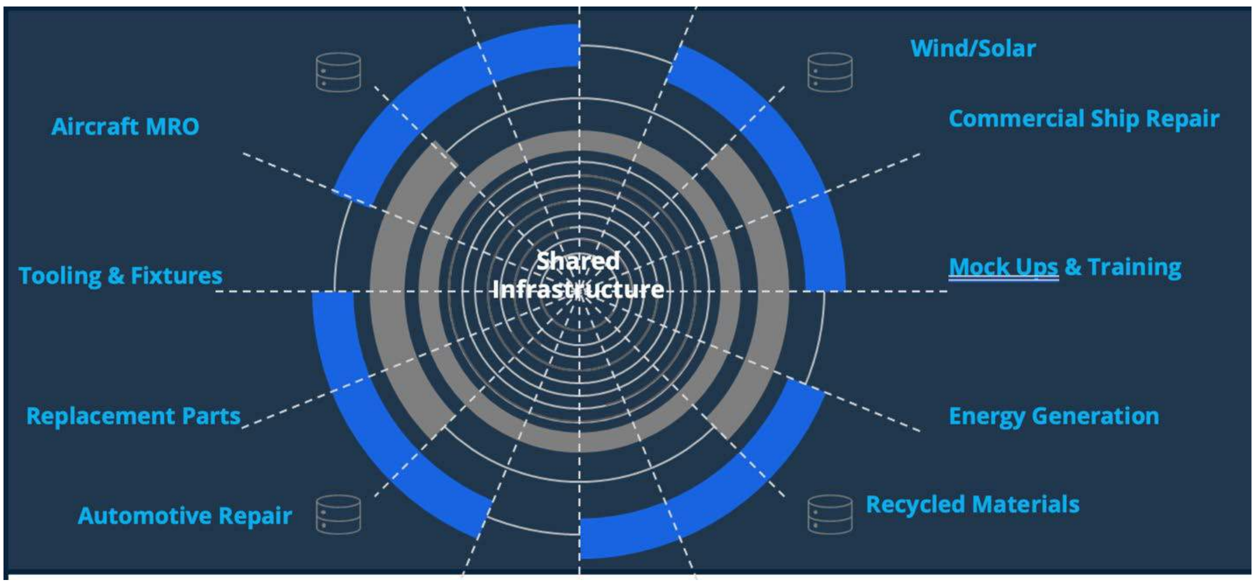

Figure 19: Industrial applications using Additive Manufacturing each employing discrete manufacturing processes and benefitting from a shared infrastructure.

Guam currently has a relatively small market for aerospace maintenance, repair, and overhaul with total economic activity of $3 million. Singapore houses 120 aerospace companies and is the current hub of Asia Pacific MRO activity in an area approximately the size of Guam (281 sq. mi vs. 212 sq miles).

Growing by a compounded annual growth rate of 8.6% over the past two decades and a total annual output of more than $8.0 billion, the Singapore aerospace industry is a key economic driver for Singapore. As a one-stop center for all MRO services and large precision engineering suppliers, Singapore has captured over 10%[23] of the global MRO market.

Building aerospace maintenance capabilities on Guam provides an alternative to Singapore and an opportunity to capture and grow the market in a proximal location to Asia – on US soil. United Airlines and Vietnam Airlines are currently evaluating relocating their MRO activities from China to Guam.

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[23] "Singapore Aerospace". US International Trade Administration. Sept 2020.

Because of the sheer number of aircraft and the time needed to build capabilities, this would be an iterative process, but even at low volumes, this presents a significant opportunity for Guam.

4.0.1. Projected Growth Models

The success of GAMMA will be measured through the type of business growth shown in Figure 19 with a gradual, measurable increase of activity which centers around US Navy demand, but then expands to other areas including aircraft MRO, commercial ship MRO, energy, oil and gas parts, the Australia-UK-US Navy Submarine Technology agreement, other DoD, and medical/dental device production.

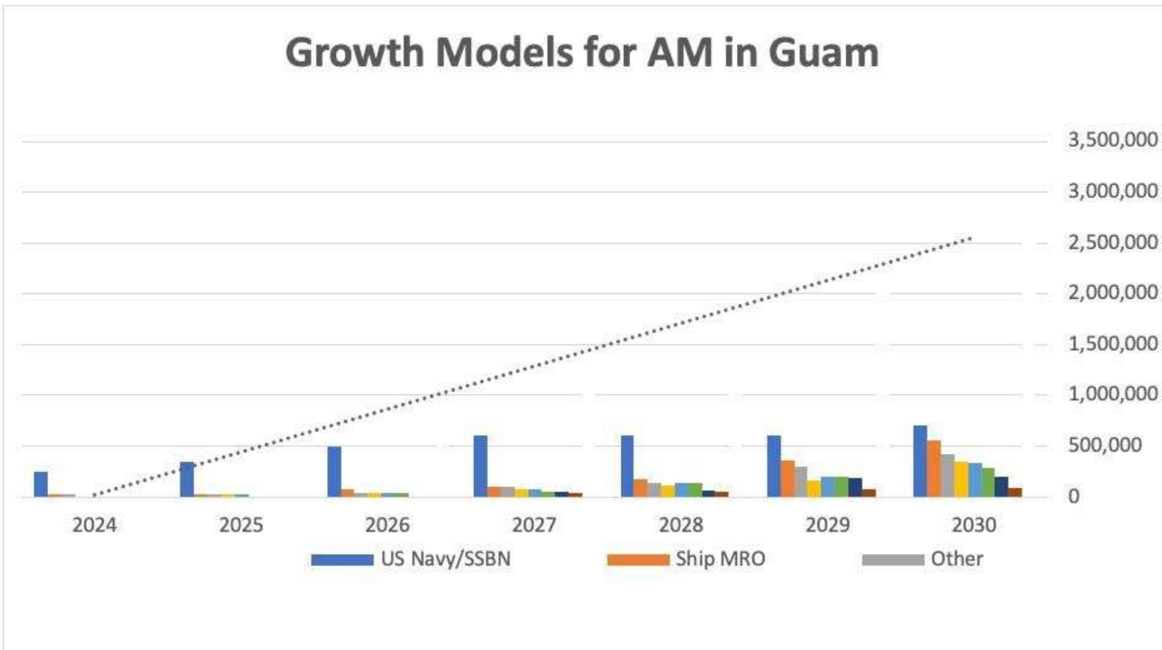

Figure 20. Extrapolated demand sources and revenue 2024 - 2030

Equally as important will be the development of 'Other' (shown in grey in Figure 20) which indicates the development of locally owned enterprises focused on solving local supply issues.

Additional KPIs:

- Development of exports or transshipments, with an aim to fill normally empty containers leaving Guam with products for other destinations.
- Growth of manufacturing jobs and related employment (local commerce in area of the facility).
- Monitoring of Guam's GDP in relation to manufacturing activity.

4.4.3. GAMMA Consortium (After the Launch)

ASTRO America and the Guam Economic Development Authority have documented support for the GAMMA initiative through letters from a wide variety of enterprises and institutions.
The commitment of experienced educational, commercial, economic development and workforce organizations as a Consortium will bridge the gap between the current situation in Guam and delivery of tangible results for the citizens of Guam. The insight of such operations and enterprises in developing

skilled workforce and being able to deliver high quality products is critical to ongoing success and business development while incorporating the knowledge of Guam-based stakeholders.

Prospective Members include:

- **Higher Education**: University of Guam, Guam Community College, Colorado School of Mines
- **Local government:** Office of the Governor of Guam, Guam Economic Development Authority, Guam Bureau of Statistics & Plans
- **Utilities & Infrastructure:** Guam Waterworks Authority, Guam Power Authority, Guam International Airport Authority, Port Authority of Guam
- **Industry groups and firms:** ASTRO America, BlueForge Alliance, Big Metal Additive, Boeing, Blue Forge Alliance Additive Manufacturing Green Trade Association, Sintavia, 3D Systems, Divergent 3D, EOS North America, Newport News-Huntington Ingalls, Big Metal Additive, Impossible Objects
- **Regional groups and firms**: Cabras Marine Corporation, Bella Wings
- **Labor and workforce organizations:** Society of Manufacturing Engineers, Tooling U-SME, Guam Workforce Development Board/Department of Labor, Guam Contractors Association Trades Academy
- **Manufacturing USA Institute**: America Makes Institute

5. Policy Implications and Opportunities

5.1. Potential Economic Impact

Guam's economy is dominated by two sectors: military and tourism. The military is the larger of the two, with estimates for its share of the economy exceeding 33% of the island's total economic activity pre-pandemic.[24] These two sectors face sharply different near-term trajectories. Military activity is set to grow over the next five years, as a result of major U.S. military commitments to prioritize Guam in its Indo-Pacific operational strategies. Tourism was devastated by the COVID pandemic but has slowly rebounded; in 2023 tourism built up by 178%[25] compared to 2022, from 216,915 visitors in 2022 to 603,831 in 2023. However, that is still 63% lower than the 1,628,565 visitors in pre-pandemic 2019.

Guam's economy grew in 2021 by 1.1%, a turnaround from the sharp 11.4% decrease in 2020 wrought by the COVID-induced recession.[26]

Accordingly, economic diversification remains a top priority of Guam's Governor Lou Leon Guerrero, as evidenced by her establishment of an Economic Diversification Working Group in 2020 public/private task force to address this priority, together with the Guam Chamber of Commerce. Its function is to build off Guamanian business' critical support provided to the military and tourism, and identify new sources of sustainable jobs and growth on-island.[27]

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[24] "Guam Economy Profile." September 18, 2021. Index Mundi.

[25] "Gross Domestic Product for Guam, 2023." Bureau of Economic Analysis. March 2024.

[26] "Gross Domestic Product for Guam, 2021." Bureau of Economic Analysis. November 2, 2022

[27] "Governor establishes Economic Diversification Working Group," Guam Post. December 30, 2020

5.2. Workforce and Employment

Increasing wage levels is a priority for the government of Guam. Wages for the AM labor force trend to higher-than-median rates with estimated total pay for a 3D Printing Engineer at $84,279 per year in the US, with an average salary of $76,344 per year or ~ $40 per hour[28]. This figure contrasts with the median hourly wage in Guam in 2022 of $15.26. Access to workforce training on-island, with the ability to manufacture, invent and produce on Guam will result in potential wages increases for a trained workforce.

5.2.1 Potential Job Growth

Job projections for GAMMA are divided into the three components: **1) workforce development and education; 2) lab-to-market testing and qualification facility; and 3) AM marketplace/incubator.**

The preliminary estimate for year one and two for Workforce and Education is 8 FTEs (Full Time Employees) which includes instructors and professors, job placement, and education services/administrative support.

For the Testing and Qualification facility, the estimate is 8 FTEs which includes a facility manager, application engineers, mechanical engineers, machine operators, and materials engineers.

There is an excellent opportunity to employ 5 student interns as well. Approximately 4 project managers and 2 FTEs for related administrative support will be needed for requirements gathering and engagement with DoD stakeholders.

Two important additions are a GAMMA Executive Director and a Business/Financial Manager. The Lab-to-Market Center will begin to attract Consortium members to establish 'boots on the ground' in Guam. This totals 31 FTEs by Year Two.

The Additive Manufacturing Lab-to-Market Center (a place for CONUS-based companies to establish a footprint in Guam) depends upon a consortium, which has been developed by ASTRO in concert with the Guam Economic Development Authority. This group includes major industrial companies such as Newport News, Big Metal Additive, Sintavia, Austal, Boeing, 3D Systems, Divergent, Ingersoll, EOS, Cabras, and Speed3D. These organizations have provided letters of support expressing their interest in helping to establish the Guam AM Ecosystem via GAMMA. If these organizations follow through on these letters, we could estimate another 30+ personnel within three years.

Innovative concepts such as a 'Semester Abroad' program that rotates students from CONUS colleges and universities could increase the student interns and build the knowledge assets within GAMMA.

[28] "Occupational Employment and Wages in Guam – May 2021." US Bureau of Labor Statistics, Western Information Office.

	Projected Jobs		
	Year 2	Year 4	Year 6
Higher Education (*Instructors, Job Placement*)	8	12	16
Project Management Stakeholder Engagement & Administration	8	18	20
Engineering & Lab Management	8	20	20
Student Interns	5	10	14
Industry/Incubator	2-5	10-15	15-30
Total	**31-34**	**70-75**	**85-100**

Table 4: Estimated FTEs needed to implement GAMMA initiative.

5.5. Federal Agency Engagement

5.5.1 EDA Tech Hubs Grant

In Q2 2023, GEDA, BSP and ASTRO America prepared and made submissions to the U.S. Economic Development Agency's (EDA) Regional Technology and Innovation Hub (Tech Hubs) program. Starting with a Strategy Development Grant, the intent was to have Guam become designated as a Tech Hub and then to apply for an implementation grant of up to $70 million.

5.5.2 USDA RISE Grant

In March 2024, GEDA, BSP and ASTRO America prepared and made submissions for a Rural Innovation Stronger Economy (RISE) Grant from USDA supporting the establishment of the Guam Additive Manufacturing Business Incubator and Technology Accelerator (GAMBIT-A). The target grant would be $2M across a four year term to enable the formation of a business incubator utilizing AM on Guam.

Grant	Status	Next Steps
PEO SSBN	Commitments made	Monitor process
EDA Tech Hubs	Not awarded	None
USDA Rise	Grant process canceled due to lack of funding	Monitor web site

Table 5. Status of grant applications and potential funding

5.5.3. Grant Funding Activities

Grant raising activity will be an ongoing effort even while and after GAMMA is initiated and implemented. Close collaboration between Gov Guam, GEDA, UoG, Guam Chamber of Commerce and

Guam Department of education will be required to ensure the ongoing funding, growth and operation of GAMMA and any related incubator and business development activities. Access to experts in transshipment, export and small business development will most likely be required.

Federal funding opportunities from a range of government bodies will continue to be pursued including, but not limited to:

- U.S. Department of Commerce Economic Development Administration
- U.S. Department of Agriculture Office of Rural Development
- U.S. Department of Defense Office of Local Defense Community Cooperation
- U.S. National Science Foundation
- U.S. Air Force Research Laboratory
- U.S. Office of Naval Research
- U.S. National Aeronautics and Space Administration

6.0 Conclusion: The Need for GAMMA

Guam is attempting to diversify its economy beyond military- and tourism-related services and construction. In that vein, creating a new manufacturing industry requires access to a stable customer-base with potentially increasing demand. Ultimately, the goal is to develop a capability for building replacement parts for a variety of products on-island. The prospect of doing so with 3D printing, eliminates a challenging logistical tail, and can create direct jobs (potentially 10-30 initial full-time equivalent hires to serve as educators, technicians, material processors, software engineers, prototyping and test-lab personnel), and indirect multipliers (aspiring for an additional set of new hires in the hundreds at Guam locations of mainland U.S. 3D printing businesses, Guam start-ups, import/export specialists, and other related ancillary organizations) at the marketplace/incubator as well as spin-off enterprises.

To jumpstart this development, the team focuses on the most readily evident customer-base and co-investor in the GAMMA project—the U.S. Navy's submarine industrial base. As capability grows, and use-cases proliferate, the ecosystem will expand to address broader market categories. For example, the center may be expanded to support development of additive manufacturing capabilities that would service Allied navies, including Australia's burgeoning shipbuilding industrial base. Eventually, it may also grow to help commercial markets as well. But at the outset, the GAMMA plan hinges on addressing growing needs for reliable submarine component sourcing, close to the operational point-of-need. Justification for this approach depends squarely on geo-strategic realities in the Indo-Pacific.

Guam lies 1,700 miles from Taiwan, 1,900 miles from the Korean peninsula, and nearly 4,000 miles from the nearest US state (Hawaii). Its location in the Western Pacific makes Guam one of our nation's most strategic hubs for military operations in the Indo-Pacific region. However, its remoteness also poses significant logistical challenges – particularly for delivery, inventory, and replacement of spare parts for key naval platforms, including attack (SSN) and strategic (SSBN) submarines. Parts that should otherwise take days to requisition into this area of operation can often take weeks – if not months – due to supply chain bottlenecks originating in the continental U.S.[29]

Indeed, in the last several years, submarine component budgets have only met 40%-50% of replacement part requirements. As a result, production parts are not in inventory when needed by the submarine industrial base, leading to significant delays in procurement services for forward deployed platforms.[30] Demand for similar components in the Indo-Pacific region are projected only to increase in the next decade, as a common Australia-U.K.-U.S. submarine industrial base grows in accordance with the AUKUS agreement to help the Royal Australian Navy (RAN) acquire nuclear powered submarine platforms and additional U.S. platforms increase their regional presence.[31]

In November 2023, U.S. Under Secretary of the Navy Eric Raven emphasized the need to accelerate such international collaboration in submarine production, couching AUKUS as being "about fundamentally changing and integrating three industrial bases in different parts of the world to produce maximum effect to serve our mutual national security efforts."[32]

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[29] The Defense Logistics Agency (DLA) and Naval Supply Systems (NAVSUP) are currently meeting 40% - 50% of U.S. submarine spare parts requirements. As a result, parts are not in the inventory when needed by the Navy's public shipyards, leading to significant delays in maintenance service. Defense News. Sept 21, 2022.

[30] Eckstein, Megan. "Submarine fleet needs more spare parts to stem maintenance delays: Less than 30% of submarine maintenance work is completed on time," Defense News. Sept 21, 2022.

[31] White House. Joint Leaders Statement on AUKUS. March 13, 2023

[32] Eckstein, Megan. "Navy takes early steps with Australian, UK vendors on shared sub work," Defense News. November 1, 2023.

To that end, Guam's position is not only a critical staging point for submarines operating in the Pacific, but also a potentially geo-strategic hub for industry members to converge with Navy operators and academia to train, manufacture, and validate submarine parts on U.S. soil, and then rapidly re-deploy systems into theater, as indicated in figure 25.

With access to adequate metal-casting capacity limited for the submarine industrial base, the U.S. Navy's Program Executive Office for SSBN has begun to turn to additive manufacturing as a potentially alternative approach. Such technology includes Australia-based directed-energy deposition 3D printing technology to produce nickel aluminum bronze components. However, a concerted investment of time and resources are needed to establish an AUKUS-oriented submarine industrial base to meet production needs,[33] including skilled labor, advanced manufacturing machinery and qualified testing & evaluation.

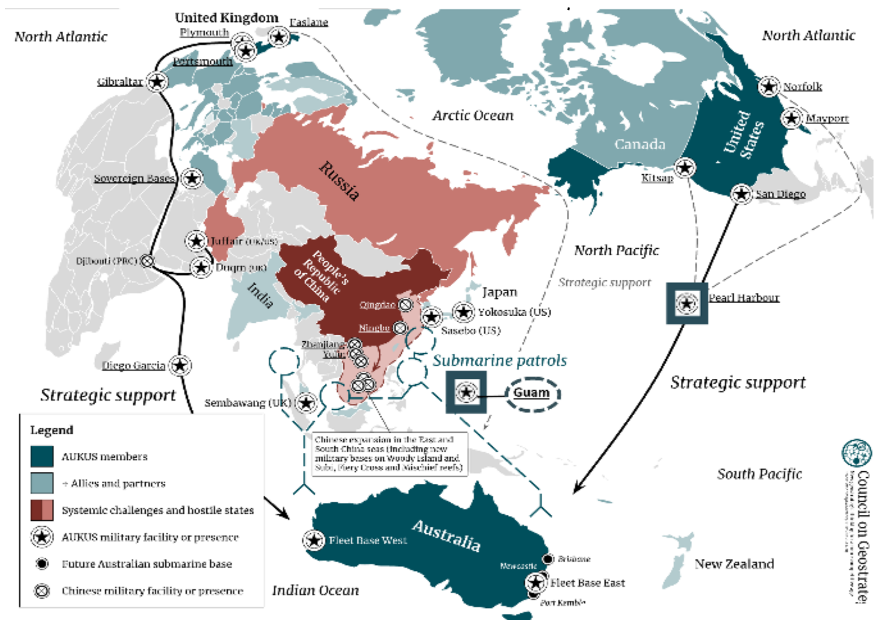

Figure 21: AUKUS Map

The Congressional Budget Office illustrated the dramatic imposition on the industrial base needed to address the Navy's latest submarine construction plan, with estimates of a fifty percent increase in tonnage over the next 10 years built by manufacturers who previously handled far lower demand levels.

> *The Navy currently takes six to nine years to build a new submarine. That means that for a few years in the 2030s, five types of submarines (including both SSBNs and large payload submarines) would be in production under Alternatives 2 and 3; four types of ships would be in production throughout much of that decade under Alternative 1. Alternative 2 would see three types of ships in production in the 2040s and beyond, whereas under Alternatives 1 and 3, just two types of ships would be in production by about 2045. With three types of submarines currently in production (Columbia class, Virginia class, and Virginia class with VPMs), the Navy is experiencing cost overruns, construction delays, and missed delivery dates. Adding more classes of ships to the pipeline could tax the ability of the shipyards and the Navy to manage production even more. In addition, under the 2024 plan, the quantity of submarine construction (as measured in thousands of tons of Condition A-1 weight, which is analogous to the measure of lightship displacement for surface ships) would increase by more than 50 percent over the next decade.*[34]

[33] Team Submarine Public Affairs. "Navy's Needed Revitalization of the Submarine Workforce Accelerates," April 11, 2024.
[34] Congressional Budget Office. "An Analysis of the Navy's Fiscal Year 2024 Shipbuilding Plan," October 11, 2023.

Consider the figure below, which includes cumulative figures reflecting VIRGINIA Class submarines (including ships with a Virginia Class Payload Modules), a next generation attack submarine, large payload submarines, and the COLUMBIA Class strategic submarine.

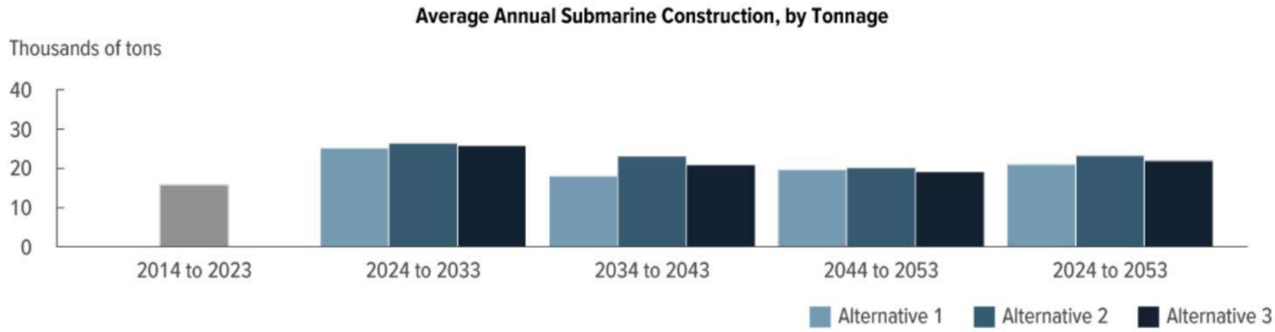

Figure 22. projected submarine output by tonnage. Source: Congressional Budget Office

To overcome challenges to meeting these high demands, additive manufacturing presents an important solution-set. Accelerating its insertion into submarine supply chains will require coordinated efforts to acquire a highly skilled production workforce and address qualification requirements, based on Naval Sea Systems Command (NAVSEA) technical requirements.

GAMMA essentially sets the stage for localizing every facet of military part-production in a single place. Mitigating logistical challenges of fulfilling part requisitions from thousands of miles away, the proposed program will ensure a Guam-based rapid part-replacement system. This effort requires installing a set of institutions, industries, and mechanical engineering professionals currently absent from the island. Consolidating a global sourcing network into a single GAMMA entity entails three aspects:

1) **Workforce Pipeline -** ensuring a skilled manufacturing workforce on Guam combining relocation to Guam of experienced CONUS-based experts with newly educated/trained Guam-based personnel.
2) **Qualification Laboratory** – full qualification and certification capabilities for components, ensuring parts meet design intent and requirements and are fit for service, including capabilities to test and evaluate final parts to ensure acceptance for Naval Sea Systems.
3) **Marketplace/Business Incubator –** establishing a state-of-the art, comprehensive production facility for an on-island supply chain. Technologies include additive manufacturing, design and engineering, machining, welding, and post-processing.

Once in place, GAMMA will support generation of new highly skilled mechanical engineering jobs, growing steadily over the next decade to service Navy projects, as well as eventually meeting burgeoning commercial production markets across the Indo-Pacific. With a state-of-the-art qualification lab in place, it is expected that GAMMA will grow to provide testing services for disparate supply chains ready-for- import to the continental U.S.—whether in the shipbuilding industry or others, including aerospace, automotive, or even medical devices. In the end, GAMMA's impact is meant to be profound, economically— establishing new high-tech jobs and sources of investment in Guam, and militarily—important capabilities for replacing essential submarine components in a cost-effective and timely manner. The local government and the U.S. Navy are committed to implementing this vision, and are joined with ASTRO in launching the first phase of this plan.

NOTIONAL MILESTONE SCHEDULE: Implementation Plan

Figure 23. Timeline of GAMMA Phase 0

PHASE	Deliverables	Milestones
PHASE 1	**Deliverable 001 Month 1**	**Phase 1 Kick-off Meeting and Technical Review with all stakeholders** 1. Phase 0 results review 2. Detailed Program Plan & Calendar 3. Meeting Minutes 4. Implementation plan for input/feedback
	Deliverable 002 Month 2	**Preliminary Designs** 5. Preliminary Design of Module 1 6. Preliminary Design Module 2 7. Conceive prospective ancillary modules – configuration and expansion
	Deliverable 003 Month 3	**UoG Satellite Campus commissioned by Mines** 8. Satellite Campus Program Director hired 9. Administration/implementation of Mines satellite campus in Guam

	Deliverable 004 **Month 3**	**Module Container Procurement (1-3)** 10. Procurement and design of modular container-style buildings. **Long lead time item payment required for delivery in Month 7.**
	Deliverable 005 **Month 4**	**Program Management – Quarterly Report** 11. Technical progress report 12. Mid-term financial report
	Deliverable 006 **Month 4**	**Industry Day & RFI** 13. Industry event to position needs and announce RFI for Use Cases
	Deliverable 007 **Month 4**	**Procurement Order #1** 14. Production equipment procurement orders 15. Test/Evaluation Lab equipment procurement orders **Long lead time item payment required for delivery in Month 6.**
	Deliverable 008 **Month 6**	**Module Transition to Guam Strategy** 16. Strategy for transport to Guam 17. Strategy for permitting/zoning in Guam 18. Strategy for stationing in Guam 19. Preliminary SOPs and operator training/familiarization planning
	Deliverable 009 **Month 6**	**Quality Management Plan** 20. Quality Management System development/plan 21. Consideration of key certifications and requirements (i.e. ISO, NAVSEA, etc.)
	Deliverable 010 **Month 7**	**Program Integration – Quarterly Report** 22. Technical progress report 23. Mid-term financial report
	Deliverable 011 **Month 8**	**USE CASES #1-#4** 24. Award of first four Use Cases

	Deliverable 012 **Month 8**	**Staging of Module 1** 25. Staging Module 1 in CONUS and ancillary modules
	Deliverable 013 **Month 9**	**Education Quarterly Report** 26. Mid-term progress report on KPIs and 27. Mid Term financial report
	Deliverable 014 **Month 9**	**System Integration Plan for Module 1** 28. System Integration plan development
	Deliverable 015 **Month 10**	**Program Integration – Quarterly Report** 29. Technical progress report 30. Mid-term financial report
	Deliverable 016 **Month 10**	**System Integration – Module 1** 31. Implementation of system integration (machine installation and workflow execution 32. Integration of power, gas, airflow, feedstock handling, EHS, fire/hazard)
	Deliverable 017 **Month 11**	**Guam-based System Integration – Module 1** 33. Guam-based site preparation; documents and installation plans
	Deliverable 018 **Month 12**	**Shipping of Production Module 1** 34. Shipping of Module 1 & Ancillary Container(s)
	Deliverable 019 **Month 13**	**Procurement Order #2** 35. Production equipment procurement orders 36. Test/Evaluation Lab equipment procurement orders **Long lead time item payment required for delivery in Month 12.**

	Deliverable 020 **Month 12**	**Education Quarterly Report** 37. Mid-term progress report on KPIs and 38. Mid Term financial report
	Deliverable 021 **Month 12**	**Program Integration – Quarterly Report** 39. Mid-term technical progress report including test results and perspectives on requirements documents and installation plans in Guam; appropriate platforms for follow-on equipment installation; Preliminary use of *in situ* monitoring and rapid qualification/inspection processes; preliminary SOPs and operator training 40. Mid-term financial report
PHASE 2a	**Deliverable 022** **Month 12**	**Industry Day & RFI - #2** 41. Industry event to position needs and announce RFI for Use Cases
	Deliverable 023 **Month 15**	**Module Installation on Guam – Module 1** 42. Installation of Module 1 & Ancillary Container(s)
	Deliverable 024 **Month 15**	**USE CASES #5-#8** 43. Award of Use Cases
	Deliverable 025 **Month 15**	**Staging of Module 2** 44. Staging of Module 2 in CONUS and ancillary modules
	Deliverable 026 **Month 16**	**Factory Acceptance Testing – Module 1** 45. AM production of test articles and preliminary evaluation
	Deliverable 027 **Month 16**	**Workshop 1- Stakeholder Engagement in Guam** 46. Workshop in Guam with PEO SSBN, PEO SSN, CSS-15, PHNSY-Guam Detachment, NAVSEA 05T, SIB, AUKUS Stakeholders, UOG, GEDA.

	Deliverable 028 **Month 16**	**Education Quarterly Report** 47. Mid-term progress report on KPIs and 48. Mid Term financial report
	Deliverable 029 **Month 16**	**Procurement Order #3** 49. Production equipment procurement orders 50. Test/Evaluation Lab equipment procurement orders **Long lead time item payment required for delivery in Month 20.**
	Deliverable 030 **Month 16**	**Validate AM and CNC systems** 51. Preliminary use of *in situ* monitoring and rapid qualification/inspection processes 52. Development of preliminary SOPs and operator training, familiarization 53. Identify appropriate platforms for follow-on equipment installation
	Deliverable 031 **Month 16**	**System Integration – Module 2** 54. Guam-based staging at UOG - Guam-based site preparation; documents and installation plans for Guam 55. Develop requirements documents and installation plan in Guam 56. Implementation of system integration in CONUS (machine installation and workflow execution 57. Integration of power, EHS, fire/hazard, etc while in CONUS
	Deliverable 032 **Month 17**	**Program Integration – Quarterly Report** 58. Technical progress report 59. Mid-term financial report
	Deliverable 033 **Month 17**	**Workshop 1 Report** 60. Report on Workshop findings, strategy and next steps
	Deliverable 034 **Month 17**	**System Integration Plan for Module 2** 61. System Integration plan development

	Deliverable 035 **Month 18**	**Shipping of Production Module 2** 62. Shipping of Module 2 & Ancillary Container(s)
	Deliverable 036 **Month 18**	**Education Quarterly Report** 63. Mid-term progress report on KPIs and 64. Mid Term financial report
	Deliverable 037 **Month 19**	**Program Integration – Quarterly Report** 65. Technical progress report 66. Mid-term financial report
	Deliverable 38 **Month 21**	**Module Installation on Guam – Module 2** 67. Installation of Module 2 & Ancillary Container(s)
	Deliverable 039 **Month 21**	**Education Quarterly Report** 68. Mid-term progress report on KPIs and 69. Mid Term financial report
	Deliverable 040 **Month 22**	**Program Integration – Quarterly Report** 70. Technical progress report 71. Mid-term financial report
	Deliverable 041 **Month 22**	**Factory Acceptance Testing - Guam** 72. Factory Acceptance Testing – Module 2 in Guam
	Deliverable 042 **Month 22**	**Staging of Module 3** 73. Staging of Module 3 in CONUS and ancillary modules 74. Mid-term technical progress report including test results and perspectives on requirements documents and installation plans in Guam; appropriate platforms for follow-on equipment installation; preliminary use of *in situ* monitoring and rapid qualification/inspection processes; preliminary SOPs and operator training/familiarization

	Deliverable 043 **Month 24**	**Education Quarterly Report** 75. Mid-term progress report on KPIs and 76. Mid Term financial report
	Deliverable 044 **Month 23**	**Stakeholder Engagement in Guam – Workshop 2** 77. Workshop in Guam with PEO SSBN, PEO SSN, CSS-15, PHNSY Guam Detachment, NAVSEA 05T, DIB, AUKUS Stakeholders, UOG and GEDA.
	Deliverable 045 **Month 24**	**Workshop 2 Report** 78. Report on Workshop findings, strategy, and next steps
PHASE 2b	**Deliverable 046** **Month 25**	**Procurement Order #4** 79. Production equipment procurement orders 80. Test/Evaluation Lab equipment procurement orders **Long lead time item payment required for delivery in Month 30**
	Deliverable 047 **Month 25**	**Program Management – Quarterly Report** 81. Technical progress report 82. Mid-term financial report 83. Sustainability Strategy and Financial Projections
	Deliverable 048 **Month 25**	**Industry Day & RFI - #3** 84. Industry event to position AM needs and announce RFI for Use Cases
	Deliverable 049 **Month 25**	**System Integration Plan for Module 3** 85. System Integration plan development - CONUS
	Deliverable 050 **Month 26**	**System Integration – Module 3** 86. Guam-based staging at UOG 87. Develop requirements documents and installation plans in Guam 88. Implementation of system integration in CONUS (machine installation and workflow execution 89. Integration of power, EHS, fire/hazard, etc. while in CONUS

	Deliverable 051 **Month 27**	**Program Integration** 90. Technical progress report 91. Mid-term financial report
	Deliverable 052 **Month 27**	**Shipping of Production Module 3** 92. Shipping of Module 3 & Ancillary Container(s)
	Deliverable 053 **Month 27**	**Education Quarterly Report** 93. Mid-term progress report on KPIs and 94. Mid Term financial report
	Deliverable 054 **Month 30**	**Module Installation on Guam – Module 3** 95. Installation of Module 3 & Ancillary Container(s)
	Deliverable 055 **Month 30**	**USE CASES #9-#15** 96. Award of Use Cases
	Deliverable 056 **Month 30**	**Education Quarterly Report** 97. Progress report on KPIs and 98. Financial report
	Deliverable 057 **Month 31**	**Program Integration Quarterly Report** 99. Technical progress report 100. Mid-term financial report
	Deliverable 058 **Month 32**	**Factory Acceptance Testing - Guam** 101. Factory Acceptance Testing – Module 3 in Guam
	Deliverable 059 **Month 36**	**Education Quarterly Report** 102. Mid-term progress report on KPIs and 103. Mid Term financial report

	Deliverable 060 **Month 31**	**Program Integration Quarterly Report** 104. Technical progress report 105. Mid-term financial report
	Deliverable 061 **Month 36**	**Education Quarterly Report** 106. Mid-term progress report on KPIs and 107. Mid Term financial report
	Deliverable 062 **Month 36**	**Program Integration – Final Report** 108. Technical progress report 109. Mid-term financial report 110. Final report

Appendix I

Prospective Demand Pull

The following analysis entails descriptions of factors contributing to demand for both Defense and commercial parts businesses that could be addressed via a Guam-based additive manufacturing industry. The first section focuses on information concerning the submarine industrial base that can be issued in a public-releasable document.

1. Submarine Industrial Base

Given a long history of Department of Defense (DoD) activity on Guam, the most recent Government Administrations have continued to concentrate U.S. military interests in Asia, with Defense Secretary Austin once describing the Indo-Pacific as DOD's "priority theater." Forces based in Guam remain central to such an effort as the closest U.S. territory to the contested South China Sea.[35]

This importance is reflected in the $11 billion committed to a U.S. military buildup in Guam over the next five years. Such an investment will reinforce the two major military installations on the island. Naval Base Guam is a homeport to several U.S. Navy nuclear powered submarines and maintenance tenders as well as maintenance/support activities for U.S. Pacific Fleet forces.

Submarines assigned to Submarine Squadron 15 in Guam primarily conduct critical intelligence, surveillance, and reconnaissance missions undetected throughout the Pacific.[36]

The Navy has already planned to build two *Virginia*-class submarines and one of the much larger *Columbia*-class every year starting in FY2026, effectively five times the work that is performed today (one *Virginia*-class per year). This represents an enormous commitment from the Defense Department, one that would be difficult to achieve using traditional approaches.

On top of that commitment, according to NAVSEA officials, current delayed shipyard performance, which includes delays to work progress associated with job- specific material and equipment issues and work stoppages, still await technical resolution. However, in March 2020, the Government Accounting

Office identified multiple survey responses that specifically identified parts or materials as the cause of delays rather than shipyard factors.[37]

There is also potential for a Guam-based AM center to support provisions of the AUKUS agreement. AUKUS supports collaboration among key allies to advance Australia's Indo-Pacific-based submarine fleet development, including "Innovation," which would "accelerate our respective defense innovation enterprises and learn from one another, including ways to more rapidly integrate commercial technologies to solve warfighting needs."[38]

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[35] Garamone, Jim. "Austin Emphasizes Partnership as Path for Peace in Indo-Pacific." Department of Defense. June 2022

[36] Submarine Force Pacific.Go Guam Initiative. https://www.csp.navy.mil/Go-Guam/About-Go-Guam/

[37] GAO. NAVY SHIPYARDS. Actions Needed to Address the Main Factors Causing Maintenance Delays for Aircraft Carriers and Submarines. March 2020

[38] White House Fact Sheet: Implementation of the Australia – United Kingdom – United States Partnership (AUKUS). April 5, 2022

1.1 Why Additive Manufacturing for the US. Navy on Guam?

Over the last decade, Naval Sea Systems (NAVSEA) Command reports that 70-80% of submarine maintenance availabilities have run late, due largely to shortfalls in materiel. Moreover, submarine spare parts budgets managed by the Defense Logistics Agency (DLA) and the Naval Supply Systems Command (NAVSUP) have only met 40%-50% of current requirements. As a result, parts are not in inventory when needed by the Navy's public shipyards, leading to significant delays in maintenance service.[39]

During FY 2015 through 2020, the Navy spent an average of $2.1 billion per year performing high priority maintenance on submarines, surface ships, and aircraft carriers. Parts and materials shortages have been identified as one of four main challenges, contributing to 2,525 days of maintenance delays from 2015-2020 for 'intermediate maintenance' alone.[40]

These conditions have only compounded maintenance and repair challenges when operating in remote locations such as Guam, where a detachment of the Pearl Harbor Naval Shipyard (PHNSY) is being built.

To address these issues, additive manufacturing (AM) has the potential to produce parts on-demand at the point of need, consolidating supply chains, cutting lead times, and significantly reducing logistical footprints. While this technology has been explored for new ship construction and occasionally applied for *ad hoc* repair, its systematic use in submarine sustainment has been limited.[41]

"The US Navy is facing significant challenges procuring spare parts for their submarine fleet, greatly impacting their maintenance program. Nearly 40% of the Navy's attack submarines are either undergoing repairs or awaiting maintenance. The issue has been attributed to a shortage of skilled workers, delays at shipyards, and disruptions in the supply chain."[42]

Shortages of parts are contributing to these maintenance delays. While unable to quantify the effect of those shortages on delays, CBO has highlighted a "cannibalization" rate whereby the Navy borrows parts from one ship to complete maintenance on another, causing readiness delays for the cannibalized ship.

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[39] Eckstein, Megan. "Submarine fleet needs more spare parts to stem maintenance delays: Less than 30% of submarine maintenance work is completed on time," Defense News. Sept 21, 2022.

[40] Government Accountability Office, GAO Report 22-104510. Navy Ship Maintenance. February 2022.

[41] Government Accountability Office, GAO Report 16-56. Defense Additive Manufacturing. October 2015.

[42] Johnson. "Navigating the Depths: The US Navy's Quest for Submarine Spare Parts" Maintenance World. October 2023.

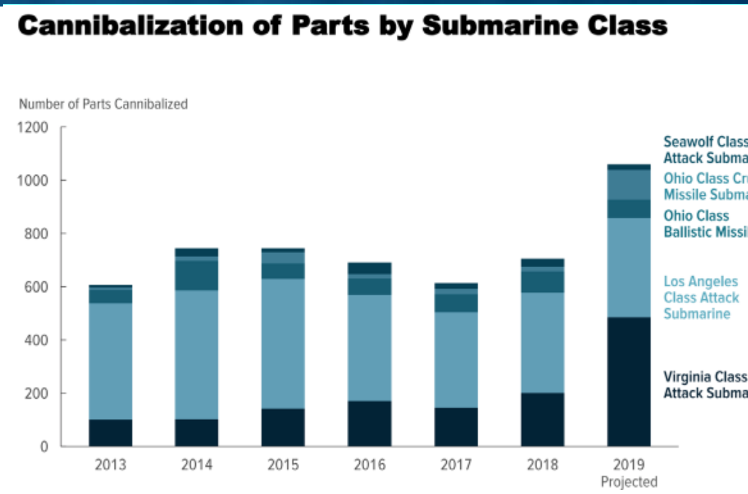

Figure A1. Source: Congressional Budget Office. "The Capacity of the Navy's Shipyards to Maintain Its Submarines."

This 50%-60% submarine spare part budget shortfall identified by DLA and NAVSUP demonstrates the necessity for alternative sources of supply, including just-in-time production at the point-of-need, potentially offered by AM. Such capabilities would complement tenders and the PHNSY detachment servicing several submarines operating around Guam (including Submarine Squadron 15 stationed at Polaris Point). With Pearl Harbor Naval Shipyard & Intermediate Maintenance Facility located some 3,500 nautical miles away, a new AM outfit on-island promises to reduce part requisitions from the otherwise closest point of the U.S. submarine industrial base.

Additive manufacturing is being increasingly considered important for this key logistical support, offering novel approaches to custom-built tools, prototypes, and replacement components. Such activities, long in use by the Navy's organic industrial base, can be deployed effectively in support of the Guam Detachment of Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility (PHNSY & IMF). Personnel from this new unit have indicated that over the next 5 years, there are plans to build maintenance/repair capabilities for submarines and other naval platforms. Facilities[43] may require support for reverse-engineering or spare part requisition – perhaps via 3D scanning technology or 3D printed processes.

The Navy has a strong history of using additive manufacturing for each of the "application categories" up until the direct qualified/certified production. The launch of both the US. Navy AM Center of Excellence and the Accelerated Training in Defense Manufacturing (*ATDM*) program, both located in Danville, VA are a key part of the US Navy's strategy to build much-needed skilled workforce in several fabrication methods, as well as build a functioning and valid alternative to traditional forging and casting using AM.

NAVSEA's publication of qualification guidance for Directed Energy Deposition and Laser Powder Fusion are the culmination of considerable public-private engagement by NAVSEA 05 Technology Office, particularly by the Additive Manufacturing Technical Warrant Officer team.[44] The U.S. Navy currently has

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[43] "Spending By State FY21 Supplemental Report." Office of Local Defense Community Cooperation, U.S. Department of Defense,

[44] Rettaliata, Justin. "Engineering Standards: Best Practices and Emerging Technologies NAVSEA Additive Manufacturing Overview." Naval Sea Systems Command. August 3, 2022.

5 completed Technical Data Packages (TDPs) for submarines and 50 more in construction, based on a January 2024 update. It also has procedures for producing parts in exigent circumstances.

1.2 Market Size Estimation & Assumptions:

Quantifying demand for AM services that could augment these activities remains challenging, particularly given the sensitive nature of the Navy's work in Guam. Nonetheless, based on direct communication with Guam-based personnel from PHNSY & IMF, Submarine Squadron 15, a Navy shipbuilding lead system integrator, and private local shipyards servicing military sealift command, it is reasonable to anticipate robust "market-pull" for 3D printing.

It is apparent that being able to produce fully qualified parts produced using AM on Guam for submarines holds great potential and value for the U.S. Navy as well as AUKUS not just in terms of the cost of hard-to-source parts but in the potential for vastly improved delivery times and reduced hidden costs such as time.

Example:

Traditional Production:

- A key pump component for a submarine repair costs (notionally) $24,000 to produce using casting but takes 24 months to complete.
- Only 1 component is required and the usual casting house refuses to do one-offs so another qualified house needs to be located.
- The part, produced traditionally on CONUS will also be subject to shipping times and potential delays.

AM Production

- A key pump component for a submarine produced on-island using AM costs (notionally) $48,000 but takes just ten weeks for fabrication, post-processing and qualification.
- The cost per part will remain the same at low-volume (1-20 parts, size-dependent) production.
- There is no lengthy supply chain risk with this solution.

The examples above offer different opportunity costs depending on the need and criticality of the part. Choosing the traditional production method incurs less monetary cost but significant time-to-part, which may mean a submarine is waiting for up to 2 years for replacement. The AM option costs double in terms of actual cost-per-part but enables the submarine to be operational in a fraction of the time.

If five such parts were produced in one year, that would be counted as revenues of $240,000 without any cost-benefit analysis of the time savings.

2. Commercial Shipping

2.1. Commercial Ship Repair on Guam

Cabras Marine Corporation (CMC) and its affiliates are the leading provider of pilot, tug, barge, spill response, firefighting, and ferry services on Guam. Providing ship repair and maintenance, parts and operational readiness to military and commercial ships. Multi-faceted – they repair tugboats, barges, destroyers, LCS (Littoral Combat Ships) and submarines.

Cabras services approximately 50 ships/year with small jobs running $25K - $50K per vessel and a few large projects of $5M - $6M. Many of the commercial ships are manufactured in Japan, Korea, China, and Singapore. Part obsolescence is an issue with replacement components. Immediate needs include 'smalls' like valve stems, pump impellers, specialty nuts and bolts which can be difficult to source and could be a prime opportunity for Additive Manufacturing and ancillary technologies like CNC machining.

Figure A2. 3D printed Impeller. (Credit: BeamIT)

Materials include copper, nickel and related alloys for replacement parts and various steels – anti-corrosion properties are important. AM is a good fit for machinery repair and non-critical parts. For parts of increasing criticality, qualification and certification capabilities are essential – following the material specs of the America Bureau of Shipbuilding (ABS).

Sometimes, the replacement parts are simpler – a chair lever, a handle or winch, simple repairs made complex by extended supply chains, long lead times and limited availability. AM is ideal in these situations. Custom tools and work aids are another application that could benefit the Cabras workforce – drill guides, workholding devices, and more could easily be printed for specialized applications to improve ergonomics and efficiency.

Commercial ships must always be ready for action. Time and availability of tugs and vessels is an issue for Cabras as they often pay higher prices for components to avoid lost revenue resulting from long lead times for parts. Scarcity causes the need for new sources of supply, and this is the gap filled by AM. In cases like these, the need justifies the higher costs of AM-manufactured components.

There is also a need for AM-created mockups and training tools with Cabras as they often work with nuclear components and piping systems/confined spaces where mockups and careful planning are required before repairs can be performed. AM facilitates the faster creation of these tools and the ability to iterate and incorporate learnings over time. 3D scanning and creating accurate replicas for these needs would be extremely valuable.

2.2. Market Size Estimation & Assumptions*:* Understanding that AM could support Cabras' operations – there is also need for supporting technologies like CNC machining, welding, and grinding. Qualification and certification are also non-negotiable here. Assuming AM contributes to 10% of the maintenance and repair activities, the market value would be approximately $1.2M (ROM). This is a reasonable estimate of volume as the commercial ship repair and maintenance services market is projected to grow from $34.60 billion in 2022 to $45.70 billion by 2029, at a CAGR of 4.10%. As awareness and technical knowledge increases among the Cabras workforce, the value of AM will increase.

3. Commercial Air and Aerospace Market

3.1. Additive Manufacturing in Aerospace

The aerospace industry was one of the earliest commercial adopters of additive manufacturing and continues to make significant investments in technology development. In fact, the latest generations of commercial airplanes fly with 1000+ 3D printed parts although few are flight critical. Companies like GE have worked closely with the FAA to meet certification requirements and build confidence in AM parts.

Demand for AM in Aerospace:

- Lightweighting for fuel savings
- Unique shapes provide advanced capabilities
- Improved durability and increased efficiency of turbines
- Complex components and multi-material applications
- Monolithic parts that reduce the need for manual assembly

Current barriers to broader AM adoption in Aerospace

- Certification and standards
- High cost of AM material
- Limited build size
- Slow production

Technology advances in machines, materials and software will alleviate these challenges over time. More aerospace parts would be produced by AM currently except for the existing limitations of size, materials, accuracy, and more finely detailed features in printed parts.

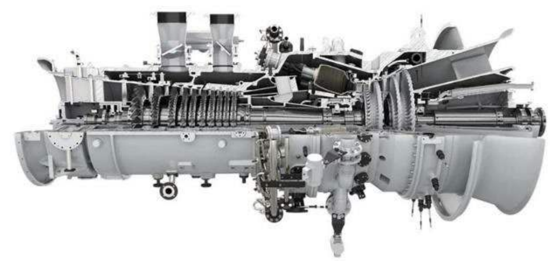

Figure A3. Siemens uses AM technology to repair turbine blades like the ones found in their SGT-600 gas turbine shown here. Credit: Siemens Energy.

Utilizing AM for Aerospace Repair/MRO allows users to get acquainted with AM technology and workflow and to deliver meaningful improvements. In turbines – for energy and aerospace – AM provides a novel way to repair turbine blades and add new features. These 'hot parts' benefit from the addition of high-temp materials at the turbine tip where thermals create the most wear. In this case AM improves the component from its original state.

Companies like Lufthansa Teknik, Air France, GE, Etihad and others are expanding their use of AM for MRO.

Figure A4. 3D printed metal stator turbine blades. Credit: EOS

Currently used in high volume production in approximately 100 MRO installations worldwide, a single multi-functional AM machine has the capacity to repair tens of thousands of turbine blades annually. Currently, production repairs have been performed on more than 10 million components over time with AM.

The global fleet of 25,000 commercial aircraft and 50,000 military aircraft have a mandated time between overhaul (TBO) of around 5000 flight hours, creating a large and growing demand for automated repair equipment. Various Additive Manufacturing systems are currently certified for aviation repair in 15 countries.

3.1.1. Market Size Estimation & Assumptions

Guam currently has a relatively small market for aerospace MRO with total economic activity of $3 million. Singapore is the hub of Asia Pacific MRO activity in an area approximately the size of Guam (281 sq. mi vs. 212 sq miles). Singapore houses 120 aerospace companies.

Growing by a compounded annual growth rate of 8.6% over the past two decades and a total annual output of more than $8.0 billion, the Singapore aerospace industry is a key economic driver for Singapore. As a one-stop center for all maintenance, repair, and overhaul (MRO) services and large precision engineering suppliers, Singapore has captured over 10%[45] of the global MRO market. (trade.gov)

Building aerospace maintenance capabilities on Guam provides an alternative to Singapore and an opportunity to capture and grow the market in a proximal location to Asia – on US soil. United Airlines and Vietnam Airlines are currently evaluating relocating their MRO activities from China to Guam. Because of the sheer number of aircraft and the time needed to build capabilities, this would be an iterative process, but even at low volumes, this presents a significant opportunity for Guam.

3.1.2. APAC MRO Market

Aerospace MRO (ROM)				
	# of Aircraft			
AsiaPac	2023	2033	% Change	
Narrowbody	2114	2925		
Widebody	1333	1564		
Regional	211	270		
Turboprop	651	782		
	4309	5541	29%	
	$M USD			
MRO	2023	Per Aircraft	2033	Per Aircraft
Airframe	$ 3,000	$ 0.696	$ 3,900	$ 0.704
Engine	$ 10,000	$ 2.321	$ 11,500	$ 2.075
Component	$ 3,100	$ 0.719	$ 3,700	$ 0.668
Line	$ 2,000	$ 0.464	$ 2,600	$ 0.469
	$ 18,100	$ 4.201	$ 21,700	$ 3.916

Figure A5. Aircraft types and MRO costs in APAC region not including China. Source: ARSA

The APAC aircraft MRO market is significant[46] and will continue to grow to over 5,000 aircraft in the region within the next 10 years. MRO providers in the Asia-Pacific region are expected to face a capacity crunch as airlines return more of their fleets to service post-pandemic. Also, the region is witnessing an increase in the penetration and expansion of Low Cost Carriers (LCCs), increasing the demand for aircraft MRO. The airlines in the region are also planning to strengthen their MRO capabilities and award contracts to other specialized MRO providers.

[45] “Singapore Aerospace.” US International Trade Administration. Sept 2020.

[46] “Global Fleet and MRO Market Forecast 2023-2033”. ARSA.

Considering a new Boeing 737 costs $100M -$125M, the average maintenance expenditure at $4.2M per aircraft/year is a smart investment. Additive manufacturing can contribute to many MRO areas including Engines and Components. Tools, tooling, work aids and guides can be used in other areas.

In the chart, we assume a modest number of aircraft Year One in Guam (10) and that AM could fulfill 7% of the Engine maintenance only – resulting in a market value of $3.64M. This would double the current market size of Aircraft MRO in Guam and would take time to scale up. The market size increases significantly by scaling the number of aircraft serviced in Guam, and by incorporating AM and related technology into other MRO areas.

$M USD			
	Estimated Market Value		
# of Aircraft	10	25	50
Airframe	$ 6.962	$ 17.405	$ 34.811
Engine	$ 23.207	$ 58.018	$116.036
Component	$ 7.194	$ 17.986	$ 35.971
Line	$ 4.641	$ 11.604	$ 23.207
TOTAL	$ 52.005	$ 130.013	$260.026

Figure A6. Estimated market value of Aircraft MRO in Guam at various quantities of aircraft – and the amount of work anticipated to be done with Additive Manufacturing (future state).

3.1.3. Current Guam Aerospace MRO Market Activity (2022-23)[47]

	Maintenance, repair and overhaul (MRO)	Parts manufacturing and distribution	Total economic activity
Guam	$2,000,000	$1,000,000	$3,000,000

Figure A7. Current Guam Aerospace MRO

3.2. Energy Generation/Turbomachinery

In addition to aerospace jet turbines, AM is successfully used in repair and maintenance of industrial gas turbines used for energy generation. Turbomachinery is critical for energy generation. Its high-performance parts feature complex designs that must be extremely robust and powerful even at temperatures beyond the melting point. Additive manufacturing is suitable for numerous applications here: blades and vanes, fuel injectors, impellers, swirlers, burners and combustion chambers, cladding, seals, housings, and more.

Figure A8. Euro-K burner – turbine component that can burn gaseous or liquid fuels due to complex channels created by Additive Manufacturing. Credit: EOS

Machines use a process called Directed Energy Deposition (DED) to build 3D metal parts by depositing feedstock (powder or wire) into a precisely controlled pool of melted metal. Fiberoptic lasers supply thermal power while advanced motion control systems produce the required geometries for the parts.

Turbomachinery can also be interpreted more broadly as 'rotating equipment' which includes oil and gas, water and wastewater treatment and other similar industries

[47] "Global Fleet and MRO Market Forecast 2023-2033". ARSA.

and components such as valves and pumps. Spare parts like these can be repaired or manufactured with AM.

The components used in Turbomachinery and Rotating Equipment are also applicable to shipbuilding and submarines.

Figure A9. APAC Gas Turbine MRO Market Leaders

Asia Pacific had a significant revenue share of the global turbomachinery market in 2022[48] owing to the increased investments in and development of the gas distribution network, a rise in the refining and petrochemical industries in developing nations like India, rising energy demand, a slowdown in coal energy production in China, expansion in the chemical industry, and increased awareness of the use of natural gas. Asia Pacific region has the fastest growth rate of turbomachinery.

3.2.1 Market Size Estimation & Assumptions:

The global gas turbine MRO market was valued at $11.56B in 2021 and is expected to grow at a CAGR of 6.70% from 2022-2030.[49] The Asia-Pacific gas turbine MRO market is expected to grow at a CAGR of over 3% (2020-2025). Factors such as the aging fleet of gas turbines, the need to maintain operational efficiency, and stringent emissions controls are major drivers. Rising demand for cleaner energy from gas turbines vs. coal-fired plants will also boost the market. It's reasonable to predict that Guam could capture some of the APAC market for turbomachinery MRO. Primarily on-island at first, but by building capabilities in AM and supporting technologies, Guam could support MRO for export to other APAC countries.

4. Ancillary parts

4.1. AM for Tools, Tooling and Fixtures

Tools, jigs, and fixtures are aids in manufacturing and maintenance that can increase accuracy and quality while reducing cycle time and improving worker ergonomics and safety. Traditional methods of manufacturing these tools require machining, welding, and assembly – or sourcing from external vendors which can result in long lead times and higher costs.

[48] "Asia-pacific aircraft MRO market size & share analysis - growth trends & forecasts (2023 - 2028)". Mordor Intelligence.
[49] "Gas Turbine MRO market in the Power Sector Analysis". Coherent Market Insights. Aug 2022.

3D printing these tools is cost effective and allows for multiple iterations and adjustments to be done quickly and easily. Examples are drill guides, clamps, patterns and positioning tools.

Figure A10. A drill guide bushing 3D printed in resin. Credit: Formlabs

3D Printing provides the opportunity to create custom tools and fixtures that are easy to handle and match workers' requirements. Designing customized, ergonomic tooling that's also more light weight than traditionally designed tools is another benefit of AM.

Digital files can be easily modified, allowing designers to customize tools or aids. Fixtures can be cost-effectively produced for each individual user and project need. The customization opportunities open up greater control over tasks and further enable ergonomic support for workers, resulting in higher accuracy and fewer injuries.

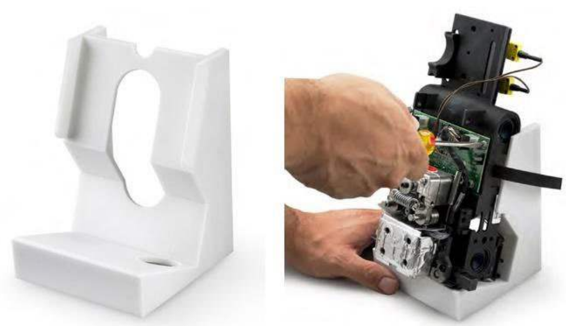

Figure A11. 3D printed jigs for easier assembly. Credit: Stratasys

According to Jabil's 2021 3D Printing Trends survey, additive manufacturing applications have skyrocketed in just two years. In their recent study, more than half (57%) of participants surveyed report that their company uses AM/3D printing for tooling, jigs and fixtures, up from 30% in 2017 and 37% in 2019.[50]

Below is a sample of time and cost savings utilizing 3D Printed Tools/Jigs/Fixtures vs. traditional CNC from a case study with Oreck conducted by Stratasys.[51]

METHOD	COST	PRODUCTION TIME	TOTAL INSPECTION TIME
CNC	$250	7 hours	30 days
AM	$55	3.5 hours	1 day
SAVINGS	$195 (78%)	3.5 hours (50%)	28 days

Figure A12. Cost comparison of conventionally machined jigs and fixtures (CNC) to AM-produced ones at Oreck[6].

[50] "3D Printing Technology Trends." Jabil and Dimensional Research. March 2021
[51] "Additive Manufacturing reduces fixturing costs up to 65percent at Oreck," Stratasys. January 2022.

4.1.1. Market Size Estimation & Assumptions:

Currently, little demand exists for tools, tooling and fixtures on Guam. One of the larger barriers to adoption of AM for tooling and fixtures is the small manufacturing market and lack of awareness. This is another application that has strong cross-pollination with DoD work and the aviation and ship MRO work. There is also application for the power and water authority in tools for repair and work aids to help technicians perform tasks more efficiently and safely – improving ergonomics and workplace satisfaction.

4.2. Replacement Parts

Currently, spare parts manufacturers are faced with a range of challenges stemming primarily from the production and storage of spare parts. Cost is one issue as traditional manufacturing models require volume production to amortize fixed costs over a larger number of parts. But often spare parts are required in much smaller volumes, so spreading the costs over the smaller quantity makes traditional methods cost-prohibitive. Locating a spare part and shipping it the other side of the world can take weeks.

Figure A13. 3D Design file for a brushless (electric) motor ready to download and 3D Print from a digital warehouse. Credit: Cults3D.

'Part no longer available' is common with older equipment and products. With AM, manufacturers can 3D scan obsolete parts and produce new components with 3D printing. Application opportunities exist at different levels of criticality or service severity. At lower levels of criticality, decisions can easily be made at lower levels of an organization to use AM to print replacement parts. Many opportunities exist here. However, more critical parts require part certification, qualification and much more rigor in decision making.

Figure A14. Appliance manufacturer Miele partnered with BASF's Replique to offer 3D printed replacement parts like these for their vacuum cleaners. Credit: Miele 3D4U

Digital warehouses are fully digital repositories that store electronic files, 3D models, and any other type of blueprint necessary to 3D print parts or products. The digital model file is sent to a 3D printer at a facility or a local on-demand service. Home appliance manufacturer Miele's project, called 3D4U, lets customers order accessories and spare parts that are 3D printed at a service closest to them. As a result, Miele says they have expanded their product portfolio and offered better, faster service to their customers.

In one use case, at a Ford factory in Cincinnati, two plant workers used 3D Printing to create replacement parts and tools for the production line by troubleshooting common issues. They designed production aids, buttons, and levers and printed them for use in the plant. Ford has saved millions of dollars and the two workers became very popular for special requests from co-workers for these tools.

Process repeatability is among the biggest concerns for many OEMs and suppliers. Quality standards must be set for spare parts and ensure that 3D-printed parts match these specifications. Intellectual property is also an issue. Adoption will continue to grow, and more replacement parts are added to the market every day. Spare Parts 3D worked with Whirlpool to determine that 7% of their part SKUs could be made with AM.[52]

4.2.1. Market Size Estimation & Assumptions: This marketplace is difficult to quantify because it could encompass basically anything that exists on the island from obsolescent components to simple knobs, buttons, and levers. The critical success factor in this application is the ability to access digital design files for existing parts and components (3D4U or SpareParts3D) and to easily scan and reverse engineer existing components without digital files.

By establishing a local distributed manufacturing site or service bureau on Guam like Oerlikon, Jabil, Shape ways, or similar, existing systems and processes for reverse engineering, manufacturing, and qualification could be adapted for the Guam market or transshipment for export. This would be an attractive ‘plug and play’ model.

4.3. Automotive Repair and Replacement Parts

The automotive market was also one of the first adopters of AM technology, first producing rapid prototypes, then rapid-tooling and now production parts. Today, a convergence of technological, market and environmental trends is radically transforming the automotive industry, and AM is becoming an important tool to enable this transformation. Much of the automotive industry’s use of AM technology is in manufacturing new vehicles – but some use cases for automotive repair exist.

Recently, General Motors was able to additively manufacture replacement parts in Australia for Police Vehicles – specifically seat recline levers. Because the tooling no longer existed and this was a short run for production, AM was the right solution. The process provided an 85% cost avoidance and 70% MOQ (Minimum Order Quantity) reduction over traditional processes.[53]

Figure A15. The metal water connectors for AUDI W12 engine were 3D printed on demand. Credit: AUDI

In automotive, parts are manufactured by suppliers, not the OEM (GM, Ford, Hyundai) and there are numerous automotive safety standards that components must comply with, and considerations for manufacturing with AM. To produce AM automotive replacement parts in Guam, it would need to be in an aftermarket scenario. Licensing part files via AC/Delco, Tacti (Toyota) or other parts resellers would be needed – along with robust testing and certification capabilities.

This area is highly dependent upon the specific AM technology employed in the manufacturing process. Only certain materials and processes are suitable for automotive parts. Also, the Class A components, which are the ones that the driver/passenger can see and touch, must have specific appearance, durability, scratch/UV resistance, color retention and other qualities. Crash testing is important for non-structural parts as well, to ensure added parts do not become a hazard in a crash. The ability to certify and qualify components is essential to this marketplace.

[52] “Spare Parts 3D joins up with Whirlpool on a 3D printing project.” Spare Parts 3D. November 2021

[53] “Additive Manufacturing in Automotive Service and Repair” - Tom Curtis, General Motors - RAPID + TCT Conference, May 2023

4.3.1. Market Size Estimation & Assumptions: With approximately 120,000 passenger vehicles on Guam, demand for AM replacement parts would be relatively low as AM is currently suitable for only a small percentage of automotive applications.

The exception would be commercial trucks, public transit, and emergency vehicles. In these cases, revenue is at risk or public safety could be jeopardized. This would justify the use of Additive Manufacturing in a high value component.

Building a digital inventory of parts allows companies to print components on-demand vs. waiting for replacements to be shipped. In fact, Deutsche Bahn has 3D printed 100,000 spare parts for its trains significantly increasing the availability of trains and routes and transforming rail maintenance.[54] The ability to additively manufacture replacement parts for any vehicle would be at the discretion of the manufacturer or aftermarket parts provider.

Having ample ancillary technologies available such as CNC machining, welding, painting and coating could help to build relationships with these manufacturers or vehicle leasing companies providing the opportunity to manufacture parts additively or traditionally, as needed, due to time constraints, availability or part obsolescence.

4.4. Ancillary Markets

4.4.1. Mockups, Models, and Training Tools

In hazardous environments like power generation, nuclear, pressure piping, and more, mockups and training are required before repairs and maintenance can be performed. Creating mock-ups by hand is a time-consuming and mostly inaccurate process. Models can take days and weeks to prepare, causing workers to lose valuable time, and the results are not always true to form.

Figure A16. AM is used increasingly in architectural and constructions mockups. Credit: Zortrax

Additive manufacturing allows the quick build of accurate models for training and run-through purposes. Using 3D files, architectural drawings or 3D scanning technologies, scaled replicas of any environment can be created – increasing safety, efficiency and performance.

3D model creation with Additive Manufacturing is also a cost-efficient method of tangibly evaluating designs in architecture and civil engineering.

4.4.2. Market Size Estimation & Assumptions: This market would be relatively small but should be considered as one aspect of the larger aggregate market space. Improvements in safety and preparedness in hazardous environments and confined spaces by using AM would be a significant benefit. With architectural models, the ability to quickly iterate designs and produce a tangible example could accelerate development in AEC (Architectural, Engineering and Construction) projects.

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[54] E. Geerts. "Deutsche Bahn reaches 3D printing milestone with 100,000 parts." Rail Tech.com. May 2023.

4.4.3. Surgical Guides and Anatomical Models

THE BEST POTENTIAL MARKETS ARE THOSE WITH A CROSSWALK TO WELL-UNDERSTOOD DEFENSE MARKET SEGMENTS LIKE AEROSPACE MRO, ENERGY GENERATION, AND SHIP REPAIR.

Combined with medical imaging systems and digital conversion software, AM has become a critical tool for advancing personalized care in medical and dental applications.

Figure A17. 3D printed pelvic bone uses patient-based CT scan data for use in surgical practice and preparation. Credit: Stratasys

Additive Manufacturing technology has helped redefine the concept of personalized surgery in the production of realistic anatomical models and single use surgical cutting, pinning, and drilling guides based on real patient data. Today, the combination of these and other customized AM-produced devices are reducing surgical times and associated costs, while improving patient outcomes.

Every patient is different, and in the case of tumors and other abnormalities, understanding exactly the shape, size, and location of the intrusive growth is vital to removing or treating it. Medical data obtained from CT scans can be turned into a 3D model that, when printed, can educate patients on their condition and how their medical team will approach it. The medical team can use that same model to determine a path forward and even practice before getting into the operating room.

As of July 1, 2019, the American Medical Association (AMA) is using provisional CPT Codes corresponding to surgical planning, guides, 3D anatomical models and corresponding products and services. CPT stands for Current Procedural Technology and allows for billing of these services to insurance providers.

AM in dentistry is used for manufacturing crowns, bridges, and dentures. By building from patient-specific 3D data, fit and function are superior. In Orthodontics, clear aligners such as Invisalign or Smile Direct Club are created with 3D printing. An AM-equipped dental lab on the island could provide fast, high-quality dental care to the citizens of Guam.

4.4.4. Market Size and Assumptions: The market size for medical and dental is based upon number of patients. As a factor of population, the Guam market is relatively small (170,000). Supporting other surrounding islands with capabilities would increase this market size slightly. However, the quality-of-life improvements, public health benefits, and improved outcomes for patients should be a compelling factor in pursuing this market space – aside from the business considerations.

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