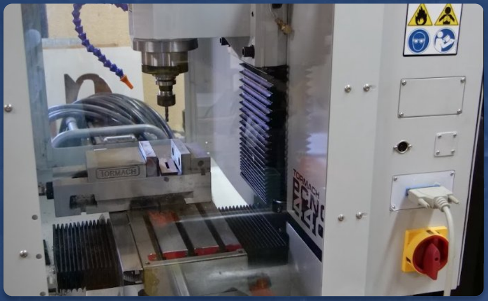
Applied Science & Technology Research Organization of America
ASTRO America

GUAM ADDITIVE MANUFACTURING AND MATERIALS ACCELERATOR

BASELINE ADDITIVE MANUFACTURING READINESS

Developed for Government of Guam and
Guam Economic Development Authority

Phase I, Deliverable 7
April 2023



ASTRO America

What this report is about

ASTRO America is conducting a 12-month assessment on the viability of establishing industrial additive manufacturing (AM) capabilities in Guam. Phase 1 was conducted over 6 months to analyze preliminary feasibility. Phase 2 will conceive an implementation plan to help overcome logistical challenges re-supplying military and civilian operations on a remote island. This plan must also support sustainability and growth.

Key Findings in Phase 1

ASTRO America found community elements upon which to build a potentially viable AM sector, including—

Research/Higher Education *(University of Guam)*

Technical Training *(Guam Community College)*

Federal Government Demand *(Departments of the Navy, Air Force, Army, Other)*

Robust U.S. & Local Development Agencies *(Small Business Admin, Dept of Agriculture, GEDA, Other)*

Commercial Interest *(Bank of Guam, Bella, Cabras Marine, Won Pat International Airport Authority, Guam, Guam Power Authority, Guam Shipyard, Newport News Shipbuilding, Port of Guam, United Airlines)*

info@astroa.org

GUAM ADDITIVE MANUFACTURING FEASIBILITY STUDY FOR THE GUAM ECONOMIC DEVELOPMENT AUTHORITY

The Guam Economic Development Authority (GEDA) contracted with ASTRO America to evaluate Guam's readiness to develop additive manufacturing (AM) capabilities. Several Guam-based entities contributed to ASTRO America's preliminary analysis, culminating in a workshop on: 1) composition of industrial AM capabilities and 2) on-island conditions that may be re-configured to sustain AM operations.

For industrial applications, AM processes include: use of **software** for designs, build-preparation, and formatting; disparate **3D printer systems** (and feedstock); **part-removal and finishing** (machining and heat treatment); and accepted **inspection and validation methodologies.** Development of an ecosystem with these elements requires low-volume part-demand as well as investments in research, workforce, and capital equipment. To these ends, the U.S. Department of Defense (DoD) is an ideal partner for co-development, given its own supply chain needs and precipitous growth in Guam.

Theoretically, developing an AM capacity on-island would offer new sources of spare parts, built on-demand to service fleets of military ships, aircraft, and vehicles. This Phase I report offers insights into Guam's readiness to support such an enterprise and sets a foundation for an implementation plan in Phase II. Such a plan is to be premised on addressing a diversified customer-base, with sustained demand stretching across military and commercial sectors, from shipbuilding and aerospace to medical device supply chains.

The ensuing Phase I analysis concludes that Guam possesses basic building blocks for establishing a high-tech manufacturing sector.

Figure 1. Costly warehousing and logistics often hinder ship maintenance and repair. As an alternative, Naval Sea Systems Command is developing acceptance criteria for 3D printed parts, a development which will greatly reduce lead-times and requisition expenses, and create high tech jobs in Guam, U.S. territory in the Indo-Pacific region

Principally U.S. and Allied military interests may serve as initial consumers of this capability. Its healthy business climate could attract both private and public investment, while a robust higher educational system offers important workforce development capacity. Of utmost importance, UoG's ability to partner with other U.S. institutions could support development of a state-of-the-art test/evaluation laboratory to validate performance/quality of manufactured parts to meet key end-users' standards.

1.2 PHASE I DELIVERABLES

Over the course of twelve (12) months starting in 2022, ASTRO America has been undertaking the Guam Additive Manufacturing (AM) Feasibility Study. The purpose of the feasibility study is to conduct a comprehensive analysis to determine the viability of a local AM industry in Guam. The project will be completed in two phases.

PHASE I (6 MONTHS)

In terms of this study's Phase I outputs, GEDA stated that its expectations for baseline analysis on Guam's economic readiness for feasible AM adoption included: (1) assessing current capabilities and needs for supply chain development; (2) potential strategies for developing such a workforce and capabilities; (3) potential demand, including U.S. Government stakeholders.

GEDA also indicated it expected the following outcomes: (1) identification of Guam-based stakeholders; (2) assessment of current Guam's supply chain capabilities; (3) convening of Guam-based stakeholders (4) ensuring of local input on regional economy, community development, and academic institutions.

The following table provides an illustration of the key milestones and timeline of Phase I:

DELIVERABLES	MILESTONES
Phase 1 –Deliverable 001 (Month 1)	**Kick-off Meeting and Preparation** *a.* Presentation on assembled team *b.* Detailed Program Plan & Calendar *c.* Meeting Minutes *d.* Implementation plan for input/feedback
Phase 1 –Deliverable 002 (Month 1)	**Baseline Analysis Inputs** *e.* Current conditions: manufacturing, logistics, workforce development *f.* Economic analysis (current supply and demand for manufactured parts, systems, subsystems) *g.* Stakeholder outreach for manufacturing and academia *h.* Department of Defense considerations *i.* Workshop Engagement for participants, speakers, and facilitators *j.* Workshop Engagement for participants, speakers, and facilitators *k.* Workshop Agenda Preparation
Phase 1 – Deliverable 003 (Month 2)	**Operational, Economic Assessment; Pre-workshop Interviews** *k.* Additive Manufacturing Supply Chain Development Needs and Gap analysis *l.* Inputs on local and regional economic/business considerations *m.* Workforce capacity/higher education *n.* Inputs on INDOPACOM requirements *o.* Workshop Engagement for participants, speakers, and facilitators *p.* Workshop Agenda Preparation
Phase 1 – Deliverable 004 (Month 3)	**Guam Workshop** *q.* Workshop Agenda Preparation/Organization *r.* Stakeholder engagement/facilitating *s.* Session/notes and conclusion
Phase 1 – Deliverable 005 (Month 4)	**Guam Workshop Conclusions** *t.* Sessions Notes Detailed/Analyzed *u.* Interim workshop report drafted
Phase 1 – Deliverable 006 (Month 5)	**Final Report (Phase 1)** v. Guam workshop read-out: preliminary report for comment/input
Phase 1 – Deliverable 007 (Month 6)	w. Final report on Guam Baseline Additive Manufacturing Readiness

Table 1. Phase I milestones and Timeline

1.4 TABLE OF FIGURES

1.5 TABLE OF TABLES

1.6 TABLE OF ABBREVIATIONS

3D CAD .... 3-dimensional computer aided design
3MF .... 3D manufacturing format
ADR .... alternative dispute resolution
AM .... additive manufacturing
AMOC .... Advanced Manufacturing Operations Cell
AMMTO .... Advanced Manufacturing and Materials Technologies Office
ASTM .... American Society for Testing and Materials
ATDM .... Accelerated Training in Defense Manufacturing
AUKUS .... Australia, United States, United Kingdom
BRAC .... Base Realignment and Closure
BS .... Bachelors of Science
CAD .... computer aided design
CASREPs .... Casualty Reports (equipment)
CBC .... Cabras Marine Corporation
CEDDERS .... Center for Excellence in Developmental Disabilities Education, Research, and Service
CMM .... coordinate measuring machine
CNC .... computer numerical control
CONUS .... Continental US
CT .... computer tomography
DED .... directed energy disposition
DEI .... diversity, equity, inclusion
DIU .... Defense Innovation Unit
DMDV .... Digital Manufacturing Data Vault
DoD .... Department of Defense
DOE .... Department of Energy
DURIP .... Defense University Research Instrumentation Program
EBM .... electron beam melting
EDA .... Economic Development Administration (Department of Commerce)
EDM .... electro-discharge machining
EPSCoR .... Established Program to Stimulate Competitive Research
ERF .... Emergent Repair Facility
FAA .... Federal Aviation Authority
FDA .... Food and Drug Administration
G3 .... Guam Green Growth
GCC .... Guam Community College

GDP	gross domestic product
GE AESS	GE Aviation Engine Services Singapore
GECCO	Guam Ecosystems Collaboratorium for Corals and Oceans
GED	General Educational Development
GEDA	Guam Economic Development Authority
GPA	Guam Power Authority
HIP	hot isostatic pressing
HSGC	Hawaii Space Grant Consortium
IEDO	Industrial Efficiency & Decarbonization Office
IOT	internet of things
ISO	International Standards Organization
JIT	just-in-time
LPBF	laser powder bed fusion
MCAD	mechanical computer aided design
MDA	Missile Defense Agency
MDAP	Major Defense Acquisition Programs
ME	mechanical engineering
MEF	Marine Expeditionary Force
MEX	material extrusion
MILSTRIP	military standard requisitioning and issue procedures
MRL	manufacturing readiness level
MRO	maintenance, repair and overhaul
NAVSEA	Naval Sea Systems Command
NDE	non-destructive evaluation
NGB	Naval Base Guam
NGSC	Nasa Guam Space Grant
NSF	National Science Foundation
NUWC	Naval Undersea Warfare Center
OEM	original equipment manufacturer
OLDCC	Office of Local Defense Community Cooperation
PACDIM	Pacific Dry-dock and Integrated Maintenance
PBF	powder bed fusion
PHNSY	Pearl Harbor Naval Shipyard
PIPCHE	Pacific Island Partnership for Cancer Health Equity
PISBDCN	Pacific Islands Small Business Development Center Network
PPP	Paycheck Protection Program

RCUOG .... The Research Corporation of University of Guam
REACT .... Reverse Engineering and Critical Tooling laboratory
RISE .... Rural Innovation Stronger Economy
ROK .... Republic of Korea
RSO .... Rapid Sustainment Office
SBA .... Small Business Administration
SSBCI .... State Small Business Credit Initiative
SSBN .... nuclear-powered, ballistic missile-carrying submarine
STEAM .... science, technology, engineering, art, math
STEM .... science, technology, engineering, math
STL .... Stereolithography format
TDP .... technical data package
THAAD .... Terminal High Altitude Area Defense
TSTF .... transshipment task force
UoG .... University of Guam
UV .... Ultra Violet
WAAM .... wire arc additive manufacturing

2. INTRODUCTION AND PROGRAM OVERVIEW

2.1 BACKGROUND

Economic diversification remains a top priority of Guam's Governor Lou Leon Guerrero, as evidenced by her establishment of a Economic Diversification Working Group in 2020 public/private task force to address this priority, together with the Guam Chamber of Commerce[1]. 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. To this end, ASTRO America was contracted by the Guam Economic Development Authority (GEDA) to assess the feasibility of a local additive manufacturing (AM) industrial base on Guam that will serve as a new economic engine for the island and U.S. Department of Defense activities in the region.

Indeed, Guam's geographic position makes it critically important to U.S. military operations in the Indo-Pacific region. While strategically important, Guam's remote location also creates supply chain and logistical challenges for the support of military assets on-island and in the region[2]. Currently, no major manufacturing capacity on Guam exists to support local fabrication. Spare parts for maritime, automotive, medical, and energy generator supply chains must be imported from long distances, creating repair backlogs and inflating sustainment costs.

To evaluate these conditions, the research team from ASTRO America was composed of 2 economists, 4 subject matter experts in additive and advanced manufacturing, and 3 experts in government operations and public-private partnerships. Each was tasked with identifying key stakeholders both on Guam and the continental U.S. (CONUS), in order to ascertain the current conditions of the economy, infrastructure, education, research capabilities, potential manufacturing demand, availability of capital, and skilled workforce on Guam as it pertains to bringing sustainable AM to the island.

1. "Governor establishes Economic Diversification Working Group," Guam Post. December 30, 2020.

2. Doornbos, Caitlin. "Pentagon report recommends expanded forces in Guam, Australia to challenge China in the Pacific," Stars & Stripes. November 29, 2021.

2.2 RESEARCH APPROACH

In the first three months of its feasibility assessment, the ASTRO America team undertook more than 40 external virtual meetings with individuals representing disparate stakeholder groups in Guam. Appendix 1 is a log of these meetings reported in Eastern Standard Time. These engagements were supplemented by research into economic, demographic, and military factors that would inform the format of the workshop that took place on-island.

As part of the Phase I feasibility assessment, the team toured various relevant sites (See Appendix 2: On-island meetings) and conducted a 1-day workshop in Guam on November 13-19, 2022, engaging local stakeholders to determine: (1) current capabilities and needs for supply chain development; (2) potential strategies for developing such a workforce and capabilities; and (3) potential demand, including U.S. Government stakeholders. (See Appendix 3: Workshop Agenda).

Interviews and participants included local members from academia, government, business, infrastructure, banking, military and non-governmental organizations that were invited to represent a range of viewpoints and backgrounds (See Appendix 4: Workshop attendees).

At the workshop this information was presented (Ref: Appendix 5: Workshop Findings) and during the afternoon breakout sessions, all participants were invited to share their viewpoints, ideas and make comments as well as given an opportunity to add written ideas on posted questions on the walls. In addition, an online questionnaire was offered for more detailed feedback.

3. AM OVERVIEW

3.1. WHAT IS ADDITIVE MANUFACTURING?

Additive manufacturing (also known as 3D printing) is a relatively new manufacturing process that builds parts layer by layer directly from 3D digital data. It is unlike traditional machining and milling production processes that cut away material to make the desired shape, and instead additive manufacturing (AM) builds a part from nothing, using fine layers of material laid down into the 3D space. (Figure 2.)

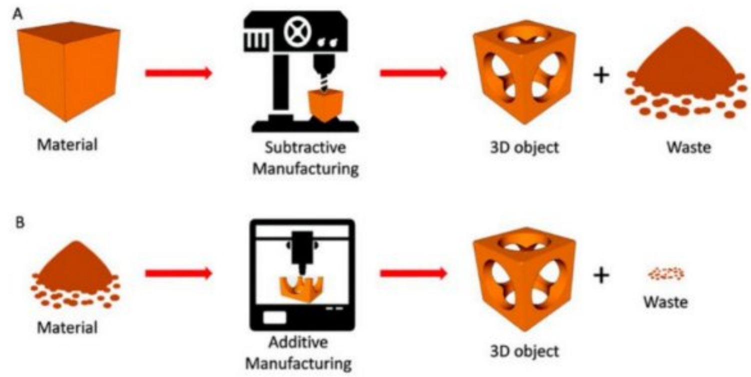


Figure 2. Traditional machining method versus 3D printing (Source: BitFab)

AM was developed/ commercialized in the U.S. in the 1980s and was initially used as a rapid way to produce viable polymer prototypes of products for automotive and other consumer products industries. Besides rapid prototypes, AM was also applied to building investment casts and fast, inexpensive production of tooling for traditional manufacturing. Since then the technology, materials and software have evolved to levels of accuracy, viability and usage that the inventors would never have thought possible.[3]

In the mid-1990s, processes for building metal parts via AM became possible, including a process first developed in Leuven, Belgium known as laser powder bed fusion[4] – a highly-precise method of melting metal powder-particles into a shape, layer-by-layer. Over the course of the next decade, this technology has advanced as a critical solution for FDA-approved medical implants, since porous biocompatible titanium structures can only be produced using this process.

Other high-precision industries including aerospace, defense, and energy generation have since initiated protocols to accept metal 3D printed parts as well. With GE and other aerospace companies building FAA-approved components such as jet engine fuel nozzles and heat exchangers, the technology's adoption has spread across multiple industry-verticals and markets[5].

Outside of metallic AM, a variety of applications have increasingly leveraged the benefits of AM including pioneering work by Invisalign for rapid production of custom dental aligners[6], Siemens for custom in-ear hearing aids, and a variety of tooling such as jigs, fixtures[7],

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3. Gibbs, Samuel. "Chuck Hull: the father of 3D printing who shaped technology". The Guardian. Sun 22 Jun 2014

4. KU Leuven. Additive Manufacturing Research.

5. Saunders, Sarah. "GE Aviation Announces 100,000th 3D printed Fuel Nozzle Shipped from Auburn Plant." 3DPrint.com. August 24, 2021.

6. Gianluca M. Tartaglia, Andrea Mapelli, Cinzia Maspero, Tommaso Santaniello, Marco Serafin, Marco Farronato, and Alberto Caprioglio. "Direct 3D Printing of Clear Orthodontic Aligners: Current State and Future Possibilities." National Library of Medicine, April 5, 2021.

7. Goehrke, Sarah. "Automated Jig And Fixture Generation Eases 3D Printing Onto The Factory Floor." Forbes. February 3, 2021

guides, and investment casting molds[8]. Additive manufacturing's ability to generate otherwise unattainable geometries has allowed component producers to reduce part-counts, and enhance system efficiency, such as the production of large complex cooling ducts applied to electronic systems cooling channels.

As AM technology improved, so has the 3D computer aided design (CAD) software to further AM adoption. Customized digital AM tools produced by Materialise and other 3D specialists help engineers tailor part concepts to AM formats including, optimizing configurations, orientation, and shape. They are also appropriately converted to the [STL file] format which allows for 3D printers to process the data. These tools have also been used effectively in maintenance, repair, and overhaul operations to reproduce obsolete parts. To do so, new reverse-engineering software tools have been developed to 3D scan and then 3D print parts to replace out-of-service parts. Such an activity is the principal focus of a major U.S. Air Force initiative called Pacer Edge[9], undertaken by the Rapid Sustainment Office.

3.1.1. TYPES OF ADDITIVE MANUFACTURING PROCESSES

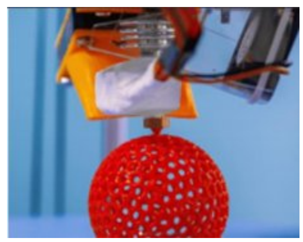
While AM started with just a couple of key commercial technologies – Stereolithography from 3D Systems and Fused Deposition Modeling from Stratasys, there was a rapid development of additional and alternative methods for AM production as well as materials to match. From a small choice of materials in the past, the AM industry now offers a wide range of metals, polymers, ceramics, biologicals, sand and concrete.

ISO/ASTM defined seven categories of AM processes as follows[10] :

8. Kuester, Evan. "The Impact of Additive Manufacturing on Investment Casting." Foundry Management and Technology. April 27, 2022.

9. Bihlajama, Leyinzca. "OC-ALC unveils DOD-first in additive manufacturing." 72nd Air Base Wing, Tinker Air Force Base. Aug 25, 2022.

10. ASTM International, a standards development organization, was formerly known as the American Society for Testing and Materials.

AM PROCESS	DESCRIPTION	EXAMPLE APPLICATIONS	
Vat Polymerization	Uses UV light to selectively cure polymer resin		*Figure 3. 3D printed jawbone showing key blood vessels and anomalies for surgical planning (Source: 3D Systems)*
Powder Bed Fusion	Laser or electron beam selectively melts the powder to form the shape		*Figure 4. Metal 3D printed hip cups*
Material Extrusion	Polymer is heated and extruded out of a nozzle		*Figure 5. Parts made through the extrusion method. (Source: Ion Industries)*
Binder Jetting	A jetted resin is selectively deposited and binds powder together		*Figure 6. Binder-jetted parts (Source: ExOne)*
Material Jetting	Liquid resin is jetted out of a nozzle and cured		*Figure 7. Medical models created via Material Jetting technology. (Source: Stratasys)*
Sheet Lamination	Sheets of materials are cut and stacked to form an object		*Figure 8. Sheet laminated ceramic bearing (Source: CAM-LEM)*
Directed Energy Deposition	Feedstock (powder or wire) is injected into a molten pool created by an energy beam (laser, electron or arc		*Figure 9. DED technology enables the rapid production of robust, precise metal parts. (Source: Big Metal Additive)*

These technologies may have some similarities but each delivers distinct advantages and materials that can be used in different applications. Some more recent technologies that don't quite fit into the categories above include: Direct Ink writing, for electronic circuits and bioprinting; Cold Spray which uses high-speed blown powder without melting, concrete 3D printing for infrastructure, and hybrid systems that combine AM and subtractive methods in one platform.

3.1.2. THE INDUSTRIAL AM PROCESS

Although some AM technologies listed above have fairly simple operations, for high-end industrial AM, there are a series of steps that can be complex and time-consuming that have to be completed for parts to be viable. For any industrial AM initiative to be successful, all of these steps need to be planned and executed with a high level of discipline.

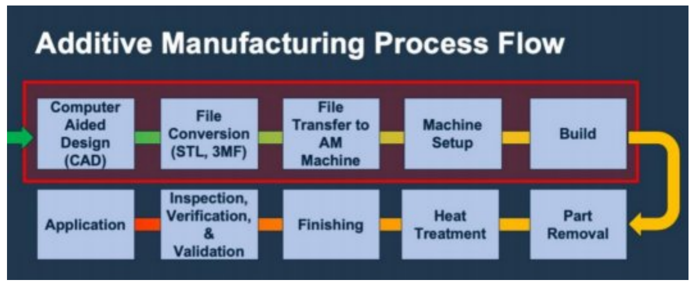


Figure 10. The AM process flow (Source: Craig A Brice)

The steps in the first row of Figure 10 apply to all 3D printers.

- **Computer Aided Design (CAD):** Additive manufacturing is 100% driven by 3D digital data, which is generated by design engineers using 3D CAD software. The leading and most commonly used 3D CAD platforms include: Siemens NX, SOLIDWORKS, Autodesk Inventor. Newer and less expensive CAD systems that are commonly used in schools include: PTC's OnShape and Autodesk Fusion. All these platforms are capable of delivering designs tuned for AM.

- **File Conversion:** Standard 3D file formats for AM are STL and 3MF. All CAD data must be able to be converted into these formats to continue.
- **File Transfer to AM Machine:** Once the data is converted, the files are transferred via Ethernet, thumb drive or cloud communication.
- **Machine Setup:** All 3D printers are delivered with their own control software (often called slicing software) to enable the 3D data to be checked for errors, and sliced into build layers. The more advanced AM systems also enable settings (where appropriate) for print parameters, toolpath control, laser settings, nozzle dimension, infill, temperature, print speed etc.
- **Build:** Once all the setup is complete, the build of the parts can begin.
- **Part Removal:** Depending on what AM system is in use, part removal can be very simple or quite complex. For basic desktop 3D printers, part removal is often as easy as removing a part from the build plate with a palette knife.

However, for high-end metals systems (Powder Bed Fusion etc.) parts often have to be removed using Wire EDM (Electrical Discharge Machining) to detach the metal parts from the build plate.

Post Processing is necessary for almost all 3D printed parts although requirements can vary widely depending on what system is in use.

- **Heat Treatment:** Often parts created using Binder Jetting undergo solution annealing, aging or hot isostatic pressing (HIP). Metal parts from Powder Bed fusion or DED (Directed Energy Deposition) will need some kind of heat treatment, usually in a furnace, and often require HIP to close or reduce porosity.
- **Finishing:** Almost all 3D printed parts need some kind of finishing, for example, removal of supports from vat polymerization or powder bed metals. Many parts also require polishing, either manually or using CNC (Computer Numerical Control), tumbling or finishing machines, painting, where appropriate.
- **Inspection, verification and validation:** Inspection of parts is a requirement to ensure that all parts are within tolerances and free of defects. This can be performed manually with calipers, or using CMM 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.

A fully functioning industrial AM operation often requires many more systems and processes alongside the 3D printers, and so a lab will often be populated as per Figure 11.

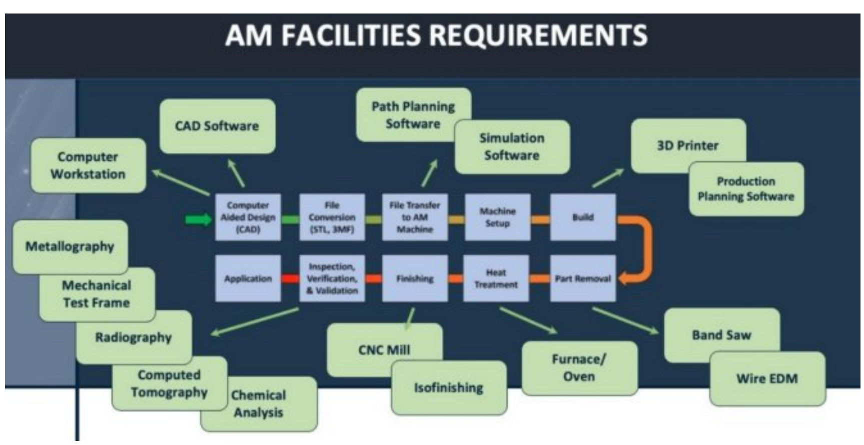


Figure 11. Typical equipment array for industrial AM

3.1.3. WHAT AM BRINGS TO THE TABLE

Recent estimates by the US Department of Energy (DOE) show that AM, compared to traditional manufacturing can slash production waste and materials costs by nearly 90% and cut manufacturing energy use in half[11]. This is also why the European Union has launched a major circular economy additive manufacturing initiative, to advance innovation and waste reduction across the world within strategic production industries and is fast becoming a major focus of global research.[12]

AM's most cited benefit is enabling part designs that otherwise would be composed of a multitude of parts assembled across a disaggregated global supply chain. The previously referenced additively manufactured aircraft engine nozzle, for example, is built as a single part from a 3D printer and improves fuel efficiency by 15% and reduces weight by 25% over conventionally made nozzles. If produced using conventional casting methods, every injector inside the fuel nozzle would require at least 20 parts welded and brazed together[13].In addition, AM realizes the ability to produce parts at low volumes, without tooling and long production/ assembly lines — essentially to manufacture outside of the traditional manufacturing shop floor. Since AM systems have a relatively small footprint, part production is theoretically possible anywhere a 3D printer is installed. Such flexibility can alter the traditional formulation of supply chains, enabling localized, point-of-need production and to produce parts on demand, which addresses months or even years it takes to source one-off replacement parts.

Figure 12. Innovative lightweight aerospace bracket delivers improved part performance with 50% less weight (Source: 3D Systems)

AM also enables the development of new classes of parts that are no longer restricted by traditional production methods (See Figure 12). In essence, AM parts can be made with just about any geometry, allowing for lighter weight parts, improved part performance and consolidation of assemblies into a single part.

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11. "Additive Manufacturing: Building the Future. July 2019", Office of Technology Transitions. U.S. Department of Energy; Masurtschak et al., "Impact of Additive Manufacturing towards the Environmental Sustainability". Erasmus Center of EU. Jan. 2018.

12. "Europe Examines Additive Manufacturing to Foster Circularity in Defence." European Defense Agency. June 24, 2022.

13. "GE Aviation reaches milestone with 100,000 fuel nozzle tips". Metal AM Magazine. August 17, 2021

In the last 10 years, AM systems have finally been able to achieve much higher levels of repeatability and reliability, often achieving six sigma performance levels, making AM parts contenders for production-grade requirements and supply chains.

Because of this increased part quality and repeatability, AM-produced parts have been gaining acceptance into mainstream manufacturing and supply chains. As an example, GE uses more than 300 AM parts in its GE9X aircraft engine (Figure 13), helping improve performance by lowering manufacturing costs, reducing material wastage, reduced weight of the assembly, simplifying the supply chain and offering faster time to market.

Figure 13. Ranked the world's most powerful engine by Guinness World Records, the GE9X engine uses more than 300 AM parts. (Source: GE Additive)

The global AM market is now estimated by the ASTM Wohlers Report at a value of $15 billion in 2022[14]. Major aerospace companies and operations including NASA, Blue Origin and SpaceX now use AM to leapfrog technology development in the production of aircraft, satellite and rocket parts.

According to the Wohlers' Report as of February 2022 the Food and Drug Administration (FDA) had cleared more than 250 medical devices made by AM. It also takes a role in the vision of "Industry 4.0", also called 'The Fourth Industrial Revolution', which combines cyber-physical systems, the Internet of Things (IoT) and robotization to deliver smart digital manufacturing workflows and processes.

3.2. WHY CONSIDER ADDITIVE MANUFACTURING FOR GUAM?

3.2.1. ADVENT OF JUST-IN-TIME

Supply chain management underwent a global revolution with the advent of Just-in-Time (JIT) methodologies. Pioneered in Japan (Toyota is often credited with being the first)[15] JIT manufacturing became extremely popular in the United States

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14. "3D Printing and Additive Manufacturing, Global State of the Industry," Wohlers' Report 2022

in the past thirty plus years, broadly favoring lean production models with slim inventories and quick transportation times. To make JIT work, "supply-chain relationships might require multiple suppliers, closer locations, and suppliers that can provide materials with minimal notice." This creates "the problem that smaller orders will be needed for JIT. Therefore, new negotiations may be needed because of minimum order requirements. Even if a slightly higher price is paid, the cost difference could be offset by the low cost of inventory."[16] JIT can work well if the manufacturer has multiple supply options, with cheap transportation costs, and flexible minimum order sizes. Guam will inherently struggle with JIT production models as the island's remote location, small population, requirement for Jones Act compliant shipping from the U.S., and other factors exacerbate structural difficulties in the JIT model.[17]

Industrial AM can assist in JIT manufacturing models by providing the opportunity to produce parts at the point of need and on demand. Otherwise, JIT can exacerbate supply chain challenges by discouraging prepositioning of part inventories/production processes. AM, in contrast, may potentially reduce supply chain delays, avoid minimum order quantities while keeping inventory costs low.

3.2.2. SUPPLY CHAIN ISSUES FOR PARTS

Sourcing spare parts is an example where flexible AM could solve existing supply chain problems. JIT has extended to a range of industries. Among the two dominant on-island industries (tourism and Defense), such practices affect maintenance of aircraft—essential to transporting both vacationers as well as commercial and military supplies. Guam is home to a relatively busy airport, A.B. Won Pat Guam International Airport, which sees approximately 1.4 million departures as well as 1.4 million arrivals per year, with gross take-off weight of 4-5 billion lbs. per annum.[18]

These aircraft require significant sustainment and repair in Guam as well as longer term overhaul (and re-engineering) activities at national maintenance facilities supporting the Guam-based aircraft, such as United Airlines' San Francisco-based installation. A key component of aircraft maintenance/repair involves replacing old/

15. Wilson, Georgia. "Timeline: The history of just-in-time manufacturing." Manufacturing Magazine. December 1, 2021

16. Calderone, Len. "The Benefits of Just-In-Time inventory." Manufacturing Tomorrow. June 1, 2017. Calderone, Len. "The Benefits of Just-In-Time inventory." Manufacturing Tomorrow. June 1, 2017.

17. Jones Act of 1920 mandates that all cargo shipping between U.S. ports occur only on U.S.-flagged vessels, and not foreign vessels. The Jones Act is credited with artificially inflating cost of shipping goods to Guam. Gilbert ¸ Haidee Eugenio. "Guam seeks exemption from federal law to ease cost of shipping gasoline." The Guam Daily Post. March 26, 2022

18. "Number of flights," Won "Number of flights," Won Pat International Airport Guam.

worn-out parts (anything from mundane interior products, such as passenger tray-tables to essential flight-critical components, such as engine fuel nozzles).

COVID-19 worsened logistical challenges affecting key part supply chains, delaying an already strained system for requisitioning spare-parts for aircraft and their engines.

For example, casted metal parts, that otherwise should only take a month to deliver have now reportedly taken a year and half to receive, through traditional manufacturing channels.[19]

According to one study, "a large 747-type aircraft can have nearly 6 million individual parts produced by a global supply chain of approximately 550 companies, some of which may not exist a decade from now. Sustainment organizations struggle with long lead times, resulting in maintenance delays or grounded aircraft. [The Air Force] reported lead times as long as 800 days for constant speed drive castings… [In] 2016, 29% of all U.S. Marine Corps F/A-18 Hornets were grounded pending spare parts."[20]

As Middle East airline Etihad has demonstrated, additive manufacturing offers another potential option. Etihad is the first airline to be authorized by the European Union Aviation Safety Agency to leverage AM to perform maintenance, repair, and overhaul activities, manufacturing and flying 3D printed parts in-house. They have focused on driving part-costs and delivery times down, with the ability to print up to 50% of airplane cabin-parts on demand.[21] Separately, GE Aviation Engine Services Singapore (GE AESS) has introduced metal AM technology for engine airfoil repair and manufacture[22].

Replicating such techniques, under FAA approval, would establish a critical new capability in Guam. Absent on-island parts manufacturing capacity, the only alternatives are either importing parts, or refurbishing/reusing used parts. Importing is costly, both in terms of dollars and time. Refurbishing or repurposing components requires existing parts to have been available on-island and in usable condition.

However, Guam has experienced a steady decline in overall imports. As data from the port of Guam shows, this decline began pre-COVID (container traffic fell 18

19. Lampert, Allison, et al. "Aircraft parts output is being grounded by worker shortages." Reuters. September 27, 2022.

20. Totin, Ashley. MacDonald, Eric. Conner, Brett. "Additive Manufacturing for Aerospace Maintenance and Sustainment." Defense Systems Information Analysis Center. November 2, 2019.

21. Yerman, Jordan. "Parts on Demand: 3-D Printing Brings Efficiency to MRO." APEX. March 22, 2018.

22. Chuanren, Chen. "GE Aviation Claims Industry First for Additive Manufacturing in MRO." Aviation Week. November 23, 2021.

percent from FY 2016-2019) and has not rebounded since (FY 2021 was still below FY 2018).[23] (See Figure 14).

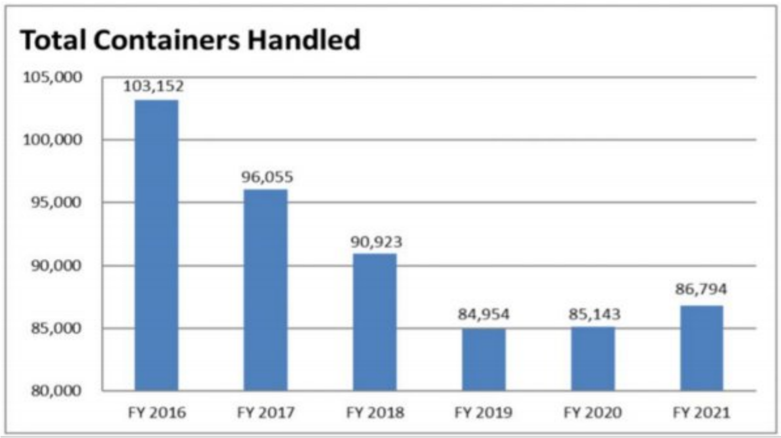

Figure 14. Port of Guam statistics on total containers handled from 2016 - 2021

Another affected industry is the automotive market. In fact, multiple participants at the 2022 workshop in Guam expressed interest in discerning how additive manufacturing might reduce lead-times for replacement automotive parts on-island. In response, ASTRO America analysts indicated that AM has long been used in specialized manufacturing (particularly Formula-1 and other high performance car segments). Increasingly, AM practitioners have explored how this experience might be applied to requisitions of civilian (after-market) car parts.[24] The potential for an on-island 3D printer to be able to produce small numbers of parts could reduce wait times and potentially costs for people who need car repairs. Furthermore, it could also provide savings for auto repair establishments who otherwise have to choose between stocking inventory or ordering as parts are needed.

However, currently the manufacturers' warranties would be voided if using part production process that was not validated by the original equipment manufacturer via methods similar to those discussed in Section 5.4.8. To address these challenges, leading additive innovators, including Siemens are developing new software tools that can enable companies to provide part-designs to authorized additive part producers to ensure appropriate quality control; Guam could serve as a potential pilot for such an initiative. In essence, orders could be filled via a digital library of parts, serving customers by 3D printing goods on-demand in Guam as well as customers based elsewhere within the Indo-Pacific region.[25]

3.2.3. SUPPLY CHAIN OPPORTUNITIES

Such a development has the potential to address immediate supply chain challenges in this remote location but also help resolve cross-border production

23. "Vessel Calls". Port Of Guam. 2021.

24. Renshaw, Jerry. "How the Automotive Industry is Using 3D Printing," Advanced Autoparts. January 2, 2020.

25. See Siemens DiMax software,

disruptions exposed by the COVID-19 pandemic.[26] These disruptions were described in great detail in the United Nations-sponsored report which found “maritime connectivity in the Pacific region” to have “suffered a significant setback due to the Pandemic.” As a result, multinational corporations are described as operating at an inflection point, “restructuring their supply chains at the risk management level as fragmented production strategies showed vulnerability in the COVID-19 crisis.”[27]

Such a sentiment echoed discussions ASTRO America researchers had with Guam-based companies including United Airlines representatives who indicated newly determined plans to re-locate major maintenance repair and overhaul facilities to serve Asia. Restructuring of supply chains for closer availability and greater resilience provide opportunity for new entrants to integrate themselves into supply chains. Guam’s position as a potential transshipment hub for the region highlights potential to insert itself as one such pathway for serving both U.S. and Asian markets. However, to realize the full extent of that opportunity, Guam has to be able to produce items of value for suppliers. Guam‘s production of durable goods was only 11.7% of its GDP in 2021, about one-third of the share of production of durable goods compared to the United States as a whole (32.7%).[28] This shows that Guam has substantial room to increase its durable good production to be closer to the American average. Additive manufacturing of replacement parts for aerospace and defense markets is one means to accomplish industrial rebalancing and diversification. Given supply chain opportunities identified on and off island, the potential is there—as long as lead system integrators or original equipment manufacturers will qualify/certify Guam-based suppliers through processes explored in section 5.4.7.

First and foremost, however, opportunities for supply chain improvements in the Defense sector are likely to take precedence over other economic segments, due to the urgency and sheer market size.

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26. Twinn, Ian. Qureshi, Navaid. Lopez Conde, Maria, Garzon Guinea, Carlos. “The Impact of COVID-19 on Logistics.” International Finance Corporation. June 2020.

27. “COVID-19 and Its Impact on Shipping and Port Sector in Asia and the Pacific”. United Nations ESCAP. September 30, 2020

28. Calculation using BEA data for Guam table 1.1 https://www.bea.gov/sites/default/files/2022-10/gugdp1122.pdf compared to US BEA data table 3 https://www.bea.gov/sites/default/files/2022-02/gdp4q21_2nd.pdf

4. GUAM OVERVIEW

4.1. CURRENT GUAM ECONOMIC CONDITION AND DOMINANCE OF ONLY TWO INDUSTRIES

4.1.1. MARKET PROFILES IN GUAM

Guam's economy is dominated by two sectors: the 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.[29] These two sectors face sharply different near-term trajectories. Military activity is set to grow over the next five years, as a result of a major commitment of U.S. military strategy to prioritize Guam. Tourism was devastated by the COVID pandemic and has been slow to rebound. Prolonged impacts of COVID, coupled with the sharp appreciation of the U.S. dollar is likely to depress tourism in the short and intermediate terms.

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.[30] The increase in economic growth was led by on-island demand with personal consumption contributing to more than 2 percent of island GDP growth; private fixed investment and government spending also contributed significantly as shown in Figure 15. Holding back economic growth was a sharp decline in exports, including international tourism on-island as international visitors spending is considered an export for GDP accounting purposes. Exports alone would have caused total Guam GDP to shrink by over 3 percent. Given exports relative share of GDP the gross decline in exports was about 50 percent in 2021, driven by an over 75 percent decline in international visitors in 2021.

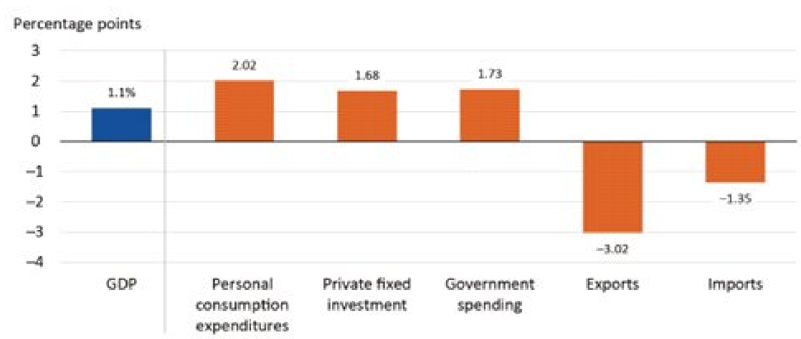

Figure 15. Guam: Contributions to the Percent Change in Real GDP, 2021

29. "Guam Economy Profile." September 18, 2021. Index Mundi.

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

4.1.2. GUAM: A STRATEGIC HUB FOR U.S. FORCES IN THE PACIFIC

According to the Congressional Research Service, the two-decade long buildup of military forces in Guam has been focused on "increasing U.S. operational presence, deterrence, and power projection for potential responses to crises, disasters, or other contingencies to support Japan, Republic of Korea (ROK), the Philippines, Taiwan, or others in Asia." These policy priorities were affirmed by President Obama's so-called "pivot to Asia" in 2012 and the issuance of U.S. Department of Defense Strategic Guidance stressing U.S. objectives for countering China's own potential Anti-Access/Area Denial (or A2/AD) goals. By 2020, 60 percent of the Navy's vessels would be assigned to the Pacific, including 6 of 11 aircraft carriers. At the center of U.S. plans was staging key Navy, Marine Corps, and Air Force assets in Guam. In August 2014, then-Deputy Defense Secretary Bob Work labeled Guam as our nation's "strategic hub" in the Pacific.[31]

The Trump and Biden Administrations have continued to concentrate U.S. military interests in Asia, with Defense Secretary Austin recently describing the Indo-Pacific as DOD's "priority theater" and highlighting the presence of more than 300,000 American service members in the region "working with allies and partners to ensure the rules-based international order is maintained." Forces based in Guam remain central to such an effort as the closest U.S. territory to the contested South China Sea.[32]

Figure 16. This aerial view of Naval Base Guam shows Apra Harbor with several Navy vessels in port, Aug. 24, 2020. (MacAdam Kane Weissman/ U.S. Navy)

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.[33]

Ballistic Missile submarines can also be serviced in Guam and they represent a critical element of the U.S. nuclear triad deterrence posture against U.S. peer

31. Kan, Shirley A. "Guam. U.S. Defense Deployments". Congressional Research Service. November 2014.

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

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

competitors. Additionally, Andersen Air Force Base serves as an important staging area for long-range bombers, including B-1, B-2, and B-52 aircraft, as well as the 37th Maintenance Group to sustain quality aircraft, munitions, and equipment. Bomber aircraft are essential for overcoming A2/AD challenges, allowing U.S. forces to project unsurpassed military power (for both heavy conventional attacks as well as potentially strategic/nuclear strikes)—far and wide throughout the Indo-Pacific region. Moreover, there is a growing Marine Corps resulting from a transfer of forces from Okinawa residing at Camp Blaz.[34]

In addition to the 154,000 civilian American citizens on the island, there are nearly 22,000 U.S. military personnel and their families. Given the threat posed to the American people and the critical assets deployed there, Admiral Phillip S. Davidson, Commander of the U.S. Indo-Pacific Command has designated funding for a new forward-deployed complex to oversee extensive air and missile defense of Guam his number 1 priority. Accordingly, in 2023, the Missile Defense Agency has committed $1 billion to jumpstart construction of a network of defensive missiles, command, and control, radar capacity, and other countermeasures to provide "360 degree" protection of Guam.[35]

Figure 17. Guam remains pivotal in defending U.S. and Allied interests in light of territorial/ trade aspirations of China and North Korea's ambitions.

However, the island's remote location presents considerable logistical challenges for resupplying both military and civilian stocks, especially from CONUS-based suppliers. According to both military and civilian stakeholders interviewed as part of this study, year-long shipping delays for hard-to-source replacement parts oftentimes cause shortages for ships, aircraft, automotive, and medical equipment parts, potentially impairing fleet readiness. Submarine Squadron 15 based in Guam maintains a long-lead item part list, much of which may one day be fabricated by additive manufacturing. As the U.S. Navy presence grows with a strong submarine fleet, a capability for supporting local and rapid repair will be critical to maintaining readiness in the western Pacific region.[36]

34. "USMC Reactivates Base On Guam." Marine Corps Base Camp Blaz.

35. Olson, W. "Guam Missile Defense No. 1 priority in deterring China, INDOPACOM Leader Says." Stars & Stripes. March 5, 2021.

36. ASTRO America meeting with Submarine Squadron 15 Commodore at Polaris Point. November 15 (ChST), 2022.

4.1.3. MILITARY CONSTRUCTION

The U.S. military has committed to major expansion in Guam with defense contracting rising sharply, a particularly important decision given the problems ongoing in tourism. DoD contracts hit a record $750 million in fiscal year 2022 with a long term $990 million contract to Black Construction-Tutor, Hensel, Phelps and more helping to drive the increase.[37] U.S. Federal military and non-military spending contribute roughly $2 billion of the overall $6 billion annual on-island GDP.[38] The chart below highlights growth in military construction on-island.

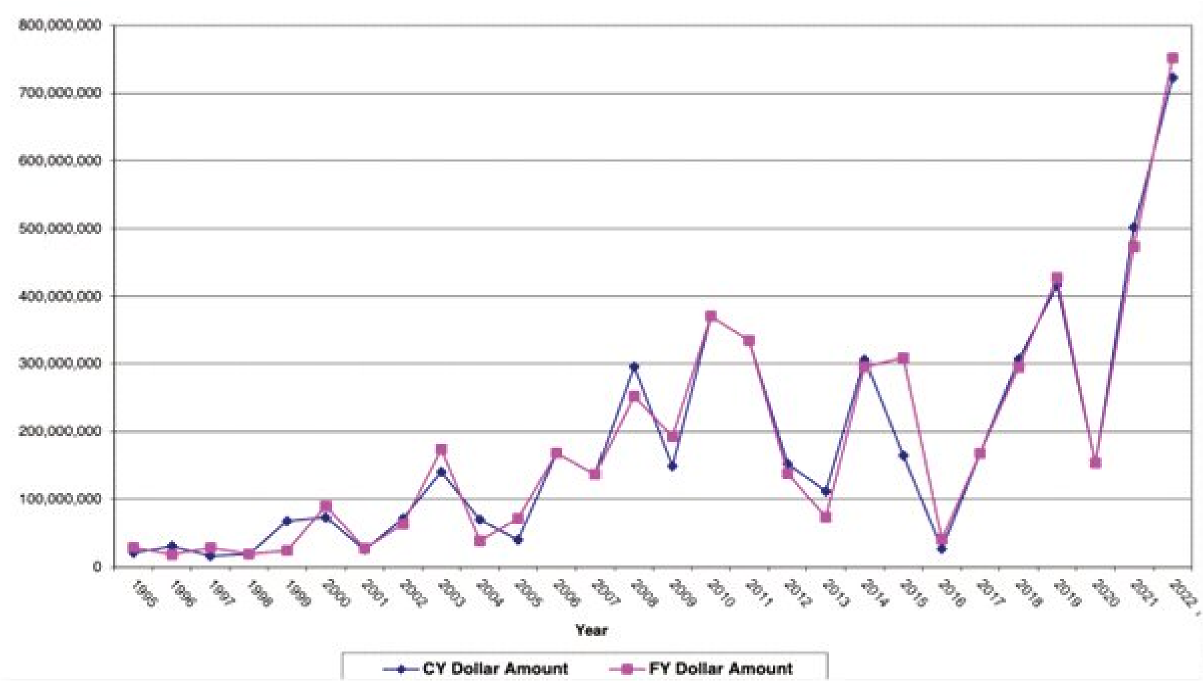

Figure 18. DOD Construction Contracts Archive, 1995 through FY 2022

4.1.4. CONCRETE 3D PRINTING AND GUAM

Construction is a key economic activity in Guam with the military buildup, demand for more housing and ongoing hotel construction. Utility of concrete 3D printing is a topic that has thus been raised frequently throughout this research phase. It is clear that there is a construction squeeze in Guam caused by a combination of several factors: lack of skilled labor, restrictions on the availability of H2B visas that have only recently been lifted, and supply chain delays of imported construction materials such as concrete, steel etc.

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37. “Department of Defense Contracts, Guam”. Bureau of Labor Statistics.

38. “Guam Economy”. Country Reports.

Additionally, real estate prices in Guam are very high and in 2022 the median house price on Guam was $426,000[39], up by 12% from 2021. With the plan to move 5,000 Marines and their families to Guam over the next 3 years, housing demand is going to increase, although supply remains depressed.

Figure 19. ICON's Vulcan 3D printed construction system. Source: DesignBoom

Consequently, there is a lot of pressure to develop affordable housing for both islanders and military personnel, and to do it quickly. Concrete 3D printing is therefore of growing interest to the Island for the potential of offering rapid construction of less expensive buildings, as well as requiring fewer skilled workers, less energy to construct and which adhere to building codes.

The DoD has also seen the potential for concrete 3D printing, for example with the Marine Corps conducting research with 3D printing of concrete for structures since 2018, most recently at Camp Pendleton via the Defense Innovation Unit (DIU). The US Army is also researching 3D printing of structures via the DIU at Ft. Bliss TX.[40]

ICON is one of the leading companies in the field of 3D printed concrete structures, with plans to build a community of 3D printed homes in Texas starting in the near future.[41] Representatives at ICON have indicated that their structures have been certified to meet Miami-Dade Wind-Level standards of up to 195 mph, as well as seismic testing. They are moving towards ensuring 3D printed structures can meet building codes and insurance requirements.

Figure 20. 3D printed barracks at Camp

39. Eugenio, Haidee. “Hard to find a house as Guam’s new median home price surges to $426k.” Pacific Daily News. October 3, 2022.

40. “Defense Innovation Unit and US Army’s Installation Management Command Begin Construction of Three 3D printed Barracks at Fort Bliss.” Defense Innovation Unit. April 5, 2022.

41. ICON web site. https://www.iconbuild.com/

4.1.5. TOURISM

Such technology could be applied to building accommodations for tourism in Guam if validated according to universally accepted civil engineering standards. However, the business model would need to be evaluated in the context of contemporaneous demand, given recent declines in commercial traffic in recent years. Prior to the pandemic Guam's tourism industry was growing with more than 1.631 million visitors in fiscal year 2019.[42] Korea and Japan combined for 86 percent of total visitors, with mainland America/Hawaii only accounting for 6 percent of total travelers. Chinese tourism was quite small, representing just 1 percent of total visitors, indicating a potential source of continued growth as Chinese international tourism was projected to grow substantially over the coming decades.

Post pandemic tourism remains minimal. For the calendar year 2022 there have been only 223,553 arrivals (through October).[43] Visitor source has changed with Korea now accounting for over 70 percent and America for 15 percent. Japan only accounts for 4 percent, down from over 40 percent pre-pandemic. For a direct comparison, October 2022 arrivals were only 26 percent of October 2019 levels. Tourism has substantial area to continue to rebound, but even a doubling from current levels would leave the industry at perhaps half of the pre-pandemic levels.

42. "Fiscal Year 2019 Summary, Guam." Guam Visitors Bureau.

43. "October 2022 Monthly Arrivals Summary, Guam". Guam Visitors Bureau.

4.1.6. LABOR MARKET

Guam's labor market has rebounded sharply from the devastation caused by COVID. Unemployment has declined to only 4.8% in June 2022, after having reached 16.5% in March, 2021.[44] Over the past twelve months (June 2021-June 2022) private sector employment rose 4.1% resulting in a total of 47,2000 private sector jobs, while employment by the Government of Guam rose more slowly at 2.4% to 11,350 total jobs. Federal government employment fell slightly (0.5%) and is at 3,920 jobs. The largest sectors of employment remain service sector jobs, retail trade, government, construction as this chart shows total employment by major categories:

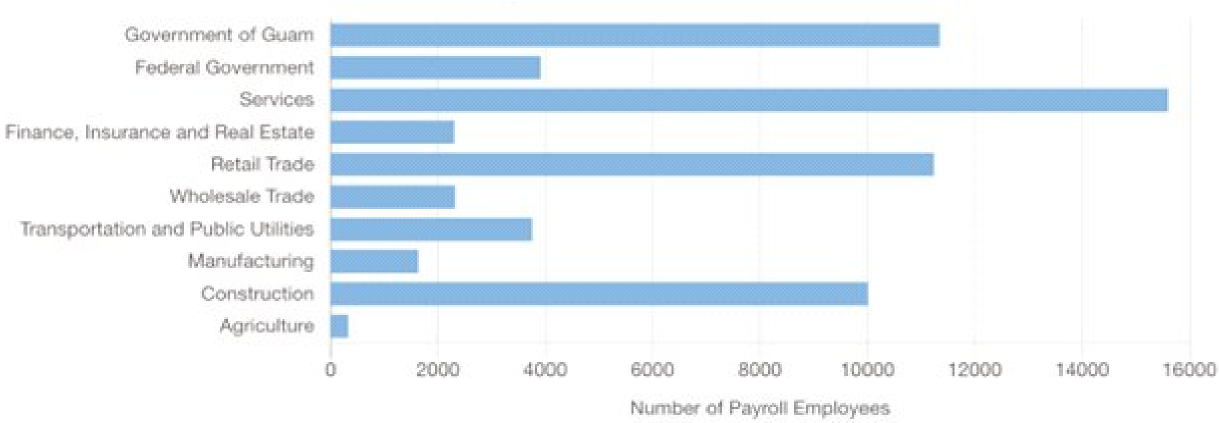

Figure 21. Current Employment Statistics June 2022

Wages in Guam remain lower than in the rest of the United States with average hourly earnings on island at $19.10 compared to $28.01 for the U.S.[45] Lower wages are the case across the board with construction wages at $17.05 (vs $26.87) and production workers being paid $16.34 (vs $20.71).

44. "Current Employment Statistics – September 2022." Guam Bureau of Labor Statistics

45. "Occupational Employment and Wages in Guam – May 2021." U.S. Bureau of Labor Statistics.

4.2. GUAM'S FOCUS ON ECONOMIC DIVERSIFICATION

4.2.1. ACTIVITY OVERVIEW

Economic diversification has been designated a top priority for Guam, given the weaknesses highlighted during the COVID pandemic that decimated tourism and the supply chain. In January 2021, the Governor of Guam established the Governor's Economic Diversification Working Group to investigate new sources of sustainable jobs while reducing reliance on the two main industries – tourism and military – and build more self-sufficiency, while developing new ways to inventively recycle more waste.[46]

Proposed alternative industries include:

- Alternative Dispute Resolution (ADR)
- Guam Captive Insurance
- Guam Trust Incentives Act Program
- Relocation of High Wealth Businesses/Individuals from Asia
- Pharmaceutical Manufacturing
- Construction & Labor
- Ship Repair Industry
- Safe Haven Port
- Silicon Village Initiative
- Satellite Launching Industry
- Aquaculture and Agriculture

Though AM did not appear on this list, it has the potential to contribute to several of these areas, including construction, ship repair, space/satellite and agricultural industries. Nonetheless, no major manufacturing capacity on Guam currently exists to support local fabrication. Other industry segments including development of spare parts for maritime, automotive, medical, and energy generator supply chains must be imported from long distances, creating repair backlogs and inflated sustainment costs.

46. "Guam Governor Establishes Economic Diversification Working group." Marianas Variety News. Jan 2, 2021.

4.2.2. TRANSSHIPMENT

Rather than sustain these shortages and corresponding economic hardships, Guam is seeking to leverage its substantial port infrastructure to increase supply imports. In doing so, Guam hopes to address part shortfalls, but also assume a new role as an American transshipment hub in Asia. In December 2021, the Governor actually enacted a measure establishing the Transshipment Task Force (TSTF), under a provision authored by the local legislature's Vice Speaker Tina Rose Muña Barnes. This initiative was later affirmed with the award of a U.S. Department of Commerce Economic Development Administration grant to conduct an island-wide survey to discern appropriate public and private sector transshipment goals. In so doing, Guam will examine activities such as manufacturing, assembly, distribution, export business activities, and transfers between transportation modes. A number of factors are coalescing around the outlook and traction gained by such a priority.[47]

For one, U.S. policy in the Indo-Pacific region remains focused on sustaining peaceful relations, indicative of America's crucial commercial and cultural interests in the region. According to a recent White House fact sheet, the Indo-Pacific accounts for 60 percent of the world's current Gross Domestic Product (GDP) and contributes more than two-thirds to present global economic growth. Two-way trade totals over $1.9 trillion between U.S. and Association of Southeast Asian Nations (ASEAN)—the #1 destination for U.S. foreign direct investment.[48]

Additive manufacturing can play an important and, in specific ways, a catalytic role in supporting such commerce, and in turn, advance the island's transshipment strategy. For instance, the success of transshipment within Guam depends upon the ready availability of parts and equipment. If Guam-based interests are able to 3D print such components under JIT conditions, they may be able to strengthen global supply chains with immediate part-requisition. Additionally, Guam's ability to designate goods manufactured on-island as "Made in America" will help channel overseas trans-shipment activity into the United States. The value of this designation is the result of U.S. commercial diplomacy which has occurred over the last six years and may thus improve Guam's role in producing parts for domestic consumption—especially for government customers who prioritize "Made in America" designations.

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47. Pacific News Center. "Guam awarded EDA grant to build transshipment industry." December 2, 2021

48. The White House. "Indo Pacific Strategy of the United States," February 2022.

4.3. AM AND THE GREEN ECONOMY FOR GUAM

Beyond transshipment to the U.S. as well as Indo-Pacific based nations, Guam may seek to adapt AM as part of its internal consumption policies as well. On an island small and remote as Guam, recycling of materials and developing a self-contained, circular economy is among priorities[49] of thought leaders in the community—including researchers at the University of Guam. However, major parts of the local economy (including a largely fossil-fuel based energy market) would need to be substantially altered to realize such a goal. Ideally, no material used in a fabrication process would need to be brought to the island and no end-of-life material would need to be removed for disposal. Used products could be recycled into new feedstock that could be used in a manufacturing process to make a new item. Such a dynamic would reduce material waste but also reduces energy consumption necessary for primary feedstock fabrication and the transportation costs and environmental impact required to get it to the island. Research and development into 'cradle-to-cradle' material recycling, meaning the development of products that can be truly recycled, is a key initiative at the University and remains a focus of the G3 Makerspace. While it is still early in its development, the team has already recycled consumer polymer packaging into AM filament and is generating consolidation processes for making polymer 'bricks' that can potentially be used in low requirement structures such as bus stop awnings.

Toward similar goals, the U.S. government has written extensively on the role that additive manufacturing can play in addressing climate and decarbonization goals. In fact, the U.S. Department of Energy (DOE) estimates that AM has the potential to reduce waste and materials costs by nearly 90% and cut manufacturing energy by 50% when compared to traditional manufacturing processes.[50] The green benefits of AM have also inspired the European Union to launch major circular economy additive manufacturing initiatives to address manufacturing waste reduction within strategic industry segments.[51] This manufacturing topic area is fast becoming a major focus of global research and development. For Guam to have a robust and competitive manufacturing industry base, it will be necessary to adopt not only new processes like AM but adopt green workflows that reduce or eliminate waste and fabricate at the lowest cost possible cost and the lowest possible environmental impact.

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49. "Updates on Integrated Solid Waste Management Plan and Zero Waste Master Plan" Office of the Governor, Guam.

50. Additive Manufacturing: Building the Future. Office of Technology Transitions. U.S. Department of Energy July 2019.; Masurtschak et al., Impact of Additive Manufacturing towards the Environmental Sustainability. Erasmus Center of EU. Jan. 2018

51. "Europe Examines Additive Manufacturing to Foster Circularity in Defence." European Defense Agency. June 24, 2022.

5. CURRENT CAPABILITIES AND CONDITIONS ASSESSMENT OF GUAM

5.1. MANUFACTURING WORKFORCE AVAILABILITY

5.1.1. CURRENT MANUFACTURING WORKFORCE ASSESSMENT OVERVIEW

With a total population of 153,836 according to the 2020 Island Areas Census[52] and total employment of 58,390[53] in 2021, the largest single occupations on the island were office administrative support workers (8,030), construction and extraction workers (5,790) and food service and serving-related (5,580). While tourism and government comprise the main sources of industries in Guam, transportation and material moving (4,780) and installation, maintenance and repair (3,180) are significant sectors.

5.1.1.1. Availability and Skills

The availability of current skilled manufacturing workers, as categorized by the Bureau of Labor Statistics on Guam is low, but not zero. Table 2 presents a picture of current skilled manufacturing employment on Guam. Note that some workers may be employed in areas where they have skills in others (e.g. someone working at a restaurant may also be able to be administrative office staff).

JOB ROLE	AVAILABILITY
Welders, Cutters, Solderers and Brazers	190
Mobile Heavy Equipment Mechanics	130
Maintenance Workers, Machinery	70
Aircraft mechanics and Service technicians	60
Engineering Technologists and Technicians	60
Electrical Engineers	60
Mechanical Engineer	40
Miscellaneous Assemblers and Fabricators	30

Table 2.. May 2021 State Occupational Employment and Wage Estimates Guam

52. "2020 Island Areas Census Data on Demographic, Social, Economic and Housing Characteristics for Guam." United States Census Bureau. October 20, 2022.

53. "May 2021 State Occupational Employment and Wage Estimates." US Bureau of Labor Statistics.

5.1.1.2. Mean Wage Levels

According to the US Bureau of Labor Statistics, in May 2021 workers in the Guam Metropolitan Statistical Area had an average hourly wage of $19.10, about 32% below the national average of $28.01.[54]

Guam area employment was more highly concentrated in 9 of the 22 occupational groups including management, construction and educational instruction while twelve groups had employment shares significantly below their national comparison including production, healthcare practitioners and technical workers.

Guam has stated a need to increase wage levels overall and as increased salaries are necessary to attract certain skilled workers it should be no surprise that the highest paid average annual wages on island are for doctors: the 100 doctors on island earn an average of around $200,000 a year. Engineering and architectural managers are among the higher earners on the island at just under $100,000 (slightly below lawyers but 20 percent above other managers). Electrical engineers also earn significantly more (by nearly $75,000) than the average Guam worker.

Many of the jobs likely created by additive manufacturing would have above median wages, based on current wage scales. This is the case for engineers, and various mechanics and service technicians. Even the welders, cutters, solderers, and brazers category currently earns above the mean Guam workforce average ($19.65 vs $19.10). Should additive manufacturing facilities be created on island, increased demand for these workers in both the production and operation phases should further increase wages in these sectors.

Guam's existing workforce would be unlikely to be able to fully utilize a mid-to-large-scale additive manufacturing facility. Additional workers with skills would be needed. One solution could be found by retraining workers on the island from other sectors, who would be enticed by the higher wages and new opportunities in these jobs. Construction and tourism-related workers would be one source of new workers as would some of the unemployed/out of the labor force. Another solution would come from increased migration from off-island. These workers may have to come from other American sources, depending on the security requirements for work on a dual-use facility, or from other countries pending necessary work visas. New workers would likely need additional services on-island increasing total demand on-island, population, and economic output.

Fully capturing the impact of a new additive manufacturing facility on Guam will need to account for the increased demand for these types of workers, and their

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

corresponding demand for goods and services. This may increase wages across the board as, for example, if construction workers try to retrain/skill into manufacturing then the supply of construction workers fall. Meanwhile demand for new construction may rise as new housing is needed for imported workers. The share and magnitude of these effects depends on the total number of new workers needed, the differences in time horizon between construction of the facility and operation, and the share of workers that come from existing vs. off-island immigration.

5.2. ACADEMIC SKILLS NECESSARY FOR AM

5.2.1. FUTURE ACADEMIC/SKILL NEEDS AND HOW TO ADDRESS THEM

Additive manufacturing operations have workforce skills and requirements that are similar to other manufacturing industries; however, there are specific skill sets within AM that are unique and should be properly addressed. This section highlights some of those unique needs required for an AM-centric workforce. The workforce can be divided into three main categories – 1) technician/machine operator, 2) engineer/project manager, 3) AM manager. Each category requires a different skill set for success.

5.2.1.1. Technician/Machine Operator

AM machines span the spectrum of complexity with regard to operation, care, and maintenance. On the easy end of the spectrum, desktop polymer extrusion machines can be operated and maintained by self-taught individuals. Many companies selling equipment in this space have created software that is very easy to use and machines that require very little setup and regular maintenance. Furthermore, many companies and individual users/makers have created online and open tutorials that can quite effectively train a new user on how to operate and maintain a desktop system. In theory, a sufficiently motivated individual could train themselves on how to operate a desktop polymer extrusion machine by using nothing more than openly available training videos and manuals from the internet.

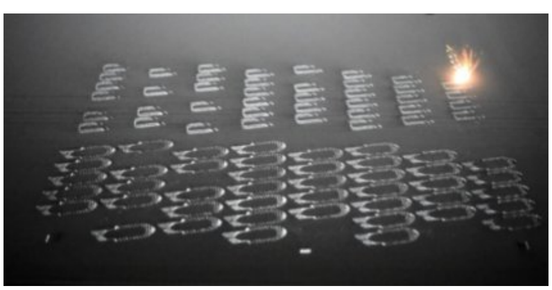
Figure 22. Powder Bed Fusion 3D printing

At the other end of the spectrum are complex AM machines, such as metal powder bed fusion systems, that require days or weeks of dedicated training and instruction for successful operation. For operators of these machines, it is useful to have at least working knowledge of the AM process flow by training on a simple machine (like polymer extrusion machines described above) though the technology is different enough that it is not required. For these much more complex machines, hands-on training is required, and one cannot rely on internet videos for training. The original equipment manufacturers (OEM) offer included operational training when a machine is purchased. They also offer paid training courses for additional users or for those who did not buy new equipment directly from the OEM. There are also third-party training courses in generic AM operation from various entities (e.g., University of Louisville, Accelerated Training in Defense Manufacturing (ATDM), Danville, Virginia). These are usually not machine-specific but give the participant a top-level overview of the requirements for operation, feedstock handling, and other critical aspects of machine operation and care. This type of generic training does not exist on Guam but would be necessary to build a robust AM industrial base on the island. As the two examples above show, this type of training can be created and administered by either a local university (University of Guam or Guam Community College) or through the creation of an entity similar to the ATDM in Danville, Virginia.

5.2.1.2. Engineer/Program Manager

The engineer does not necessarily need hands-on understanding of an AM machine, though it can certainly be helpful. The main tasks of the engineer are part design/optimization, process selection (including non-AM methods), cost (including make/buy decision), and production management. The training needs are more varied and complex than a machine operator who only needs to understand the detailed aspects of machine function. Engineers can be further segmented into BS-level and graduate level – the former capable of basic engineering design and trade study functions while the latter will have additional experience and training in research/development.

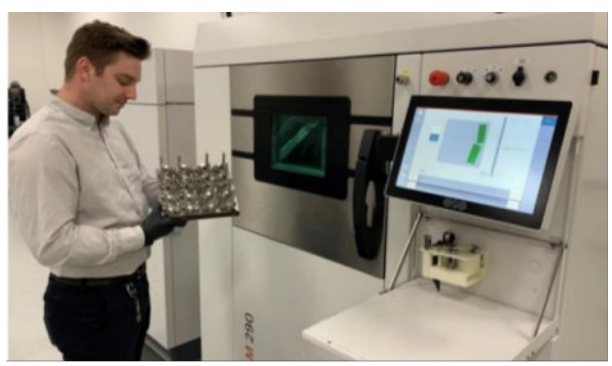

Figure 23. AM operator removing parts from a platform

Part design is the first skillset needed for an AM engineer. Training in this area is necessary as the design benefits and constraints for AM are quite different and unique when compared to traditional manufacturing techniques. Designs that capture and leverage the unique aspects of AM (such as topology optimization) require specialized training. Basic training in this skillset is available through open access resources on the internet – mainly from software providers – though this level of training is not thorough or detailed enough for a production-level AM engineer. Third party resources are available from many entities including AM consultancies and academia. Design, being mainly computer-based, is a function that can be learned using distance education; however, it is best coupled with actual hands-on operation of a printer such that the learner can see the benefits and limitations of their design on real, AM fabricated parts. Guam Community College already offers training in 3D architectural design but not in 3D mechanical engineering design, which is necessary for AM fabrication. A dedicated class or bootcamp run through GCC would be a good resource for AM capability on Guam.

Process capability is the second skillset needed by the AM engineer. There are many different modalities of AM and the engineer needs to know the benefits and limitations of each method such that they can make an informed process selection decision. Many universities are now offering overview/introductory courses in AM and this should be required for anyone who is working on a daily basis with AM technology. Some schools (e.g., Colorado School of Mines) offer AM process introduction courses in online formats which would allow remote learners on Guam to gain familiarity with AM processes. While this is generally sufficient, it is always better to have hands-on experience with the AM equipment to fully appreciate the operation, benefits, and limitations.

Materials understanding is the third aspect of AM needed by the AM engineer. The material systems, including specific alloys, are often similar or identical to alloys used in other processes though lately new AM-specific alloys have been in development. The processing conditions in AM, which are highly non-equilibrium, can produce unexpected microstructures and mechanical properties in the final parts. A thorough understanding of these unique aspects is necessary for the AM engineer. While design and process training has been developed by third parties, dedicated materials training has lagged. Certain institutions (e.g., Colorado School of Mines) offer distinct courses in materials for AM and cover all relevant engineered materials classes – polymers, metals, and ceramics. This type of training is necessary for the AM engineer.

Finally, the AM engineer needs project management training, including aspects of costing such as unit production costs and capital amortization and depreciation. As AM is considerably less mature than traditional manufacturing processes, the understanding of the cost structure for AM is also considerably less mature. A thorough understanding of the design, process, and material benefits and limitations coupled with a thorough understanding of project management and industrial operations is necessary for a fully trained AM engineer. This last aspect is not typically found in college engineering curriculums but is learned on the job. Access to relevant internships and part-time jobs for BS students in an AM engineering program is helpful to the eventual success of the employee.

5.2.1.3 AM Manager

There are no specific training requirements for an AM manager. Ideally, this role would be filled by someone who has acceded the ranks either as an operator/ technician, engineer, or both. The manager oversees the entire operation and thus must know details of machine operation, maintenance, and cost while also understanding the high-level details of design, process, and materials. Business acumen is as important as technical know-how for the AM manager.

5.2.2. UNIVERSITY OF GUAM CURRENT CAPABILITIES AND OFFERINGS

The University of Guam (UoG) was founded in 1952 and has a full-time faculty of ~180. It is a small public institution with an enrollment of 2,400 full-time undergraduate students and 715 part time students. Popular majors include Business, Biology, Criminal Justice and Safety Studies.

The University offers Bachelor's degrees in 34 fields and Master's degrees in 11 fields.

Currently UoG's School of Engineering[55] only offers a Bachelor's in Civil Engineering as a way to develop workforce for the island's burgeoning construction needs. No graduate degrees in this space are as of yet offered. UoG does not currently offer mechanical engineering (ME) education but, through a partnership with the University of Hawaii Manoa, allows students to complete an ME bachelors degree with their final two years enrolled in Hawaii. While certainly beneficial in offering new opportunities for Guam residents, concerns have been raised that this program may be encouraging students to leave the island and pursue employment elsewhere. This potential "brain drain" phenomenon is further elucidated in 5.3.4. Nonetheless, federal investments have been made to support ME development through a Hawaii-Guam partnership, including the NASA Guam Space Grant (NGSG,) which is an affiliate of the Hawaii Space Grant Consortium (HSGC). A significant goal of the program is to encourage interdisciplinary studies and research and to train future generations of space scientists and engineers. In April 2020, UoG was awarded a Space Grant the full amount of $750,000 ($150,000 per year).[56]

5.2.2.1. Experienced in Grant-Funded Research

The Research Corporation of the University of Guam (RCUOG) was established in February 2014 to create an efficient managerial environment for managing and

55. "History of the School." University of Guam, via the website: https://www.uog.edu/schools-and-colleges/school-of-engineering/about.php

56. NASA Space Grant program. University of Guam, via website: https://www.uog.edu/nasa-guam-space-grant/information.php

winning grants. The institution is a land-grant university, and has research units in several areas including: The Marine Lab; the Water & Environmental Research Institute; the Western Pacific Tropical Research Center; the Center for Excellence in Developmental Disabilities Education, Research & Service; the Micronesian Area Research Center. This arrangement demonstrates a key level of sophistication necessary to pursue, manage, and execute large scale federal sponsorships. Moreover, UoG is taking advantage of its eligibility to receive specific set-asides from the National Science Foundation's Established Program to Stimulate Competitive Research (EPSCoR). This program ensures allocation of additional federal research dollars aimed to enhance the research competitiveness of targeted jurisdictions (state, territory or commonwealth) by strengthening science, technology, engineering and mathematics (STEM) capacity and capability through a diverse portfolio of investments from talent development to local infrastructure.

In 2021, UoG ranked in the top 43% of institutions for total grant-funded research and development expenditures. These included:

- National Science Foundation–funded EPScoR Guam Ecosystems Collaboratorium for Corals and Oceans (GECCO) grant
- The National Cancer Institute–funded Pacific Island Partnership for Cancer Health Equity (U54-PIPCHE) grant
- The National Oceanic & Atmospheric Administration–funded Sea Grant
- CEDDERS funding.
- Renewed cycles of NASA EPSCoR Research Infrastructure Development funding
- Funding for the Pacific Islands Climate Adaptation Science Center.

Overall, in 2021, UoG received over $44 million in research and sponsored funding, which included $8.5 million from the U.S. Department of Commerce Economic Development Administration to help fund construction of two new buildings on campus. Federal funding to UoG in FY2020 and FY2021 was unusually high, as with most other universities across the country, due to grants derived from post-COVID relief enacted by Congress.[57]

57. University of Guam. Office of Research & Sponsored Programs FY 2021 Annual Report.

Figure 24. UoG Annual Grant Funding, 2011-2021

UoG teams have been successful in leveraging federal grants from a range of organizations such as: U.S. Departments of Agriculture, Commerce, Defense, and Energy, the Small Business Administration, and National Science Foundation. ASTRO noted that UoG has not yet leveraged other key funding sources available. During Phase II, ASTRO America will be further exploring availability of federal support to expand such investment, especially for equipment acquisition, research and operations, workforce development, and business incubation/attraction.

5.2.2.2. Partnerships

It is clear from discussions and meetings both before and during the Guam Workshop that if an AM facility is implemented in Guam, the University would be heavily involved, including locating a new AM research, part-testing, and instructional center on UoG property. Thus, UoG would be a primary and key partner to ensure success of the initiative.

The current lack of degree-based academic studies and research in mechanical engineering at UoG leading to AM means that UoG will need to partner with other institutions including CONUS-based universities to develop skills, and for them to provide temporary workforce for research and testing as any AM initiative is started. This could take the form of online degree courses with other institutions as well as in-person, on-island research opportunities for CONUS-based graduate students. UoG already partners with other universities in Hawaii, Japan and South Korea to enhance student learning opportunities. It could also involve temporary rotation of researchers and graduate students from CONUS-based universities in Guam to help operate equipment and undertake research, development, testing, and evaluation of AM-processed materials.

5.2.3 GUAM COMMUNITY COLLEGE

Guam Community College (GCC) was established in 1977 to serve secondary and post-secondary students. It is the only Community College on the island and its primary service area is the island.

GCC enjoys a reputation for high-quality career and technical education programs and serves a predominant number of Micronesian and Asian students. GCC offers one bachelor's degree (four-year degree), 24 associate degrees (two-year programs), and 17 certificates (one-year programs). GCC also offers a U.S. Department of Labor approved Apprenticeship program in conjunction with over 100 island employers. Over 500 apprentices are currently enrolled in the program. Additionally, GCC offers Adult High School, General Educational Development (GED®) and English as a Second Language.[58]

Although GCC offers a 40-credit hours certificate in Computer-Aided Drafting and Design (CADD), it is focused solely on AEC (Architectural, Engineering & Construction) science and not Mechanical Engineering. However, the CADD II course does offer some basic 3D printing experience, with AutoCAD Revit software. GCC also offers courses and certifications in welding and metal cutting, as well as Engineering Technology.

GCC partners with private industry to develop and implement training courses tailored to on-island employers' needs. These courses are marketed as "boot camps," providing fast-response pre-apprenticeship training to deliver "starting skills" and knowledge in the following areas:

- Information Technology
- Caregiver / Medical Home Health Aide **x 2**
- Medical Coding & Billing **x 2**
- Heating, Ventilation and Air Conditioning (HVAC)
- Certified Nursing Assistant (CNA)
- Surveyor Technician
- Ship Repair IV
- Construction III
- Diesel Mechanic
- Ship Repair V
- Safety Officer
- Heavy Equipment
- Truck Driving III
- Welding
- Cyber Security
- EMT
- Security

Figure 25. 'Boot Camp' training offered by GCC[59]

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58. "Course Descriptions and SLOs". Guam Community College. Academic Year 2022-20223. Accessible via website: https://www.guamcc.edu/sites/default/files/ay2022_2023_gcc_catalog.pdf

59. Information available via GCC Continuing Education & Workforce Development: https://guamcc.edu/CEWD

Based on interviews with administration officials, Guam Community College has the capacity to develop and implement basic skills training for AM on the island to including courses in:

- Mechanical Computer Aided Design (MCAD) software
- Design for AM
- Introduction to 3D printing operations
- Post-processing skills

5.2.4. SECONDARY EDUCATION/STEM

5.2.4.1. Public Schools

To set the foundation for potential AM training at GCC, the college could also contribute insights and guidance to develop AM-related STEM/STEAM initiatives in the K-12 system.

The Guam Department of Education serves 30,000 school children across 26 elementary schools, eight middle schools, six high schools and one alternate school, with 4,000 employees.

5.2.4.2 STEM Charter Schools

While it seems there is some curriculum set for 'engineering' in the schools, comments from workshop attendees emphasized that there is no established STEM/STEAM curriculum in place at this time. Since 2015, Guam has run public Charter Schools focused on STEM education

iLearn Academy. Grades K-5 - In 2015, the iLearn Academy Charter school was founded to provide a Grade K-5 curriculum with an emphasis in technology/ robotics, science and math. As of 2022, the school reportedly had 740 students. The school does not have any 3D software or printers but has expressed interest in adding them to the curriculum.

SIFA (Science is Fun and Awesome) Learning Academy Charter School. Grades K-8 - Founded in 2017, SIFA's 348 students focus on robotics and mechanical engineering. Staff indicated they do not have 3D software or printing, but have interest in its future adoption in the curriculum.

CareerTech High School. Grade 8-12 - CareerTech was founded in 2021 and currently has 75 students enrolled. School staff indicated they do not have 3D software or printers and would unlikely prioritize its adoption. A school administrator did highlight the school's current offering of a 3D modeling course, and thus may have basis for future printing skills development.

5.2.4.3. STARBASE Guam

In 2020, STARBASE Guam was sponsored by the Office of the Assistant Secretary of Defense for Manpower and Reserve Affairs to implement week-long STEM classes for 5th grade students. In 2021, the program initiated hands-on learning for students to explore robotics, rocketry, and solar vehicles. As part of that curriculum, 3D CAD (OnShape) and 3D printing are taught.[60]

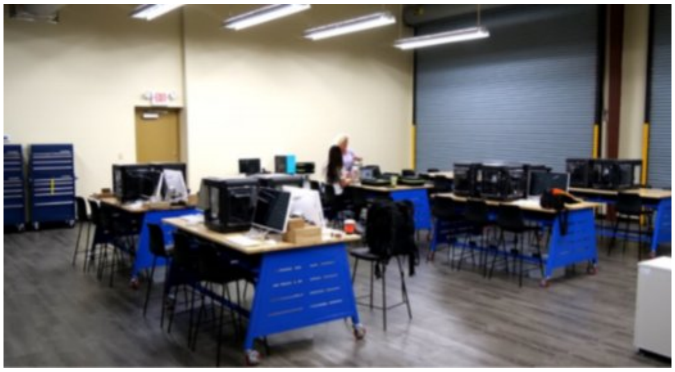

Figure 26. STARBASE Guam classroom setup with 3D CAD stations and Makerbot 3D printers

In its first year, STARBASE Guam has introduced more than 1,000 students to STEM initiatives and in the 2022/23 school year is expanding its classes to 6th and 8th grades.

5.2.4.4. G3 Maker Space

Figure 27. The G3 Makerspace opening night

Guam Green Growth (G3) Makerspace[61] is a facility that opened in 2022 by University of Guam at the historic Chamorro Village. The space incorporates basic AM, as well as laser cutting and machining. It also offers tools for researching recycling of materials for reuse, as well as serves as incubator space for start-up businesses. The Makerspace is introducing citizens to the idea of being able to make things in a welcoming, helpful environment and is staffed by a small team of technicians, engineers, and resident entrepreneurs. This facility has individual team members utilizing 3D CAD, but as of yet, no introductory classes on the discipline.

Part of the Makerspace's mission is focused on research for recycling of products for alternative uses. Such sensitivity to the circular economy remains in-line with

60. DOD STARBASE-Guam information is available via the website: https://www.starbaseguam.org/

61. Guam Green Growth information is available via: https://guamgreengrowth.org/

UoG and other stakeholders' view of its importance to economic and environmental health.

5.2.4.5. Building more STEM studies in Guam

During the November 2022 ASTRO America-run workshop in Guam, a group of UoG and GCC educators highlighted what would be needed to set up conditions for attracting diverse participation in STEM, with a specific focus on 3D printing. The consensus of these individuals was that increased availability of engineering skills on the island would naturally stimulate development of Guam-based entrepreneurs and lead to more self-sufficiency and prosperity.

Their recommendations to set the stage for such conditions included:

- Establish more STEM classes in public schools
  - Training teachers
  - Provision of science kits
  - Working with Guam Department of Education to emphasize STEM curriculum
  - Increasing instances of career days for teachers
- Build awareness of the AM career/learning opportunities through media and advertising
  - Teachers, grandparents, parents are biggest influencers
  - Build use cases
  - Build awareness of potential for increased wages
- Inform students of required skills development and career-track to enter AM workforce
  - Connect all concerned parties to a coordinated effort so that AM-focused engineering and STEM is available through multiple sources at public and private schools, Makerspace, STARBASE, colleges and the University
  - Build apprenticeship and entrepreneurship opportunities
  - Develop interdisciplinary degrees and a career path
  - Enable work experience system for manufacturing and construction
  - Enable high school student internships for summer months
  - Enable anyone on the island to solve social needs through innovation
  - Develop industry sponsors to support and fund

5.2.4.6. Conclusions on Workforce Development

Guam's focus on boosting science, technology, engineering, and mathematics (as well as use of technology in the arts) generally appears comparable to initiatives in other EPSCoR (Established Program to Stimulate Competitive Research) jurisdictions in the U.S. Efforts such as the G3 Makerspace and STARBASE Guam have sustained increased demand despite the COVID-19 pandemic, and enrollment in STEM K-12 schools remains steady. University of Guam and Guam Community College appear prepared to deliver courses on AM, machining and other related fields, as well as rapidly develop and deliver courses in mechanical engineering. However, in the early stages of initiating an AM discipline on-island, UoG will most likely require partnership with other universities that maintain advanced Industrial AM programs, in order to support AM oriented graduate and post-graduate studies and research. However, a foundation remains in place from which to build such capabilities.

5.3. CIVIC AFFAIRS

5.3.1. DIVERSITY, EQUITY, INCLUSION (DEI)

An effective initiative to advance AM on-island would focus on meeting part-demand with a sustainable industry reflective of Guam's population. Establishing AM's permanence on-island requires maximum accessibility across a relatively small population. Thus, development of a future 3D production workforce would necessarily entail understanding and advancement of diversity, equity, and inclusion (DEI). In the 2020 census[62], Guam reported 46% of its population identifying as Native Hawaiian and Other Pacific Islander alone, and is the largest race group on the island. Chamorro people comprised 50,000 of that group.

The University of Guam has long fostered successful DEI initiatives across the island and in November 2020 the University's Island Wisdom committee established the Inadahi yan Inagofli'e' Diversity, Equity, and Inclusion Council.

Figure 28. UoG Diversity, Equity Inclusion Center

62. "2020 Island Areas Census Data on Demographic, Social, Economic and Housing Characteristics for Guam." United States Census Bureau. October 20, 2022

In November 2022 the Diversity, Equity, and Inclusion (DEI) Center was opened to maximize resources and provide support to ensure every facet of the University embodies equity, diversity, and inclusion.

University enrollment in Guam is dominated by students identifying as Asian, Native Hawaiian or Pacific islander, at almost 92%,[63] with more female students than male.

Faculty has similar ratios, with 77.5% identifying as Asian, Native Hawaiian or Pacific islander, and 16% as White.

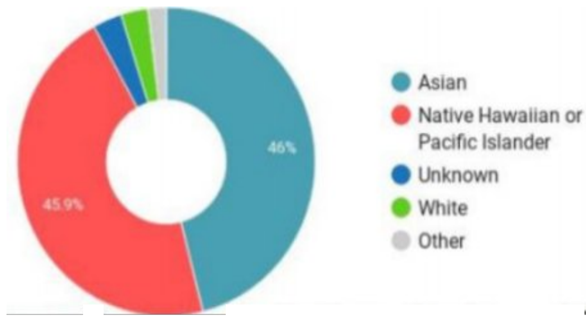

Figure 29. UoG Faculty Composition by Ethnicity

Guam Community College also has a high diversity rate with 84% of students identifying as Chamorro and Filipino, and 58% of students being female. Key to an appropriate AM workforce development program will be a collaboration with GCC, reflective of on-island populace.[64]

5.3.2. WOMEN IN STEM

Such an initiative might also aspire for balance in other demographic terms as well, including gender balance. Such a goal may seem achievable given the higher proportion of women to men enrolling across the board at University of Guam, with women claiming 53% of the science and healthcare studies student body. However, at the college of engineering, women remain a minority, comprising 24% of the (civil & architectural) engineering students.[65]

By comparison, in CONUS, there is an average of 49% female students studying architecture but only about 20% studying mechanical engineering.[66] Since the engineering courses at UoG are currently focused on civil and architectural engineering, this means that Guam may be lagging behind in both areas of engineering. AM-oriented study has the potential to help level the playing field through consistent engagement and advocacy by education-oriented organizations. Organizations such the Society of Manufacturing Engineers (SME) have teamed up with Women in 3D Printing to close skill gaps within the industry and attract new talent to choose a career in 3D printing. Through national

63. “UOG Racial Demographics.” College Factual.

64. Guam Community College Fall 2020 Enrollment Diversity.” Office of assessment, Institutional Effectiveness and Research, November 20 2021.

65. Hernandez, Julianne. “Defying National Trends, more women on Guam entering STEM fields.” PNC Guam. February 14, 2021

66. “Women in Architecture” American Institute of Architects. January 6, 2020

conferences, mentorships, and skills training workshops, such activity aim to lower barriers to entry into the profession. Similarly, such an initiative could effectively support entry to AM fields on-island in concert with other organizations, such as the Guam Women's Chamber of Commerce, founded in September 2013 to boost women's voices and action in job creation. Such partnerships will be important for building an institutional framework for growing/expanding AM workforces over the long-term in Guam.[67]

5.3.3. DOD/COMMUNITY RELATIONS ON GUAM

Civil-military affairs on Guam have been greatly shaped by dynamics between the U.S. federal government and local governments. The U.S. military presence on Guam has driven much of this relationship since the U.S. involvement following the Spanish-American War, and again in World War II, after Guam was liberated from Imperial Japan's occupation (1941-1944), when Chamorro people endured brutal atrocities. Overall, the U.S. military's presence, while strategic for the nation, has also raised significant complexities in DoD-Guam relations, particularly related to land rights and cultural concerns.[68]

The issue of land return has existed since World War II and there have been several efforts to return lands to Guam or the original landowners. The most significant of these efforts began with former Del. Robert Underwood and passage of the Guam Excess Lands Act of 1994. Addressing the issue of land, the Department of Defense committed to a "net negative" land strategy as a result of the realignment of Marines to Guam. Former Delegate Madeleine Bordallo attempted to codify this commitment in her Guam Land Return Act of 2018.

Although the commitment to a "net negative" land strategy is not codified, Governor Leon Guerrero, is likely to achieve a major land transfer to Guam for the purposes of constructing a new public hospital.[69]

In recent years the U.S. strategic focus on its military, economic and diplomatic posture in the Indo-Pacific region put a lot of focus squarely on Guam. Before the Obama Administration announced its "Pivot to the Pacific," the U.S. military was already undergoing the largest environmental impact statement in U.S. history regarding the realignment of military forces to Guam. The increased focus on the region may prove economically beneficial to Guam with unprecedented attention by senior-level leaders in the Department of Defense and from successive Presidential administrations. However, this increased attention also reprises legacy

67. "SME & Women in 3D Printing join forces to build diverse manufacturing workforce," Metal AM. May 17, 2022.

68. Letman, Jon, "Guam: Where the US Military Is Revered and Reviled," The Diplomat. August 29, 2016.

69. "Bordallo introduces Guam Land Return Act," The Guam Daily Post. March 21, 2018.

issues including challenges of the military's environmental impacts, continued concerns about land holdings and desires for a greater role in federal decision making.

The continued focus on the Indo-Pacific region offers local Guam leaders, Congressional officials and federal agencies an opportunity to address many of the long enduring complexities facing Guam's policymakers. It also may serve as a means for evolving the relationship between Guam and the federal government, leveraging new technologies to overcome major technical and political challenges in the region. For example, in discussions with the U.S. Naval Sea Systems Command and the Program Executive Office for Ballistic Missile Submarines (SSBN), ASTRO America personnel were informed of interest in expanding AM workforce development and technology development for both U.S. and Allied submarine producers/maintainers. In particular, there is potential for a Guam-based AM center to support provisions of the Australia-United Kingdom-United States (AUKUS) agreement. This agreement 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."[70]

Accordingly, Section 6.2 includes considerations for developing an AM training and technology insertion center at the University of Guam which could function as a means to support U.S. Navy personnel, their support contractors, as well as counterparts from other military services and Allied nations, including Australia. In so doing, Guam government institutions will further support U.S. interests and military assets. Such an initiative will require enhanced levels of trust and cooperation among all parties, similar to other public-private partnerships across military communities in Rota, Spain; Norfolk and Danville, Virginia; and San Diego, California.[71]

5.3.4. DEMOGRAPHICS/CENSUS (INSIDE/OUTSIDE GUAM)

Establishing such an AM-focused initiative will rely on developing a workforce that is Guamanian at its core. However, when asked if sufficient workforce capacity resides on the island, both employers and learning institutions highlighted the Chamorro diaspora largely residing in Hawaii and mainland U.S. According to the 2020 Census, 50,420 people on Guam identified as Chamorro alone with no

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

71. Navy Line. "U.S. Navy Accelerates Uptake of 3-D Printing for Spare Parts," Maritime Executive. December 2020.

additional detailed Native Hawaiian and the Pacific Islander group or race group.[72] Census reports from 2010 identified that 88,310 Guamanian/Chamorros were living in the United States. [73]

With so many Chamorro people living in CONUS compared to the population on-island, any initiative to build a new AM capability needs to dedicate efforts both to encouraging participation from within Guam as well as enticing those residing off-land to re-locate to Guam.

Corresponding outreach may involve highlighting opportunities for entrepreneurship, high-income employment, and prospects for establishing new high-tech industries for the region.

5.4. WHAT MANUFACTURING WORKFLOW WOULD BE NEEDED TO SUSTAIN AM IN GUAM?

5.4.1. IOT MANUFACTURING WORKFLOW

This section steps through the infrastructure requirements necessary to establish an infrastructure for building such industries. To begin with, this study assumes a baseline need for an additive manufacturing laboratory/prototype production facility on Guam. The assumption, based on extensive investigation of on-island capabilities, is that very little of this infrastructure currently exists on-island such

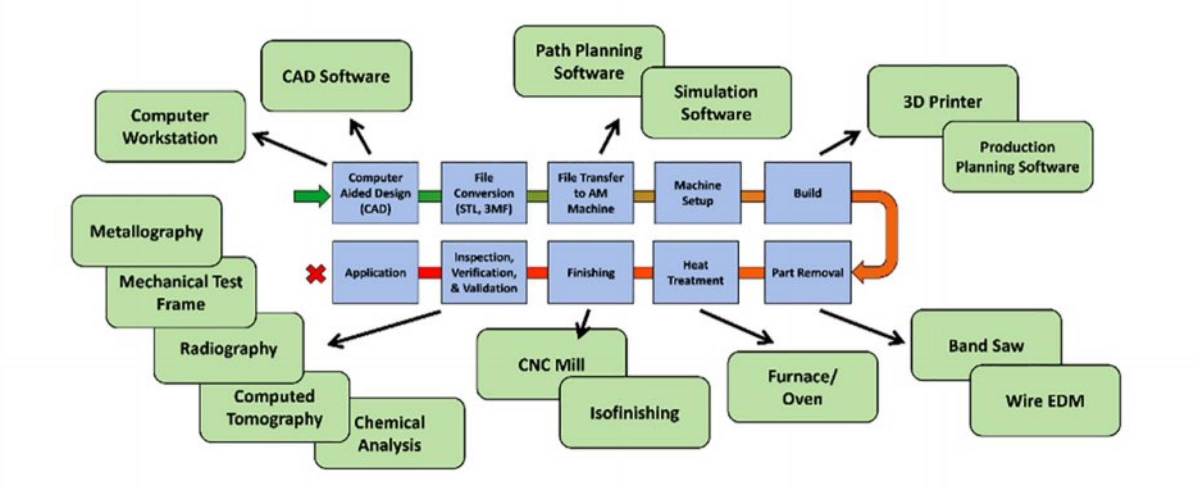

Figure 30: IoT manufacturing workflow for additive manufacturing

72. "2020 Island Areas Census Data on Demographic, Social, Economic, & Housing Characteristics for Guam." United States Census Bureau. October 20, 2022.

73. "United States Census Bureau, 2010"

that it could immediately support a dedicated manufacturing industrial base in Guam. Most of what is described in this section will have to be created from the ground up.

Figure 30 shows the AM process flow along with some (not all) of the required hardware, software, and other resources necessary to establish a commercial AM fabrication capability. Starting in the upper left of the diagram, this section will step through each section and highlight the capability needs that are required to create a functional facility.

5.4.2. COMPUTER AIDED DESIGN (CAD)

Software capable of creating 3D models is widely available from numerous vendors. A table of some of the most commonly used software packages in additive manufacturing is shown below:

Autodesk Fusion 360/Inventor	SketchUp	Dassault SOLIDWORKS
Siemens NX	3D Systems 3DXpert	Onshape

Most CAD software can run on a standard desktop computer, though complex rendering often requires a dedicated graphics card. Some software can be free though often with severely constrained capability. Some software is available on a monthly subscription basis (e.g. Autodesk Fusion 360), some is an annual license, and some is a one-time perpetual charge with annual maintenance (Siemens NX or Dassault's SOLIDWORKS). The cost can be anywhere from around $50/month to $15,000 per year, depending on capability. Finally, some software is run on the cloud – not just the basic design aspects but also sophisticated high-computational time activities, including generative design optimization and photo-realistic rendering.

Other software runs locally on a specific machine and requires a hardware key to make it fully operational. Generally, the customer and the part requirements will dictate software selection. For example, the Department of Defense or its contractors (as customers) may not allow highly sensitive part files to be stored in the cloud; parts with very complex designs may require highly sophisticated advanced software and hardware. Almost all CAD vendors offer free versions of the software to students and academic institutions, but more advanced capabilities will require substantial investment.

5.4.3. PATH PLANNING AND SIMULATION SOFTWARE (FILE CONVERSION; FILE TRANSFER TO AM MACHINE)

Similar to CAD software, path planning and simulation software is widely available from various vendors and capable of running on most standard desktop machines. Many commercial 3D printers include a proprietary software solution for slicing and path planning parts (See Figure 31). The user will take the 3D model created using their preferred CAD program and load it directly into the printer using a compatible 3D printer- ready file format (such as STL or 3MF). The 3D printer software then slices the model into virtual discrete layers and rows and creates a path plan to build each layer/row based on parameter sets for that specific machine. Some printers do not include a dedicated slicing or path planning tool. For these systems, an open-source slicing program can be used (e.g., Cura from Ultimaker). These generic slicing tools can be configured to match the processing conditions of most 3D printers. Finally, for sophisticated printing operations using multi-axis robots, a full simulation package is often used to not only slice the part but simulate the build to avoid any potential collision errors that might damage equipment or potentially harm an operator. Examples of this type of software are 3D Systems' 3DXpert (See Figure 32), Ansys' Additive Print, or Materialize's Co-AM. These simulation software packages are often in the $10,000 to $50,000 range depending on capability and license structure.

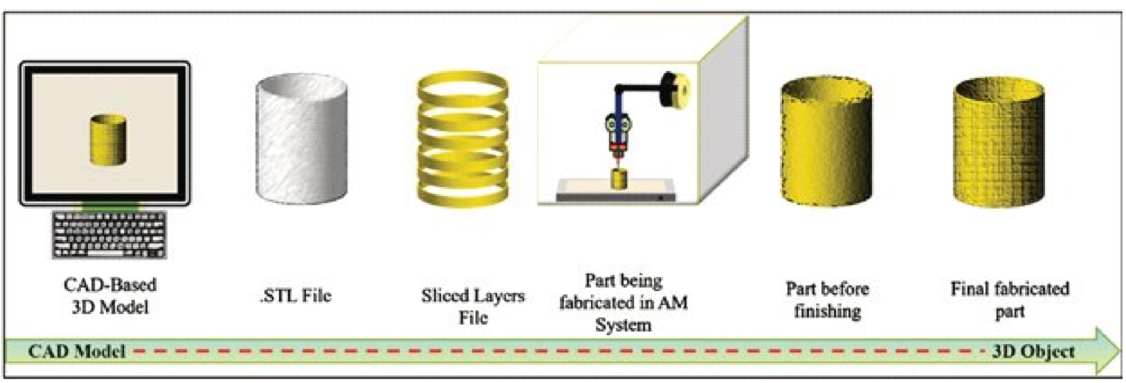

Figure 31: Typical AM software format converting CAD to STL and preparing for 3D printing[74]

5.4.4. PRODUCTION PLANNING SOFTWARE (MACHINE SETUP; BUILD)

The final category of AM software is for production planning. This is used in large operations to track orders, production, inventory, operational status, and many other manufacturing operational metrics.

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74. Chu, Tiankuo et al. "3D printing-enabled advanced electrode architecture design," Carbon Energy. May 5, 2021.

Figure 32: Example of production process planning, illustrated by 3D Systems' 3DXpert software suite

These tools can be beneficial for large operations that run many different printers and have sophisticated production logistics that must be tracked and documented. Examples of this software are AMFG, Oqton Manufacturing OS, and 3D Trust. For laboratory or prototype-scale AM facilities, this software is not required.

5.4.5. AM SYSTEM (3D PRINTER)

Additive manufacturing systems span many different techniques and can have a wide variety of facility requirements. Desktop-sized machines can be operated using standard 110V power outlets in an office environment with no other special considerations. These are mostly polymer systems – either filament extrusion or resin bath. Examples of these systems are shown in Figure 33.

Figure 33: Example of desktop additive manufacturing systems - Markforged polymer extrusion system on left and Prusa vat photopolymer system on right.

There are some desktop-style machines that can do both ceramic (e.g., Bison 1000, Tethon 3D, Omaha, NE, USA) and metal (e.g., Sinterjet M60, Sintertek, Istanbul, Turkey). These machines may require higher power (up to 208V) as well as ancillary processing equipment such as debinding ovens, sinter furnaces, and specialized powder handling equipment. This makes them less viable for office environments, and more appropriate for a laboratory or light industrial setting.

The next step up in size are commercial AM machines that fabricate a wide variety of materials across all three main material types– polymer, ceramic, and metal. These machines are designed for production and require, at a minimum, facility space designed for laboratory or light industrial use. These machines operate on 208V up to 480V and usually require chilled water loops (or dedicated stand-alone chillers) and ventilation to remove fumes or process gasses from the working environment. Examples of mid-size industrial AM systems are shown in Figure 34.

Figure 34. Examples of mid-sized industrial AM machines. On the left, a metal powder bed fusion machine from Renishaw and on the right a polymer extrusion machine from Stratasys.

The largest industrial AM systems require specialized industrial facilities. These machines can be the size of a small bedroom and need facility space that is rated for light industrial use (at a minimum). The largest AM machines can have a dozen lasers each requiring a dedicated circuit for power (see Figure 35). These machines use large volumes of feedstock powder which requires special storage and handling facilities as some metal powders are classified as flammable solids. Robotic AM systems can be quite large as well. These generally use a wire (metal) or filament (polymer) feedstock though they can also work with metal powders. These large industrial systems will require 480V power, bottled or cryogenic process gas, chilled water for cooling, and compressed air for pneumatic actuation.

Figure 35. Example of large 12 laser industrial powder bed fusion system from SLM Solutions.

5.4.6. POST PROCESSING EQUIPMENT (PART REMOVAL; HEAT TREATMENT; FINISHING)

Once the 3D printing operation is complete, the parts usually need some post processing to make them useful. The first step is removal of the structure from the substrate plate. For polymer systems, this can often be done with a putty knife. For metal parts, the printed part is often metallurgically bonded to the substrate and is not easily removed without tools. A metal band saw, or abrasive cutoff saw can be used to roughly remove the part from the baseplate. For a more precise cut, a slotting cutter on a CNC mill can be used. However, a wire electro-discharge machining (EDM) is the preferred method for precision removal of parts bonded to a metal substrate.

Once the part(s) are removed, thermal processing is necessary to remove residual stress from the part and/or optimize the microstructure. A simple box oven capable of at least 1100°C is the minimum requirement for metal parts. For reactive parts made from alloys such as titanium, a vacuum or inert furnace is often required. Additional thermal processing steps may require other factory equipment – for example, a specialized heat treatment for certain metal alloys requires rapid quenching of the heated part in a water or oil bath, using highly specialized equipment.

Figure 36: Hot Isostatic Press

Finally, many critical applications require AM parts to go through a hot isostatic pressing (HIP) thermal treatment(See Figure 36). This is a pressurized high temperature treatment where the pressurized gas inside the furnace assists with closing porosity or other defects within the part. HIP furnaces require dedicated facilities and are considerably more expensive than their standard, non-pressurized counterparts. For this reason, it is common in the industry to outsource the HIP operation and there are several vendors that provide toll HIP services. For AM processes that do not fully melt and consolidate material but only bind or glue the feedstock together (ceramic and metal bound particulate AM), other specialized furnaces are required. These furnaces are designed to sinter ceramic and metal powders at an economically viable rate.

Final finishing is often required and the equipment necessary is varied. Simple grit blasting to smooth the surface is done for most metal powder-based AM parts. This involves common equipment – a cabinet with compressed air and blasting media. For higher quality surfaces beyond simple bead blasting, an isofinishing process can be used. This involves a container full of abrasive media (anything from walnut shells to engineered ceramic beads) where the parts are tumbled in the media for a period of time. This process can smooth and polish most exterior surfaces and is good for additive parts that have considerable complexity and would be difficult, if not impossible, to smooth and finish using hand tools. The last step is CNC machining. This step is not always required but is often used to clean up surfaces that require high tolerances (e.g., mating surfaces between two parts). This can be accomplished with standard CNC milling equipment. Often this is a separate piece of equipment and is dedicated to only conducting machining operations. However, there are some AM systems that are hybrid and can accomplish both additive and subtractive operations in one machine. For this, the motion controls are the same, but the end effector is swapped out between additive and subtractive operations. The hybrid approach can save cost and floor space in an AM factory setting.

5.4.7. PART REQUISITION

Critical to an effective AM manufacturing workflow are effective processes for part requisition, process qualification, and part certification. For military parts, the Department of Defense has an existing certification process for part requisition known as MILSTRIP (Military Standard Requisitioning and Issue Procedures). This system or any other DoD certified requisition system could be used to place orders for needed spare parts or original parts for military applications. These MILSTRIP procedures in 1998 were incorporated into an on-line ordering platforming designated by DepSecDef as the DoD EMALL. The DoD EMALL has subsequently become designated as the preferred on-line ordering platform for the entire Federal Government. It is now called FedMall. FedMall, and DoD EMALL before it, can handle MILSTRIP, on-line catalogs, on-demand manufacturing practices, and credit card purchasing. It is also the preferred method for defense contractors to access National Stock Numbered parts managed by DLA. With modest development funding, a Guam Advanced Manufacturing Corridor could be added to FedMall.[75] Similar commercially available systems for procurement, production, distribution and inventory management could be used for non-military parts.

In order to assess the Indo-Pacific market for certified military and commercial parts that could be fabricated by AM, data is needed for spare parts for the Navy, Marine Corps, Air Force, and other agencies, as well as possible commercial end-users. AM would likely only be considered if traditional distribution channels or warehousing could not satisfy part-order needs for the end-use customer.

5.4.8. 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 material that can achieve specific material and mechanical properties and can be repeatable and reproducible. Process repeatability means being able to produce material that meets 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.

75. Defense Logistics Agency. FedMall Program description.

Demonstration of consistent material properties is typically achieved using a statistical-based approach[76] 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.

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.

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. 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[77], wire directed energy deposition[78]) that

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

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.

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 sample 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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77. "Requirements For Metal Powder Bed Fusion Additive Manufacturing," NAVSEA Technical Publication S9074-A2-GIB-010/AM-PBF, January 21, 2020.

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

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 non-destructive 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.

5.4.9. REGULATORY REQUIREMENTS

Local, state, and federal requirements must be addressed when operating an AM facility. Many AM techniques involve the use of high energy beams of radiation for melting material – either laser or electron beam. These beams require special care due to their physical and health hazards and are regulated based on class. Feedstock material for AM is often in powder/particulate form and this can also create physical (e.g., explosion/fire) and health (e.g., inhalation) hazards. Proper procedures for storage and handling feedstock material are also regulated to ensure safe operation of the facility. Environmental regulations are also important in an AM facility. While waste products are generally less when compared to traditional manufacturing, there are still material waste streams that must be handled properly. This includes waste feedstock (powder), machining waste, chemical waste, contaminated filters, and other typical waste products from manufacturing operations.

It is unlikely that the necessary infrastructure and capabilities needed to support a dedicated additive manufacturing industrial base in Guam currently exists, and would instead need to be created from the ground up. This includes equipment for fabrication and post-processing, raw material supply chains, software, a skilled workforce, and testing equipment. Additionally, specialized services such as chemical analysis/testing, NDE testing (e.g., CT scanning), and hot isostatic pressing would likely need to be developed on island for these parts of the AM industrial base to be economically viable. In the initial start-up phase these could be outsourced off-island, but over the long term they would need to be created internally.

5.5. AVAILABILITY OF AM MATERIALS:

Materials for additive manufacturing fall into three main categories – 1) substrate plates, 2) feedstock, and 3) miscellaneous consumable materials.

1. Substrate plates (also known as build plates) are necessary for many different types of AM processes. For powder bed fusion AM, the substrate is the base material that supports the powder bed and provides an attachment point for the parts being fabricated (Figure 37). These substrate plates are usually the same alloy as the powder being used in the system though it is not required to be the same since it is usually removed and reused. Standard plate material can be used for PBF AM substrate plate though they are required to have a specific hole pattern for rigidly mounting in the machine and a specified surface finish with a high tolerance flatness. Other AM processes such as directed energy deposition AM also require a build plate but generally have fewer restrictions. An adequately sized piece of material can be toe-clamped to a worktable without specific requirements for hole patterns or surface flatness. Standard plate material can be used for both substrate applications and traditional CNC milling operations can be used to prepare the surface and the bolt holes for attachment. Additionally, the plates can be reused if the substrate is not included in the final part but will have to be prepared (e.g., surface milling) prior to reuse. A web search does not reveal dedicated metal suppliers in Guam; however, it is likely that sourcing raw metal plate is easily done via regional suppliers in Japan, South Korea, and other east Asia countries.

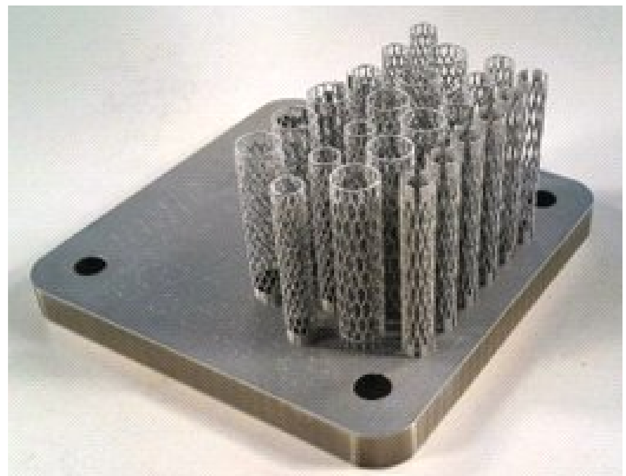


Figure 37. Powder bed fusion AM build showing flat build plate with attachment holes (photo credit: CSIRO)

2. Feedstock is the material used to create the AM fabricated parts. It is either supplied in particulate form (e.g., powder) or filament/wire form. Certain processes can also use metallic foil. Polymer filament to support material extrusion AM processes is widely available due to Material Extrusion (MEX) being the most popular and common AM method globally. There are a number of MEX systems in Guam and feedstock supply for common materials does not seem to be a challenge. For metal DED AM processes, standard welding wire can be used for fabricating parts. A web search produced at least one welding

fabricator on the island so there is an existing supply chain for welding consumables including feedstock wire. However, the wire used as filler in traditional welding/joining is not the same material being pursued in AM applications. Wire feedstock purity is critically important for achieving the desired grain morphology and properties in the material being deposited. The alloys of interest for AM fabrication will most likely have to be specially shipped to the island either through the existing supply chain of distributors or special order from suppliers in the region (similar to plate material – Japan, South Korea, and east Asia). Powder feedstock will be more challenging to source as it is unlikely that there is a current supplier/distributor on the island. Like the other materials, powder suitable for AM is available in the region from major industrialized nations. It is important that the powder be fabricated under tight control and globally recognized standards as it has a higher likelihood of quality issues (e.g., composition, morphology) compared to solid filament/wire feedstocks. Also, unlike other feedstocks, metal powders are classified as flammable solids and certain alloys are not allowed to be shipped by air carrier and must be distributed via ground/sea transport. The powder flammability often makes it necessary to store them in rooms with a tightly controlled atmosphere. This could impact availability and lead time for non-standard alloy compositions.

3. All AM processes require miscellaneous consumable supplies over the lifetime of their operation. For welding-type processes such as WAAM, the consumables are similar to those used for welding/joining but are consumed at a higher rate due to the higher duty cycle in AM versus traditional welding. These items include compressed process gas (e.g., nitrogen, argon), contact tips in the welding gun, guide tubes, feed rollers, and many other things. For more complex machines like PBF AM, there are various filters, gaskets, optics, etc. that need routine replacement. Given the lack of an established AM supply chain on Guam, most consumable hardware will need to be shipped in from the original equipment supplier or from an equivalent third-party source.

5.5.1. MATERIAL SOURCES AND SUPPLY CHAIN

Additive manufacturing (AM) feedstock materials are available in either powder or wire form depending on the specific type of AM process being used. Because of the intricacies involved in AM processes, it is important to use materials that are specially designed for use in AM machines and for the process being used. Important aspects to consider are described below.

Powder feedstock - For powder feedstock, factors such as particle shape (morphology), particle size, particle size distribution, purity, and microporosity affect the way the powder acts during the manufacturing process and will ultimately play a role in the microstructure and properties of the material being produced. In the early days of AM powder-based processes, it was common to use metal powders that were produced for alternative powder-based metal manufacturing processes, mainly because there were very few metal powders being made specifically for AM processes. Currently, however, many types of AM powder feedstocks are available that are being made explicitly for use in AM processes. These powders are tailored to precisely control the many factors elaborated previously. Material producers such as Praxair, Oerlikon Metco, Sandvik, Carpenter Technologies, Voestalpine, Aubert & Duval, Hualiu, MANA Materials Technology, and others all produce a wide variety of metal powders for use in AM powder-based processes. Primary manufacturing locations are in the US, Europe, and China, although AM powders can be ordered from company representatives and from other distributors in nearly every part of the world. Specially designed AM powders are also being manufactured by smaller startups such as 6K Additive in the US and elsewhere. A partial listing of AM powder feedstock producers and compositions they offer is shown in the table below.

Wire feedstock - Probably the most critical aspect for wire feedstock is the purity of the wire itself and the absence of any surface contaminants, but other important factors include uniformity in the wire diameter and the absence of defects in the wire. Wire feedstock supply relies heavily on the welding industry, hence there are numerous suppliers and material compositions available throughout the world. There are several producers that make wire feedstock specifically for AM processes, such as Alloy Wire and Perryman Company. In all cases, it is essential to be sure the wire feedstock being selected is of the utmost purity and consistency. A partial listing of AM wire feedstock producers and compositions they offer is shown in the table on the following page.

AM METAL POWDER FEEDSTOCK		
SUPPLIER	TYPICAL COMPOSITIONS OFFERED	MORE INFORMATION
Praxair	Cobalt alloys Copper alloys Iron alloys Nickel alloys Titanium alloys	https://www.praxairsurfacetechnologies.com/en/materials-and-equipment/materials/additive-manufacturing-powders
Oerlikon Metco	Nickel alloys Cobalt alloys Iron alloys Titanium alloys	https://www.oerlikon.com/am/en/offerings/metal-powders/
Sandivik	Co-Cr alloys Copper alloys Steel alloys Ni alloys Ti alloys	https://www.metalpowder.sandvik/en/products/applications/additive-manufacturing/
Carpenter Technologies	Steel alloys Ni alloys Ti alloys Al alloys	https://www.carpenteradditive.com/metal-powders
Voestalpine	Steel alloys Ni alloys	https://www.voestalpine.com/highperformancemetals/australia/en/home/products-brands/products/additive-manufacturing-powders/
Aubert & Duval	Ni alloys Co alloys Steels alloys Ti alloys	https://www.aubertduval.com/products/powders-for-additive-manufacturing/
Hualiu	Steel alloys	https://www.hlpowder.com/stainless-steels/additive-manufacturing-powder/
MANA Materials Technology	Ni alloys CoCrMo alloys Steel alloys Fe alloys (HEA's) Ni-Cr alloys Ti alloys Al alloys	https://www.mana-metal.com/additive-manufacturing-powder/
6K Additive	Ni alloys Ti alloys Steel alloys Tungsten Molybdenum	https://www.6kinc.com/6k-additive/6k-additive-metal-powders/

AM METAL WIRE FEEDSTOCK		
SUPPLIER	TYPICAL COMPOSITIONS OFFERED	MORE INFORMATION
Alloy Wire	Ni superalloys Stainless steel alloys Be-Cu alloys Many others	https://www.alloywire.com/applications/wire-additive-manufacturing/
Perryman Company	Ti alloys	https://www.perrymanco.com/additive-wire
Numerous welding suppliers		

Table 3. AM feedstock sources

Until such time as to when Guam may have an on-island materials facility, all AM materials will need to be sourced from vendors (typically US-based) such as those above, but might be sourced from South Korea, Japan, or Australia as appropriate. This will require a consistent supply to be shipped to Guam normally via ships but sometimes air freight when necessary.

5.5.2. 3D PRINTED CONCRETE MATERIALS

For any initial implementations of 3D printed concrete on Guam, it would be necessary to source approved materials from the vendor, most likely being shipped from the mainland US in the early stages. Given time, it is possible that locally-sourced materials on Guam could be certified and approved, but that is a process of 2 or more years.

Given the near-term need for a considerable increase in the number of affordable homes in Guam and the vast potential offered by 3D printing of concrete structures, using this technology to print homes and other structures on Guam holds significant potential and should perhaps be part of a separate study to more thoroughly assess the feasibility.

5.6. AVAILABILITY OF FACILITIES BOTH SHORT-TERM AND LONG-TERM

As part of the study, the team spent some time observing potential locations on-island as well as through internet real estate searches.

The implementation of an Industrial AM lab would most likely take two stages: With the first being a starter laboratory that could support both AM prototyping processes as well as qualification methodologies described above (both non-destructive and destructive inspection). The period of time that such a facility was used would depend on the development of a more permanent solution. Over the long term, it is expected that a larger center would be built to house corresponding manufacturing, research & development and testing, as well as workforce development components. This second facility would likely be built on UoG property. Given enough funding and the right demand conditions there is a possibility for more than one lab on the island: one for production and another for research and/or education. The specific configuration, construction requirements, lay-out, staffing, and mission are to be a principal subject of a later PHASE II report.

Starter Facility

A potential starter facility might require rented space, categorized as Light Industrial.

Basic Specifications

- Ground floor, fully enclosed, air-conditioned space with minimum 12 foot high ceiling.
- Concrete floors
- Class: Light industrial
- 2,500 – 5,000 sq ft
- Warehouse spec overhead sliding doors, 12 foot minimum overhead clearance
- Power: 480V 3-phase power. 200 A but 400A preferred
- High bandwidth Internet availability
- Ideally close to UoG and Airport or Port

PROPERTY AVAILABILITY

Port of Guam

From the tour of the port, it would seem that there were very few existing (available) structures that would fit the requirements.

Guam Airport Authority

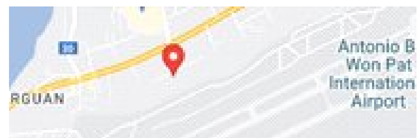
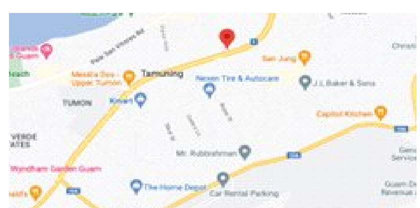
The Airport has some spaces on its property, and there are others as private real estate. The Airport also has future plans to build more industrial space on its property.

University of Guam

UoG has a lot of older buildings that would not seem to accommodate the requirements; however, a Main Lab could be established on UoG property if enough funding became available.

Commercial Real Estate

There are a number of existing properties on the island as well as future potential sites. While there do not seem to be many properties, there are some potential properties that might work, with some additional fit-out. (as of January 4 2023).

 *Figure 38*	167 E.T. Calvo Memorial Parkway G, Tamuning, GU 96913 6,500 sq ft. $6,400/month	
 *Figure 39*	1st floor 456 South Marine Corps Drive, Tamuning, GU 96913 7,288 sq ft $19,350/month	
 *Figure 40*	171A Guerrero Street 3C, MidPac Properties, Tamuning, GU 96913 3,000 sq ft $4,421	
 *Figure 41*	371 South Marine Drive, Tamuning, GU 96913 6,400 sq ft $9,300/month	

Conclusion: Guam has existing light industrial capacity for both short- and long-term use, although refit will most likely be required. University of Guam also has potential sites for a new facility as long as funding can be matched.

6. SOURCES OF FUNDING/FINANCING

Starting-up and operating an additive manufacturing capability in Guam requires resources to offset a range of costs associated with capital expenditures (facility construction and equipment purchases), staffing (researchers, instructors, and management/administration), and community development (seed-funding to attract long term federal & private investment).

It is important not to confuse funding and financing as they are often used interchangeably but are not the same. Funding is the money that is needed. Financing is the ability to borrow money to bridge temporal mismatches between the time that money is needed for construction and operation and the time it may be available from either grants or revenue generated by a new AM center. Phase II will detail specific approaches to securing resources; however, this section explores issues, authorities, and programs that may be explored further in that next phase.

6.1. FEDERAL FUNDING

Overall, investment strategies must be configured to sustain long-term growth through public private partnership. On the government side, capital sources should be focused on advancing the public good, including—

a. **Defense Supply Chain Resilience;** building up new capacity to meet critical industrial base shortfalls for U.S. and Allied forces
b. **Economic Development;** supporting communities as they respond to emerging local defense activities and overcome distressed economic conditions
c. **Research Infrastructure;** required for high-quality Defense-relevant research such as cutting-edge technology/instrumentation at geographically pertinent universities
d. **Business Incubation;** creating high-wage jobs, accelerating new enterprise formation, support industry clusters and maximizing local productive assets in low-income area
e. **Workforce Development;** supporting education and (re-)training generations of engineers, technicians, and designers in high-tech manufacturing positions

6.2. TECHNOLOGY INSERTION & EDUCATION

Federal funding has been identified as the primary source with the U.S. Defense Department likely to be the anchor funding. Under category (a) and (e) above, an academic/industry coalition can be formed for technology insertion into *Major Defense Acquisition Programs (MDAPs)*. Phase II may explore an approach to lifecycle-support for U.S. attack submarines (SSNs), strategic missile submarines (SSBN), and/or Allied platforms through the Australia-U.K.-U.S. (AUKUS) agreement.

An AM technology development center was recently developed in Danville, Virginia with substantial seed-funding provided via Program Executive Office SSBN; over the next several years federal investment in this center is likely to double to support operations. Developing an AUKUS-affiliated AM and technology insertion center in Guam to serve U.S. and Allied industrial bases would enable development of workforce, development, testing, and evaluation capabilities for advanced manufacturing to address part-sourcing across SSN/SSBN lifecycles.

According to representatives of industry and academia based in CONUS and Guam as well as Australia, there is strong interest in collaborating with the U.S. Navy to develop a consortium that could combine both DoD and private sector resources to accelerate adoption of AM – both in direct support of Submarine Squadron 15 and PHNSY assets on-island as well as of AUKUS-related stakeholders in relative proximity to Guam.

Such federal funding would necessarily require supplemental support from the Government of Guam to offset costs of building infrastructure—such as facility construction on-site at the University of Guam, consistent with GEDA or UoG mandates/authorities.

Such a concept also envisions acquisition of advanced technology—including multiple 3D printers, pre- and post-processing tools, and testing equipment (such as sophisticated inspection technology required to validate part properties for Navy/DoD adoption). Defense University Research Instrumentation Program (DURIP) grants are supporting purchase of research equipment at 77 institutions across 30 states in Fiscal Year 2023, enabling universities to perform state-of-the-art national security related research. Applying for such assistance through the Office of Naval Research could help satisfy requirements under category (c) above. Depending on the types of testing equipment acquired, such procurement would represent a critical national asset-- the sole forward-deployed DoD AM qualification capability in the world.

6.3. MANUFACTURING COMMUNITIES

This capability would be useful not only to support vehicle, armament, or ship maintainers at military installations on-island, but also to validate parts produced and used by new businesses in Guam. In order to attract/retain existing businesses and stimulate new business on-island, key federal authorities may be leveraged that catalyze high-tech ecosystem growth. For example, the U.S. Department of Agriculture Rural Development office has designated the entire island as eligible for investments via its grant initiatives. Among them is the **Rural Innovation Stronger Economy** (RISE) Grant Program, offering grants for business incubators and workforce development centers. Application of such federal funding would satisfy category (d) above and serve as a platform to entice experienced contract-AM companies to re-locate to the island and employ a new AM-centric workforce.

With incubator space set up through such a grant, companies would leverage low-rent space and shared equipment/infrastructure to 3D print prototypes/parts for validation at the aforementioned AUKUS-affiliated AM & technology insertion center (where companies' potential workforce could also receive training), accelerating private investment into Guam at the incubator space and possibly elsewhere (e.g. shipyards, airport, or Naval base).

To complement these efforts, both the U.S. Department of Commerce's Economic Development Administration (EDA) and Department of Defense's Office of Local Defense Community Cooperation (OLDCC) might support (b), contributing necessary resources to drive critical investments for economic diversification. The recently enacted FY2023 Consolidated Appropriations Act (Public Law 117-328) included $50 million for the EDA's *Regional Innovation Program* that could be applied to extend opportunities for AM job development into other parts of the economy. Specialized training, supply chain development, and export promotion assistance could be curated for specific industry-verticals such as commercial aircraft MRO, energy generators, and health care support. Additionally, over the last decade, OLD-CC's Defense Manufacturing Community Support Program has contributed long-term community investments to "strengthen national security innovation and expand the capabilities of the defense manufacturing industrial ecosystem."[79] The funding and technical assistance provided through the program enhances a region's ability to narrow gaps and address needs in defense manufacturing in the areas of:

- Critical skills training

79. "Defense Manufacturing Community Support Program. US Department of Defense, Office of Local Defense Community Cooperation.

- Facilities development
- Research and development
- Small business support

Barriers-to-entry to source the Defense industrial base are substantial. Receiving adequate qualification from both lead system integrators and the Defense agency end-use customer remain among the most substantial challenges facing prospective suppliers. Thus an OLDCC (Office of Local Defense Community Cooperation)-sponsored initiative could be applied to ensure a new AM-focused ecosystem was established in Guam to address requirements particularly tailored to DoD requirements. Whether educating skilled workforces or establishing new AUKUS-affiliated AM facilities, a grant could support advancement of research to validate AM processes for submarine repair or national security related activities. Moreover, resources could further apply to guiding small businesses inside a potential incubator through the qualification/certification processes set forth by appropriate technical warrant officers and other authorities.

6.4. CIRCULAR ECONOMY

The U.S. Department of Energy (DoE) has a number of relevant programs to support funding and financing vehicles. These programs typically require a cost share composition. Also, performers are encouraged to partner with key DoE laboratories. Within DoE, additive manufacturing had remained the principal domain of the Assistant Secretary for Energy Efficiency & Renewable Energy's Advanced Manufacturing Office over the last decade. This office was just recently divided into two agencies: *Advanced Manufacturing and Materials Technologies Office* (AMMTO) and the I*ndustrial Efficiency & Decarbonization Office* (IEDO). AMMTO focuses on accelerating innovation in the manufacturing sector and supporting a domestic clean energy technology manufacturing economy. IEDO focuses on reducing industrial greenhouse gas emissions and increasing industrial resource efficiency. Addressing these key areas in Guam through technology research could support categories (c) and (d) above as a collaboration between public utilities (Guam Power Authority and Guam Waterworks Authority) and research institutions such as UoG, the National Renewable Energy Laboratory and Oak Ridge National Laboratory.

The U.S. Environmental Protection Agency also has an array of programs relevant to additive manufacturing including new vehicles established by recent federal legislation. As with other agencies, vehicles often require a blend of different sources of capital, vary in what type of entity can apply for support, and also use vehicles such as loans, loan guarantees, and grants. The Greenhouse Gas

Reduction Fund includes $27 billion to assist localities in leveraging outside capital for a range of subject areas. This fund is mainly meant to foster the creation of green banks which could be a highly effective way of funding elements of Guam's transshipment goals. Also directly relevant to additive manufacturing is the grants for ports to install, purchase and replace zero-emission port equipment and technology as well as other activities. Important to note here is that private organizations can apply for this support which may carry with it certain advantages to the port's balance sheet.

Many of the aforementioned federal programs require a nonprofit or academic partner to serve as the prime contractor or grant awardee. If an AUKUS-affiliated technology insertion center were to be established, the University of Guam appears to have the structures/policies in place to lead such an effort. CONUS-based institutions such as the Colorado School of Mines and ASTRO America as well as international partners (e.g. the Royal Melbourne Institute of Technology) with experience running similar operations might contribute personnel and resources to support development of a AM testing/evaluation laboratory. They also could provide support in establishing business incubator space. However, the most important development would be the establishment of a community-based consortium to support collaborative research, technology insertion and workforce development on-island.

Figure 42. Potential government seed funding

Figure 42 illustrates both a hypothetical consortium as well as possible ecosystem development support from the federal and local government. This concept will be refined in Phase II.

6.5. FINANCING: PRIVATE SECTOR BANKING AND PUBLIC

An AM facility will require financing to match the upfront construction and operation costs with the sources of funding. There is general belief that Guam has a sufficient banking system to provide financing in excess of $60 million for viable projects. Participants at the workshop and in private conversations highlighted multiple banks on island and their ability to work together to syndicate loans for broader commercial projects. Banks on island seem to have the experience of working together, sharing risk, opportunity, and coordinating for commercial projects at the $50 million or more scale.

Lending requires streams of repayment, and any advanced manufacturing plant would need to produce revenue to repay the loans. Issues regarding collateralization and to whom the loan would go were raised. Participants on-island noted that banks are a great source of capital for new manufacturing and the banking industry on Guam has been able to support many projects lending hundreds of millions of dollars. Private sector banks appear open to participating in projects aimed at diversifying the island's economy, bringing new jobs and new skills to the region as well as new revenues.

The Federal government can assist in financing both through direct lending programs and by offering loan guarantees (removing risk from the private sector). Banks on the island report being adept at packaging loans through existing government guarantee programs such as the Small Business Administration or Department of Agriculture. These programs often provide federal government support in the form of credit enhancements (e.g. risk against default). Guam has received over $13 million from the federal State Small Business Credit Initiative (SSBCI).[80] SSBCI funds were allocated to GEDA to be used to fund a loan guarantee program with a specific goal “to increase the availability of funds to spur entrepreneurship in the community, create new start-up business and to expand existing ones”. This loan guarantee program can guarantee up to 75 percent of a loan up to $500,000 for a period of up to seven years.

One proxy for the ability of private banks in Guam to access funding for businesses was the response during the COVID pandemic with the federal Paycheck Protection Program (PPP). PPP were a series of forgivable loans designed to help workers that required employers to go through banks or other lenders to access federally guaranteed funding. There were 2,208 PPP loans made in Guam with Bank of Guam making the most (650), First Hawaiian Bank (540), Community First Guam Federal Credit Union (359), and Coast 350 Federal Credit Union (344)

80. “Temporary Economic Assistance and Mitigation.” Guam Economic Development Authority.

rounding out the leaders.[81] Together these four comprised 86% of total PPP lending on island.

Federal government credit assistance did not appear to be a prerequisite for all private banks. There appeared general confidence among a wide variety of leaders on the island that banks were willing to take risks to fund projects. However, federal or GEDA supported lending could make the cost of such financing less expensive.

One question that remains to be explored is who is the borrower? If the University of Guam were to be the lead sponsor for an AM facility then perhaps it could be the central point, both in receiving grant funding from the federal government and in applying for the financing through various mechanisms. Alternatively if the facility itself as a legal entity were to borrow, how would it engage with lenders, particularly absent its own credit history? Finally, there is the question of collateral in terms of the physical printers, computers, and technology required in the facility. That could be a source of collateral that would require ownership and liability.

Specific blended financing sources may be attractive to Guam as it adopts a transshipment approach. Most significantly sized transshipment economic projects, including free zones can often combine federal, local, private, university, philanthropic, and nonprofit sources. Moreover, more than one program from each of these categories can be drawn, e.g. more than one federal agency, a business and private investor, and so on.

With regard to private financing support, Guam is most likely to gain attractive private participation from institutional investors. These would have a long-term repayment horizon with lower rates. This structure would allow Guam the patience it needs to launch and grow business activity. Institutional investors include sovereign wealth funds, pension funds, and endowments.

These institutional funds may, at times, be easier for Guam to pursue through financial intermediaries albeit not with as favorable a rate. Third-party money managers vary widely in their project preferences, rates, and length of investment horizon. Certain ones can provide only debt or only equity, while others have flexibility. The types of money managers include: open-ended investment funds, closed-ended investment funds, asset managers, merchant banks, corporate funds, and opportunity zone funds.

A key source of favorable capital for Guam to tap is philanthropic foundations which would be highly likely to find Guam's priority projects attractive. Activities envisioned by Guam elsewhere use foundations. Foundations can offer grants, loans, equity, debt, and insurance. They include foundations with sizable

81. "Paycheck Protection Program Snapshot." Federal Reserve Bank of San Francisco.

endowments, donor-advised funds established by high-net-worth families as a vehicle for giving, venture philanthropies, and those with a targeted subject area. For projects without a clear quick route to financial return, a foundation can be a highly effective source of funding without a requirement to pay back funds. Importantly, Guam can make most effective use of foundation support by combining the proceeds with outside sources of capital or with Guam's balance sheet.

6.6. ROBUST LOCAL DEVELOPMENT AGENCIES

Guam has a robust structure of local development agencies and sources of funding to support them.

- **GEDA** – Guam Economic Development Authority's charter to "develop a sound and sustainable economy through innovative programs that preserve and promote local culture, economic opportunities and quality of life." The organization actively delivers programs and incentives for new business, funding, economic development, innovation, and property development.[82]
- **Small Business Development Center, Pacific Islands Network:** Founded by University of Guam, the Pacific Islands Small Business Development Center Network (PISBDCN) operates centers throughout Guam and the Federated States of Micronesia. In 2021, the group assisted small businesses with securing capital infusion of $1,808,736, assisted 475 Pacific Islands clients who created or saved 1,357 jobs and had a total of 178 trainings.
- **Guam Department of Agriculture:** The Guam Department of Agriculture was established to protect and promote the agricultural resources and economy of the Territory of Guam by research, quarantine, control and conservation. The organization is involved in numerous conservancy projects and issues grants to research teams such as the University of Guam to execute them.

82. Guam Economic Development Authority web site.

7. CURRENT DEMAND SIGNALS

7.1. U.S. DEPARTMENT OF DEFENSE NEEDS

The Department of Defense (DoD) has indicated plans to invest more than $11 billion in Guam over the next several years—largely in construction projects. This level of investment is consistent with Guam's place as the U.S. territory with the most DoD investment. Military spending accounts for 46% of the island's Gross Domestic Product (essentially $18,550 per Guam resident). In Fiscal Year 2021, the Department of Defense spent $2.9 billion in Guam. Figure 43 shows the last eight years of contract awards in Guam, denoting this upward trend.[83]

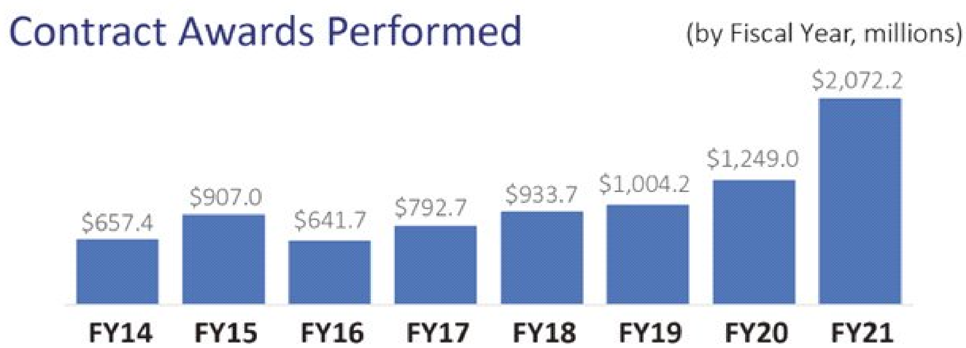


Figure 43. Department of Defense – Office of Local Defense Community Cooperation Report

The U.S. Navy, Marine Corps, Army, Air Force, Missile Defense Agency are all contributing to this build-up and reflect Guam's strategic significance outlined in Section 6.3.4. They also each present unique opportunities for addressing military readiness through additive manufacturing technology.

7.1.1. NAVAL BASE MAINTENANCE OPERATIONS (AND DEFENSE INDUSTRIAL BASE)

Additive manufacturing is increasingly considered important for 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

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

may require support for reverse-engineering or spare part requisition – perhaps via 3D scanning technology or 3D printed processes.

This activity supplements maintenance/repair services performed aboard U.S. Navy tenders (ship-based machining/repair capabilities). Additionally, over the last decade, the Navy has also been expanding its Emergent Repair Facility (ERF) at Naval Base Guam to help perform routine maintenance and repair of homeported attack submarines (SSNs) as well as other visiting submarine and surface ships at Naval Base Guam (NBG). Project management teams are expanding repair/maintenance areas along with stay-behind crew to support theater assessments and certification/proficiency deployments. The Navy is also building capabilities to support submarine voyage repairs as required by the Fleet. This includes both nuclear and non-nuclear specific maintenance and repair functions and a permanent towed array processing facility. Quantifying demand for AM services that could augment these activities remains challenging, particularly given the sensitive nature of the Navy's work in Guam. For that reason, a separate Phase II study commencing after this report's issuance will include calculations of the potential total addressable market for AM 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. The Navy Supply Office at Submarine Squadron 15 tracks all supply parts and lead times for equipment casualty reports (CASREPs), and can serve as an important source of information— both for different priority part orders as well as incidences of "cannibalization." This practice involves removing parts from one military-platform that may be in port for an extended period to outfit another—figuratively "robbing Peter to pay Paul" as one Navy stakeholder described it.

Figure 44. 3D print / sand-casted vacuum rotor (U.S. Navy)

PHNSY often uses unique part-inventory tools to data-mine spare parts available to replace appropriate ship components. Long-lead or hard-to-source items are key candidates for AM. Several parts of the Naval Sea Systems Command's organic industrial base have pioneered methods for using additive manufacturing in the maintenance/repair field. For example, according to Naval Undersea Warfare Center (NUWC) Keyport (Washington State), a replacement Vacuum Rotor in a strategic missile submarine is typically a difficult-to-source part. In 2014, this part typically cost $19,000, and could take up to 48 weeks to requisition for the Navy's Trident (submarine) Refit

Facility in Kingsport, Georgia. Navy personnel on-site in Georgia reverse engineered the part, developing a 3D computer-aided design and emailed the file to NUWC. They, in turn, were able to 3D print a sand-casting mold for the part using a ExOne binder-jet system (See Figure 44). A foundry then used the mold to build the part quickly using a casting process. All told, this method took 8 weeks. With four units built annually, it can save the Navy $20,000 per year.[84]

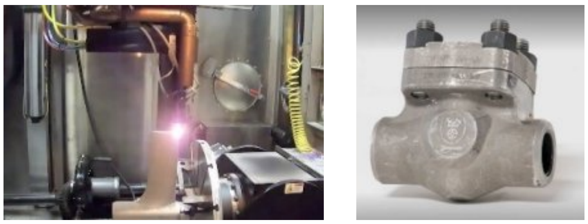


Figure 45. 3D printed drain strainer orifice 3D printed at HII-NNS.

Aside from such tooling processes, additive manufacturing is now proving effective in building parts directly for use on navy ships. Indeed, in October 2018, Naval Sea Systems Command (NAVSEA) announced it had approved the first 3D printed part, a prototype drain strainer orifice (DSO) assembly, for shipboard installation (See Figure 45). Installed on a USS Harry S. Truman (CVN-75) steam line, it is designed to maintain steam pressure when removing condensation from a line by preventing steam from escaping. According to the Navy, 3D printing the part was a “leap in shipbuilding” akin to breakthroughs in the 1930s, “when modern welding processes quickly replaced rivets in joining steel plates on ship hulls.” Built by submarine and aircraft carrier producer Huntington Ingalls Industries– Newport News Shipbuilding, this part demonstrated the utility of building critical parts on-demand using metal laser powder bed fusion AM technology. Now, a component whose delivery can take months is 3D printed in a matter of hours.[85]

NAVSEA has since accelerated its development of acceptance criteria for AM-built components for critical ship parts even while various Department of the Navy organizations, such as Marine Corps Logistics Base Albany (Georgia) or Naval Undersea Warfare Center Keyport (Washington), have long used AM for tooling, prototyping, and non-critical parts. NAVSEA’s publication of qualification guidance for Directed Energy Deposition and Laser Powder Fusion (referenced above in Section 9.3.3.2) are the culmination of considerable public-private engagement by NAVSEA 05 Technology Office, particularly by the Additive Manufacturing Technical Warrant Officer team.[86] That office’s input prior to the workshop in Guam as well as HII-NNS’ workshop participation contributed to a wider understanding of AM feasibility and requirements for adoption on-island. HII-NNS maintains a presence

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84. Morris, Kyle. “Rapid Manufacturing & Repair Case Study: Casting Cores Cost & Time Savings: $4k & 4 weeks.” Naval Undersea Warfare Center – Keyport. 2014.

85. Werner, Ben. “Palm-Sized 3D-Printed Part Represents Leap Forward In Shipbuilding.” U.S. Naval Institute News. Oct. 12, 2018.

86. Rettaliata, Justin. “Engineering Standards: Best Practices and Emerging Technologies NAVSEA Additive Manufacturing Overview.” Naval Sea Systems Command. August 3, 2022.

in Guam to support contract maintenance and could prove pivotal in considering how best to integrate AM into on-island repair.

The two ship spare part examples above (vacuum rotor and drain strainer orifice) show two different examples of how AM may be applied – either indirectly (through tooling or cast molds) or directly (through 1-for-1 replacements). The latter required processes to accept an onboard component by a Navy official, due to the new method employed to build the part. The former did not require as much regulatory burden because – although the method to create a mold was novel— casting itself is a tried-and-true method for metal fabrication and was readily accepted. The figure below illustrates a demand spectrum of the varying skillsets, products, materials, destructive and non-destructive testing requirements, as well as fabrication technology potentially of interest via AM.

The Navy has a strong history of using additive manufacturing for each of the "application categories" up until the direct qualified/certified production. One of the Navy's earliest AM adopters was Carderock Naval Surface Warfare Center which has been 3D printing ship models for prototyping and testing for over 15 years. Additionally, as early as 2008, Carderock researchers were applying stereolithography AM to build highly precise propellers on unmanned undersea vehicles for demonstration/testing. Today, Carderock's AM specialists are helping lead a community of Navy researchers in AM practices. As recently as October 18-19, 2022, approximately 30 representatives from nine of the 10 warfare centers in the Naval Sea Systems Command and other Navy research installations from across the United States met at Naval Undersea Warfare Center (NUWC) Division Newport for a meeting of the Additive Manufacturing Warfare Centers Working Group to discuss their latest efforts in the domain.

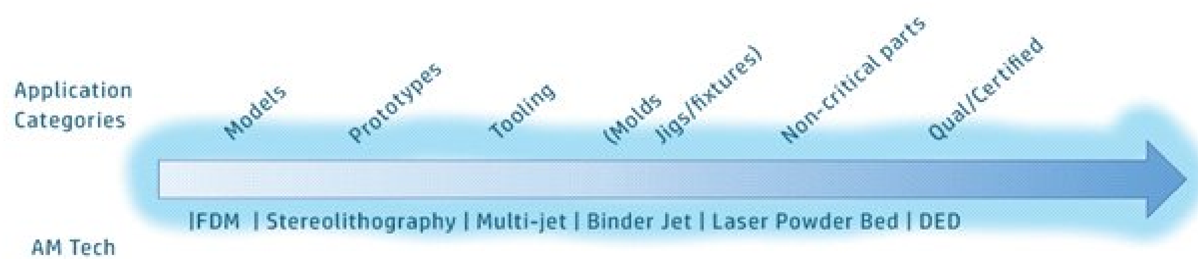

Figure 46. Spectrum of potential part manufacturing in Guam via AM

They briefed each other on major AM projects and initiated collaborations that would leverage respective specialty areas and facilities. Warfare centers have AM technology that vary in sizes, materials, and capabilities. Roughly three quarters are polymer systems used for rapid printing of fixtures, prototypes and tooling in direct support of their projects. The remaining systems are specialized, such as printing large scale, metal, energetics, electronic materials and new materials.[87]

Such a community would serve as a critical resource for new Navy-centric AM activity, particularly for a strategic operational site such as Guam (See Figure 46).

7.1.2. US AIR FORCE RAPID SUSTAINMENT OFFICE (RSO)

Within the Air Force Life Cycle Management Center, the Rapid Sustainment Office (RSO) is responsible for finding ways to save money and improve efficiencies in the sustainment of aircraft and other weapon systems throughout the Air Force fleet. RSO focus areas include robotics and automation, advanced manufacturing and condition-based maintenance. Increasingly, personnel from this office draw on AM to address hard-to-source parts, particularly for decades-old aircraft, including the B-52H long range bomber which entered service in the early 1960s. Given the platform's age, supply chain shortfalls persist; part vendors no longer build requisite parts or have gone out of business.

These sourcing issues are not confined to the airframe components. Acute shortages occur in the aircraft engine part-supply as well. RSO has attempted to tackle "cold start" cases-- sourcing challenges when it takes more than 300 days to procure replacement parts. According to GE, the Air Force faces approximately over 800 cold start parts every year. [88]

To remedy the problem, GE and the RSO conceived the Pacer Edge program, located at the Oklahoma City Air Logistics Center (OC-ALC) at Tinker Air Force Base. This program leverages 3D printing to source obsolete parts. Its multi-phased approach involves procuring several metal laser powder bed fusion AM systems deployed at OC-ALC, training Air Force personnel in additive design, build-preparation, and manufacturing, and then testing/evaluation of parts for ultimate use in Air Force platforms. If successful, the Air Force will for the first time validate replacement of flight-critical parts built conventionally with 3D printed alternatives.

At the outset, Pacer Edge involved the development of digital 3D technical data packages (TDPs) for four cold start aircraft engine parts that are difficult to source. Once established, parts were 3D printed via metal laser powder bed fusion AM and then tested/evaluated using statistical analysis. Working with the Defense Logistics Agency and Air Force Research Laboratory, RSO has thus accelerated insertion of 3D printed parts into the supply chain to address sustainment challenges within a new center now referred to as Reverse Engineering and Critical Tooling laboratory.

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87. "Additive Manufacturing Working Group Meets at NUWC Division." *What's up Newport*. November 10, 2022.

88. Sertoglu, Kubi. "GE and Air Force Advance Pacer Edge Program," 3D Printing Industry. May 12, 2022.

The Pacer Edge program provides a compelling example of how the Air Force could establish a process for both replacing important (but obsolete) parts via 3D printing and developing long term high-tech capabilities at an Air Force facility. Decisions concerning large scale AM investments for sustainment on Air Force installations are determined by RSO leadership; criteria for prioritizing such investments include the military facility's proximity to appropriate post-processing and testing capabilities. Because of the early stage in Guam's development of such capabilities, authorization for procuring industrial AM equipment at Guam's Andersen Air Force Base is unlikely in the short-term, according to RSO personnel. However, should conditions change on-island, Air Force personnel have indicated that these decisions could be revisited. Meanwhile, bombers serviced at Andersen remain among the fleet's oldest—not only B-52Hs, but B-1s and B-2s as well, among other aircraft. Reverse engineering activities honed at the REACT Lab at OC-ALC would serve as a potential model to address hard-to-source parts for these platforms and corresponding engine components as well. However, Air Force acceptance of AM-built components would require an established approach to qualification that will likely be honed through the Pacer Edge program over the next couple of years.

The 36th Maintenance Group stationed at Andersen Air Force Base in Guam has developed a basic 3D printing space on-base. This capability allows airmen to prototype or model potential maintenance solutions or temporary fixes to low-risk interior components. Over the long term, AM support for Air Force missions in Guam would require a more permanent workforce, not likely to rotate off-island after a couple years. Such a function could be fulfilled by support contractors working either off-site (nearby) or on-base, or through joint operations with Navy stakeholders, if they should acquire industrial AM capacity.

7.1.3. MARINE CORPS

In January 2023, Camp Blaz at Asan Beach, Guam became the first newly activated Marine Corps in over 70 years. At this installation, nearly 4,000 acres are being developed to host multiple barracks, five firing ranges, two aircraft hangars, and associated infrastructure. Other projects will include a physical training complex and an urban combat training facility.[89]

While only 40 Marines and about 110 civilians have been working at the base as of December 2022, Stars & Stripes reports that this presence will grow to 5,000 Marines over the next few years, including 1,300 members of the III Marine Expeditionary Force (MEF) and an additional 3,700 Marines that will be assigned to the installation on a rotating basis. The III MEF, which is a forward-deployed

89. Helfrich, Emma. "Marine Corps Activates Sprawling New Base on Highly Strategic Guam." The Drive. January 26, 2023.

formation of the Marine Air-Ground Task Force made up of several subordinate units, is currently headquartered at Marine Corps Base Courtney located in Okinawa, Japan.[90]

When it comes to soldier systems and ground vehicles, the Marine Corps typically leverages research & development undertaken by the U.S. Army's Development Command which has multiple laboratories working on 3D printing technologies. Other applied AM research including topics related to aviation, missile and armament systems, leverage work undertaken by the Office of Naval Research. However, the Marine Corps has conducted substantial experimentation with "expeditionary" or "point-of-need" AM for several years. This activity considers self-sufficient expeditionary fabrication labs for spare parts, which include additive as well as subtractive production, as well as 3D scanning to reverse engineer parts. Such activity involves largely portable additive manufacturing equipment contained within shipping containers along with other manufacturing equipment to provide temporary repair measures. The first main lab will go into the field in 2023.[91]

Concurrent to this work, the Marine Corps has also established a Digital Manufacturing Data Vault (DMDV) led by SYSCOM's Advanced Manufacturing Operations Cell, or AMOC, to establish a secure, digital repository that Marines anywhere could tap into for help building needed spare parts with 3D printers. [92] Further, the Marine Corps has been conducting research with 3D printing of concrete for structures since 2018, most recently at Camp Pendleton via the Defense Innovation Unit (DIU).[93]

Camp Blaz's eventual build-up may lead to demand for AM to support future presence of aircraft, motor vehicles, and other platforms in need of replacement parts may portend a potential market-pull for AM to be examined in Phase II.

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90. Wilson, Alex. "Marine Corps Hosts Encore Activation Ceremony for Camp Blaz." Stars and Stripes. January 26, 2023.

91. Burke, Matthew. "Marines on Okinawa ready to bring 3D printing to the fight." Stars and Stripes. July 15, 2022.

92. Fuentes, Gidget. "Marine Corps want a digital blueprint locker for access to 3D printing plans anywhere." USNI News. July 5, 2021.

93. Hanaphy, Paul. "Us Marines use ICON 3D printing to create concerete structures at Camp Pendleton." 3D printing Industry. August 4, 2020.

7.1.4. MISSILE DEFENSE AGENCY

Missile Defense Agency director Vice Admiral Jon Hill recently described an "evolved threat," from China, in the form of increasingly advanced ballistic and cruise missiles, hypersonic weapons and even potential threats from space. In the face of such a multi-faceted threat, MDA has thus begun to lay plans for the most advanced missile defense system in the world on Guam, including distributed components to include subterranean and mobile components. At the core of this system is to be a fixed Aegis Ashore missile-defense site, similar to the one the U.S. Navy currently operates in Romania. MDA is currently conducting Environmental Impact Studies while it tries to identify suitable land for a fixed implementation.[94]

Such a system will complement more tactical systems, such as the Terminal High Altitude Area Defense (THAAD) missile defense system deployed at Guam's Andersen Air Force base and operated by Army personnel (though for training purposes, Guam-based forces deploy THAAD to Rota, Marianas). [95] Much like its fellow DoD agencies, MDA has also invested in development of additive manufacturing to address critical challenges in utilizing unique geometries and materials. In particular, it has invested in 3D printing technology that would utilize uniquely lightweight metals in order to reduce payload sizes. Its Manufacturing Technology program recently undertook projects to explore 3D printing of C-103 Niobium metal alloy as well as carbon-carbon continuous fiber structures. They announced interest in understanding statistical variation of metal AM parts; cyber-security of print files and machines and means for certifying production parts (comparable to topics explored in Section 7.3.4.2)[96]

Given such activity, Phase II of this feasibility study will necessarily include additional data on AM relevance to MDA's mission in Guam and corresponding demand signals.

7.2. COMMERCIAL

7.2.1. ANTONIO B. WON PAT GUAM INTERNATIONAL AIRPORT AUTHORITY

Manufacturers of commercial aircraft have used AM in casting and tooling for large airframe components and even more broadly in the production of engine parts. The largest such producers in the U.S., including Boeing, Airbus, General Electric,

94. Trevithick, Joseph. "Decommissioned Navy Cruisers Could be the Answer to Guam's Missile Defense Needs." The Drive. November 11, 2021.

95. Bisht, Inder. "Lockheed to Upgrade Aegis Weapon System for Guam Deployment." The Defense Post. December 29, 2022.

96. Cox, Steven, DR. "ManTech Overview." Missile Defense Agency. February 23, 2021.

Honeywell, Pratt & Whitney, and Rolls Royce have extensive 3D printing operations focused on maximizing benefits of 3D printing for designing fuel efficient and high-performing components. Today, Boeing reports that both its Defense and commercial programs include over 70,000 production parts that have been 3D printed. Moreover, in 2022, the company 3D printed over 14,000 load-bearing heavy tools to facilitate aircraft manufacturing[97].

Despite such AM usage in aircraft fabrication, it is not yet extensively employed by commercial airlines in maintenance/repair. Other end-users including cargo carriers FEDEX and UPS have begun to adopt the technology, but use-cases still remain limited.[98] Nonetheless, players in key commercial markets remain open to widening AM usage, especially if it can help overcome pertinent logistical challenges and supply airplane spare parts in remote locations. In discussions with the Guam Airport Authority, it was evident that this sentiment extended to Guam, where the commercial aviation market is diversifying. As of 2022, the A.B. Won Pat Guam International Airport is host to 10 commercial airlines as well as four cargo operators.[99] It has 38,347 sq. ft of maintenance facilities, 207,212 sq. ft of aircraft hangar space, 67,006 sq. ft of office space and 937,900 sq. ft. of vacant ground area. In 2019, Guam Airport welcomed 1,365,270 visitor arrivals. By 2021, that number had fallen to 61,010 but is trending back up with flights in September 2022 totaling 2,208 compared to 1,156 in September 2021.[100]

Throughout the Airport property, open land and disused facilities remain available for repurposing for light-industrial activity; however, new tenants will be limited to a maximum lease of 5 years. As a potential site for development, AM vendors and users might consider such space, should a market servicing commercial air carriers develop – especially for aircraft maintenance, repair and overhaul (MRO). Currently, contractors such as Pacific Airport Services support MRO on-site (without AM capabilities) in support of Japan Airlines.

The company with the largest presence at A.B. Won Pat Airport is United Airlines (formerly Continental), with just over 900 employees in Guam. Within this number are 67 on-island maintenance team-members. While this number has been declining over the last several years, due to attrition and employees electing to move to mainland hubs or airports, the airline indicates that opportunities to return home will materialize should positions on Guam be reinstated. [101]

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97. Broda, Adam. “3D printing matures for tooling.” Boeing Innovation Quarterly.

98. Jackson, Beau. “Fedex Launches 3D Printing Inventory and Repair Company Forward depots.” 3D Printing Industry. January 25, 2018.

99. “A.B. Won Pat International Airport, Guam, Corporate Profile.”

100. “A.B. Won Pat International Airport, Guam, FY 2022 Statistics:

101. Leon Guerrero, Phil. “United ramping up Japan-Guam flights.” Guam Daily Post. April 20 2022

The airline also indicated its Guam operations may grow in importance as a major hub for supporting aircraft traveling to Japan, China, and other parts of Asia.[102] According to the company's Guam-based executives, development of AM capabilities might even strengthen its potential bid to become the company's principal MRO site for East Asia.[103]

Additionally, the airport authority's development plan focuses on attracting other airlines to Guam, as well as promoting Guam as a transshipment hub for cargo carriers. Indeed, Air Vietnam expressed interest in building a $280 million MRO facility for its aircraft and third-party carriers on Guam in October 2022. However, aforementioned restrictions on long-lead leases have discouraged the company from proceeding with such investment.[104]

Airport authority officials relayed interest in exploring how AM could be adopted to enhance maintenance repair and overhaul capabilities and perhaps offset such setbacks. In discussions with ASTRO America as well as feedback provided during the November 2022 workshop, AM is viewed as a potential solution to address costly inventories and delays for part imports—topics to be further explored in Phase II.

7.2.2. PORT OF GUAM

As a vital part of Guam's economic infrastructure, the Port Authority handles more than 90 percent of the island's total imports. The United States provides some 60 percent of Guam's imported goods, with the balance of Guam's trade coming from the Asian and Pacific markets of Japan, Taiwan, the Philippines, Hong Kong, and – to a lesser extent – Australia, New Zealand, and islands of Micronesia. Additionally, the port hosts maintenance and repair facilities encompassing approximately 53,600 square feet, operated by a disparate number of private and public sector entities.[105] These stakeholders form a Port Users' Group who met with ASTRO America researchers to explore how AM could be leveraged for ship repair and maintenance. In addition to supporting vessels' replacement-parts, considerable attention was focused on how cranes fall into disrepair at the port; theoretically, AM could be used to build gantry parts that often take several months to requisition.

Above all else, however, the principal subject discussed with this community was Guamanian aspirations to become a transshipment hub in order to diversify the

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102. Stole, Jasmin. "United Airlines unveils new look for Guam fleet". Guam Daily Post. Feb 20 2016.

103. ASTRO discussion with Sam Shinohara, United managing director for Guam & Micronesia operations, Nov 2022

104. Licanto, Nestor, "Air Vietnam Aviation expresses interest in building facility at Guam Airport." Kuam News, October 27, 2022.

105. Port Authority of Guam Facts and Figures.

economy. Port users reflected on the establishment of a public-private task-force whose aim is to map out a strategy for turning the island from a net-importer to a strong platform for exports to points across the Indo-Pacific region (as well as to the continental U.S.).[106] In a document co-authored by Staff from the Office of Guam 's Vice Speaker and University of Guam, Emory University, and St. Mary's College, the Port Authority of Guam is described as having the ability to "move containerized, break-bulk, and fresh fish cargo. Not only does Guam have easy access to manufacturing hubs in the Asia-Pacific supply chain, but its strategic location also allows the United States to secure the defense of the nation and protect its allies."[107] The government of Guam has launched a Transshipment task force focused on leveraging both its unique geographic location and sizable port facilities. As ASTRO America initiates Phase II, plans for an on-island AM capability will need to consider the task force's findings and recommendations.

Cabras Marine Corporation (CBC)

A major player in the Port Users Group is Cabras Marine Corporation (CBC), which advertises its services as delivering critical tug, towage, spill response and maintenance services to both the Port of Guam and the military. CBC's primary focus is in supporting repairs to the Military Sealift Command fleet, including Fleet Oiler (PM1), Special Mission (PM2), Prepositioning (PM3), Service Support (PM4) ships. Recently, the company hired the former commanding officer of Submarine Squadron 15, with the expectation that CBC might eventually expand opportunities for support to key Navy platforms stationed in Guam. If they gained access to AM, the company indicated that it could prove useful in tooling, prototyping or even direct part replacement.

The Pacific Dry-dock and Integrated Maintenance (PACDIM) facility onsite uses a floating dry dock. CBC owns the only waterfront full-service shipyard facility on Guam and the neighboring islands. The closest repair facility with similar capabilities resides in the Philippines. Additionally, CBC maintains a welding shop on-site.

CBC is active in recruiting and training maintenance staff including sponsoring the Ship Repair Bootcamp[108] in collaboration with Guam Community College. This collaboration has resulted in free training in marine mechanics, shipwright carpentry and electrical skills, and immediate employment as an apprentice. While these programs represent relatively extensive offerings, participation from prospective students/apprentices has been limited, according to company officials.

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106. Chargualaf, Wayne. "Transshipment task force holds first meeting." PNC Guam. June 28, 2021.

107. Luo, Wang, et al. "Transhipment on Guam". Report to 36th Guam Legislature, 2021.

108. "Upcoming ship repair boot camp V." Cabras Marine Corporation.

7.2.3. MEDICAL

Guam Regional Medical City participated in the workshop and provided insights into the high costs of health care and challenges accessing regular supplies for traditional goods/services for both in-patient and outpatient facilities. Its ambition is to become a regional hub for medical support across Micronesia (as illustrated in Figure 47). 3D printing is commonly applied to surgical procedures and medical modeling in the US. However, attendees noted that Food & Drug Administration approval is required to implement processes involving direct patient contact.[109]

Figure 47. GRMC ambition to serve as a medical hub for southeast Asia

7.2.4. AUTOMOTIVE REPAIR

The automotive industry has been involved in AM research for 20 years mostly in the areas of rapid prototyping. In the last 10 years, 3D printed parts became more commonplace firstly in Formula 1 vehicles, followed closely after by commercial automotive OEMs.

On Guam in fiscal year 2021, there were 118,299 registered vehicles[110], with vehicle sales volume of 5,685 in 2020[111]. The ongoing military buildup including additional Marines and their families will only cause those numbers to increase.

Workshop attendees expressed a frustration at the long lead times for automotive parts to be shipped to Guam and indicated interest in exploring if replacement parts can be made using industrial AM.

While this has potential, there are also barriers – namely that replacement of parts that are not endorsed by the automotive OEM (Original Equipment Manufacturer) will void the vehicle warranty and so approvals from automotive OEMs would have to be developed. As previously noted, vendors such as Siemens are already working to address these kinds of challenges and, going forward, has potential to offer solutions for problems exactly like this.

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109. "3D Printing of Medical Devices". Food & Drug Administration. March 26, 2020.

110. 2021 Guam Statistical Yearbook, Bureau of Statistics and Plans.

111. Guam car sales data. CarsalesBase.

7.2.5. ENERGY/WATER

Given the complex and large-scale machine and equipment requirements of power and water systems, OEMs in this space were early adopters of additive manufacturing and are some of the most prolific users of these capabilities and parts.[112] Consequently, a Guam-based additive center would have an immediate value for Guam Power and Guam Waterworks Authorities, specifically in the areas of maintenance, repair and replacement parts given the logistical issues presented by Guam's location.

Key suppliers of energy generator technology such as Siemens Energy and Cummins are among the most prolific users of additive manufacturing. Indeed, AM has taken on a major role in development and production of components and spare parts for Siemens Energy in recent years. In addition to setting up its own AM production lines and acquiring AM service provider Materials Solutions in 2016, the company is now expanding its commitment in this area with its investment in the start-up MakerVerse-- connecting industrial clients with a global network of certified additive manufacturing suppliers for projects like design prototypes and producing on-demand spare parts.[113]

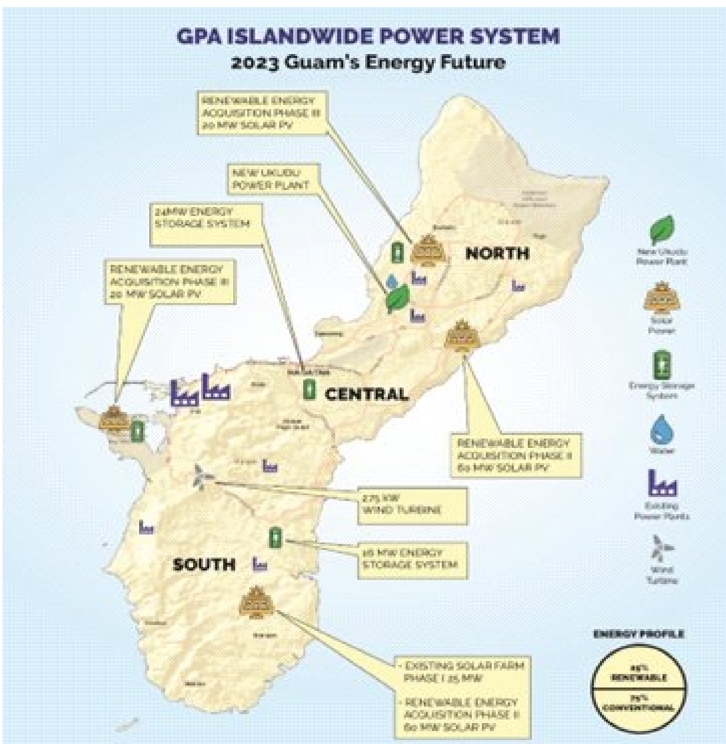

Figure 48. Future planned sites for Guam Power generation

However, where AM may be particularly helpful is in helping Guam pursue its plans for expanded renewable energy sources. Today the Guam Power Authority (GPA) generates electricity with systems leveraging both conventional fuel oil and renewable energy – currently, GPA has 25.3 MW of renewable capacity with an additional 160 MW of solar photovoltaic and 150 MWH of energy storage – which will help achieve a 25% Renewable Portfolio Standard mandate by 2024. Figure 48 depicts Guam's

112. O'Connor, John. "New Ukudu power plant breaks ground." Guam Daily Post. July 21, 2022.

113. "Siemens Energy Invests in New Digital Platform," Siemens March 1, 2022.

plans as of 2023 for diversifying its fuel sources, including solar, hydro, and even wind sources.[114]

The US Department of Energy and GE Renewable Energy are currently collaborating on a project to improve windpower efficiency and production costs, using 3D printing of wind turbine blades. This project utilizes both thermoplastic and metal AM to pursue modern blade manufacturing. According to GE, turbine blade tips fabricated using 3D printing and thermoplastic composites will have several benefits, including being lighter than conventionally manufactured counterparts. Lightweighting allows larger rotors on turbines to generate more power while also easing the strain on the entire turbine, reducing wear and tear on its gearboxes, drivetrains, bearings, and foundation, and reducing lifecycle costs for turbine operators.[115]

Additionally, manufacturer Drupa is now developing AM processes for both building and performing maintenance on wind turbines. “Not only the production of wind turbine components can be done with the help of 3D printing, but also the repair or replacement of parts is made much easier and does not require the relevant parts to be removed and transported somewhere else.” Its customer Danish wind turbine producer Vestas claims:

“With more than 68GW under service and turbines installed in 75 countries, often in remote areas, a technology [such as AM] to produce and distribute spare parts locally could potentially help reduce cost and downtime on our customers’ turbines.”[116]

One of the primary benefits of additive manufacturing is the reduced lead time for producing components. Traditional manufacturing methods often require a significant amount of time for design, prototyping, and mass production. Additive manufacturing, on the other hand, can produce functional parts in a matter of hours, allowing for quicker implementation of new ideas and solutions. This can be especially useful to power and water authorities when dealing with emergency situations or when a component needs to be replaced quickly.

Additive manufacturing allows for increased customization and complexity in component design, which can be beneficial for large scale power and water requirements. The ability to produce custom parts and tools on demand can help improve the efficiency and reliability of power systems, as well as address unique

114. DeRivi, Tanya. “Guam Power Authority bolsters resilience and charts path to 50% renewables.” American Public Power Association. May 3, 2021.

115. Everett, Hailey. “Powering the renewable energy transition with 3D printing: wind.” 3D Printing Industry. March 1, 2022.

116. “Printing energy – How Additive Manufacturing can boot the wind energy Industry.” Drupa. March 19, 2019.

problems and requirements that may arise. This can also lead to a reduction in the amount of spare parts and specialized tools that need to be kept on hand.

During the ASTRO Workshop held in Guam, both the Power and Waterworks Authorities were represented and identified timely access to replacement parts and tools as a critical and ongoing problem. There was optimism that a Guam-based additive center could help address these issues, but there were concerns regarding utilization of additive produced parts and their quality; there was less of a concern related to tooling. Since the OEM suppliers are already using additive to produce many of these parts – for both initial installs and replacement/repairs – perhaps Guam additive center will one day produce quality and reliable parts for this sector, coordinating with equipment suppliers on the development of an additive part list to mitigate part shortfalls. Meanwhile, the U.S. Department of Energy may help determine if there is partnership to implement AM for Guam's energy/water needs.

PHASE 1 CONCLUSIONS

RECOMMENDED FOCUS AND ACTIONS

Throughout the entire process of Phase I the focus has been on ascertaining if conditions exist, or can potentially exist, to support industrial AM on Guam. It appears likely that if sufficient funding were made available, such conditions could materialize to support a sustainable, productive 3D printing sector.

Such an initiative would build off existing elements on-island, including:

- **Research/Higher Education:** Led by the University of Guam, the island has a sound, healthy establishment of higher education, research and grant funding activities to make industrial AM feasible. Academic partnerships with University of Hawaii, as well as Taiwan and South Korea also set the stage for further partnerships in the AM academic space.
- **Technical Training:** Guam Community College leads the way in technical and skills training especially with regard to fast reaction in implementing new courses. STEM initiatives including G3 Maker Space, STARBASE Guam, and the public STEM charter schools show that the island population has a desire to deliver better STEM education, leading to students with desired and desirable skills.
- **Federal Government Demand:** Discussions with Departments of the Navy have made it clear that there is a lot of interest for an AM center of excellence in Guam, with potential for the funding to support it. Less clear is support and demand from other sections of the military who might take a 'wait-and-see' position.
- **Robust U.S. & Local Development Agencies:** Guam has a robust structure of local development agencies and sources of funding to support them including GEDA, Small Business Development Center, Pacific Islands Network, and Guam Department of Agriculture.
- **Commercial Interest:** There are several entities in Guam with commercial interests in a local AM center of excellence, including: Bank of Guam, Bella, Cabras Marine, Guam Airport Authority, Guam Power Authority, Guam Shipyard, Newport News Shipbuilding, Port of Guam, United Airlines, RHMC.
- **Community Interest:** Community support of the initiative seems quite strong with the Guam Chamber of Commerce, the Womens' Chamber and other groups voicing support.

For an AM industrial capability on Guam, many critical elements will be required. These include: use of software for designs, build-preparation, and formatting; disparate 3D printer systems (and feedstock); part-removal and finishing (machining and heat treatment); and accepted inspection and validation methodology. Development of an ecosystem with these elements requires low-volume part-demand as well as investments in research, workforce, and capital equipment. To these ends, the U.S. Department of Defense (DoD) is an ideal partner, given its own supply chain needs and precipitous growth in Guam.

MANUFACTURING READINESS FOR INDUSTRIAL AM

MRLs were designed by DoD to provide a maturity model based on well-developed criteria that assist in identifying the maturity of a manufacturing effort on a program or a technology. These are defined in Figure 49. We feel that Guam is at MRL Levels 1-2, and for industrial AM to be successful in Guam, it would need to develop to MRL 10. The building blocks to achieve this exist but are not tuned and positioned as of yet for even close to full-scale production. Requirements to achieve a higher state of manufacturing readiness include adequate funding and time and are predicated on there being sufficient demand to support such an activity.

Manufacturing Readiness Level (MRL)

Material Solutions Analysis	1	Basic manufacturing implications identified.
	2	Manufacturing concepts identified
	3	Manufacturing proof-of-concept developed
	4	Capability to produce the technology in a laboratory environment
Technology Development	5	Capability to produce prototype components in a production relevant environment
	6	Capability to produce a prototype system or subsystem in a production relevant environment
Engineering and Manufacturing Development	7	Capability to produce systems, subsystems or components in a production representative environment
	8	Pilot line capability demonstrated. Ready to begin low rate production.
Production and Deployment	9	Low rate production demonstrated. Capability in place to begin full rate production.
Operation and Support	10	Full rate production demonstrated and lean production practices in place.

Figure 49. Manufacturing Readiness Level Definitions.

RECOMMENDED ACTIONS

1. Build plans to attract an AM ecosystem, including members of industry, academia, and government in Guam that could eventually achieve a Manufacturing Readiness Level (MRL) 10.
    a. Identify total addressable market for AM products in Guam
    b. Consider and assemble a consortium of Guam-based stakeholders to collaborate in building such an ecosystem.
    c. Develop and implement a specialized AM workforce development concept in Guam.
    d. Establish plans for developing requisite facilities for AM design, prototyping, production, post-processing, and testing/validation,
    e. Initiate plan for technology and platform acquisition and corresponding maintenance and operations (to include consistent access to needed materials/feedstock).
2. Affirm buy-in from leading U.S. Department of Defense and economic development policymakers seeking to sustain U.S. national security and economic interests in the Indo-Pacific.

RECOMMENDED FACILITIES

Given the results of the feasibility study for Phase I a potential plan for building AM capabilities on-island entails development of three related facilities (See Figure 50). These facilities would be primarily established under the management of the

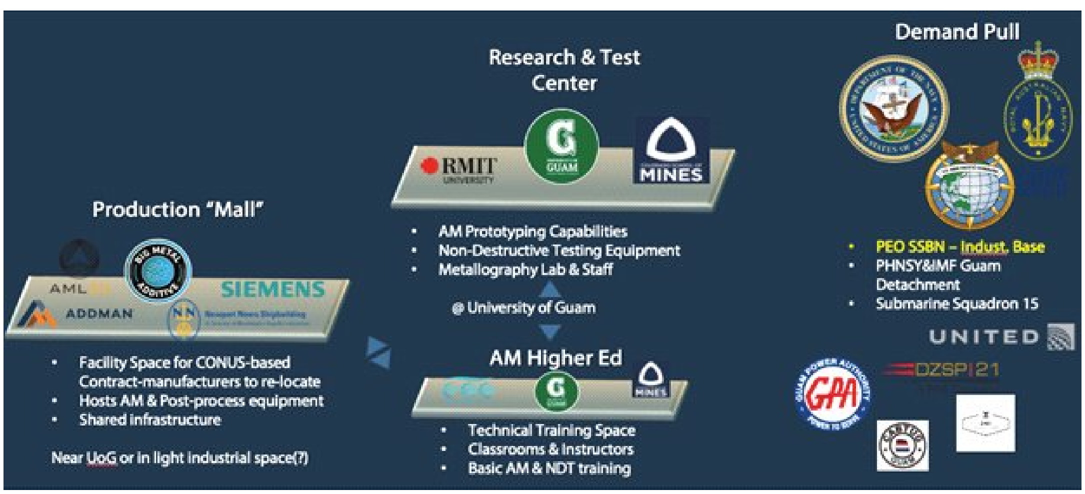

Figure 50. The possible future vision of Industrial AM facilities on Guam

University of Guam and Guam Economic Development Authority. They would be configured to leverage assistance and sponsorship from outside institutions, including external universities, U.S. and Allied governments, and industry.

First is a Research and Test center supporting prototyping capabilities as well as advanced quality inspection (e.g. metallography lab) to validate part production for use by DoD and other stakeholders.

Second, a ‘Business Incubator’ (Shown as 'Production Mall' in Figure 50) would provide a setting for existing contract additive manufacturers and start-ups to re-locate assets in Guam. The facility could host both 3D printers and post-processing equipment, under a shared infrastructure arrangement potentially supported by government.

Finally, an integrated approach to education and technical skills training to enable long-term sustainability of this effort in Guam.

CONCLUSIONS

Ultimately, Guam possesses the fundamental building blocks required to establish a high-tech manufacturing sector--

- Strong Demand-Pull (DoD – principally Navy submarines)
- Business climate to attract both private and DoD investment
- Workforce Development Capabilities
- Advanced Research Institution

However, as Phase II will demonstrate, much work remains to be done in establishing an ecosystem tailored to distinct AM requirements as well as unique economic and geo-political conditions in Guam.

A robust public-private partnership will depend on subsequent efforts to attract private investment into contract-manufacturers in Guam (possibly residing at an incubator space), collaborative research and part testing/evaluation in an academic setting, and a strong workforce development program. Demand from both Defense and commercial sectors will be required to sustain such an operation; however, such a pull will depend on two factors: (1) strong buy-in from a DoD/Navy customer willing to invest in research/prototyping infrastructure and (2) a novel capability to expedite transfer of pre-approved digital design-data from original part manufacturers to authorized 3D printer operators on-island. Realizing this concept has transformative potential to create new jobs and breakthrough additive manufacturing capabilities in Guam.

ABOUT THE AUTHORS

Craig Brice is a Professor of Practice in Mechanical Engineering as well as director of the Additive Manufacturing Program at Colorado School of Mines, which focuses on undergraduate and graduate education in additive manufacturing. Previously, he focused on additive technology at Lockheed Martin and NASA Langley Research Center, including work on alloy development, process monitoring and feedback control systems, and qualification/certification.

Rachael Dalton-Taggart is project manager at ASTRO America, coordinating technical and policy analysis across the Guam project team. She is also CEO of Ashbridge Communications, providing strategic marketing in additive manufacturing and industrial software and manufacturing to clients across North America and Europe. Previously, she spent two decades directing marketing and communications activities for leading additive and software companies such as 3D Systems and Geomagic.

Jason Gorey is executive director of ASTRO America, overseeing the organization's day-to-day operations. Previously, he worked in multiple national security positions, including executive secretary of the Defense Production Act Committee, coordinating multi-agency task forces on essential national defense supply chains. He also has extensive experience in intelligence and cyber security, having served as an Army intelligence officer and Senior Foreign Affairs Officer at the Department of State.

Theodore Hack served for 30 years in the U.S. Navy from which he retired as Assistant Chief of Staff for Warfare, Requirements, Planning and Assessments for the US Submarine Force, Atlantic Fleet. During his career, he commanded the USS Guardfish (SSN 612) and USS Orion (AS 18) and worked as the Director of Navy Programs and Congressional Liaison Officer for Submarine Programs in the Navy Office of Legislative Affairs. For 18 subsequent years, he was General Dynamics' primary Government Relations liaison with Congress on Submarine programs.

Matthew Herrmann is a senior advisor at The Roosevelt Group representing a wide range of clients on Congressional appropriations and authorization matters, federal budget process, strategic planning, strategic communications, Base Realignment and Closure (BRAC), and Indo-Asia-Pacific policy matters. For over a decade prior, he worked on Capitol Hill serving as Chief of Staff to Congresswoman Madeleine Bordallo (Guam), Ranking Member of the House Armed Services Subcommittee on Readiness.

Aaron Klein is a leading macroeconomist with 20 years experience at the intersection of economics and policy. From 2009-2012, he served as deputy assistant secretary for economic policy at the Department of Treasury, working on financial regulatory reform and helping secure passage of the Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010. He also played leading roles on responding to the economic crisis, housing finance reform, transportation and infrastructure policy, and Native American policy.

Michael Likosky serves as an economist and leads the infrastructure practice at 32 Advisors, a New York City-based consulting firm. He previously co-chaired California Gov. Edmund Brown Jr.'s Task Force to Modernize the California Infrastructure Bank and played a key role in growing the U.S. Treasury Department's $187 billion Build America Bond program. He also advised leading pension funds on the deployment of $10 billion into U.S. infrastructure in a Clinton Global Initiative program.

Neal Orringer is president of ASTRO America, where he serves as Chief Executive Officer. In 2010, he joined the Obama administration, as the U.S. Department of Defense Director of Manufacturing, leading Manufacturing Technology and Defense Production Act programs. In 2012, he launched the pilot Manufacturing USA institute focused on Additive Manufacturing. For a decade, he was an executive at 3D printing companies (GE and 3D Systems). He is a recipient of the Exceptional Civilian Service Medal.

William Tredway is a manufacturing fellow and consultant to ASTRO America, leveraging 34 years of experience in industrial R&D. Previously, he applied expertise in materials science and engineering and manufacturing technology to develop new technologies and perform early-stage product development for Raytheon Technologies Corporation (RTX, formerly United Technologies Corporation). He has led multi-disciplinary project teams in additive manufacturing and other technologies.

APPENDIX 1. CALL LOG

Date	Time (EDT)	Purpose	External Org
8/25/2022	2:00 PM	Potential DOD investment / Supply/Demand	Defense Innovation Unit & Big Metal Additive
8/23/2022	6:00 PM	Guam Project Kick-Off Meeting (deliverable 1)	GEDA
9/2/2022	9:30 AM	Pacer Edge (Air Force Qualification)	GE
9/9/2022	11:30 AM	potential machine supplier investment	Big Metal Additive
9/13/2022	9:30 AM	potential Navy investment in CapEX, R&D	Office of Naval Research
9/14/2022	6:00 PM	Planning call	GEDA
9/15/2022	4:30 PM	additive Naval applications on Guam	Pearl Harbor (+Guam Detachment)
9/15/2022	6:15 PM	Initial UoG introduction	UOG President
9/18/2022	6:00 PM	Initial Intro call	Guam Community College
9/19/2022	11:00 AM	Pacer Edge (Air Force Qualification)	GE Additive
9/19/2022	6:00 PM	Initial Intro call	Guam Power Authority
9/19/2022	7:00 PM	Initial Intro call	Guam USDA/Rural Development
9/21/2022	11:00 AM	Potential DOD investment / Supply/Demand	Defense Innovation Unit & Big Metal Additive
9/22/2022	6:00 PM	Deliverable 2	GEDA
9/27/2022	6:00 PM	Workforce prep discussion	UoG leadership
9/28/2022	10:00 AM	Parts Qualification discussion	NAVSEA
9/28/2022	7:00 PM	Workforce discussion	Guam Chamber of Commerce
9/29/2022	6:00 PM	Manufacturing capability	CABRAS Marine
10/3/2022	4:00 PM	Concrete/Manufacturing R&D and demand	Defense Innovation Unit
10/3/2022	6:00 PM	Demand / Manufacturing need	Newport News
10/4/2022	7:00 PM	Mechanical Engineering	UoG leadership
10/6/2022	6:00 PM	AM Capability AF	36th Maintenance group
10/10/2022	6:00 PM	Infrastructure/site selection	Guam Water
10/10/2022	7:00 PM	small business/manufacturing	Bella Wing
10/11/2022	7:00 PM	Finance	Bank of the Pacific
10/12/2022	7:00 PM	Finance	Bank of Hawaii
10/17/2022	10:00 AM	Air Force qualification	Air Force Research Laboratory
10/18/2022	5.30 PM	Diversity	UoG, Dr Enriquez
10/18/2022	6:00 PM	Grant funding	UoG, Dr Rachael
10/19/2022	5:00 PM	Guam Industry Forum participation	SAME
10/20/2022	6:00 PM	Infrastructure/ Import-Export	Airport Authority
10/26/2022	1:00 PM	AF AM Strategy	Rapid Sustainment group
10/26/2022	6:00 PM	Status update	BSP
10/26/2022	6.30 pm	Intro to Port Authority	Port Authority
10/28/2022	6:00 PM	Introduction	STARBASE
11/2/2022	6:00 PM	Shipbuilding/repair in Guam	Newport News
11/2/2022	7:00 PM	Deliverable 3	GEDA/BSP
11/3/22	7;00 PM	Introduction to healthcare	GMRC
11/4/22	8:30 AM	Follow up	PEO/SSBN
11/5/22	7:00 PM	Introduction	Womens' Chamber
11/6/22	5:30 PM	Follow up	G3 MakerSpace

APPENDIX 2. ON-ISLAND MEETINGS

GUAM ON-ISLAND MEETING LOG

Date	Time (EDT)	Purpose	External Org
11/14/2022	10:00 AM	Site visit, meet and greet	G3 Makerspace
11/14/2022	1:00 PM	Site visit, meet and greet	Guam airport authority
11/15/2022	10:00 AM	Briefing	Navy Base Guam
11/15/2022	11:00 AM	Site visit, meet and greet	Port of Guam Users' group
11/15/2022	1:00 PM	Presentation by Neal O	SAME Forum
11/15/2022	3:00 PM	Site visit, meet and greet	University of Guam
11/16/2022	10:00 AM	Site visit, meet and greet	Guam Community College
11/16/2022	11:00 AM	Site visit, meet and greet	STARBASE Guam
11/17/2022	all day	AM Workshop	ALL
11/18/2022	10:00 AM	Radio Interview	K57 Radio
11/18/2022	11:00 AM	Status Meeting	Guam BSP
11/18/2022	11:00 AM	Working group - diversity and STEM	UoG, Starbase, GEDA, G3 Maker space
11/18/2022	2:00 PM	Status Update	Governor of Guam

APPENDIX 3. WORKSHOP AGENDA

Guam Additive Manufacturing Feasibility Workshop

Hyatt Regency Guam | 1155 Pale San Vitores Road
November 17, 2022 | 9:00am - 5:00pm

Plenary Session (9:00AM – 12:00PM): What is needed?

9:00 am	**Remarks and Introduction** Melanie Mendiola, GEDA
9:10 am	**Keynote** Honorable Lou Leon Guerrero
9:20 am	**ASTRO America Introduction: Mission & Methodology** Neal Orringer, ASTRO America
9:30 am	**Introduction to Advanced/Additive Manufacturing** Craig Brice
10:00 am	**Guam AM Feasibility study: Assessing pathways to Parts on-Demand!** Neal Orringer
10:20 am	**BREAK**
10:30 am	**What Is Needed for an "Industry 4.0" Manufacturing Capability On-Island?** Craig Brice -Digital Design and Cyber-physical production -The Design-Build-Test Continuum -Workforce (Migrated vs. On-island)
10:50 am	**What Is Needed to Sustain This Capability On-Island? Pt 1** Jason Gorey -U.S. Navy Demand (PHNSY/IMF Guam Detachment, USMC, Non-Organic,) -U.S. Air Force Demand (Anderson AFB) -U.S. Army/MDA -Commercial (Medical, Airlines, GPA, Other)
	What Is Needed to Sustain This Capability On-Island? Pt 2 Aaron Klein / Michael Likovsky -Banking System -Import/Export -Broadband -Federal/Local Government Reqs
11:15 am	**What Is Needed for AM Part Acceptance?** Neal Orringer -Qualification/Certification -Direct/Indirect Manufacturing
11:30 am	**Listening Session - Interactive Q&A With Attendees**
12:00 pm	**Lunch – Part Demonstration**
1:00 pm – 4:15 pm	**Break Out Sessions: Where are we now?**
4:15 pm	**BREAK**
4:30 pm	**Closing Summary / Committees**

APPENDIX 4. WORKSHOP ATTENDEE LIST

Prefix or Military Rank	Name	Organization Name
Ms	Rach Taggart	ASTRO America
Monsieur	Neal Orringer	ASTRO America
Mr.	Jason Gorey	ASTRO America
Dr.	Craig Brice	Summit Manufacturing Consultants LLC
Mr.	Matthew Herrmann	The Roosevelt Group
Ms	Melanie Mendiola	Guam Economic Development Authority
Mr.	Melvin Tabilas	Guam Economic Development Authority
Mr.	Charlie Hermosa	Bella Wings Aviation
Mr.	Glenn Leon Guerrero	University of Guam
Ms.	Monica Guerrero	Bureau of Statistics and Plans
Ms.	Cathleen Moore-Linn	Research Corporation University of Guam
Dr.	Rachael Leon Guerrero	University of Guam
Mr.	John Becka	Bella Wings Aviation
Mr	Aaron Ferrer	Guam Green Growth
Ms.	Esther Camacho	Bureau of Statistics and Plans
Executive Director	Vera Topasna	Community Defense Liaison Office
Mr.	Eric Plinske	Guam Regional Medical City (Hospital)
Ms.	Maria Eugenia Leon Guerrero	Bank of Guam
Mr.	Jeffrey Grimes	Cabras Marine Corporation
Dr.	Anita Enriquez	University of Guam
Civilian Contractor	Frederick (Joe) Schneider	Huntington Ingalls Industries
Mr	Joseph Diego	USDA Rural Development
Mr.	Miguel Bordallo	Guam Waterworks Authority
Mr.	Brett Railey	Guam Waterworks Authority
Mrs.	Mauryn McDonald	Guam Waterworks Authority
Ms.	Lola Leon Guerrero	Bureau of Statistics and Plans
Dr.	Leah Beth Naholowaa	STARBASE GUAM
Quality Division Director	Robert Bass	Guam Detachment (PHNSY)
Mr.	Christopher Hunt	PHNSY&IMF Det Guam / Project Superintendent
Mr.	Cedrick Castillon	Guam Economic Development Authority
Mr.	Joaquin Cook	Bank of Guam

MR.	Stephen Librando	Bella Wings Aviation
Mr.	Joseph Certeza	G3 Maker's Space & Innovation Hub
Mr.	Kenneth Lujan	Small Business Administration
Ms.	Catherine Castro	Guam Chamber of Commerce
Technical Sergeant	Jesse Dillard	36th Maintenance Squadron, Andersen AFB
Dr.	Roseann Jones	University of Guam
Staff Sergeant	Andrew Bouffard	Air Force
Mr.	Carlos Taitano	University of Guam
Dr.	Laurie Raymundo	University of Guam Marine Laboratory
Director	Chirag Bhojwani	36th Guam Legislature - Committee on Regional Affairs, the Guam Buildu, and Technology
Mr.	Michael Quitugua	Bella Wings Aviation
LTC(R)	David Okada	University of Guam
Mr.	Javier Jose Garrido	Bella Wings Aviation
Mr	Shawn Garcia	Reflection Dental
Mr.	Tyrone Taitano	Office of Infrastructure Policy and Development
Mr.	Austin Grant	Guam International Airport Authority (GIAA)
Dr.	Artemio Hernandez	Guam International Airport Authority (GIAA)
Mr.	Gerard Toves	Department of Labor
Dr.	Juan Flores	American Job Center, Department of Labor
Supervisory Mech Engineer	Clifford Imamura	Pearl Harbor Naval Shipyard
Mr.	Jehn Joyner	Cabras Marine Corporation
Mr.	Jehn Joyner	Cabras Marine Corporation
Mr.	Jordan Panuelo	Guam Green Growth
SPORD Manager, P.E.	Jennifer Sablan	Guam Power Authority
Engineering Manager, P.E.	Vincent Sablan	Guam Power Authority
Mr.	Mathews Pothen	Guam Shipyard
Gov. Contractor	Timothy Blackwell	DZSP 21 LLC
Mr	Peter Barcinas	University of Guam
Dr.	Kate Moots	University of Guam—College of Natural & Applied Sciences
Mr.	Christopher Kelley	MCS Contractors
Ms.	Myracle Mugol	Guam Green Growth
Ms.	Angelica Paulino	Guam SBDC
Mr.	Shaun Hosei	GCC

APPENDIX 5. WORKSHOP FINDINGS

Highlights of the Workshop

Why ASTRO America and GEDA convened this workshop

Economic diversification remains a top priority of Guam's Governor Lou Leon Guerrero, as evidenced by her recent establishment of a public/private task force to address this priority, together with the Guam Chamber of Commerce.[1] 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. To this end, ASTRO America was contracted by the Guam Economic Development Administration (GEDA) to assess the feasibility of a local additive manufacturing (AM) industrial base on Guam that will serve as a new economic engine for the island and enhance military operations in the region.

Indeed, Guam holds significant strategic importance to the U.S. military due to its geographic location in the Indo-Pacific region. While strategically important, Guam's remote location creates supply chain and logistical challenges for the support of military assets on-island and in the region.[2] Currently, no major manufacturing capacity on Guam exists to support local fabrication; spare parts for maritime, automotive, medical, and energy generator supply chains must be imported from long distances, creating repair backlogs and inflating sustainment costs.

Figure 1. Governor Leon Guerrero gives opening remarks at the workshop

As part of its Phase I feasibility assessment, ASTRO America conducted a 1-day workshop in Guam on November 17, 2022 to engage local stakeholders to determine: (1) current capabilities and needs for supply chain development; (2) potential strategies for developing such a workforce and capabilities; and (3) potential demand, including U.S. Government stakeholders.

Workshop participants included local attendees from academia, government, business, infrastructure, banking, military and non-governmental organizations that were invited to

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[1] "Governor establishes Economic Diversification Working Group," Guam Post. December 30, 2020. https://www.postguam.com/news/local/governor-establishes-economic-diversification-working-group/article_4bcacd92-49b2-11eb-bebe-5f34b50282ea.html

[2] Doornbos, Caitlin. "Pentagon report recommends expanded forces in Guam, Australia to challenge China in the Pacific," Stars & Stripes. November 29, 2021. https://www.stripes.com/theaters/asia_pacific/2021-11-29/pentagon-military-global-posture-review-indo-pacific-china-3797592.html

represent a range of viewpoints and backgrounds (See Appendix A: attendee list). This memo comprises section (s) of Deliverable 4, Phase I, session/notes and conclusions.

Figure 2. Dr. Craig Brice presents the fundamentals of additive manufacturing

Feedback Process

In the first three months of its feasibility assessment, the ASTRO America team undertook more than 40 external virtual meetings with individuals representing disparate stakeholder groups in Guam. Appendix B is a log of these meetings reported in Eastern Standard Time. These engagements were supplemented by research into economic, demographic, and military factors that would inform the format of the workshop that took place on-island.

At the workshop this information was presented (Ref: APPENDIX D) and during the afternoon breakout sessions, all participants were invited to share their viewpoints, ideas and make comments and were given an opportunity to add written ideas on posted questions on the walls (Appendix C1). In addition, an online questionnaire was offered for more detailed feedback. (Appendix C2).

What Attendees Said

In general, workshop attendees affirmed findings presented by the research team during the workshop. Such an outcome was largely expected due to many attendees' involvement in the virtual meetings in the prior weeks. However, the workshop allowed for in-depth commentary as well as guidance on which issues the assessment should prioritize.

Demand Signals – Spare Parts for DoD, Medical, Energy, Automotive

Attendees included representatives of the U.S. Department of Defense (DoD), and its associated industries, as well as health care industry, private industry supporting public utilities, airport and port authorities and financial services. Their unique experiences on the island

Figure 3: Spectrum of potential part manufacturing in Guam via AM

contributed a broad set of insights to discern appropriate stakeholders who might leverage U.S. Navy, supporting private shipyards, and at least one major Navy Lead System Integrator.

Defense. Clearly, the growing multi-billion dollar build-up of DoD tenants at bases across the island presents opportunities for novel approaches to logistical support. For example, the new Guam Detachment of Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility (PHNSY & IMF) indicated plans over the next 5 years to build up support for submarines and other platforms; facilities may require reverse-engineering or replacement-part requisition. Naval Sea (NAVSEA) Systems Command is developing acceptance criteria for AM-built components (for critical ship parts)[3] even while various Department of the Navy organizations, such as Marine Corps Logistics Base Albany (Georgia) or Naval Undersea Warfare Center Keyport (Washington), have long used AM for tooling, prototyping, and non-critical parts. These comments offer a spectrum of the varying skillsets, products, materials, destructive and non-destructive testing requirements, as well as fabrication technology potentially of interest via AM as illustrated in Figure 3. Another key AM end-user is Huntington-Ingalls Newport News Shipbuilding (HII-NNS), which is working closely with both additive manufacturing equipment manufacturers and NAVSEA to accelerate technology adoption/acceptance across the fleet. HII-NNS' presence at the workshop as well as critical inputs to discussion over workforce development and conditions for naval maintenance support contributed to a wider understanding of AM feasibility and requirements for adoption.

Medical. Guam Regional Medical City participated in the workshop and provided insights into the high costs of health care and challenges accessing regular supplies for traditional goods/services for both in-patient and outpatient facilities. Its ambition is to become a regional hub for medical support across Micronesia (as illustrated in Figure 4). 3D printing is commonly applied to surgical procedures and medical modeling in the US. However, attendees noted that Food & Drug Administration approval is required to implement processes involving direct patient contact.[4]

Figure 4: GRMC ambition to serve as a medical hub for southeast Asia

Aviation & Automotive. The aerospace industry has been an early AM adopter, and achieved Federal Aviation Administration approval for inserting flight-critical components including the

[3] Rettaliata, Justin. Engineering Standards: Best Practices and Emerging Technologies NAVSEA Additive Manufacturing Overview. Naval Seay Systems Command. August 3, 2022. https://www.dsp.dla.mil/Portals/26/Documents/Conference/2022%20Briefings/Rettaliata_NAVSEA%20AM%20Overview_DSP%20Conference%20Panel_3%20Aug%202022.pdf?ver=o0ux5WIUH2SX3eXLxaSvCg%3D%3D
[4] Food & Drug Administration. 3D Printing of Medical Devices. March 26, 2020. https://www.fda.gov/regulatory-information/search-fda-guidance-documents/technical-considerations-additive-manufactured-medical-devices

most celebrated application—General Electric's fuel nozzle. In this case, a metal 3D-printed fuel nozzle tip was integrated into the LEAP aircraft engine in 2015—since then over 100,000 have been manufactured. The original redesign consolidated 20 separate components into one single 3D-printed part. Other applications have been applied to build geometries that cannot be fabricated in other ways, including use of 3D printing to build General Motors seat brackets that are both 40% lighter and 20% stronger than traditional counterparts.[5]

Figure 5. Wider view of workshop

Attendees, including members of the Port Authority, Airport Authority and commercial aviation industry, indicated interest in exploring how AM could be adopted more readily to maintenance repair and overhaul (MRO) activities in order to avoid costly inventories or delays for part imports. Others expressed interest in reverse engineering applications for other sectors, including the automotive market. However, it was agreed that additional considerations would need to be made to engage vehicle producers given original equipment warranty policies.

Utilities.

As with the health care sector, representatives of the Guam Power Authority indicated some challenges discerning an appropriate business model for integrating additive manufacturing into the on-island power supply chain (for spare part requisition). Key suppliers of energy generator technology such as Siemens Energy and Cummins are among the most prolific users

[5] Crawford, Mark. ASME. Combining Parts Simplifies Assembly. October 22, 2022. http://asme.org/topics-resources/content/combining-parts-simplifies-assembly

of additive manufacturing.[6] Both GPA and Guam Water Authority offered insights into the University of Guam as an ideal location for a potential AM (light-medium industry) site, given its existing infrastructure for handling both large electrical consumption as well as water management.

Workforce Availability and Workforce Opportunities

During the workshop the research team suggested that current workforce availability for AM would be minimal. No one at the workshop disagreed.

Training Profile	Relevant Exposure	Availability
Unskilled/High School Diploma	None or limited exposure to hobbyist 3D printers	Most likely available
Vocational Certificate/Degree	Most likely welding, machining, sheet metal fabrication	Some availability
Mechanical Engineer (PE)	CAD, modeling & simulation, testing & analysis, characterization, metrology	Low availability
Undergraduate (intern)	CAD, testing & analysis, characterization, metrology	Zero availability
Post-Graduate (researcher)	CAD, physics-based modeling, machine learning	Zero availability

Table 1. Current availability of skilled workforce on Guam for AM

Many attendees indicated building blocks for establishing such a capability existed, if afforded appropriate resources to established institutions such as the University of Guam, Guam Community College, and local school system. While a small minority expressed pessimism over short-term ability to develop/attract necessary talent, attendees shared their experience of creating tailored on-island "boot-camps" and necessary skills training programs, academic activities and on-line program scouting. It was noted that competition from other states and countries for skilled labor remains a barrier.

One participant noted in the online questionnaire:
"Careers and career paths are key. Employees need to see that they can earn a living comparable to what they would be able to get off island."

A further concern about ensuring educators were adequately compensated was also raised.

Visa Labor

Some attendees had the view that an AM center could only be successful through the use of specialty occupation or research and development visa labor. While such a policy might address

[6] AM has taken on a major role in development and production of components and spare parts for Siemens Energy in recent years. In addition to setting up its own AM production lines and acquiring AM service provider Materials Solutions in 2016, the company is now expanding its commitment in this area with its investment in the start-up MakerVerse-- connecting industrial clients with a global network of certified additive manufacturing suppliers for projects like design prototypes and producing on-demand spare parts. "Siemens Energy Invests in New Digital Platform," press release. March 1, 2022.

short term requirements to set up research or production capabilities on-island, it was also stated that collaborations with Universities and schools from the continental United States (CONUS) might have greater chances of instilling long-term roots. Moreover, support from fellow U.S. nationals in military-related work would overcome any concerns over export control issues arising from foreign labor.

Retaining workforce and attracting islanders back to Guam

A key concern among attendees was the need for better paid, diverse work opportunities that would a) retain labor on the island and b) attract islanders back that have moved elsewhere. Attendees frequently noted the sizable diaspora of Chamorro people living outside Guam—reported to include 156,000 people in CONUS, according to the U.S. Census Bureau.[7] Attendees postulated that potential work associated with high tech computer-aided-design and additive manufacturing (along with presumed elevated compensation) might be viewed as sufficiently stimulating and cutting-edge to attract outside Chamorro populations to Guam. This sentiment appeared to constitute a critical element of a strategy for building up new capabilities on-island for any type of economic diversification.

Promoting Diversity, Equity and Inclusion within the island workforce

Guam has a good record of building a diverse workforce but still has challenges with developing awareness of job opportunities, according to a sub-group that was convened on Nov 18 (and related written comments) in Guam to discuss the issue.

The main outcomes and recommendations from this meeting included:

- Focus on teacher training/certification for STEM/STEAM
    - Get GDOE to include STEM in the curriculum.
- Build awareness among teachers, parents and grandparents through outreach
- Include artistic elements in digital manufacturing, that may derive from cultural inspiration
- Offer work-experience opportunities to students
- Teach students on how they can solve the 'greater social needs' on the island through their own innovativeness and entrepreneurship opportunities
- Coordinate current efforts (STARBASE, G3, GCC, etc) to build a more cohesive understanding and effort from all educational and business development professionals
- Expand scholarship/incentive opportunities for college students from Guam contingent on returning to the island and pursuing STEM (including additive manufacturing) professions.

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[7] **Monte, Lindsay M. et al. "20.6 Million People in the U.S. Identify as Asian, Native Hawaiian or Pacific Islander," Census Bureau. May 25, 2022. https://www.census.gov/library/stories/2022/05/aanhpi-population-diverse-geographically-dispersed.html**

Lack of Training and Academic Opportunities for a Workforce like this.

Guam academic facilities have addressed (or are addressing) needs for trained labor in machining, welding and shipbuilding, as well as architectural programs to support the growing DoD presence on-island. However, while additive manufacturing remains 100% driven by digital 3D data, it was challenging to find institutions that employ industrial-grade 3D CAD (software that delivers digital 3D data) in their curriculum, such as SolidWorks or NX modules.

A comment posted to the question boards noted "Middle and High schools have a varying degree of 3D printers but no curriculum. Lack of that curriculum means students are not engaged or shown the pathway to AM even from a hobbyist perspective."

However, there are initial efforts underway, and potential to synchronize key personnel with ongoing AM workforce development activities sponsored by DoD and academic institutions such as the Accelerated Training in Defense Manufacturing (ATDM) center in Danville, Virginia[8] and the Alliance for the Development of Additive Processing Technologies (ADAPT) center at the Colorado School of Mines in Boulder, Colorado.

Figure 6. Guam Green Growth Maker Space

1) Guam Green Growth (G3) Makerspace is a facility that opened earlier in 2022 by University of Guam at the Chamorro Village. The space incorporates basic AM, as well as

[8] For information on the Navy-sponsored ATDM, see: https://atdm.org/

laser cutting and machining. It also has tools for researching recycling of materials for reuse, as well as acting as an incubator space for start up businesses. The Makerspace is introducing citizens to the idea of being able to make things in a welcoming, helpful environment and is staffed by a small but enthusiastic team of technicians and engineers. This facility has individual team members utilizing 3D CAD, but as of yet, no introductory classes on the discipline.

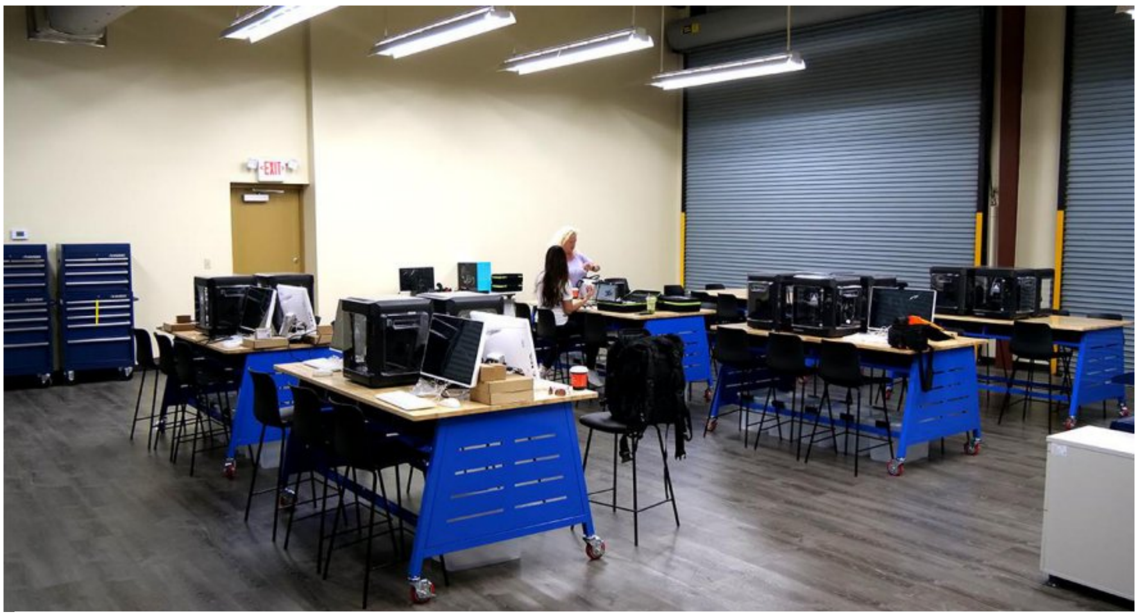

Figure 7. STARBASE Guam is a well-equipped STEM classroom sponsored by DOD

2) STARBASE Guam is a STEM initiative sponsored by the National Guard and DOD. It was started in late 2021 and in a year has served thousands of students focused on the 5th grade. STARBASE is well resourced with desktop 3D printers as well as providing instruction in 3D CAD, as well as inspiring students with projects around building and programming drones. The center is about to expand to Middle and High School outreach as an expansion of its program.

Given the time it takes to build skilled workforce, all attendees seemed to generally agree with the timeline outlined below.

Timeline		Available Workforce	Skills & Capabilities
Year 1 (immediate)	1	Insufficient workforce availability	Unskilled, high school GED
Year 3	3	Vocational skill certifications, undergraduate interns	Basic 3D CAD, 3D scanning, AM machine operations and maintenance, post-processing, testing & analysis, part repair
Year 5	5	Journeyman technicians, professional certifications, BS in engineering (mechanical/materials)	Advanced CAD design, reverse engineering, AM operations, non-destructive inspection, basic qualification testing, limited part production
Year 7	7	Post-graduate degrees and certifications	Fully integrated IoT operation, full qualification & certification workflow, complex metal part production

Table 2. Timelines to build a qualified workforce

These timelines will be successful if some of the following things occur:

- The development of 2-year and 4 -year engineering/AM courses at University of Guam, most likely in collaboration with Colorado School of Mines and other academic institutions (based in other jurisdictions ranging from Hawaii to Australia).
- The availability of 3D CAD & STEAM curricula and training at regional schools, Guam Community College and the Trades School
- Continued small business incubation and training via G3 Makerspace as well as introductory and outreach programs
- Continued expansion of STEAM outreach across various age groups by STARBASE, plus any additional summer camps
- Establishment of an awareness program across the island to inspire students, adults, military veterans to enter the workforce

Business Incubation and the Circular Economy

Although there are a few manufacturing-related entrepreneurial initiatives underway on-island (Bella Wings Aviation for example), workshop attendees pointed to a need for increased business incubation on the island. One attendee noted that the main things made on the island were “tourist items” such as souvenirs, and that there is a need to develop and produce items that are unique to Guam (can only be made on the island) – and potentially exported.

Figure 8. Neal Orringer checks out the recycling research underway at the G3 Makerspace.

In addition, on an island so small and remote as Guam, recycling of materials and developing a circular economy is high on the list of priorities. Research and development into recycling is a key initiative at University of Guam and remains a focus of the G3 Makerspace. While it is still early in the process, the team has already recycled plastic to make AM filament, and is developing melted soda bottles for making 'bricks' that can potentially be used in simple structures such as bus stops.

The U.S. government has written extensively on the role that additive manufacturing can play in addressing climate and decarbonization goals. In fact, the U.S. Department of Energy (DOE) estimates that (compared to traditional manufacturing) AM can slash waste and materials costs by nearly 90% and cut manufacturing energy use in half.[9] This is also why the European Union has launched a major circular economy additive manufacturing initiative, to advance innovation and waste reduction across the world within strategic production industries and is fast becoming a major focus of global research.[10]

Attendees expressed frustration at, but also indicated opportunity for, producing hard-to-find, but often-needed, parts that spanned across simple automotive parts all the way to parts for ships. Notwithstanding quality testing, qualification as well as licensing issues, there seems to be an opportunity for AM on-demand production of such parts stretching across a variety of industries to also include agricultural machinery, appliances as well as shipping repairs.

Attendees indicated awareness programs to help inspire Guamanians to innovate in this area would be an advantage to the island, with a likely leading role for the G3 Makerspace. STARBASE Guam could also continue to introduce students to STEM-based entrepreneurship. Ultimately, the development and availability of resources and experience in producing, testing and qualifying bespoke parts for machinery would lead to greater self-reliance on the island.

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[9] Office of Technology Transitions. U.S. Department of Energy. Additive Manufacturing: Building the Future. July 2019. https://www.energy.gov/sites/default/files/2019/07/f64/2019-OTT-Additive-Manufacturing-Spotlight_0.pdf ; Masurtschak et al., Impact of Additive Manufacturing towards the Environmental Sustainability. Erasmus Center of EU. Jan. 2018

[10] European Defense Agency. Europe Examines Additive Manufacturing to Foster Circularity in Defence. June 24, 2022. https://eda.europa.eu/news-and-events/news/2022/06/24/experts-look-at-additive-manufacturing-to-foster-circularity-in-defence

Guam Economy and Sources of Funding

The facts about the current condition of the economy of Guam are publicly available and were validated during the workshop. Attendees generally agreed on the need for economic diversity in Guam. The question remains: Would diversifying capabilities with AM on-island adequately contribute to the broader economic impact desired by the Economic Diversification task force?

Attendees considered a core set of factors that would either lead to acceleration or discouragement of AM demand. Accordingly, attendees offered details on factors related to:

- Federal funding
- Guam Government funding
- Private capital availability
- Infrastructure and energy supply
- 'Made in America' opportunities for investment and export
- Trans-shipment and Foreign Trade Zone opportunities for investment and export
- Infrastructure and Inflation Reduction federal incentives
- Commercial demand by private companies
- Jones Act considerations

Participants discussed their mixed experiences with a wide range of possible federal programs. Federal programs raised by participants include:

- Interior, including the Administration for Native Americans that fund business incubators and other DOI grants that have previously funded projects through the University of Guam
- NSF that has a program for minority serving institutions for STEM (University of Guam is such an institution)
- SBA credit programs
- Commerce, specifically, NOAA who has provided funding for projects on island
- Dept of Agriculture RISE program: The Rural Innovation Stronger Economy (RISE) Grant Program offers grant assistance to create and augment high-wage jobs, accelerate the formation of new businesses, support industry clusters and maximize the use of local productive assets in eligible low-income rural areas.
- New sources of federal SBA allocations for small businesses

Noticeably absent among academic and infrastructure stakeholders' input was mention of specific Department of Defense programs.

Additionally, multiple participants stressed the importance of utilizing a local partner in securing, structuring and anchoring federal grant and credit programs in line with customary practice. In this regard, University of Guam was raised on multiple occasions as a flexible and valuable partner. They have experience in successfully engaging with multiple federal agencies through multiple programs and possess the administrative capacity and experience to handle the complex grant process.

Financing: Private Sector Banking

There is widespread belief that Guam has a strong enough banking system to provide financing in excess of $60 million for a viable project. Participants highlighted the multiple banks on island and their ability to work together to syndicate loans for broader commercial projects. Banks on island seem to have the experience of working together, sharing risk, opportunity, and coordinating for larger scale commercial projects.

Private sector lending requires streams of repayment. Questions were raised regarding how an advanced manufacturing plant would produce revenue to repay the loans and ways funding outlays could address possible shortfalls. Issues regarding collateralization and to whom the loan would go were raised. Participants noted that banks are a great source of capital for new manufacturing and the banking industry on Guam has been able to support many projects lending hundreds of millions of dollars. Private sector banks would be happy to participate in any project aimed at diversifying the island's economy, bringing new jobs and new skills to the region as well as new revenues.

One common theme was the ability of banks to package loans through existing government guarantee programs such as the Small Business Administration or Department of Agriculture. These programs often provide federal government support in the form of credit enhancements (e.g. risk against default). Federal government credit assistance did not appear to be a pre-requisite for all private banks. There appeared general confidence that banks were willing to take risks to fund projects. It was discussed that these types of potential benefits should be explored regarding the investments under discussion.

As a whole there was a general confidence in financing capacity but less confidence in the economic use cases as to what would be built. Back to the entrepreneurship gap…who will start the company that will build demand? Or should we be looking harder at commercial industries on-island for demand for aircraft, ship and vehicle parts?

International Trade and Investment Regimes

Highly focused discussions happened about significant opportunities for Guam to capitalize on new investment and trade advantages. These discussions, together with pre-meeting ones, were organized around the transshipment positioning underway within the Guamanian government. Workshop participants stressed an optimism that the potential investments under discussion could be a way of turning the page away from past efforts to reposition Guam within international commodity chains.

Several participants raised key Guamanian strategic advantages which could be leveraged by the potential investments under discussion. For example, the port was pointed to as a logistics asset as well as a platform for advanced manufacturing. Water infrastructure was also discussed in this regard. The 'Made in America' designation was also discussed especially with an eye towards putting dissatisfying experiences behind and focusing on fresh opportunities within a changed international commercial environment. In line with this sentiment one respondent on the online questionnaire stated that Transshipment opportunities exist.

"Yes. This can happen both ways...for American manufacturers to have closer proximity to Asia and for Asian manufacturers to have the ability to have produce "Made in the USA""

These issues around international investment and trade regimes will, it is anticipated, take on even greater importance in the context of policy discussions on the island and the broader interest within the US civilian and military economies now underway.

Further Sources of Federal Government Support Availability Specific to AM

Several funding opportunities exist to advance additive manufacturing development on-island—from workforce training to research and supply chain development. Attendees discussed and shared these examples:

- The National Science Foundation recently awarded an Establish Program to Stimulate Competitive Research (EPSCoR) to the University of Guam to strengthening science, technology, engineering and mathematics (STEM) capacity and capability through a diverse portfolio of investments from talent development to local infrastructure.
- The U.S. Department of Agriculture Rural Development office maintains a robust presence in Guam, particularly since the entire island qualifies for investments via their loan, loan guarantee, and grant initiatives.
- The U.S. Department of Commerce National Institute of Standards & Technology (NIST) does not currently operate a Manufacturing Extension Partnership operation in Guam, despite being eligible for such a program that would provide technical assistance to small/medium-sized manufacturers.
- The U.S. Department of Defense awards Defense University Research Instrumentation Program (DURIP) grants. These awards will finance the purchase of research equipment at 77 institutions across 30 states in Fiscal Year (FY) 2023, enabling universities to perform state-of-the-art research that augments current and develops new capabilities.
- The Office of Naval Research, Office of the Secretary of Defense and key acquisition organizations within the Department of Defense invest in both manufacturing technology applied research as well as workforce development initiatives.
- The U.S. Departments of Labor and Housing & Urban Affairs also provide separate funding to individual technical schools or block grants to the government of Guam to support key investments in workforce as well as infrastructure.

Initial Conclusions from Workshop Event

Attendees concluded that establishing an Additive Manufacturing Center would help advance the Governor's economic diversification policies and provide needed growth for the economy. However, it was pointed out that the island lacks considerable industrial resources, including:

- Design tools (3D CAD, etc)
- Industrial AM expertise
- Post Processing expertise
- Testing knowledge and tools
- Workforce
- Feedstock sources
- Known availability of equipment manufacturers selling to Guam

It is clear that to achieve any success an AM Center of Excellence would need to be tied closely to STEAM, Maker Space and business incubation awareness efforts on Guam. Locally-sourced staff will be necessary to bring regional knowledge of needs, demand, local talent and potential business ideas to the table. Partnership between Guam's Department of Education and the U.S. Department of Education would ensure a strong STEAM curriculum is implemented and appropriately propagated across the island.

Fresh in attendees' minds was recent engagement by Virgin Orbit to establish a commercial satellite launch site in Guam. While promising investment on-island over the last several years for such activity, talks have since stalled with the company. It is apparent such an episode has justifiably left some potential stakeholders skeptical of potential technology ventures on-island from external parties. For this reason, potential private MRO investments from other enterprises, such as United and Vietnam Airlines, leave attendees cautious in their optimism about long term impact. An AM Center on-island could make such investments more attractive.

Either way, a concerted infusion of Department of Defense investment remains more certain than that of any other stakeholder. Given the scale of DoD's build-up and interest in AM as a source of innovation, energy savings, and logistical relief, military partnership seems clearly essential in building and sustaining an AM workforce/technology center.

To that end, prior to the workshop, additional insights were provided by Submarine Squadron 15 (CSS-15) for the purposes of this activity. Currently, maintenance support is provided by two submarine tenders (AS) with basic machining capabilities such as lathes, CNC machines, drill press, and grinder. These capabilities will certainly be strongly augmented by the PHNSY+IMF Guam Detachment (as intimated by workshop attendees who are currently leading efforts to build up that unit on-island); however, it will not necessarily relieve logistical challenges associated with either requisitioning replacement parts or maintaining costly inventories without new rapid manufacturing capabilities. Additionally, many of their long-lead item parts would fit within the build-dimensions of a traditional laser powder bed fusion AM system. Workshop attendees indicated proclivity to learn how AM might support fabrication of non-critical parts initially; while eventually aiming to develop a qualification/certification workflow to meet more stringent requirements in the future. Such a development was explored in other engagements with Naval Systems Command Engineering & Logistics Directorate (NAVSEA 05). Indeed, attendees were briefed on NAVSEA's ongoing process to finalize qualification guidance, including inspection rooted in extensive (thousands of) mechanical tests, showing that a new process is equivalent to the existing process.

Similarly, qualification processes were considered for engagement with Air Force assets on the island. Prior to the workshop, personnel from the 36th Maintenance Wing were contacted to discuss potential AM application to their mission at Andersen Air Force Base. Basic fused deposition modeling (FDM) capabilities are currently in operation there. However, Air Force authorities at the Rapid Sustainment Office (responsible for determining which U.S. Air Force Bases are allowed access to industrial AM technology) have indicated that Andersen will not be in receipt of larger AM investments at least until a greater pre- and post-processing capability is established elsewhere on the island. If more advanced AM technology was made available to Air Force officials in Guam, they might leverage processes/procedures being developed under contract with General Electric (a company that both supplies DoD with aircraft engines and AM equipment) to reverse engineer qualified flight critical components. Personnel from Andersen Air Force Base did attend the workshop in their personal capacity and provided some insights into potential prototyping, tooling, and modeling applications.

Going forward, it was concluded that further engagement with the U.S. Department of Defense will require high-ranking engagement to ensure adequate representation of necessary operational requirements that could be filled by AM (including maintenance and repair as well as logistics needs) – from FDM and multijet printing to large-scale directed energy deposition or particle sprays. A public-private partnership with key Guam-based stakeholders, including those in attendance at the workshop, brings great opportunity to leverage sophisticated production equipment in one of the most forward-deployed DoD areas of operation in the Indo-Pacific region.

APPENDIX 6. WORKSHOP QUESTIONNAIRE RESPONSES

Workforce & Education

1. What challenges exist in Guam for recruiting, retaining, and developing personnel in advanced computer science, mechanical engineering, and manufacturing positions? A: Pay and cost of living; A: recruiting off island is difficult. Have to develop talent locally. This can be done through partnerships with other institutions/companies.
2. How do we gauge interest in additive manufacturing professions among Guam's high school, technical school, undergraduate and graduate students? A: Opposite career day- let students "work a day" in the lab or field. Hands-on experience. A: work w/ counselors in the schools. A: For undergrad students- offer summer training/internships on how to do it. So they learn first hadn what possibilities are. A: everyperson at workshop goes to a HS & puts it out to 11^{th}&12^{th} graders. A: Offer summer camps and/or weekend workshops to train kids on 3d (hands on) to get them interested for HS. A: potential with training and ability to make larger salary than your mother/father in 1 yr. A: Guam Community College (GCC. Trades. Dean Gary Hartz. A: Career day. A: Middle & HS have varying degree of FDM printers. But no curriculum. Teachers are left to their own devices to use and maintain printers. Lack of curriculum means students are not engaged or shown the pathway to AM from a hobby perspective. Aaron Fewer. Guam Green Grown. Ferrera@trion.uog.edu
3. Can Guamanians take advantage of specialized 3D design and 3D printing curriculum currently? Is there prospective demand for such courses or apprenticeships (online or in-person)? A: Nothing available now that I know of except the SeaGrant/G3 thing @chamorro village -> this isn't enough. A: Yes. Through STARBASE. A: GUAM GREEN GROWTH Makerspace… but need more.
4. What strategies do current Guam-based businesses employ to recruit and retain specialized STEM personnel for respective workforces? Describe relevant partnerships with GCC or UoG? A: Through the university of Guam exist programs through GUAM EPSOR NSF includes for capacity building focused on STEM fields and recently a program targeting former residents to come back home for grad school. MORE OF THIS! A: Public-Private Partnerships with companies eduate students on scholarships. Employ afterwards. A: If scholarships arfe used to support individuals then payback in service could be a possibility.
5. If there were opportunities to establish partnerships with higher education institutions in the continental US, what are some key policies to consider for ensuring a qualified workforce develops and remains on-island (not exiting Guam)? A: a list of items that provides a person to attain the goals. A: Workforce- veteran-specific incentives. I already do AM for a living . use me. Skioll bridge – 6 month interns start pandering to the DoD. A: Cheap japenese materials? DoD prevents use… right? Separate DoD/Civil Sides?

DOD

6) How might GovGuam and ASTRO America's report be used to help advance preparation of DoD bases' tenant commands adoption of additive technology and coordination with key military, authorities including NAVSEA 05, Rapid Sustainment Office, Program Executive Officer Submarines, and the Office of Naval Research? A: Report could be used to go after grant funding to expand this industry

GUAM IN GLOBAL COMMODITY SUPPLY CHAINS

(1) Describe supply chain challenges experienced in key energy, medical, and MRO industries. A: Energy-utilities for my house equal 2000 sq foot home rental in N. Carlina. Go green or go home. Takes up to 1 year for product to be available. Then products become obsolete.

(2) What opportunities exist in the medical field to extend Guam's role across Micronesia? Could Guam serve as a key medical service provider across the region? A: call Paul Pineda who owns medical supply company here on Guam with ties to Dallas, TX. Issues with paying physicians equitable salaries.

(3) What potential industrial sites exist to host an additive manufacturing facility, prototyping lab, or testing/evaluation capability? What are respective pros/cons of such sites? A: UOG Is a possibility for a testing lab. A: Guam Housing and Urban Renewal Authority. Community Development Block Grant (HUD's CDGB) for funding facilities

(4) What consideration need to be factored in for preservation of indigenous culture, ancestral and historic sites before we embark on advancing Additive Manufacturing on the island? A: State Historic Preservation Office (SHPO) Approval can take a long time.

IOT MANUFACTURING & PART QUALIFICATION

(1) Are there research institutions on Guam with capacity to adopt material testing capabilities to ensure manufacturing processes may meet critical Defense, medical, or other industry standards? A: UOG would be good partner. They just need $ invested into them. A: UOG Engineering School and Health & Allied Services School.. A: AS-40/AS-39 . There are limited military assets that may be able to provide some support.

(2) How might a Guam-based research institution establish partnerships among industry, federal, and local stakeholders to advance innovations in 3D technology and adoption? A: public private partnerships are already being developed to do the validation & certification

FINANCING & MARKETING

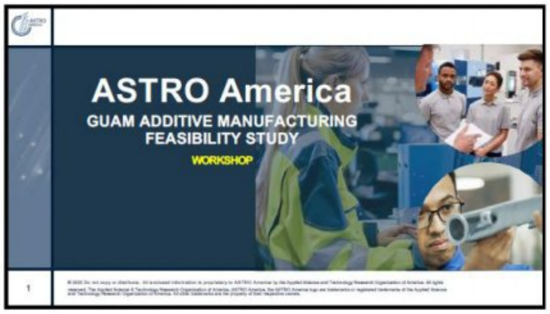
(1) What role can private sector banks play in ensuring access to capital for new manufacturing enterprises in Guam? At what scale? A: EDUCATE US THROUGH THE PLAN/PRESS AND GUAM DAILY POST
(2) What public sector incentives exist to attract investment to Guam from the continental US (part manufacturers, factory equipment providers, distributors)?
(3) Are there public financing options in Guam to support new manufacturing in Guam? A: yes. A: When ask what exports we can provide right now tourist items. We need to look at other markets. Semiconductor. UAV.
(4) Is there potential to convert Guam into a net exporter of manufactured parts to other regional destinations?
(5) Can Guam become a major trans-shipment hub for manufactured goods to the continental US, leveraging its duty-free status and federal Buy American procurement policies?

APPENDIX C2. ONLINE RESPONSES

1 What challenges exist in Guam for recruiting retaining and developing personnel in advanced computer science mechanical engineering and manufacturing positions	2 How do we gauge interest in additive manufacturing professions among Guams high school technical school undergraduate and graduate students	3 Can Guamanians take advantage of specialized 3D design and 3D printing curriculum currently Is there prospective demand for such courses or apprenticeships online or inperson	4 What strategies do current Guambased businesses employ to recruit and retain specialized STEM personnel for respective workforces Describe relevant partnerships with GCC or UoG	5 If there were opportunities to establish partnerships with higher education institutions in the continental US what are some key policies to consider for ensuring a qualified workforce develops and remains onisland not exiting Guam	1 What role can private sector banks play in ensuring access to capital for new manufacturing enterprises in Guam At what scale	2 What public sector incentives exist to attract investment to Guam from the continental US part manufacturers factory equipment providers distributors
Skill set and education in these fields. It is difficult to attract personnel in these fields due to competition from other states and countries.	If career paths can be identified and a clear way to get on the right path can be shown I believe that local talent can be trained up.	I am unaware of any programs covering 3D printing being offered at this time.	We work closely with UOG and GCC to attract new graduates but we have seen that even these individuals need further training to be at the level we need.	Careers and career paths are key. Employees need to see that they can earn a living comparable to what they would be able to get off island.	Banks are a great source of capital for new manufacturing. The banking industry on Guam has been able to support many projects lending hundreds of millions of dollars. Private sector banks would be happy to participate in any project aimed at diversifying the island's economy, bringing new jobs and new skills to the region as well as new revenues.	Tax incentives (QC program)
Individuals' education and training limitations	For high school, introduce the topic to CTE students and students in the 9th grade who are indicating interests in various career fields.	Neither UOG or GCC seem to have courses in 3D Design or 3D printing		It may be necessary for the intitutions to have programs leading to industry-recognized and accepted certification.		
Available sufficient qualified instructors and programs Competitive/attractive salaries	Providing awareness about what it entails through videls and testimonials Present the career opportunities and salary levels	If made available		Funded pathways to support capacity building and job placement		

3 Are there public financing options in Guam to support new manufacturing in Guam	4 Is there potential to convert Guam into a net exporter of manufactured parts to other regional destinations	5 Can Guam become a major transshipment hub for manufactured goods to the continental US leveraging its dutyfree status and federal Buy American procurement policies	1 How might DoD personnel stationed in Guam leverage additive manufacturing	2 What role might offbase part replacement capabilities support maintenance repair and overhaul missions using DLA or Service approved processes and materials Is there demand for offsite manufacturing and repair services onisland	3 How has remoteness affected logistical support for DoD assets in Guam How might ondemand part requisition via additive manufacturing address related challenges	4 How might existing MRO capabilities Navy Air Force Army Marine Corps Missile Defense onbase supplement 3D digital design or additive manufacturing to meet reverse engineering	5 What inputs by Guambased military tenant commands should be considered if the DoD invested in a new additive manufacturing workforce development	6 How might GovGuam and ASTRO Americas report be used to help advance preparation of DoD bases tenant commands adoption of	1 Are there research institutions on Guam with capacity to adopt material testing capabilities to ensure manufacturing processes may meet	2 How might a Guambased research institution establish partnerships among industry federal and local stakeholders to advance innovations in 3D technology and adoption
I am not aware of any major public financing options available.	I believe that there is and this should be the goal.	Yes. This can happen both ways....for AMerican manufacturers to have closer proximity to Asia and for Asian manufacturers to have the ability to have produce "Made in the USA"								
	Yee	Yes								Convene meeting of interested parties to discuss the possibilities and particulars.ol

APPENDIX 7. Workshop PPT.



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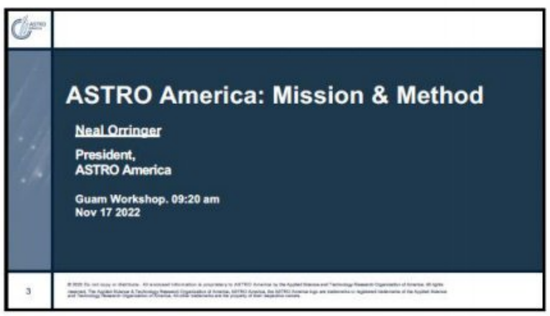

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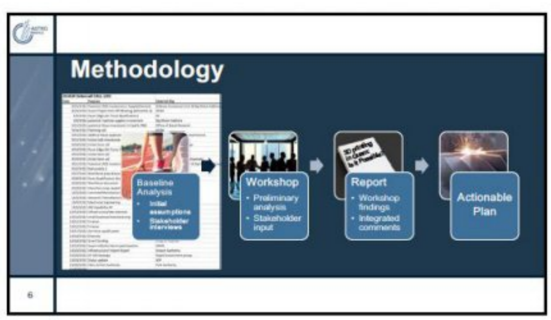

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Theoretically, you can build any shape you dream up...
...but how do we get from Design to Finished Product?
GUAM
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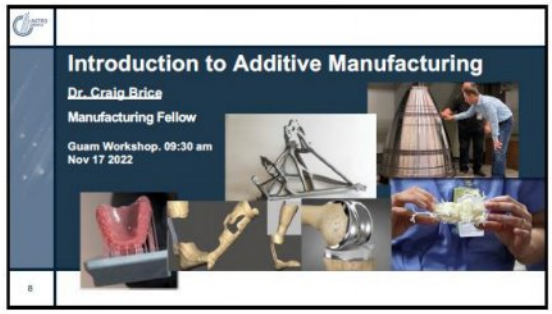
Introduction to Additive Manufacturing
Dr. Craig Brice
Manufacturing Fellow
Guam Workshop. 09:30 am
Nov 17 2022
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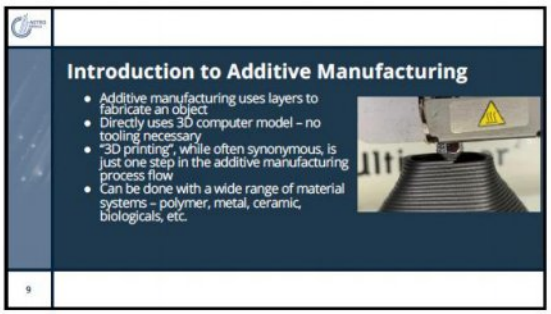
Introduction to Additive Manufacturing
Additive manufacturing uses layers to fabricate an object
Directly uses 3D computer model – no tooling necessary
"3D printing", while often synonymous, is just one step in the additive manufacturing process flow
Can be done with a wide range of material systems – polymer, metal, ceramic, biologicals, etc.
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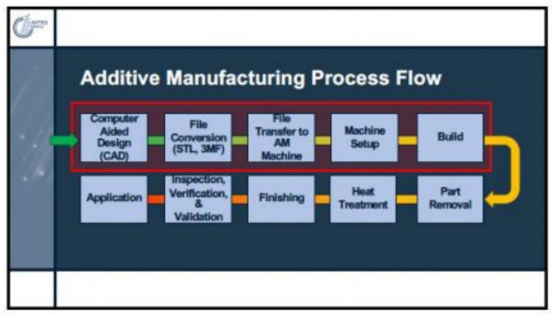
Additive Manufacturing Process Flow
Computer Aided Design (CAD)
File Conversion (STL, 3MF)
File Transfer to AM Machine
Machine Setup
Build
Part Removal
Heat Treatment
Finishing
Inspection, Verification, & Validation
Application

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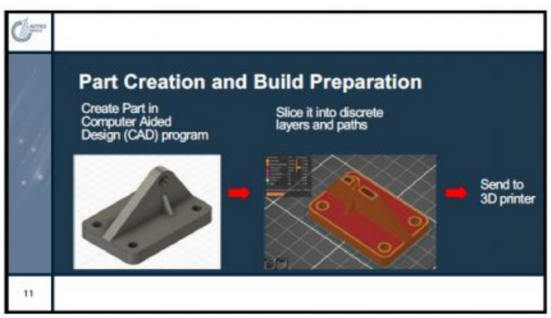
Part Creation and Build Preparation
Create Part in Computer Aided Design (CAD) program
Slice it into discrete layers and paths
Send to 3D printer
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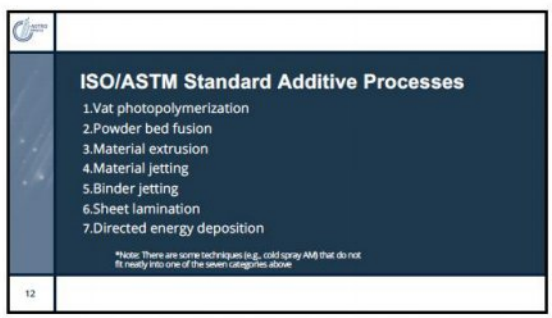
ISO/ASTM Standard Additive Processes
1.Vat photopolymerization
2.Powder bed fusion
3.Material extrusion
4.Material jetting
5.Binder jetting
6.Sheet lamination
7.Directed energy deposition
*Note: There are some techniques (e.g. cold spray AM) that do not fit neatly into one of the seven categories above
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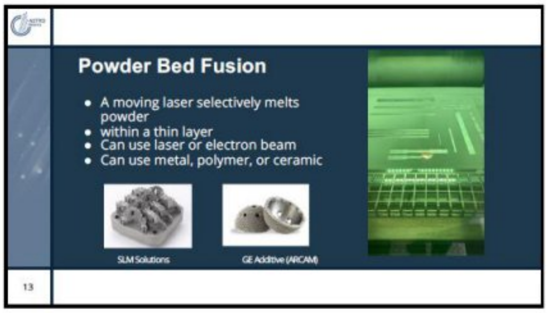

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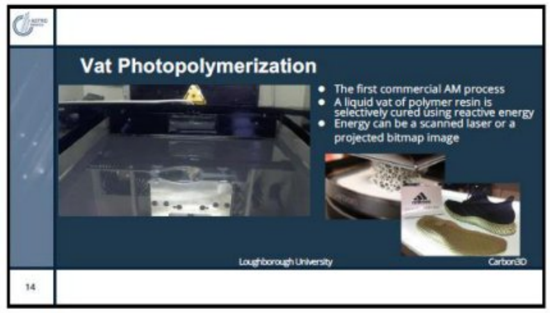

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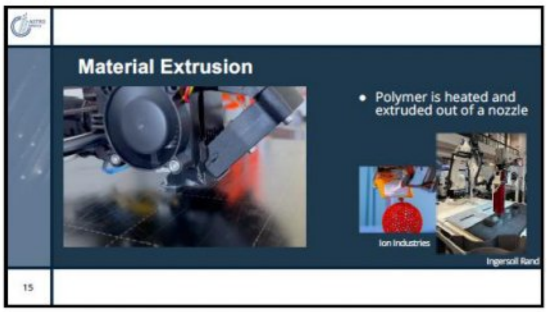

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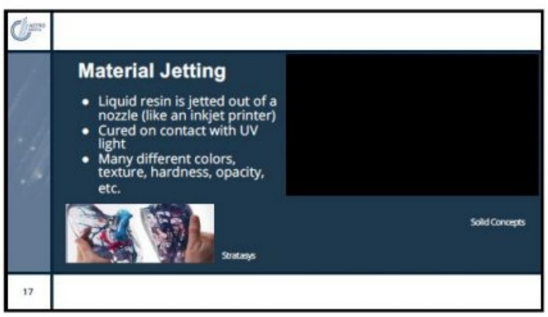

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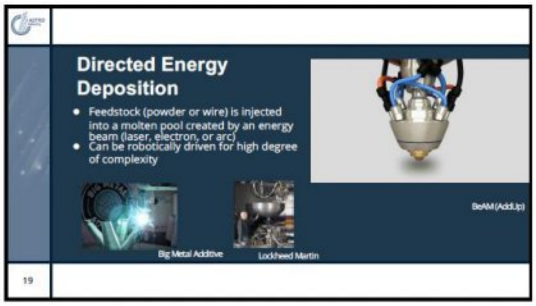

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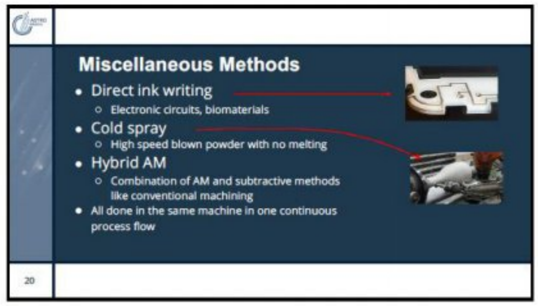

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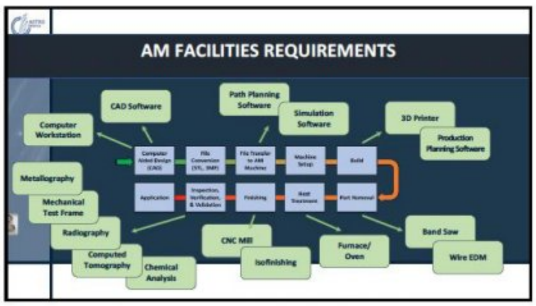

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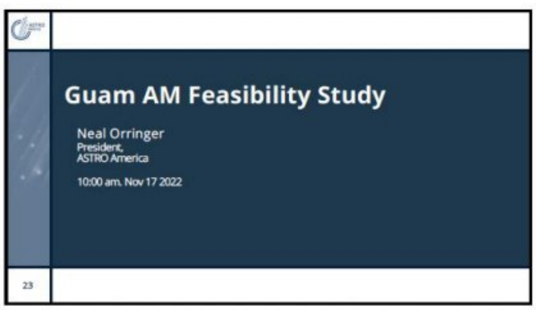

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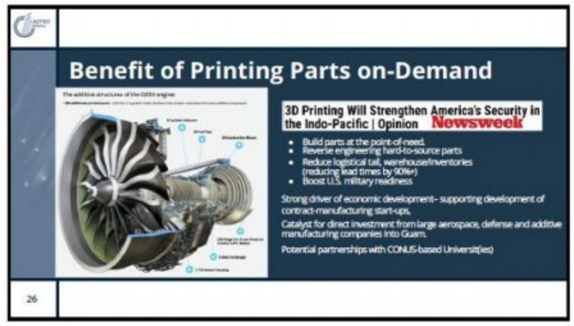

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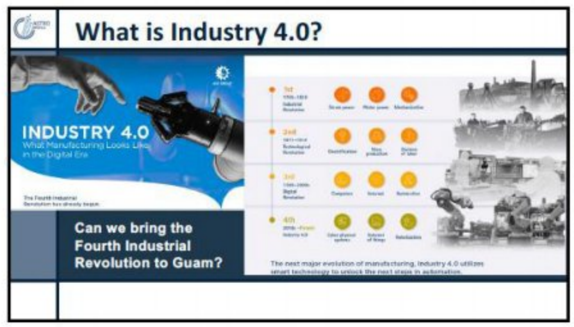

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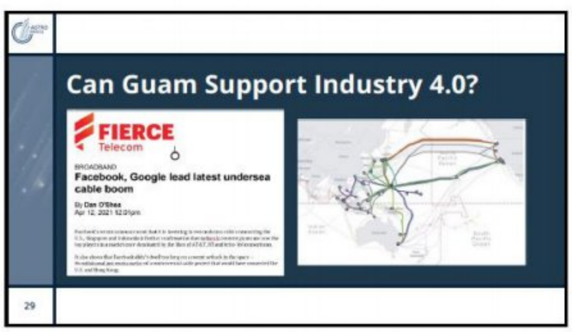

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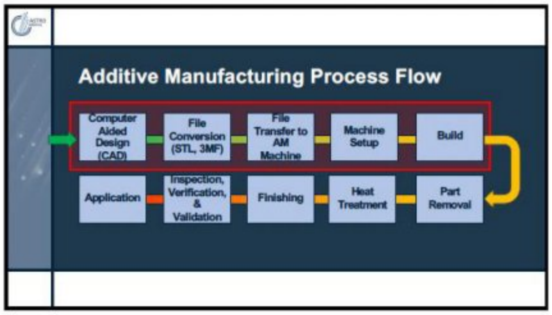

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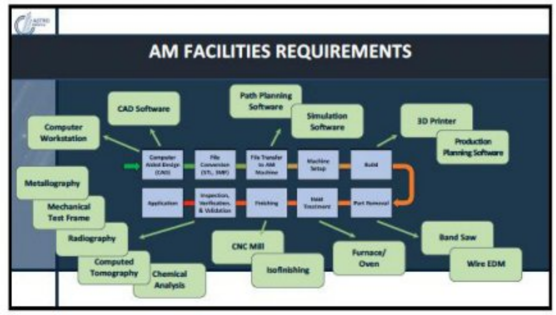

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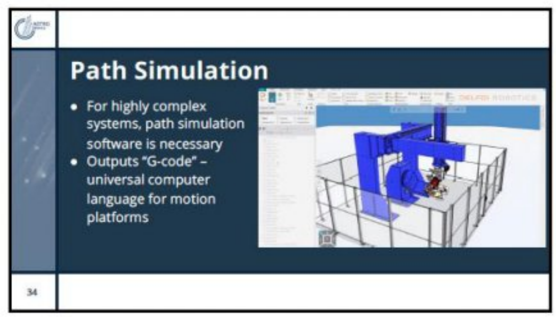

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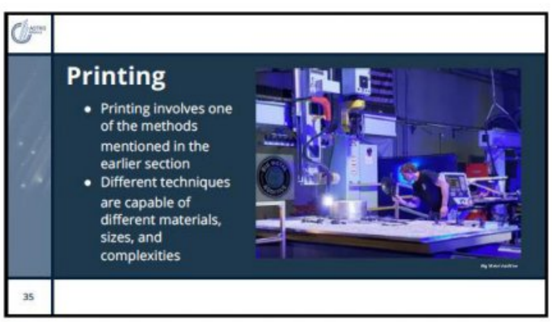

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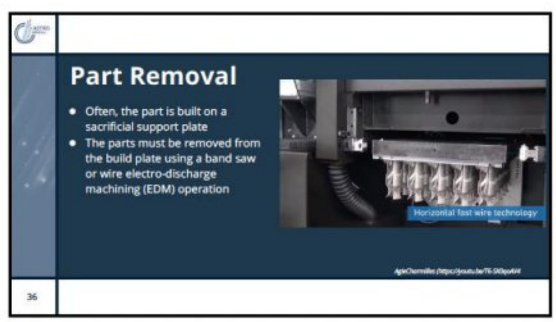

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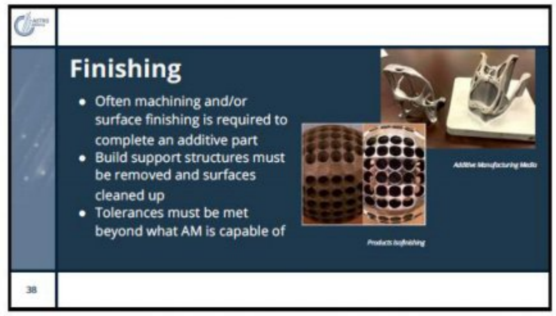

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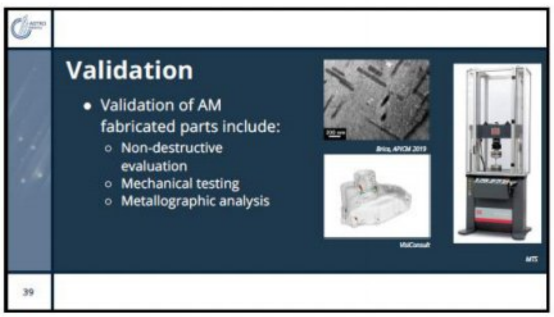

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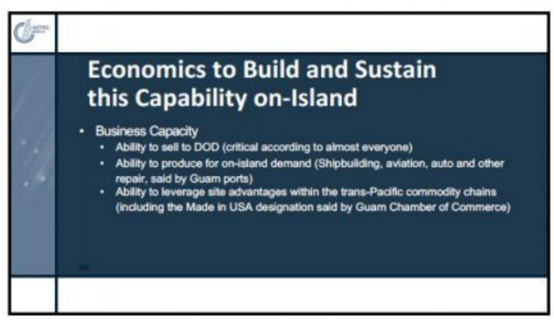

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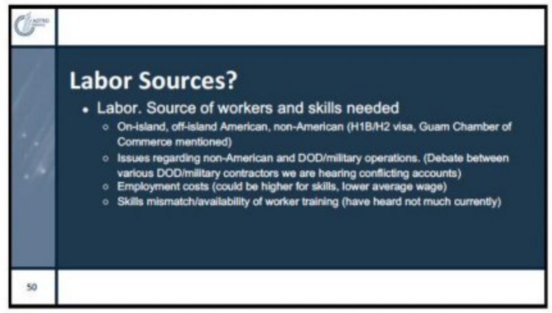

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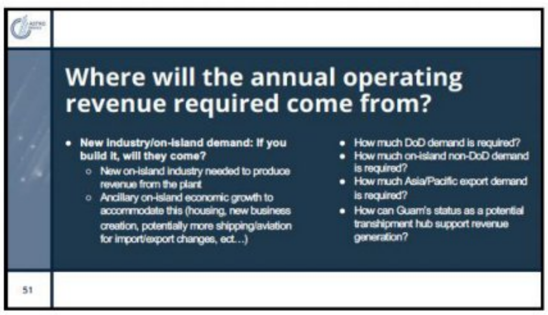

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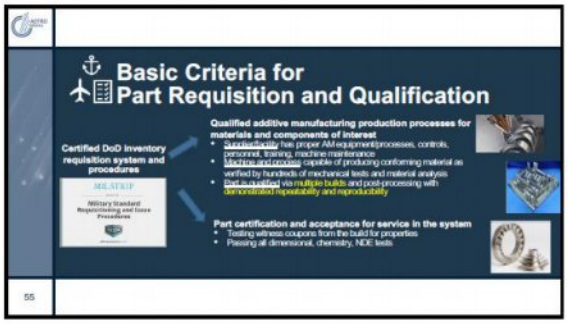

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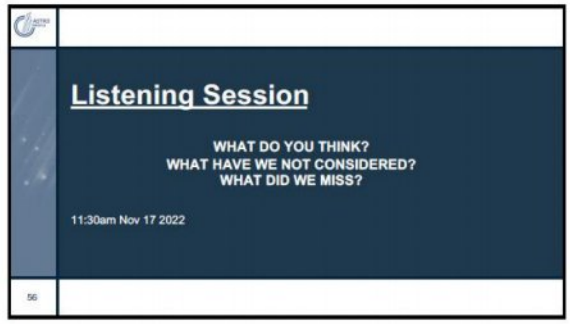

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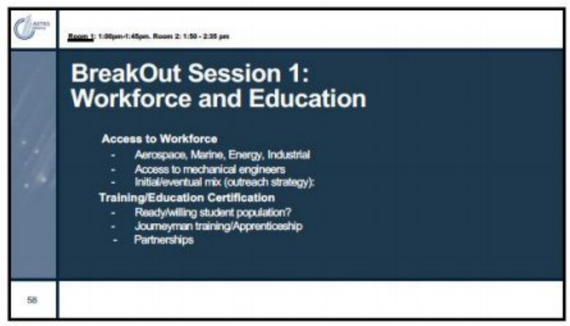

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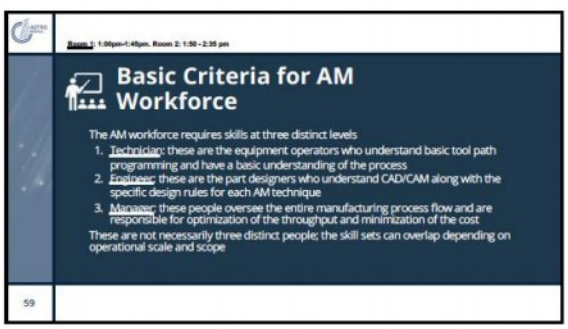

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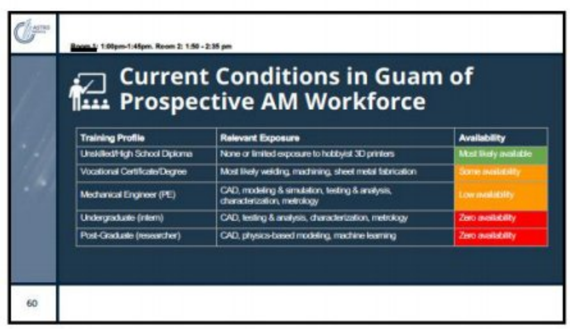

Training Profile	Relevant Exposure	Availability
Unskilled/High School Diploma	None or limited exposure to hobbyist 3D printers	Most likely available
Vocational Certificate/Degree	Most likely welding, machining, sheet metal fabrication	Some availability
Mechanical Engineer (PE)	CAD, modeling & simulation, testing & analysis, characterization, metrology	Low availability
Undergraduate (intern)	CAD, testing & analysis, characterization, metrology	Zero availability
Post-Graduate (researcher)	CAD, physics-based modeling, machine learning	Zero availability

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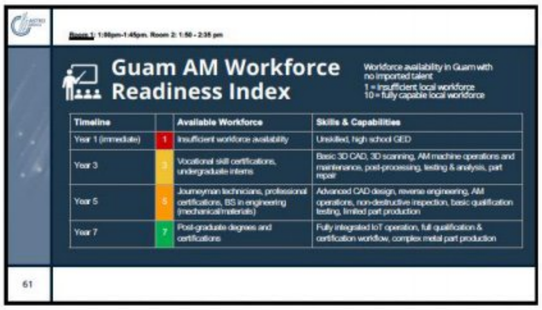

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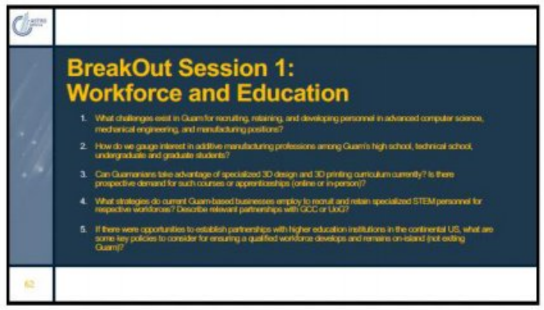

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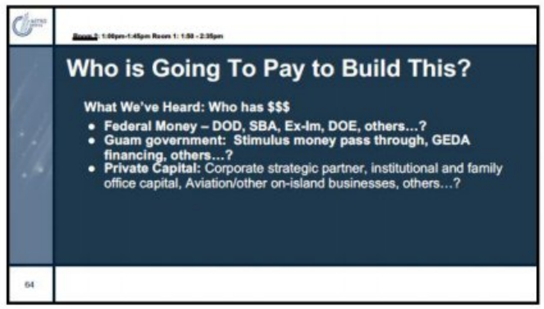

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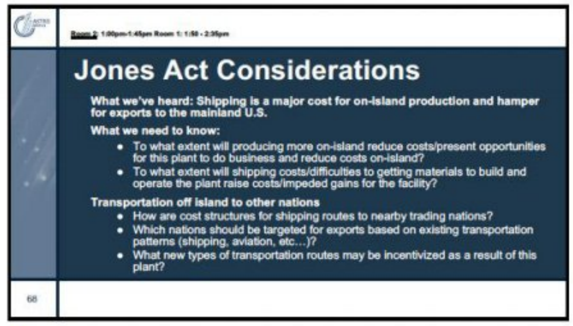

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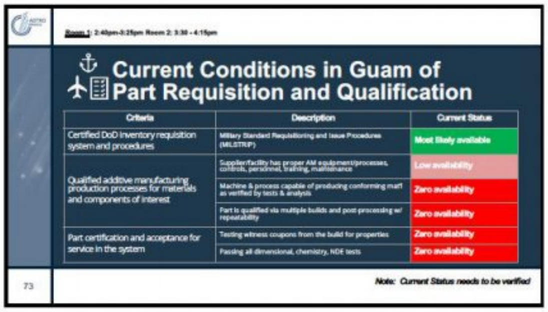

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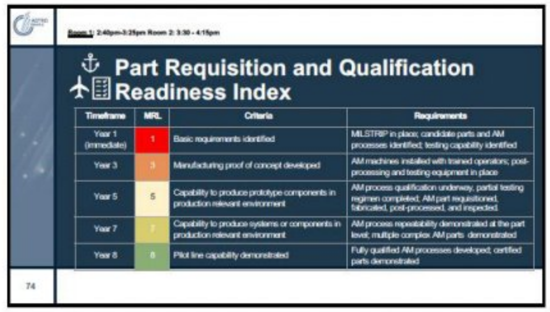

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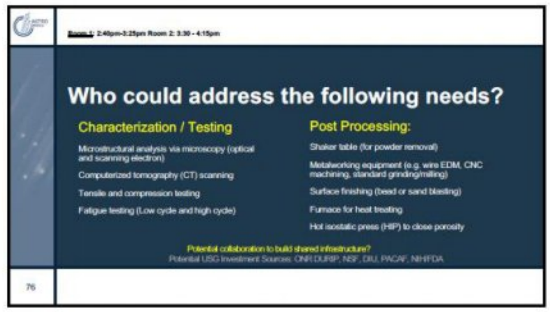

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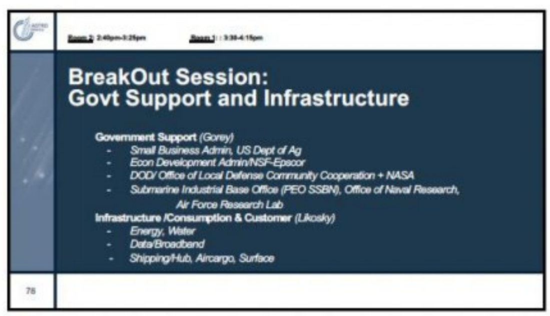

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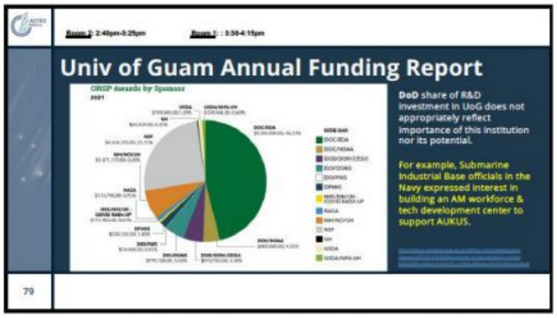

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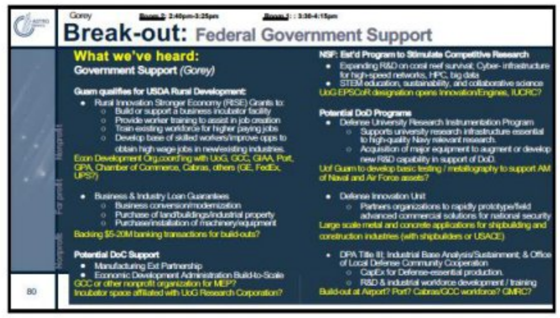

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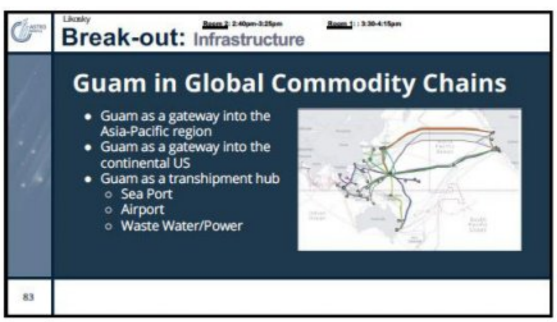

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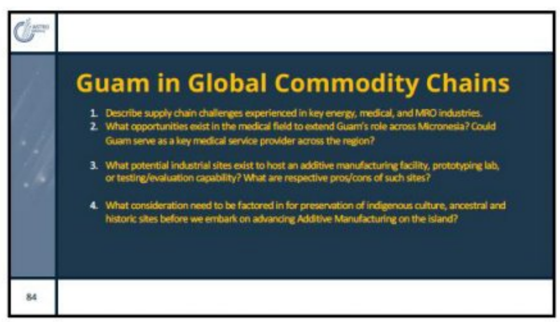

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6701 Democracy Blvd
Suite 300
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