PROJECT SUMMARY

Overview

This Phase-I research aims at a structured transition of FAME (https://github.com/neoceph/FAME), a machine learning (ML) augmented finite-volume based thermal CFD solver, into a sustainable, distributed Open-Source Ecosystem (OSE) for Additive Manufacturing (AM) and supercritical (sCO_2) researchers. FAME is available to researchers under an open-source license on GitHub and has been validated against NIST metal AM experiments [1], attracting limited academic research users. The proposed OSE will provide targeted training and illustrative use cases, covering topics such as the design and analysis of AM processes and the production of sCO_2-based energy systems. Phase I activities will include: 1) formalizing the managing organization; 2) developing an effective governance model; 3) identifying and expanding the external developer and user community; and 4) designing the onboarding, outreach, licensing, and sustainability strategies for tool support. Tool development and support are led by Dr. Abdullah A. Amin and Dr. Andrew J. Schrader from the Mechanical and Aerospace Engineering Department at the University of Dayton. These researchers bring domain expertise in the design, optimization, and application of AM and Energy Systems, directly responding to the broader need for open, reproducible, and extensible infrastructure in manufacturing and energy research and development. This proposal focuses on building the foundation for a sustainable and community-driven OSE for manufacturing and energy research.

Intellectual Merit

This project will advance the FAME framework into a sustainable, community-driven open-source ecosystem (OSE) that supports high-fidelity thermal-fluid simulations for additive manufacturing (AM) and sCO_2-based thermal management. Emphasizing reproducibility, modularity, and extensibility, FAME integrates data-augmented modeling with ray-tracing-based radiative heat transfer to accurately capture beam-powder interactions and phase change dynamics key to understanding defect formation, microstructure evolution, and thermal system performance. Designed for heterogeneous CPU/GPU architectures, the framework supports scalable simulations and enables rapid iteration. By coupling physics-based solvers with modern ML libraries, it provides a rigorous platform to develop and validate AI/ML methods for surrogate modeling, real-time optimization, and intelligent process control. The project will formalize a flexible architectural design and foster a distributed contributor base to sustain long-term innovation. Integrated training resources will support the onboarding of new users, reducing entry barriers while enabling participation in advancing computational methods for intelligent manufacturing and energy systems.

Context of OSE

Describe the long-term vision and guiding principles for the proposed OSE, such as fostering collaborative, inclusive development to ensure sustainability and ethical use. Outline specific societal or national needs addressed (e.g., bridging gaps in accessible AI for underserved communities, enhancing U.S. competitiveness in sustainable tech). Anticipate broader impacts, including economic benefits, STEM diversity, and ethical advancements.

1. **Pointer to Existing Open-Source Product:** The product is available in [Inline Citation to Repository, e.g., GitHub repo listed in References Cited].

2. **Current Status:** Detail the development and testing model (e.g., agile with automated CI/CD pipelines), dissemination methods (e.g., via GitHub releases and academic conferences), user base (e.g., 200+ active users from academia and industry, evidenced by download metrics and feedback), and contributor base (e.g., 8 core contributors and 15 occasional ones).

3. **Problem Addressed and Novelty:** Describe the problem (e.g., lack of open tools for real-time climate data analysis) and the product's novelty (e.g., unique integration of machine learning with edge computing, superior to proprietary alternatives like [cite existing solutions]). Provide substantiating evidence (e.g., user testimonials, citation counts, or pilot study results showing 30% efficiency gains).

4. **Team Qualifications:** Justify the team's expertise (e.g., PI has 10+ years in open-source software development, co-PIs have led similar ecosystem transitions; include synergistic activities from biosketches).

Broader Impacts

The FAME OSE ecosystem will democritize access to advanced thermal-fluid simulation and AI-assisted design tools across the manufacturing and energy sectors. A central aim is to train the next generation of researchers, engineers, and developers in open-source software development, digital twin technologies, and thermo-fluid modeling specific to manufacturing and energy. The project will offer annual hands-on workshops and summer schools focused on software sustainability and domain-specific applications. A targeted talent development initiative will engage institutions across various geographic regions through customized outreach and curriculum modules, helping to prepare a skilled, workforce-ready STEM pipeline. Research outcomes and practical use cases will be shared through peer-reviewed publications, conference tutorials, and freely accessible training materials hosted on the project's online platform and amplified through social media. By fostering a community grounded in open science, reproducibility, and collaborative development, this initiative will advance U.S. priorities in energy and manufacturing while ensuring the long-term sustainability of the FAME platform.

Risk Analysis/Security Plan

Identify project-relevant risks, such as contributor attrition, security vulnerabilities in code, data privacy issues, or ethical concerns in AI outputs. Reference guidance from CISA/NSA on securing software supply chains and OpenSSF best practices (e.g., adopting SLSA for build integrity). Mitigation strategies: Implement vulnerability scanning tools (e.g., during scoping audits), establish policies for patching (e.g., within 30 days of discovery), ensure data privacy via anonymization and compliance with GDPR-like standards, and maintain chain of custody through version control. Discuss Phase I activities to explore mechanisms for quality assurance, secure content integration (e.g., code reviews), identity/access management (e.g., multi-factor authentication for contributors), and safety/privacy risks (e.g., bias audits for models).

Scoping Activities for Phase I

Outline specific, actionable scoping and planning activities to assess the product's readiness for OSE transition, user base viability, and developer community potential. These will inform a potential Phase II proposal. Activities should be feasible within 1 year and $300K budget.
Specific scoping activities for Phase I include:

- **Ecosystem Discovery:** Strategy to evaluate the technological landscape via literature reviews, competitor analyses (e.g., surveying similar projects like [cite examples]), and stakeholder interviews (e.g., 20-30 users/developers). Justify OSE approach (e.g., enables distributed innovation unlike closed systems). Outline methods to identify potential users (e.g., via surveys targeting industry sectors) and new developers (e.g., analyzing GitHub forks and contributions).

- **Organization and Governance:** Activities to identify models (e.g., benchmarking against Apache or Linux Foundation via case studies), licensing (e.g., evaluating MIT vs. GPL for compatibility), CI/CD infrastructure (e.g., assessing tools like GitHub Actions for asynchronous development), quality/security processes (e.g., drafting ethical guidelines), and sustainability methods (e.g., exploring funding models like donations). Include metrics (e.g., contributor retention rates ¿50%).

- **Risk Analysis/Security:** Build on the plan above with scoping tasks like third-party security audits, privacy impact assessments, and workshops on secure development. Explore tools for identity management (e.g., OAuth) and custody chains (e.g., blockchain for provenance, if applicable).

- **Community Building:** Activities to engage users and developers, such as virtual workshops (e.g., 2-3 events with 50+ participants), hackathons (e.g., themed on product extensions), and competitions. Identify required capabilities (e.g., expertise in Python/ML for contributors) and mechanisms (e.g., online forums, research networks). Emphasize inclusivity (e.g., scholarships for underrepresented participants).

Community Outreach Plan

Outline activities to engage intellectual content developers (e.g., webinars on contribution guidelines) and identify early adopters (e.g., partnerships with organizations via targeted emails and social media campaigns). Include timelines (e.g., quarterly outreach events) and diversity focus (e.g., collaborating with minority-serving institutions).

Evaluation Plan

Describe actionable metrics (e.g., # of new contributors engaged [target: 20+], user adoption growth [target: 50% increase], governance framework drafts completed) and assessment methods (e.g., pre/post surveys, analytics from repository tools, external mentor feedback). Include quarterly reviews to track progress and adjust plans.

POSE Phase I: Enabling an Open Ecosystem for Thermo-Fluid Computational Intelligence in Manufacturing and Energy Systems

1 Research Motivation and Objectives

In a usual template I prefer writing some words about motivation as to why we want to do this and what are the objective in terms of scientific outcome. NSF is about fundamental research and they prefer hypothesis driven activities. Although for the NSF POSE, this might be different. If we need to cite anything, we do this by [1] By the end of the paragraph, I want to spell out the **scientific understanding** in terms of bulleted lists:

- **Understanding 1:** What new understanding we want to develop.
- **Understanding 2:** Any additional understanding?
- **Understanding 3:** Anything else that we missed?

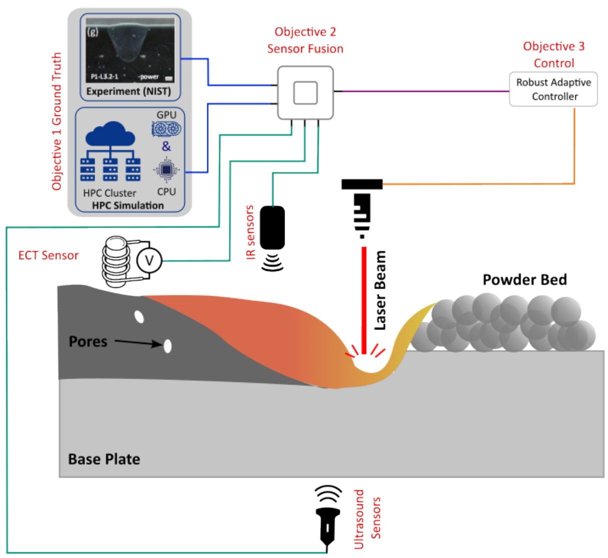

Figure 1: *Dummy figure as an example.*

In terms of novelty, what novel **novel scientific outcomes** will results as part of this fundamental research:

- We will have a growing developer and user base of machine learning based thermal CFD solver.
- The framework is highly flexible and application agnostic.
- Anything else.

Research Goal

We use textbox to highlight the research goal of the proposal.

Educational Goal

Do the same for educational goal of the proposal.

2 Background and State of the Art

Not sure if this is appropriate for the POSE proposal.

2.1 Subsection 1

Text description

Table 1: *Example table that may contain multiple rows and columns. This is a dummy table to show how to use the table environment.*

	Item 1	Item 2	Item 3	Item 4
	row 11	row 12	row 13	row 14
	row 21	row 22	row 23	row 24
	row 31	row 32	row 33	row 34
	row 41	row 42	row 43	row 44
If arrow needed	row 51	row 52	row 53	row 54
	row 61	row 62	row 63	row 64
	row 71	row 72	row 73	row 74
	row 81	row 82	row 83	row 84
	row 91	row 92	row 93	row 94

2.2 Subsection 2

More texts

2.3 Subsection 3

More texts

3 Proposed Research Approach

Proposed research approach or research activities that aligns with POSE

Objective-1: Item 1 with **sufficient highlights to ensure that the reader does not miss important key details** as there is always a chance for the panel reviewer to misunderstand the objective.

Objective-2: Another key **objective** to achieve the final goal.

Objective-3: Another key **aspect of the proposed** activitied.

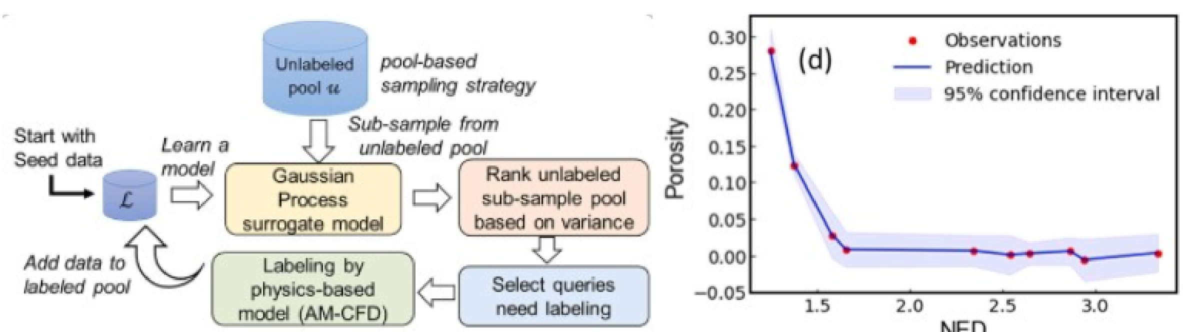

Figure 2: *Another example image with citation [?].*

4 Objectives

4.1 Objective-1: (Amin)

Goal: *Specify the goal.*

Proposed Approach: Proposed approach description.

Mitigation: Mitigation plan if any.

Expected Outcome: Explain expected outcome.

5 Objectives

5.1 Objective-1: (Amin)

Goal: *Specify the goal.*

Proposed Approach: Proposed approach description.

Mitigation: Mitigation plan if any.

Expected Outcome: Explain expected outcome.

$$m_{1\oplus\ldots n}(C) = \frac{1}{1-K} \sum_{A_1\cap A_2\ldots\cap A_n = C} m_1(A_1)\ldots m_n(A_n), \quad K = \sum_{A_1\cap A_2\ldots\cap A_n=\varnothing} m_1(A_1)\ldots m_n(A_n) \quad (1)$$

where: $m_1(A_1)$ and $m_n(A_n)$ are the basic belief assignments from source 1 (transformer sensor 1) and source n (transformer sensor n) for propositions $A_1, \ldots A_n \subseteq \Theta$; $m_{1\oplus\ldots n}(C)$ is the fused belief mass for proposition $C \subseteq \Theta$; K is the conflict mass representing total evidence conflict among m_1, ... m_n; $A_1, .., A_n$ are subsets of the frame of discernment Θ describing melt-pool regimes (insufficient, nominal, keyhole, lack_of_fusion) extending sequentially across all sources. From the fused mass function $m_{DS}(\cdot)$ we compute belief Bel("nominal") and plausibility Pl("nominal") their interval width $\mathrm{Pl} - \mathrm{Bel}$ serves as an explicit uncertainty metric.

6 Objectives

6.1 Objective-3: (Amin)

Goal: *Specify the goal.*

Proposed Approach: Proposed approach description.

Mitigation: Mitigation plan if any.

Expected Outcome: Explain expected outcome.

7 Intellectual Merit

This project will advance the FAME framework into a sustainable, community-driven open-source ecosystem (OSE) that supports high-fidelity thermal-fluid simulations for additive manufacturing (AM) and sCO_2-based thermal management. Emphasizing reproducibility, modularity, and extensibility, FAME integrates data-augmented modeling with ray-tracing-based radiative heat transfer to accurately capture beam-powder interactions and phase change dynamics key to understanding defect formation, microstructure evolution, and thermal system performance. Designed for heterogeneous CPU/GPU architectures, the framework supports scalable simulations and enables rapid iteration. By coupling physics-based solvers with modern ML libraries, it provides a rigorous platform to develop and validate AI/ML methods for surrogate modeling, real-time optimization, and intelligent process control. The project will formalize a flexible architectural design and foster a distributed contributor base to sustain long-term innovation. Integrated training resources will support the onboarding of new users, reducing entry barriers while enabling participation in advancing computational methods for intelligent manufacturing and energy systems.

8 Outreach Plan

8.1 Community Outreach

Detailing out the plan

8.2 Student Involvement

Discuss student involvement

8.3 Curriculum Development

Do we want to develop any curriculum for this project? If yes, then what is the plan?

8.4 Dissemination through Conferences

How dow we want to disseminate the research outcomes? Do we have any plan to present at conferences through workshop and attract more developers?

9 Broader Impacts

The FAME OSE ecosystem will democritize access to advanced thermal-fluid simulation and AI-assisted design tools across the manufacturing and energy sectors. A central aim is to train the next generation of researchers, engineers, and developers in open-source software development, digital twin technologies, and thermo-fluid modeling specific to manufacturing and energy. The project will offer annual hands-on workshops and summer schools focused on software sustainability and domain-specific applications. A targeted talent development initiative will engage institutions across various geographic regions through customized outreach and curriculum modules, helping to prepare a skilled, workforce-ready STEM pipeline. Research outcomes and practical use cases will be shared through peer-reviewed publications, conference tutorials, and freely accessible training materials hosted on the project's online platform and amplified through social media. By fostering a community grounded in open science, reproducibility, and collaborative development, this initiative will advance U.S. priorities in energy and manufacturing while ensuring the long-term sustainability of the FAME platform.

10 Project Timeline

Table 2: A Tentative project timeline

<table>
<tr><th rowspan="2">Research Plan</th><th colspan="4">Year 1</th><th colspan="4">Year 2</th><th colspan="4">Year 3</th></tr>
<tr><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th></tr>
<tr><td>Objective -1</td><td colspan="4"></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Objective -2</td><td></td><td></td><td></td><td colspan="4"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Objective -3</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4"></td><td></td></tr>
<tr><td>Objective -4</td><td></td><td colspan="3"></td><td></td><td></td><td colspan="4"></td><td></td><td></td></tr>
<tr><td>Education & Outreach</td><td colspan="4">Conference?</td><td colspan="4">XXX workshop</td><td colspan="4">Dayton STEM workshop</td></tr>
<tr><td>Dissemination</td><td colspan="4">Conference XXX</td><td colspan="4">Conference</td><td colspan="4">Conference shortcourse</td></tr>
</table>

11 Prior NSF Support

The PI's have no prior NSF support.

References

[1] Abdullah Al Amin, Yangfan Li, Ye Lu, Xiaoyu Xie, Zhengtao Gan, Satyajit Mojumder, Gregory J. Wagner, and Wing Kam Liu. Physics guided heat source for quantitative prediction of IN718 laser additive manufacturing processes. *npj Computational Materials*, 10(1):37, February 2024.