WASHINGTON STATE
Academy of Sciences
Science in the Service of Washington State

ADDITIVE MANUFACTURING OF ADVANCED MATERIALS (AMoAM) IN WASHINGTON STATE

Brief Summary of May 11, 2018 Roundtable Meeting

On May 11, 2018, WSAS convened a roundtable meeting of academic and industry stakeholders interested in additive manufacturing of advanced materials (AMoAM) to discuss opportunities and challenges of advancing AMoAM in WA state. Researchers from UW, WSU, and PNNL, Boeing, Pacific Rim Aerospace, Blue Origin, and Aerojet Rocketdyne participated in outlining interests, problems, and potential next steps.

Academic researchers presented the variety of programs across state universities and labs that are currently working on groundbreaking AMoAM projects and the potential uses and expansion of additive manufacturing processes. They raised concerns about the education pipeline, post processing efficiency, safety, and development of new materials. In addition, they noted that public awareness of AMoAM and its opportunities need to be expanded to encourage collaboration and increase funding of existing or new projects. Researchers voiced that it is clear AMoAM is capable of filling current manufacturing voids, while noting that there are associated costs and problems that need further investigation to understand more fully AMoAM's pitfalls. For example, there are still many unknowns about the properties of specific powders and the use of AMoAM in extreme environments in which such manufacturing could be particularly useful.

WA State's numerous programs across colleges and universities could play a crucial role in filling critical information and workforce gaps. The group agreed that to produce qualified university students AMoAM education needs to start early with programs available from middle or high school through the graduate level with the assistance of trained educators. Many voiced concerns that several AMoAM education programs exist across the state, but lack awareness impeding their ability to reach their potential. Expanding AMoAM education must also be accompanied by improved and expanded safety training as some powders of advanced materials can be dangerous. Academic researchers voiced their desire to tackle safety, programming, new materials development, and post processing optimization of AMoAM in collaboration with industry partners to better prepare graduates for employment and thus facilitate the state of AMoAM within WA.

Industry stakeholders expressed the diverse goals and environments in which they work and their visons for AMoAM opportunities for their companies. They highlighted the potential of AMoAM in the development of specialized parts or manufacturing on location as benefits that will expand the use of such manufacturing techniques in the future. Industry researchers noted other issues, such as the current high cost of production and materials, difficult certification and approvals processes, and uncertainty about AMoAM's scalability for high volume production, among others. AMoAM usage for aerospace manufacturing has sharply increased in the last decade but is hampered by lack of information of certain environmental impacts on properties (space, vibrations, extreme temperatures) and extensive regulatory processes.

Despite these concerns, WA was described as a unique environment for such industries, providing competitive advantages for companies to facilitate AMoAM developments. Leveraging

companies already in the state, such as the strong software industry in western WA, can provide expertise and enable problem solving. Cross-cutting collaborations were highlighted as a way in which industry could partner with academia to receive funds to research persisting problems with AMoAM and find ways to make such manufacturing more affordable. Additionally, industry collaboration with regulatory agencies could facilitate more clarity of regulations and streamlined processes. Representatives from both academia and industry discussed how industry funding of academic research would benefit universities by creating employable students.

AMoAM is an expanding industry that could benefit the state's economy and residents. Several key challenges to AMoAM development identified by both academic and industry participants were: informing policy makers, collaborating across public-private sector, developing a trained technical workforce, and making WA state an AMoAM leader. Awareness of AMoAM programs, needs, and trends needs improvement across the state, beginning with state lawmakers. Governmental support and funds could facilitate the process. Various stakeholders mentioned the potential benefit from collaboration among academia, education, and industry but such collaborations have yet to be fully established and efforts must be made to create such relationships.

Meeting participants laid out three next steps; each step would be overseen by WSAS organized expert steering committees. The first is to produce a brief white paper for policy makers that lays out possibilities, trends, opportunities and challenges for AMoAM within WA State. The second is to convene a meeting to discuss the creation of a potential consortium of AMoAM assets encompassing industry, university, and national laboratory researchers. The meeting would identify current resources, future needs, and opportunities and challenges to a state consortium of AMoAM stakeholders and would be funded by industry or other partners. Third, a larger meeting would focus on education and workforce development to advance WA State as an AMoAM leader. The meeting would focus on pre-college assets and programs including special high schools, postsecondary education (colleges, universities, technical colleges), retraining and uptraining of workforce, and existing trade/industry supported training.

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Summary of May 11, 2018 Roundtable Meeting

On May 11, 2018, WSAS convened a planning meeting of industry, academic and state leaders in Seattle to discuss opportunities in additive manufacturing of advanced materials (AMoAM) for Washington State. The 18 participants represented the University of Washington, Washington State University, Pacific Northwest National Laboratory, JCDREAM, Boeing, Pacific Rim Aerospace, Aerojet Rocketdyne, Blue Origin and the Washington State Department of Commerce. Some participants provided brief presentations on their respective efforts in the area; all shared in a robust discussion.

In setting the stage for the roundtable, WSAS members Tony Waas of UW and Amit Bandyopadhyay of WSU noted that all indicators suggest AMoAM will grow exponentially and will revolutionize the way we build things -- likely affecting economics, logistics and the entire supply chain in the years ahead. No longer is there a question of whether or not additive manufacturing will be broadly embraced. Rather, they suggested, the question is who can do it faster?

While some ground-breaking works are underway in the state, little is widely known by policy makers or by academic and industry peers. The low profile of AMoAM has limited collaboration and funding and, therefore, contributed to faster growth in AMoAM for the state. So, what can be done to speed up progress in Washington? And how can this pursuit be done in a way that allows the state, academia and industry to all benefit? To begin to answer these questions, some themes and next steps emerged from the roundtable presentations and discussions, such as the need for targeted education and workforce development and the possible creation of an AMoAM state-wide consortium that would facilitate collaboration and the sharing of assets between the universities, government and industry.

A white paper was proposed as a way to further detail these opportunities for policy makers. Meanwhile, some key takeaways and summaries from the roundtable presentations and discussions follow below.

Academia: Key Points from Presentations

Tony Waas, UW

- AMoAM allows for aerospace parts to be built on demand and in small lots, as well as with lighter weights (e.g., lattice structures), less waste and customized parts.
- It provides the ability to combine different types of powders to produce new materials including types of metals never previously explored.
- It will bring new jobs: Jobs that existed in the previous manufacturing era will be replaced with new jobs that didn't exist 10 years ago and created because of the new processes.
- But it will not be easy. AMoAM also poses some significant challenges. E.g., How will we determine if the parts are made correctly? Can they perform well under different environmental

conditions? Are thermal stresses built in? How can we characterize toughness with heterogeneity of materials? Are material properties reliable and repeatable in mass production? How do we optimize surface quality (e.g., secondary processes)? How do we create certification standards?

- Examples of old and new additive manufacturing machines/methods: powder bed fusion, electron beam melting, chopped fiber composite, infinite build plastics, automated tape layering, automated fiber placement.
- Recommendations:
    - We need to educate the public about opportunities created by AMoAM, which will raise broader awareness and funding opportunities.
    - A focus on overcoming challenges in processing is critical, as it drives the microstructure of a product. If the microstructure is controlled, that will ensure performance is repeatable.
    - The aerospace industry must work with regulatory authorities while developing the processes in order to speed their adoption. For example, if the FAA is involved, time to certification can be reduced. Standards also need to be defined to ease this collaboration with regulatory agencies -- e.g., define what it means to say a certain part satisfies a certain requirement.

Amit Bandyopadhyay, WSU

- WSU has been involved in additive manufacturing technology and materials systems research since the mid-1990s.
- 3D printing of hard materials has evolved significantly over those last 20 years -- e.g., metal-ceramic composites, porous metal implants and coatings, ceramic scaffolds.
    - Current implant manufacturing practices are expensive for patient-specific implants. Additive manufacturing technologies can fill a need, but more data are need on materials including reliability and reproducibility. He told the story of a 21-year-old who lost a section of his skull in an accident. With the help of additive manufacturing, researchers reverse-engineered a personalized implant for the patient.
    - Potential for drug-loaded scaffolds: As the scaffold is providing growth, the drug can be released slowly. Research showed a significant difference in healing time and performance with this technology.
    - High-melting alumina ceramic structures: Focused on small structures, and attracted NASA's interest -- e.g., first 3D-printed "lunar" material.
- Additive manufacturing can help create the next generation of materials, such as Inconel 718 nickel alloy and Ti64 titanium alloy.
    - The opportunity also exists to introduce multiple materials in a single operation.

Ramulu Mamidala, UW

- Electron beam melting
    - Titanium is very temperature sensitive, so it needs to be melted in a vacuum. Electron beam melting, using helium gas to optimize, is the best way to maintain a vacuum.

- Concerns/considerations:
    - When building layer by layer, the temperature is only measured at the bottom. Yet as the height increases, a thermal gradient develops. So, a way needs to be found to homogenize the entire structure, and that is now an active area of investigation
    - High quality powder is critical, as powder quality affects the entire process.
    - Materials are expensive: E.g., $180/kg for titanium.
- Collaboration with industry is important -- especially when considering costs.
    - Boeing has been helpful to UW, including funding capstone projects for three groups of seniors. The groups will be showcasing their project at the Future Flight meeting.

Jim De Yoreo, PNNL

- NW IMPACT (Northwest Institute for Materials, Physics, Chemistry and Technology) provides an opportunity for advancing the science of making materials that will impact additive manufacturing.
    - Mission is to make the Pacific Northwest a leader in making materials.
    - Value for the region lies in a range of technologies that depend on materials: energy, transportation, information and biomedicine.
- NW IMPACT was created to combine the strengths of PNNL and the UW.
    - Launched on January 31, 2018; expect to hire full-time director soon
    - Work is carried out in co-occupied space at UW and PNNL; they are targeting defined space in Seattle, and a building on the Richland PNNL campus beginning in 2021.
    - Institute is modeled after successful university-lab partnerships such as Argonne National Laboratory and University of Chicago, and Lawrence Berkeley National Laboratory and UC Berkeley.
    - Such collaboration helps in competing for grants and enhancing workforce recruiting.
- NW IMPACT is focusing on front-end research that will lead to translational technologies, e.g., tech that the UW Clean Energy Institute is trying to bring to commercialization.
    - Targeting grand challenges in energy and water -- e.g., identifying new ways to harvest energy and inventing new materials that lower the financial and energy costs to purify water.
    - Also, a focus on biomimicry -- mimicking materials found in nature.

Academia: Summary and Discussion

Several areas of interest emerged from the presentations including education and training, safety issues, the development of new materials and critical steps in AMoAM such as post-processing.

Educating for AMoAM: Start early and target the full range of industry needs

Preparing the future AMoAM workforce should extend from the middle and high school to graduate school levels and should start with educating the educators themselves. UW (with JCDREAM) is inviting community college instructors for a two-day additive manufacturing seminar this summer. They will also be hosting a group of Seattle area high school seniors for a one-day program, which will introduce them

to additive manufacturing and how the processes come together to make a final product. (The students will leave with Seahawks or Huskies keychains made with a 3D printer.)

Other educational efforts underway include a 3D printing program for undergraduates at Western Washington University. Pacific Rim Aerospace opened up their equipment for two high school students last year to do a 3D printing project and continues to receive calls from people who want to come in and use their machines.

Safety first!

Safety considerations were emphasized by several participants. Titanium and other powders can catch fire, especially when poured too fast. Students can get excited and, if they don't have the proper safety training and knowledge, it can be recipe for disaster. Therefore, special equipment, training and other precautions should be employed. WSU has a special type of fire extinguisher, special cabinets for powders and specific safety protocols in place such as the use of gloves and metered pouring. They also bring in safety experts to check the lab at least once a year and host a fire marshal to train students.

From new materials to post-processing

Roundtable participants suggested that academia could partner with industry in finding solutions to various steps in the AMoAM process, including how to optimally design for additive, assure consistent build quality (e.g., CAD tools to predict deformities and methods to verify if a build is what it was intended to be), maintain safety and optimize post-processing. Because structural fatigue starts on the surface, this last point is critical. The needs go beyond the design of additive processes, of course, to new materials optimized for those additive processes.

Industry: Key Points from Presentations

Jill McCallum, Pacific Rim Aerospace

- Pacific Rim Aerospace is a low-cost, high-volume production environment using additive manufacturing.
- The company's niche is in non-critical parts -- e.g., Jill showed the group a 3D-printed version of a small traditionally injection molded part used in aircraft cabins.
    - Example of the need: The small plastic hook for a pilot's headphones often breaks. This can delay or even cancel flights. But if a printer was available in a nearby maintenance hangar, they could have the replacement part within 20 minutes.
- Challenges to AMoAM include high materials and production costs, difficult certifications and approvals and lingering industry perceptions, e.g., doubt that AMoAM's potential could go beyond prototyping to high-volume production.
    - The cost balance needs to be considered: A company can't pay $500,000 for a machine and have it make $6 worth of parts.
    - Both ULTEM and PEEK -- materials FAA-approved for aircraft use -- are very costly at over $200/lb. Her company uses a material that is under $50/lb.
    - Need to work with FAA to ease process of certification and approval of new materials or,

she warned, we'll continue to make it more difficult than it needs to be.

Nyle Miyamoto, Boeing

- Boeing is accelerating its effort in additive manufacturing.
- On every 787, there are at least 80 3D-printed plastic parts.
    - This has saved a lot of material -- about 30% -- not including material that would be lost in subtractive processing.
    - However, the cost of a block of material for subtractive would be a lot lower -- e.g., $25 versus $300 for powder.
    - AMoAM is not the answer for everything, but industry is making faster machines, and the cost of powders is coming down. Eventually, parts for which we can't make the business case today will be seen on airplanes in the future.
- There is great manufacturing technical job potential: machines need people to run them and post-processing needs to be done.
- Last year, Boeing created Boeing Additive Manufacturing (BAM) with 20 sites around the world, each with different additive manufacturing capabilities. They are currently trying to integrate and combine the sites.
- Don't overlook the software component of AMoAM -- critical for the design and building of the parts.
    - Given the strength in local software companies, there could be greater opportunity for the regional production of parts.
- Boeing sees a trend in additive manufacturing moving from medical devices into aerospace, especially given the money and interest in optimizing weight.
- There are a lot of European governments and manufacturers investing in additive -- e.g., manufacturing of machines in Germany, Norsk Titanium company in Norway.

Hallee Deutchman, Blue Origin

- Long-range goal: Advance technology to accomplish millions of people living and working in space.
- While Bezos' company has been working on that mission for more than 15 years, he has only recently gone public with the efforts.
    - New Shepard, built in Kent, Wash., was the first rocket to launch, land and relaunch.
    - New Glenn was the largest domestic rocket since Saturn 5.
- The company is able to design from scratch with additive in mind, and without the hindrance of oversight from federal or international regulation. (Currently, they are only regulated by FAA during a launch. But that is changing.)
    - Therefore, their risk tolerance is higher. The worst that can happen is that they lose a test product.
    - Vertical integration allows them to move faster -- e.g., changing chemistries of powders. The turn-around time is a fraction of what it is for the legacy supply chain.
- Their focus is on complex, low-volume components. They are not worried about their speed in

building those components.
- Considerations for their components include extreme environments, including high and low temperatures and vibrations.
- Looking to a future of in-space manufacturing.
    - The International Space Station is now manufacturing plastics and has announced its intention to add metallic parts.
    - Critical need to consider differences in environmental conditions in space -- e.g., combustibility of metals, which may also more easily get loose.

Scott Miller, Aerojet Rocketdyne

- The company is focused on the propulsion of power for space and defense, and has been active in additive manufacturing since 1998.
- They print propulsion systems, and also work with metals.
    - Use their own machines, as well as work with suppliers that manufacture parts.
- Some areas of opportunity he sees for the company include design, additive for thruster (e.g., valve, injector and catalyst bed), high-temperature materials, bimetallic joints (e.g., transitioning between two different metals -- such as crest to titanium -- on propellant lines) and additive manufacturing of energy materials such as solid propellant.

Industry: Summary and Discussion

Leveraging the state's industry assets is key to bringing the state to the front of the AMoAM race.

Promoting the natural advantages of the state

Washington State doesn't necessarily have the advantage of a lot of money to entice companies. However, participants discussed the potential of leveraging the value of companies already here, such as Boeing and Blue Origin, as well as the region's strong technical and community colleges. And these assets only seem to be growing. Blue Origin, for example, has doubled the number of employees in the last year and a half. Plus, the state does have some grant money. NW IMPACT received substantial help from a Clean Energy Fund grant. Federal money is also available and may be more easily accessible if industry and academia partner in the sort of cross-cutting efforts (e.g., clean tech and maritime) of interest to the federal government.

Early targets for the state might include creating machine shops -- perhaps by getting a European company to come in, set up and produce early manufacturing jobs -- or by helping local companies that already use additive manufacturing to thrive. Looking beyond hardware to software could further utilize local assets such as Microsoft.

Participants noted that the government will generally listen to industry needs. Therefore, getting industry involved and vocal on the issue could be the avenue toward greater overall funding in AMoAM.

Preparing a workforce for local industry jobs

Washington State is in a privileged position to not only have strong universities but also leading

companies that would prefer to hire local graduates. Tailoring a curriculum to these companies' needs -- and keeping that curriculum current over time -- could result in a win-win situation for the state. Yet this opportunity is generally going untapped. Boeing, for example, has 93 key schools it looks to for recruits. The UW and WSU are not among them. Blue Origin focuses their recruiting on UTEP, Penn State and others, despite a noted preference to hire in state. Investing in additive manufacturing now at state schools could put their graduates on these companies' lists in the coming years.

While there is a growing need for university-educated engineers trained in AMoAM, tech workers that can program and run machines are key as well. Representatives from Boeing noted this as a recognized need for their company. Technical and community colleges could help fill the void by adapting to the changing technology and providing hands-on training.

Participants suggested that while every school should have one or two machines to provide students with some hands-on experience, they need not have the highest end machines. Generally, students can learn the same things on a $5,000 printer as they can on a $500,000 printer. CAD and CAM are used for all machines, so teaching those programs is critical and, again, doesn't require having the most expensive printers -- or any printer, for that matter. For the technician workforce, Lake Washington Institute of Technology could be a test bed to develop touch programs that cover the many platforms and variables involved in AMoAM -- aligned with industry's needs. Some companies also have specific areas of additive for which they are seeking candidates with expertise. For example, Boeing is interested in hiring students with training in bioinspired design.

In a personal communication shortly after the roundtable, Emily DeRocco, a national thought leader in technical workforce training, noted that efforts are underway to translate 3D printing equipment to digital formats that can be taught and learned virtually. In some parts of the country, students starting at the high-school level are already learning fundamental AMoAM skills via virtual reality before being eventually introduced to the real thing. She noted that this technology might be worth considering in Washington State to cut costs, increase access and decrease obsolescence concerns in technical workforce training programs.

Considering a consortium

Creating a fleet of dispersed yet complimentary machines around the state might optimize our manufacturing potential. One company may not have the capital to buy a million-dollar machine, for example, but could have enough to pay for time on a machine. Members of a consortium could aslo co-develop needed standards and share in research, while still being able to maintain their critical trade secrets.

Towards the possibility of creating such a consortium, participants noted that it would be important to first take inventory of the state's current assets. For example, the maritime industry tends to have some of the best machines and would be worth an exploration. A survey of analogs in other disciplines, such as for linear accelerators, could also help focus efforts and suggest processes for determining how best to allocate time in facilities and for finding the best balance between overly distributing versus overly centralizing machines. Some participants also cautioned against overly diluting investments, as that can

result in little productivity potential for any one group.

Next Steps

Additive manufacturing is expected to increase a thousand-fold in the next decade. Participants noted that if WA State doesn't get on board today, the state could miss a major opportunity. Participants agreed to continue full-speed ahead in the pursuit of raising the capacity for and the visibility of AMoAM in Washington.

The group recommended that the next step for WSAS should be to prepare a white paper that lays out the importance of and opportunities in AMoAM for the state legislature. It would highlight what efforts are currently underway in the state, the broader industry trends (e.g., Wohler reports) and the challenges that need to be overcome for the state to become a leader.

Following the white paper would be a pair of meetings. The first meeting would explore the feasibility and potential of an AMoAM consortium. Representatives from state universities, national laboratory and industry would help WSAS identify current assets, future needs and the opportunities and challenges of collaboration. The second, larger meeting would focus on the needed education and workforce development. Participants would explore curricula, pre-college school assets, postsecondary opportunities, retraining and upskilling of the current workforce, specialized high school programs and existing trade or industry supported training.

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WSAS Exploration of Additive Manufacturing of Advanced Materials (AMoAM) in WA State

Planning Meeting Agenda

Friday, May 11, 2018

Noon – 5 pm

WSAS Offices

901 5th Avenue, Suite 2900, Seattle, WA 98164

This planning activity is being led/organized by a subgroup of the WSAS's Topical Working Group on Jobs, Infrastructure, and Economic Environment, co-chaired by WSAS members Amit Bandyopadhyay and Tony Waas, Our exploration focuses on additive manufacturing of advanced materials. In this meeting, our discussions will not include the machines used for manufacturing.

Additive **M**anufacturing (**AM**) are the technologies that build 3D objects by ***adding*** layer-upon-layer of material, whether the material is plastic, metal, concrete or human tissue.

Advanced materials refer new materials and modifications to existing materials to obtain superior performance in one or more characteristics that are critical for the application under consideration. They can also exhibit completely novel properties. Discoveries in the fields of chemistry, math and physics feed into the engineering (including surface engineering and nanotechnology) of new polymers, resins, advanced fibers, metal matrix composites, structural ceramics, ceramic and other types of composites, high temperature alloys, specialty adhesives, specialty chemicals, powder metals, and thin films.

We will discuss uses of advanced materials like Titanium and alloys; Superalloys such as Inconel, steels, bimetallic alloys; high temperature ceramics such as alumina and zirconia; biocompatible ceramics such as calcium phosphates; and a variety of polymers.

Goals of the exploration:

- ◊ Increase awareness among state leaders about AMoAM, with a focus on the science, technical, jobs, infrastructure and education and training issues.
- ◊ Inform state leaders about the potential of the industry and the economic wave that could come to WA State if it has a strategic approach.
- ◊ Describe the implications of getting ready to take advantage of the AMoAM potential in WA State, i.e., what might need to be put into place for the state to be a leader.

Product of the Exploration:

- ◊ A summary that captures the essence of the discussion and plans for next steps within one month of the planning meeting.
- ◊ Identification of follow on activities.

Outcomes of the Exploration:

- ◊ Raise awareness of the AMoAM and its implications with WA policymakers.
- ◊ Create an opportunity for researchers and industry representatives to interact.
- ◊ Raise visibility and relevance of WSAS as a leader and convener around significant S&T topics like AMoAM.

AGENDA

Noon **Meet and greet; lunch served**

12:45 PM **Welcome, Introductions, About WSAS**

WSAS Board Member Don Baer and Executive Director Donna Riordan (15min)

1:00 PM **Additive Manufacturing of Advanced Materials – Academic Perspective**

Moderator: Donna Gerardi Riordan

Ice-breaker informal presentations to set the stage/context for later discussions. Presentations by academe and national laboratory. Maximum 10 minutes each followed by 20 minutes of discussion.

Speakers:

- Tony Waas, UW AMoAM in Aerospace
- Amit Bandyopadhyay, WSU AM of Hard Materials
- Ramulu Mamidala, UW E-Beam Based AM
- Jim De Yoreo, PNNL, AMoAM Science of Making Materials

2:00 PM **Break**

2:10 PM **Additive Manufacturing of Advanced Materials – Industry Perspective**

Moderator: Tony Waas

Maximum 10 minutes each followed by 20 minutes of discussion

- Jill McCallum, Pacific Rim Aerospace Corp – AMoAM for Small Business
- Nyle Miyamoto, Boeing – Additive Manufacturing at Boeing
- Hallee Deutchman, Blue Origin – AMoAM at Blue Origin
- Scott Miller – AMoAM at Aeroject Rocketdyne

3:00 PM **Break**

3:10 PM **AMoAM in the context of Jobs, Infrastructure and Economic Development**

Open forum and discussion

Moderator: Amit Bandyopadhyay

In keeping with the focus of WSAS's Working Group on Jobs, Infrastructure and Economic Development, this discussion period will focus on important issues related to AMoAM that bear on these three areas. All participants are encouraged to participate in the discussion.

4:30 PM **Action items and closing remarks**

5:00 PM **Adjourn**