Form B: IGEM-HERC Full Proposal Cover Sheet

Idaho State Board of Education

PROPOSAL NUMBER: (to be assigned by HERC)	TOTAL AMOUNT REQUESTED: $125,000

Proposal Track (select one):

- **Proof of Concept**

NSF I-Corps participation:

Have you participated in, or plan to participate in the NSF I-Corps Program? **Yes.**

If so, when did you or will you? **I-Corps Aspire, September-October 2025**

TITLE OF PROPOSED PROJECT:
Additively Manufactured Lattice Showerheads for Improved Semiconductor Processing

SPECIFIC PROJECT FOCUS:
Development of novel lattice style showerheads for use in gas distribution systems, primarily used in semiconductor processing. Systems will be fabricate using additive manufacturing techniques.

PROJECT START DATE: **7/1/26**	PROJECT END DATE: **6/30/27**
NAME OF INSTITUTION: **Boise State University**	DEPARTMENT: **Mechanical and Biomedical Engineering**
ADDRESS: **1910 University Dr., Boise, ID, 83725**	
E-MAIL ADDRESS: **osp@boisestate.edu**	PHONE NUMBER: **208-426-4420**

	NAME:	TITLE:	SIGNATURE:
PROJECT DIRECTOR/PRINCIPAL INVESTIGATOR	**Todd Otanicar**	**Professor**	Todd Otanicar (Feb 23, 2026 11:20:16 MST)
CO-PRINCIPAL INVESTIGATOR	NA	NA	NA

NAME OF PARTNERING COMPANY: **NxEdge, INC.**	COMPANY REPRESENTATIVE NAME: **Koda Bolt**
SIGNATURE:	Koda Boldt (Feb 23, 2026 11:45:48 MST)

Authorized Organizational Representative	NAME: **Ella Christiansen** **Assistant Director, Pre-Award**	SIGNATURE:

Additively Manufactured Lattice Showerheads for Improved Semiconductor Processing

PI: Todd Otanicar, Boise State University

Total Amount Requested: $125,000

SIGNIFICANCE

Our team is pursuing IGEM HERC commercialization funding to develop the lattice showerhead technology and increase Idaho economic competitiveness in the funding priority area "Microelectronics/Semiconductors" as per the request for proposal, and based on the 2023–27 Idaho Higher Education Research Strategic Plan. Our technology is currently at technology readiness level 3, and we believe it has a high potential for near-term technology transfer to the private sector. Our proposed development leverages advances in manufacturing, particularly additive manufacturing, to develop a new class of showerhead for deployment in gas diffusion systems for semiconductor processing. The proposed work will create a completely new approach to showerhead development that reduces the extreme tolerancing in conventional "hole based" manufacturing leading to improved film deposition and reductions in parts out of dimensional compliance during manufacturing.

The Problem. Currently, semiconductor equipment manufacturing faces significant challenges in in First Pass Yield (FPY) due to the incredibly tight tolerance and defect requirements. This is particularly true in the gas diffusion plates, commonly called showerheads, used in the processing of semiconductor wafers. Existing commercial designs are constrained by legacy machining limitations, leading to poor gas flow, and waste of critical materials. Idaho is home to a robust microelectronics ecosystem, with over 11,000 employees across 33 semiconductor companies[1]. The showerhead component market for semiconductor tools is expected to become a **$2 billion market by 2031**[2] while the global wafer manufacturing market generates several billions in revenue yearly. Due to the sensitive nature of semiconductor wafer manufacturing, new manufacturing developments are needed to decrease the economic loss created from incredibly tight tolerances placed on conventional systems. Our research will enable the development of advanced showerheads via additive manufacturing, which leads to a significant competitive advantage by improving film uniformity, reducing tool downtime, and enabling customized solutions for different process chambers—all while decreasing material and production costs.

Challenges & Opportunities. Additive manufacturing (AM) paired with new computational optimization models that challenge conventional modeling strategies can overcome the aforementioned problems of extreme tolerancing and low defect requirements. AM has opened up new pathways for design and manufacturing, where it is possible to prioritize performance and be less restricted by traditional machining limitations. Many contemporary design tools (e.g., ANSYS, nTop) now incorporate algorithms to enhance the mechanical performance of components—most commonly by minimizing mass and maximizing structural strength under specific loading conditions. Instead, tradeoffs are generally made between the multiple points of interest, in our case: film uniformity (affecting wafer first pass yield), film deposition rate (affecting factory throughput), and part tolerance and defect robustness (affecting lead times associated with consumables, such as showerheads). Engineered lattice structures created via AM enable multi-directional diffusion, permitting redistribution of flow within the structure[3]—unlike conventional pin hole plates where flow paths are singular and isolated[4]. This internal redistribution capability may reduce sensitivity to manufacturing defects and tolerancing, enhancing the robustness of the showerhead's performance and vastly improving FPY of showerheads during manufacturing.

Our Proposed Solution. We have developed a new type of showerhead that improves flow uniformity upon a semiconductor wafer during coating processes. This advanced showerhead utilizes a lattice structure instead of the conventional pinhole approach to create a more uniform flow field on the wafer, see **Figure 1**. Our concept is made viable by additive manufacturing that allows for the creation of lattice showerhead geometries not possible with conventional manufacturing approaches. Because of the adoption of advanced manufacturing, we can engineer flow paths that allow for higher gas diffusion across the showerhead resulting in a uniform flow impinging on the semiconductor wafer. Based on our conversations with our industry partner, we recognize that the potential impact is both in flow uniformity as well as reduced tolerances during showerhead manufacturing, but that validation of the lattice showerhead in relevant environments is critical for market adoption.

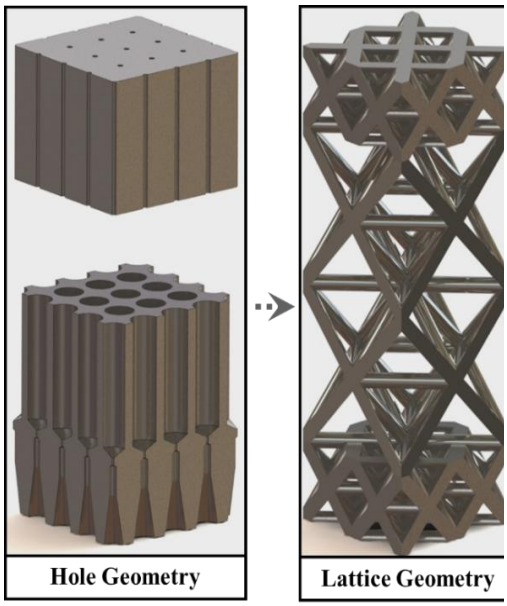


Figure 1: Schematic compares conventional pinhole (left) and proposed lattice (right) sections of showerheads.

Potential Impacts. The innovation of the proposed research lies in using additive manufacturing to develop semiconductor manufacturing equipment. In particular, creating a showerhead from a lattice structure will create more uniform gas flow over the semiconductor wafer. This results in less material waste, more uniform coating, while also allowing for reduced tolerances in showerhead manufacturing, an industry worth ~$10 million annually. This project aligns with the microelectronics and semiconductors priority as our developments directly impact the semiconductor manufacturing process. Additionally, the work is complementary to the artificial intelligence, and machine learning areas as our work in design tools leverages these technologies for design processes.

PROJECT OBJECTIVES

To develop a pathway towards commercializing the proposed showerhead technology, we will complete the objectives below to:

1. ***Optimize lattice showerhead design***—Using advanced computational modeling optimize the showerhead performance using realizable manufacturable geometric constraints.
2. ***Fabricate lattice showerhead using additive manufacturing***—Create the first additively manufactured lattice showerhead.
3. ***Test lattice showerhead in benchtop environment***—Demonstrate predicted showerhead performance in relevant benchtop testing.

PROJECT PLAN

Outlined below are details regarding the current technology readiness level, the planned progression, and detailed project objectives.

TECHNOLOGY READINESS LEVEL PROGRESSION

The proposed research project here grew out of prior research projects in fluid flow in high temperature porous systems. With our background we have quickly advanced our engineered lattice showerheads to TRL level 3 (experimental proof of concept) with computational experiments demonstrating improved flow performance relative to existing showerhead designs, see **Figure 2**. **The purpose of the application is to advance the computational TRL level to 5 (technology validated in relevant environment)** by optimizing lattice showerhead performance with reactive component gases and temperatures. While computational performance is important we plan to use **this project to advance the physical TRL to**

level 4 (technology validated in lab) by fabricating a representative metal lattice showerhead for benchtop scale testing and computational model validation. To facilitate near-term technology transfer to the private sector, our plan is to progress through the technology readiness level spectrum by taking the actions shown in **Figure 2** below.

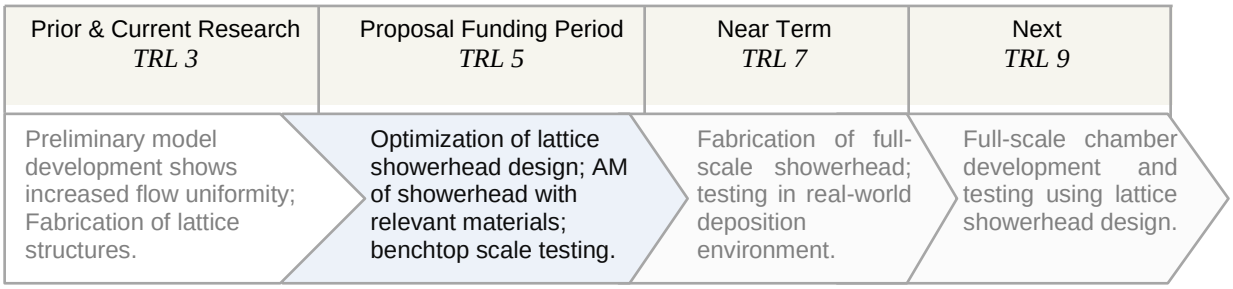


Figure 2: Development pathway leading from preliminary model development to full-scale chamber development and testing of lattice showerhead design.

OBJECTIVE 1: OPTIMIZE LATTICE SHOWERHEAD DESIGN

AM has opened up new pathways for design, where it is possible to prioritize performance and be less restricted by traditional machining limitations (**see Figure 1 right for a schematic of an AM showerhead design**). Our working hypothesis is that organized lattice structures improve on perforated plates by enabling multi-directional diffusion, permitting redistribution of flow within the structure. Researchers have only examined the use of porous media for a showerhead in a single study, to our knowledge, which S. Zou et al. showed increased flow-field velocity uniformity by up to 77.9%[4]. However, this study is purely numerical and does not work outside of assumed bulk parameters such as porosity and pore size. Researchers have not yet studied additively manufactured, or organized, structures. **Our preliminary flow modeling efforts** of a porous lattice diffusion plate that could only be fabricated via AM demonstrates a substantial reduction in vertical fluid velocity variation directly over the substrate as compared to a conventional perforated diffusion plate (**see Figure 3**). The computational simulation is based on a simple model of air flow in a reactor chamber flowing through the showerhead into the deposition chamber where the wafer is located. On the left-hand side of Figure 3, a typical pin hole style shower head reveals substantial variations in the fluid velocity near the outer edges of the wafer, resulting in non-uniform film deposition and edge losses. The same simulation, but with a porous lattice showerhead, Figure 3 right hand side, results in a substantial reduction in velocity variations across the wafer improving thin film uniformity.

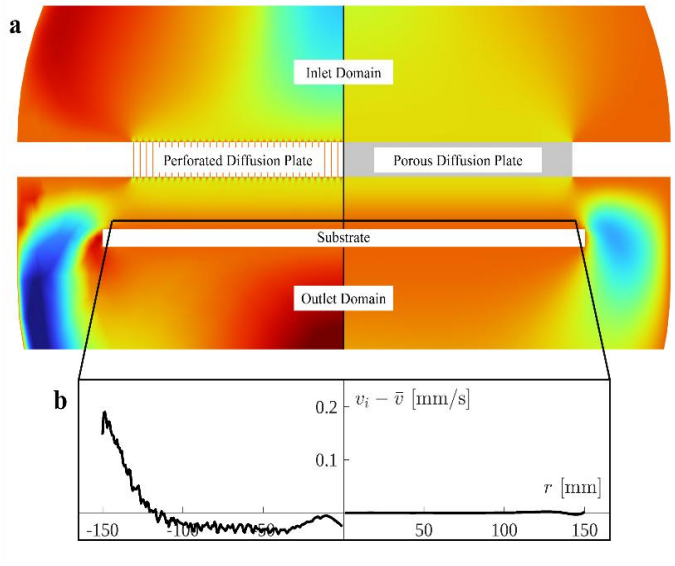


Figure 3: (a) Cross section view of conventional pin hole showerhead (left) and porous lattice showerhead (right) reactors showing the vertical component of the fluid velocity field. (b) Deviation of the vertical component of fluid velocity above the substrate.

To begin we will utilize a novel parametrization-homogenization-optimization strategy, part of a current NSF funding request focused on development of optimization design tools, to optimize a lattice showerhead that can be manufactured with existing AM tools

followed by full-scale deposition chamber modeling.

1.1 Computational Optimization and Showerhead Design

The optimization framework developed for this project integrates evolutionary computation, multi-scale physics-based modeling, and machine learning into a unified system designed to identify lattice structures with superior performance for thin-film deposition applications. The process begins with the initialization of a genetic algorithm that generates an initial population of candidate lattice designs. Each candidate is parameterized in terms of its nodal connectivity and strut diameter distribution and is subsequently passed to a pore-scale homogenization model implemented in COMSOL Multiphysics. This homogenization step reduces the geometric complexity of the lattice by calculating a set of bulk parameters, including porosity, permeability, and radiative extinction coefficient.

The homogenized properties are then introduced into a reactor-scale model that resolves the coupled physics of heat transfer, fluid dynamics, chemical kinetics, and multi-species transport under conditions representative of metal–organic chemical vapor deposition (MOCVD). The reactor model evaluates the lattice's performance in terms of deposition rate, film uniformity, and thermal stability of the showerhead. These performance indicators are returned to the genetic algorithm as objective functions, allowing the evolutionary operators to produce subsequent generations of candidate solutions.

As the optimization progresses, the system accumulates a dataset linking lattice genomes to reactor-level performance. Once a sufficient number of members have been evaluated, generally exceeding fifty, this dataset is used to train neural networks for each optimization parameter. The trained networks function as surrogate models, providing rapid approximations of objective values without requiring the full multi-physics simulation pipeline. These surrogate functions are themselves optimized to predict candidate designs that are likely to lie near the Pareto front. The predicted designs are reintroduced into the genetic algorithm population, thereby accelerating convergence toward optimal trade-offs between competing objectives. The loop of direct simulation, surrogate-assisted prediction, and evolutionary refinement continues until the maximum number of generations is reached, yielding a diverse set of Pareto-optimal lattice structures.

The genetic algorithm provides the foundation for exploring the vast design space of porous lattice structures. The lattice is defined by four planes of symmetry that partition the domain into eight identical sections. Within each section, a set of nodes serves as the fundamental structural points to which struts may connect. The genome representation therefore encodes both discrete connectivity decisions and continuous values describing the grading of strut diameters across the domain.

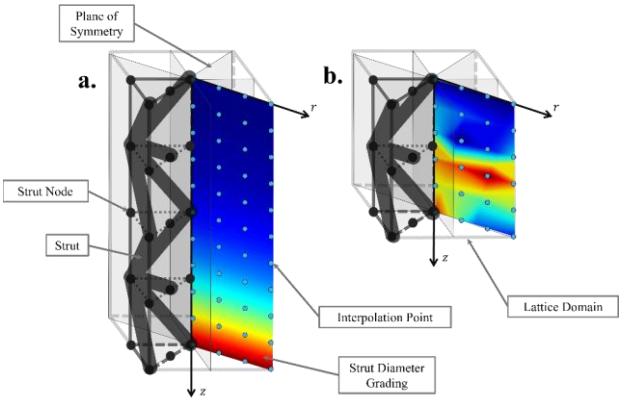


Figure 4: Lattice parameterization is shown for both double cell **a.** and single cell **b.** geometries. The figure depicts the available strut nodes, nodal connections, and planes of symmetry responsible for constructing the lattice.

The strut diameter distribution is represented by a grading function defined at selected interpolation points in the radial and vertical directions. Each interpolation point specifies a strut diameter, and the diameter at any arbitrary coordinate is determined through linear interpolation. This method enables the representation of uniform, linearly graded, and spatially complex architectures with a limited number of parameters, thereby balancing flexibility and computational feasibility. **Figure 4** depicts the nodal locations within the lattice domain, the planes of symmetry, and the strut diameter grading function.

1.2 Full-Scale Design Model

The final evaluation stage of the framework is the full-scale thermo-fluidic model, in this case an industry driven reactor-scale deposition model, which calculates performance indicators for each candidate lattice. This model integrates multiple coupled physical phenomena that are critical to MOCVD. Fluid flow is resolved through the Brinkman equation, which incorporates both viscous effects and porous resistance derived from homogenization, and based upon validation from objectives 2 and 3. Heat transfer is modeled in its conductive, convective, and radiative forms, with conjugate heat transfer coupling solid and fluid regions and extinction coefficients governing radiative transport. Multi-species transport equations are solved for relevant chemical precursors and byproducts, capturing both convective and diffusive fluxes. Surface reactions are modeled using Arrhenius-based kinetics, while volumetric reactions are included where applicable. Film growth is resolved at the substrate surface as a function of local species concentrations and surface temperature, providing a direct link between reactor operating conditions and thin-film properties.

The outputs of this reactor-scale model are the optimized lattice structure. Film uniformity is quantified through the variance in thickness across the substrate, deposition rate is measured as the average growth rate over the wafer, and showerhead thermal uniformity is assessed as the spatial distribution of temperature across the porous lattice. By embedding the reactor model within the larger evolutionary–surrogate framework, the system identifies lattice designs that simultaneously improve deposition rate, film uniformity, and thermal stability, thereby advancing the state of the art in reactor design for semiconductor manufacturing, a key driver for our industry partner.

Objective 1 Criteria for Project Success

This objective will be complete when we are able to report:

- Completion of pore-level homogenization to reduce complex model run time by 25% when including pore level fluid flow and radiative transport.
- Completion of full reactor model capable of film growth prediction while minimizing flow non-uniformity to less than 3%.

Objective 2: Fabricate lattice showerhead using additive manufacturing

A critical component of this concept is the industry need around defect tolerance, excessive tolerances in existing systems, and control in uniformity in deposition. All of these are highly impacted by the fabrication of the showerhead. Current showerheads are primarily fabricated with complex machining and hole drilling process to create the pinhole patterns. This objective fully focuses on the fabrication of the lattice showerhead design completed in Objective. **Figure 5** shows preliminary lattice patterns we have fabricated with both polymer 3D printing and with our laser powder bed fusion (LPBF) system on campus. Figures 5a and 5b demonstrate printed lattice structures, the latter showing a structure with a graded strut thickness optimized for a thermal transport problem.

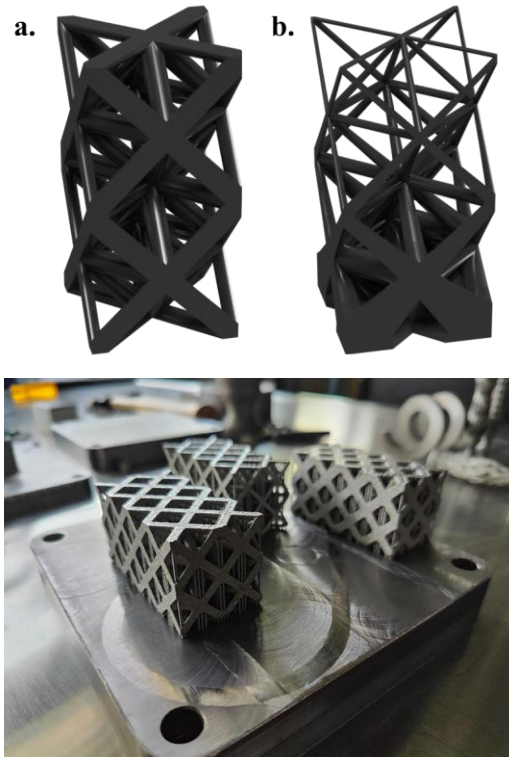


Figure 5: Additively manufactured lattice structures. a) Uniform strut, and b) graded struts manufactured with PLA. Bottom, SS316 printed lattice structures.

A key aspect of this phase is working with our on-campus recharge center to understand LPBF printer limitations on dimensional stability of printed lattice structures. Many printed designs require the

incorporation of supports, which then need to be removed after printing, which we will avoid during our system design. Another key limitation of current pinhole showerhead systems is the extreme tolerancing for dimensional stability. Our hypothesis is that the multi-flowpath nature of the lattice structure eliminates the need for strict dimensional tolerancing. While this will be tested in objective 3, it is critical to characterize the dimensional deviations that arise during fabrication. In addition to fabricating the design we will also utilize existing characterization facilities to assess dimensional deviations and surface roughness through micro x-ray computed tomography (microCT). The common usage is for exploring density variations in printed lattices, and surface roughness evaluation[5, 6]. Kaur and Singh used the microCT to reconstruct a lattice structure and demonstrate the impact on fluid flow and heat transfer, but such a reconstruction is complex and costly and would not be relevant for commercial applications. Here, we won't use microCT for reconstruction but for capturing variability in strut diameter during AM processes which will inform objective 1.

Objective 2 Criteria for Project Success

This objective will be complete when we are able to report:

- Fabrication of lattice showerhead design with plate diameter of 70 mm (~1/4 scale of conventional systems).
- Measured dimensional deviations of LPBF fabricated lattice structure.

Objective 3: Test lattice showerhead in benchtop environment

While our preliminary computational modeling demonstrates the potential for the lattice showerhead to reduce flow variation on the surface of a wafer during deposition, see Figure 3, it is critical to test this physically to advance the TRL to level 4 experimentally. Here we plan to develop an experimental test reactor capable of monitoring flow conditions across a deposition region that can be then used with models developed in prior objectives to demonstrate model performance for scale up to relevant systems. The objective of the test reactor will be to operate under flowing conditions with benign, non-reactive precursor gasses in order to obtain a pressure field across the substrate deposition region. The bench scale reactor is comprised of a housing for accepting inlet air from that is pulled across the bench scale showerhead test piece (in red), followed by airflow across a simulated wafer that integrates multiple pressure taps for mapping the pressure distribution across the showerhead (see **Figure 6**), The bench scale reactor will be used to not only advance the experimental TRL of the lattice showerhead system, but will serve to provide crucial data for model validation in objective 1. This will allow objective 1 to proceed towards modeling with chemical transport simulating real reactor conditions (advancing models to TRL 5).

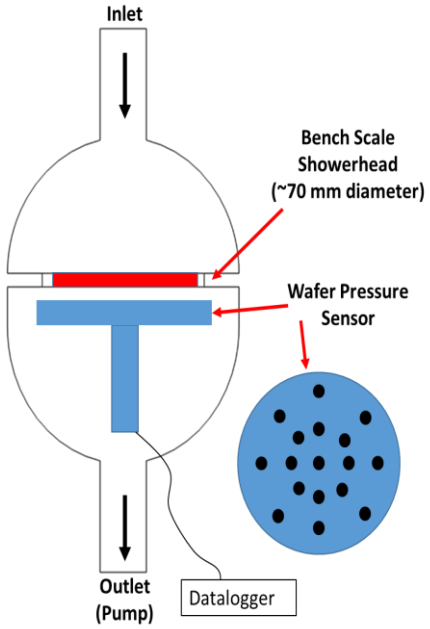


Figure 6: Experimental setup for advancing showerhead design impact on flow distribution.

In addition to conventional flow testing and spatial pressure distribution measurements, we also plan to use the benchtop reactor environment to demonstrate a critical proposed feature of the lattice showerhead, the ability for flow to redistribute. In conventional pinhole showerhead systems dimensional tolerances are critical for achieving flow performance, additionally any blockage results in catastrophic deposition performance. Our hypothesis is that by using a lattice showerhead approach the flow has multiple pathways it can follow, effectively eliminating distribution issues from blockages. Here we plan to utilize

the experimental benchtop reactor system to test this hypothesis by artificially introducing blockages and then measuring the resulting pressure distribution.

Objective 3 Criteria for Project Success

This objective will be complete when we are able to report:

- Wafer velocity pressure distribution measurement using benchtop test chamber for an AM lattice showerhead system.
- Pressure distribution measured experimentally and modeled performance match within 10%.
- Pressure distribution measurement for simulated blockages, determination of percent area blockage that results in 15% increase in spatial pressure variance.

Timeline

Here is the project timeline over 1 year that highlights how objectives advance TRL for the project.

Table 1:

#	project objectives by quarter	1	2	3	4
1	Completion of pore-level homogenization to reduce complex model run time by 25% when including pore level fluid flow and radiative transport.	X			
2	Wafer velocity pressure distribution measurement using benchtop test chamber for an AM lattice showerhead system.	X			
3	Fabrication of lattice showerhead design with plate diameter of 70 mm (~1/4 scale of conventional systems). *(TRL 3 to TRL 4)*		X		
4	Measured dimensional deviations of LPBF fabricated lattice structure. *(TRL 3 to TRL 5)*		X		
5	Pressure distribution measured experimentally and modeled performance match within 10%. *(TRL 3 to TRL 4)*			X	
6	Pressure distribution measurement for simulated blockages, determination of percent area blockage that results in 15% increase in spatial pressure variance. *(TRL 3 to TRL 4)*				X
7	Completion of full reactor model capable of film growth prediction while minimizing flow non-uniformity to less than 3%. *(TRL 3 to TRL 5)*				X

Potential Economic Impact

The Market. The showerhead component market for semiconductor tools is expected to become a **$2 billion market by 2030**[2], while the global wafer manufacturing market generates several billions in revenue yearly. Existing commercial designs are constrained by legacy machining limitations, leading to suboptimal gas flow and material waste. This research enables the creation of advanced geometries and tunable porosity via additive manufacturing, which leads to a significant competitive advantage by improving film uniformity, reducing tool downtime, and enabling customized solutions for different process chambers—all while decreasing material and production costs. Our proposed work will develop the first additively manufactured showerhead which directly impacts the semiconductor processing industry, while also being applicable to other gas diffusion applications.

Industry Partners. Our partner, NxEdge, is a leader in the manufacture of semiconductor processing tools, particularly showerheads. Our project is based on our discussions with them regarding the challenges they face in the manufacture of equipment and how to integrate advanced technology in their workflow. This project is unique as the business point of contact is Koda Boldt is a current Ph.D. student at Boise State but supported by NxEdge. This allows him to pursue fundamental research

activities that NxEdge doesn't have the capability to pursue while allowing NxEdge to drive use inspired research innovations. **Additionally, PI Otanicar and partner Boldt participated in the i-Corps Aspire program at Boise State University as part of the TRANSFORM award**. The results of our customer discovery process clearly indicate the need to demonstrate the novel showerhead in a relevant experimental setting before any adoption would be considered. Dr. Otanicar has been a participant in a Department of Energy i-Corps program, i-Corps Aspire, and has co-founded a business.

Intellectual Property. The proposed work here is already generating intellectual property with our industry partner, NxEdge, based on the very nascent research proposed here for further development. This research presents a unique opportunity to integrate cutting-edge science with NxEdge's strategic objectives, potentially transforming key processes within semiconductor manufacturing. Dr. Otanicar is also keenly focused on translating research to industry, he has 6 issued U.S. patents, multiple patents pending, and numerous issued international patents.

Table 2: Idaho Economic Impacts (Current and Future)

AREA	ECONOMIC IMPACTS
Workforce Development	Multiple graduate students and undergraduate students supported on the award, visits to NxEdge, and potential student internships (current and future).
Advanced Manufacturing Capacity	Development of novel parts with additive metal manufacturing contributing to $12 billion manufacturing market within the state of Idaho.
Showerhead Component Market	Expected market of $2 billion by 2031, additive lattice showerhead has the potential to capture a percentage of that market.

ANTICIPATED DEVELOPMENT CHALLENGES/BARRIERS

One of the largest technical challenges for the project is the dimensional deviation associated with additive metal manufacturing. We believe that the advantage of using the lattice framework inherently overcomes this because of the multiple pathways that "flow" can take within the structure eliminating the need for extreme dimensional control, which is currently necessary in current commercial pinhole showerhead systems. Our team, led by PI Otanicar, has significant experience developing complicated experimental hardware and numerical simulation tools for DOI, DOE, and ARPAE projects. Additionally, having engaged project partners on the project, including a graduate student employed at NxEdge results in detailed technical and commercialization knowledge directly within the project.

BUDGET JUSTIFICATION

For the budget, see Form D. Here is our budget justification.

#	LINE ITEM REQUEST	JUSTIFICATION	TOTAL REQUEST
1	Personnel (salary, fringe)	Support for PI, graduate students (2) and undergraduate students. PI will oversee students and overall research project effort. Graduate students will be responsible for computational work, overseeing experimental design, and test completion. Undergraduate students will work with graduate students to complete experimental work. Includes affiliated fringe rate.	$86,200.00

#	LINE ITEM REQUEST	JUSTIFICATION	TOTAL REQUEST
2	Materials/Supplies	Miscellaneous materials and supplies to build experiments. Additional funds included for RME recharge center for AM lattice showerhead builds.	$7,000.00
3	Travel		$00.00
4	Participant Support		$00.00
5	Other Direct Costs	Includes graduate student tuition, library fees, and graduate student health insurance costs.	$31,800.00
		Total	**$ 125.000.00**

PROJECT MANAGEMENT

Our team is comprised of both industry and university partners, with the PI leading the effort from Boise State University. The senior graduate student on the project is also employed with our industry partner providing a compelling linkage to industry. The PI and graduate student will communicate frequently, through both weekly lab meetings and via Slack instant messaging, we will also setup quarterly meetings with the industry partner. This allows time to make meaningful advances while also providing relevant updates. Additionally, it provides further opportunities for team members to interact with industry and understand the "customer's perspective" on the project, team is outlined below:

- Dr. Todd Otanicar (PI)— directs the Thermal Transport and Solar Energy Laboratory. His lab actively researches novel technologies for enhanced heat and mass transfer. A number of these technologies have been applied to energy projects that have been supported by ARPAE, NASA, DOI, and NSF totaling over $7 million in external funding. He will be responsible for the overall project direction, coordination with the industry partner, and supervising students. He has a track record of recruiting successful undergraduate and graduate students alike. Many of whom go on to win prestigious awards, including 2 NSF GRFP winners, 1 Rhodes Scholar, and 1 Fulbright Fellow. PI Otanicar is capable of executing the proposed project based on his prior experience that has focused on fundamental research, as an NSF PI, and projects that focused more in managing complex projects with hardware development as part of 2 ARPAE projects as PI. The latter projects and others with DOE have involved multiple partners (universities, national labs, and industry) demonstrating his ability to manage complex research projects.
- Dr. Nick Xydas (industry partner)— serves as the Vice President of Engineering and Quality at NxEdge, a leading manufacturer of semiconductor processing tools. He has a Ph.D. in Mechanical Engineering from Stony Brook University and has been with NxEdge since 2003. He will provide industrial support for the project activities, and represents a key voice for the Ph.D. pathway to industry.
- Koda Boldt (graduate student)— Ph.D. student in the Engineering Ph.D. program at Boise State University. He received his B.S. and M.S. in Mechanical Engineering from Boise State University. He is also employed at NxEdge as a Product Engineer and serves as a liaison between Boise State University students participating in the project and NxEdge development goals.

ADDITIONAL INSTITUTIONAL & OTHER SECTOR SUPPORT

The proposed project will use the Thermal Transport and Solar Energy Laboratory at Boise State University, directed by the PI. This lab space includes: a UV-VIS scanning wavelength spectrophotometer including integrating sphere attachment, Fourier transform infrared (FTIR)

spectrometer, spincoater, dipcoater, and bladecoater. Additionally, the lab has multiple cameras, low and high temperature furnaces, 2 fume hoods, ultrasonic soldering, ultrasonicator and precision balance for preparing samples, multiple dataloggers, nanovoltmeter, IV curve tracers, syringe pump, power supplies, a Rame-Hart goiniometer for measuring contact angle, a HotDisk TPS2500S thermal conductivity measurement system capable of measurements up to 1000°C, with accessories for use in a muffle furnace and a vacuum tube furnace. Numerous custom flow experimental facilities have also been built in the lab.

Additionally, the proposed project will use Research, Machining and Engineering (RME) equipment and services. It provides campus investigators with engineering design, customization, fabrication, and repair services including mechanical design, electrical and mechanical repair, and feedback on intended equipment design or modifications. Researchers use this facility to design and build new devices, structures, or experimental systems for use in a wide variety of applications, and our design engineers support equipment needs from simple fixtures to more complicated experimental tools. In particular we will use the Open Additive PANDA laser powder bed fusion (LPBF) 3D metal printer for additive manufacturing of metal components.

FUTURE FUNDING

PI Otanicar has a long history of pursuing grant funding for thermal/fluids technology development. This has included funding from the DOE for high temperature porous thermal systems. We have obtained initial funding for design tool development through the TRANSFORM program at Boise State University and have submitted a complementary proposal to the National Science Foundation to develop design tools for optimization of additively manufactured systems. PI Otanicar also has a pending proposal at NSF to sponsor multiple highly competitive graduate students to pursue PhD programs at BSU in the area of microelectronics. The proposed work is also complementary to the recent super agreement partnership with INL on "Advanced Manufacturing for Extreme Environments." PI Otanicar will continue to pursue funding support for additive manufacturing of lattice structures through DOE, NSF and industry sources.

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[5] G. Kerckhofs, G. Pyka, M. Moesen, S. Van Bael, J. Schrooten, and M. Wevers, "High-resolution microfocus X-ray computed tomography for 3d surface roughness measurements of additive manufactured porous materials," *Adv Eng Mater*, vol. 15, no. 3, pp. 153–158, Mar. 2013.

[6] I. Kaur and P. Singh, "Effects of inherent surface roughness of additively manufactured lattice frame material on flow and thermal transport," *Int J Heat Mass Transf*, vol. 209, p. 124077, Aug. 2023.

APPENDIX A: FACILITIES AND OTHER EQUIPMENT

FACILITIES: Boise State University has the necessary available laboratory facilities and supporting resources for the proposed research. Boise State University is a campus rapidly growing to accommodate rising student enrollment and an increasing focus on research. The campus is located one-half mile south of downtown Boise, the state's hub of business, government, and culture. The campus site occupies 175 acres of land and 3.7 million ft^2 of classroom, laboratory, and office space. The university has acquired land and buildings adjacent to the campus as part of a master plan that allows for continuing growth. The university houses a number of substantial facilities and resources that are available to all faculty outside of individual faculty laboratories.

Administrative Support

The PIs have access to a pool of administrative assistants as well as technical support from the College of Engineering. Boise State University also has an Office of Sponsored Projects (OSP) that assists in post-award processes and institutional administration of grants and contracts. Such functions include billing, accounting, and enforcing compliance.

High Performance Computing

The NSF-funded Kestrel GPU cluster (Kestrel) at Boise State University (Award #1229709), PI Jankowski's cluster (Fry), and Boise State's research computing cluster (Borah and R2) will be employed for the proposed research, supported by research allocations at NSF-ACCESS. Kestrel provides 44 NVIDIA Kepler K20 GPU processors, Fry, provides 32 NVIDIA Pascal P100 GPUs, R2 provides 10 P100 GPUs, and Borah provides 8 V100 GPUs that are ideally suited for the proposed simulations and training workshops. Borah is a heterogeneous cluster installed at Idaho National Laboratory's Collaborative Computing Center (C3), where Idaho institutions have been invited to install computing equipment in support of collaborative research among the universities, Idaho National Laboratory researchers, and industry partners. The cluster, including faculty buy-in nodes, has 41 nodes, each with two Intel Xeon Gold 6252 2.1G, 24-core CPUs; 4 GPU nodes, each with two NVIDIA Tesla V100s; and 1 high memory node, with 768 GB of RAM, and two Intel Xeon Gold 6252 2.1G, 24-core CPUs. The cluster is attached to 730 TB of resilient, high-performing Isilon storage that uses an Infiniband high-speed interconnect. Borah is accessible via IRON's (Idaho Regional Optical Network) 100GB connection dedicated to research and education which peers with Internet2, the nation's largest and fastest, coast-to-coast research and education network. The total Boise State GPU resources comprise 826,360 GPU-hours/year.

Boise State University Recharge Centers

Biomechanics and Mechanobiology Laboratory (BMMB)

The proposed project will use equipment in the Boise State Biomechanics and Mechanobiology laboratory (BMMB). This unit within the college Fabrication, Characterization, & Testing (FaCT) research core supports experiments to study the mechanical properties of cells and tissues. For this project the SkyScan microCT system is available for characterization of surface roughness and internal geometry of AM fabricate structures.

Research Machining and Engineering Services (RME)

The proposed project will use Research, Machining and Engineering (RME) equipment and services. The RME is a unit within the Fabrication, Characterization, & Testing (FaCT) Core research service facility. It provides campus investigators with engineering design, customization, fabrication, and repair services including mechanical design, electrical and mechanical repair, and feedback on intended equipment design or modifications. This 1000 ft^2 space is distributed between two college buildings—the Harry Morrison Civil Engineering building, and the Micron Engineering Center. Professional engineering design and machining services are available Monday–Friday during the standard 40-hour work week.

Researchers use this facility to design and build new devices, structures, or experimental systems for use in a wide variety of applications, and our design engineers support equipment needs from simple fixtures to more complicated experimental tools. We use a range of machining tools, electrical hardware, and printers to fabricate from the millimeter to meter scale. RME facilities include a fully equipped machining and fabrication shop for metal working, plastic, welding, and special instrument design. This shop employs a machinist/instrument maker, and an electronic technician, and a mechanical technician for repair and equipment maintenance. To support our full range of services, we maintain:

- Open Additive PANDA laser powder bed fusion (LPBF) 3D metal printer for additive manufacturing of metal components.
- 3D plastic printers that use additive fused deposition modeling (FDM) to print a wide range of plastics including PLA (polylactic acid, a biodegradable and bio-based plastic), ABS (acrylonitrile butadiene styrene), polycarbonate (PC), PETG (polyethylene terephthalate glycol), and TPU (thermoplastic polyurethane).
- Wire electrical discharge machining (EDM) equipment to precisely cut complex metal shapes into conductive materials
- Bandsaws for metal and plastic cutting
- Milling machines for metal and plastic machining, including a manual vertical knee mill as well as a computer numerical control (CNC) vertical milling machine for software-enabled high precision work
- Manual and precision CNC lathes for metal and plastic machining, and
- Surface grinders for metal and plastic machining.

EQUIPMENT

PI Otanicar maintains the following equipment in his research laboratories:

- Standard equipment: one chemical fume hoods, compressed air, chilled water, controllable power sources, and multiple data loggers.
- A Shimadzu UV-Vis Spectrometer
- Multiple furnaces, including tube furnace with vacuum
- High flux solar simulator (~600 kW/m^2 on $25cm^2$ spot)
- FLIR Scientific grade infrared camera
- Pressure drop test facility utilizing air as working fluid
- Rame-Hart contact angle goniometer
- HotDisk Transient Plane Source (TPS-2500S) Thermal Conductivity Analyzer
- Custom built thermal desalination test assemblies
- Custom built high temperature solid particle erosion platforms
- Ultrasonic and traditional soldering
- Nanovoltmeter

Office of Technology Transfer is responsible for the assessment, protection, development, and marketing of new technologies for commercial use and facilitates the internal and external relationships that contribute to the process. OTT also supports the advancement of innovation, entrepreneurship, and economic development through multiple programs and initiatives on campus. In partnership with the College of Innovation + Design, OTT has access to over 12,000 square feet of open-concept collaboration space. The layout allows for reconfiguration to accommodate large groups, of up to 50, or many smaller breakout-style rooms and is equipped with audio/visual, including hybrid capabilities, whiteboards, moveable furniture, and even a classroom for a more traditional teaching environment. OTT currently utilizes Sophia Wellspring as its IP management platform and IN-PART Publishing as its digital solutions provider to connect University technologies with potential industry partners. OTT licenses its digital technologies through an internally hosted online marketplace called Transact Campus. OTT is physically located in the Division for Research and Economic Developments office suite.

IDENTIFYING INFORMATION:

NAME: Otanicar, Todd

ORCID iD: https://orcid.org/0000-0002-4579-6183

POSITION TITLE: Associate Dean for Research Affairs

PRIMARY ORGANIZATION AND LOCATION: Boise State University, Boise, Idaho, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Arizona State University, Tempe, AZ, United States	PHD	05/2009	Mechanical Engineering
University of Cincinnati, Cincinnati, OH, United States	MS	12/2005	Mechanical Engineering
University of Kansas, Lawrence, KS, United States	BS	05/2002	Aerospace Engineering

Appointments and Positions

2025 - present Associate Dean for Research Affairs, Boise State University, Boise, Idaho, United States

2022 - present Professor, Boise State University, Mechanical and Biomedical Engineering, Boise, Idaho, United States

2024 - 2025 Interim Associate Dean for Research Affairs, Boise State University, College of Engineering, Boise, Idaho, United States

2022 - 2024 Department Chair, Boise State University, Mechanical and Biomedical Engineering, Boise, Idaho, United States

2019 - 2022 Associate Professor, Boise State University, Mechanical and Biomedical Engineering, Boise, ID, United States

2016 - 2022 Chief Scientist, Exaeris Water Innovations, LLC, Tulsa, OK, United States

2016 - 2019 Associate Professor, The University of Tulsa, Mechanical Engineering, Tulsa, OK, US

2012 - 2016 Assistant Professor, The University of Tulsa, Mechanical Engineering, Tulsa, Oklahoma, US

2009 - 2012 Assistant Professor, Loyola Marymount University, Mechanical Engineering, Los Angeles, CA, US

2002 - 2006 Design Engineer, GE Aircraft Engines, Cincinnati, OH, US

Products

Products Most Closely Related to the Proposed Project

1. Zuzelski M, Laporte-Azcué M, Cordeiro J, Dhakal S, Daghigh V, Keller M, Ramsurn H, Otanicar T. Design of a novel carbon/carbon composite microvascular solar receiver. Solar Energy. 2023 September; 262:111794-. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0038092X23004097 DOI: 10.1016/j.solener.2023.111794
2. Sanchez A, Goel N, Otanicar T. Novel hybrid solar nanophotonic distillation membrane with photovoltaic module for co-production of electricity and water. Applied Energy. 2022 January; 305:117944-. Available from: https://linkinghub.elsevier.com/retrieve/pii/S030626192101254X DOI: 10.1016/j.apenergy.2021.117944
3. Cordeiro J, Zuzelski M, Olima M, Crunkleton D, Otanicar T, Ramsurn H, Keller M. Vascular Carbon/Carbon composites for concentrated solar power. Composites Part A: Applied Science and Manufacturing. 2024 May; 180:108069-. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1359835X24000666 DOI: 10.1016/j.compositesa.2024.108069
4. Wingert R, O'Hern H, Orosz M, Harikumar P, Roberts K, Otanicar T. Spectral beam splitting retrofit for hybrid PV/T using existing parabolic trough power plants for enhanced power output. Solar Energy. 2020 May; 202:1-9. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0038092X20303029 DOI: 10.1016/j.solener.2020.03.066
5. Norman D, Otanicar T, Crunkleton D, Hawkins A. A NUMERICAL MODELING OF NATURAL CONVECTION AIR COOLING OF A BUTT-FUSION WELD. Proceeding of 4th Thermal and Fluids Engineering Conference. 4th Thermal and Fluids Engineering Conference; ; Las Vegas, NV, USA. Connecticut: Begellhouse; c2019. Available from: http://dl.astfe.org/conferences/tfec2019,2c0d0caa03604a42,2975c5ed0cd3eb93.html DOI: 10.1615/TFEC2019.ref.028490

Other Significant Products, Whether or Not Related to the Proposed Project

1. Stout D, Kandadai N, Otanicar T. Experimental and numerical investigation of bimodal particle distributions for enhanced thermal conductivity in particle based concentrating solar power applications. Solar Energy. 2023 October; 263:111992-. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0038092X23006266 DOI: 10.1016/j.solener.2023.111992
2. Malik S, Anderson K, Goel N, Otanicar T, Karimi S. Designing a Particle Flow Control Apparatus. Volume 8: Fluids Engineering; Heat Transfer and Thermal Engineering. ASME 2022 International Mechanical Engineering Congress and Exposition; Oct. - ; Columbus, Ohio, USA. American Society of Mechanical Engineers; c2022. Available from: https://asmedigitalcollection.asme.org/IMECE/proceedings/IMECE2022/86700/V008T10A041/1157386 DOI: 10.1115/IMECE2022-94820
3. Christen C, Gómez-Hernández J, Otanicar T. Bimodal particle distributions with increased thermal conductivity for solid particles as heat transfer media and storage materials. International Journal of Heat and Mass Transfer. 2022 March; 184:122250-. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0017931021013491 DOI: 10.1016/j.ijheatmasstransfer.2021.122250

4. Otanicar T, Wingert R, Orosz M, McPheeters C. Concentrating photovoltaic retrofit for existing parabolic trough solar collectors: Design, experiments, and levelized cost of electricity. Applied Energy. 2020 May; 265:114751-. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0306261920302634 DOI: 10.1016/j.apenergy.2020.114751
5. Wada K, Eixenberger J, Stout D, Jaques B, Otanicar T, Estrada D. Analysis of Near-Wall Pebble Bed Thermal Conductivity for Energy Applications. ACS Omega. 2023 December 28; 9(1):1614-1619. Available from: https://pubs.acs.org/doi/10.1021/acsomega.3c08202 DOI: 10.1021/acsomega.3c08202

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to information related to domestic and foreign appointments and positions.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Otanicar, Todd in SciENcv on 2025-09-15 06:34:17

February 15, 2026

Attn: John Thomas
Idaho State Board of Education
650 West State Street, 3rd Floor
Boise, ID 83702

RE: IGEM-HERC: Additively Manufactured Lattice Showerheads for Improved Semiconductor Processing

Dear John Thomas,

I write on behalf of NxEdge INC. to confirm our industrial participation with Boise State University on the proposal entitled *Additively Manufactured Lattice Showerheads for Improved Semiconductor Processing*. This proposal represents a strategic opportunity for our industry to partner with an Institution of Higher Education to jointly advance our interests.

NxEdge is a leading provider of advanced manufacturing, cleaning, coating and refurbishment services for the semiconductor and industrial thin-film sectors. NxEdges's vertically integrated suite of solutions includes precision machining, anodizing, plating, and proprietary engineered coatings designed to extend component life and enhance performance in semiconductor fabrication environments.

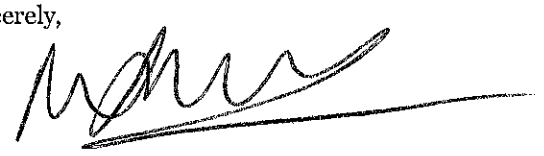
NxEdge's core competencies lie in the development of advanced coating technologies and precision small-hole drilling for gas distribution showerheads, critical components in semiconductor fabrication processes. These capabilities enable NxEdge to meet the stringent requirements of next-generation semiconductor capital equipment, where precision, reliability, and innovation are paramount. The semiconductor industry is evolving rapidly, with technology nodes advancing to 2 nm and below. This ever-demanding segment represents the cutting edge of capital equipment development and requires breakthrough solutions to support tool performance and cost targets. NxEdge is committed to delivering these solutions through continuous innovation, leveraging residence expertise in materials science, precision engineering, and applied research to help the OEM and IDM customers stay ahead in an increasingly competitive market.

I agreed to serve as a partnering company, as it represents a fundamental growth area for technology within our company. NxEdge is committed to this IGEM-HERC proposal in three ways:

1. *Facility tours*: Seeing real parts being fabricated and inspected is critical to learning. Tours of our facility in Boise allow for a direction connection to the design tools being developed.
2. *Internship Opportunities:* NxEdge takes pride in professional employment, and has cultivated internship opportunities with Boise State University for many years.
3. *Thesis/Dissertation Committees:* Serving on thesis/dissertation committees is another direct industry-university connection. I am currently serving on Koda Boldt's dissertation committee and look forward to more potential opportunities.

If the proposal submitted by Dr. Todd Otanicar is selected for funding by IGEM-HERC, we are eager to explore opportunities for collaboration with Boise State University including participation in the monthly lunch and learn networking event outlined in this proposal. We look forward to the positive impact that this initiative will have within our community and the broader industry.

Sincerely,



Dr. Nick Xydas
Vice President of Engineering and Quality