COVER PAGE

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ACCOMPLISHMENTS

The rapid advancements in fusion energy research underline an urgent need for a robust workforce capable of driving future fusion engineering and technology developments. Despite recent advancements, fusion engineering and technology are still poorly represented in the academic curricula, highlighting a pressing demand to grow the talent pipeline in this field. To address these challenges, this RENEW project aims to leverage the collective strengths of the Oak Ridge National Laboratory (ORNL), six academic institutions, including Tennessee Tech University (TTU), Tennessee State University (TSU), Tuskegee University (TU), Southern Adventist University (SAU), Missouri University of Science and Technology (MST), and University of Tennessee - Knoxville (UTK), and ten private fusion companies to create workforce training initiatives and enhance curriculum development, thereby preparing a new generation of researchers for careers in fusion engineering and technology.

Major goals and objectives

Our project pursues three major goals. (1) We will establish a student mentoring program to involve undergraduate and graduate students through consecutive summer internships at ORNL and a private fusion company, where they will gain hands-on experience with cutting-edge research and commercial applications of fusion technology. In the intervening year and beyond, students will also be mentored by ORNL and industry researchers. (2) We will collectively develop a series of fusion-focused courses and special-topics modules to be implemented at participating universities, which will be shared publicly with the broader academic community. (3) To promote the sustainability of the project efforts, we will create an inaugural entrepreneurship and innovation focused bootcamp – the Fusion Innovation Bootcamp (FIB) – for students to experience sustained training, engagement with fusion professionals, national lab researchers, and university faculties, thereby providing them with entry pathways into the fusion workforce.

Activities and accomplishments

During this reporting period, activities at TTU focused on student mentorship and curriculum development. For student mentorship, we ran a coordinated recruitment, selection, and placement process for Summer 2025 ORNL internships. To advertise this opportunity, PI Zhang created a designated project website with descriptions of the program and application instructions, and distributed flyers on TTU campus during early Spring 2025 semester. By the deadline, 20 applications were received from TTU STEM students. After an initial screening based on preparation and interests, we forwarded a group of qualified candidates to ORNL mentors. Two students were ultimately selected to participate in the 10-week, full-time internship. The grant provided support for daily expenses and housing; we issued the first paychecks to students two weeks before the start of the program, ensuring sufficient funding to cover their' initial expenses and eliminating barriers to participation. Each intern was paired with an ORNL researcher for day-to-day mentorship. The internship culminated in a poster presentation at ORNL in the final week.

To enhance fusion curriculum, PI Zhang developed three two-week fusion-focused modules designed to be implemented into existing TTU courses. The "Nuclear Fusion Power Plants" module (for the undergraduate ME2210 Thermodynamics course) connects thermodynamic theories to the design of fusion-based power plants, highlighting the roles of the blanket/first wall, cooling strategies, and heat conversion. The "Magnetohydrodynamics (MHD)" module (for the graduate ME6040 Intermediate Fluid Mechanics course) builds upon fluid mechanics theories to introduce the physics of conducting liquid metals and molten salts in magnetic fields, emphasizing MHD's impact on blanket flow control and materials selections. The "Radiation Interactions with Materials" module (for the graduate ME6360 Introduction to Continuum Mechanics course) uses continuum-mechanics frameworks to model creep, swelling, embrittlement, and radiation-induced damage in structural materials under high neutron flux. In parallel, co-PI Rao developed a one-hour "Ethics and Safety in Nuclear Fusion" session for the sophomore-level ME2910 Professionalism and Ethics course to reinforce professional and safety norms in fusion engineering. This work connects ethical reasoning directly to fusion engineering by emphasizing safety, transparency, and societal responsibility in high-risk technologies. Students will learn to examine how design and operational choices in fusion systems affect workers, the public, and the environment, reinforcing that ethical judgment and safety culture are inseparable in advancing clean-energy innovation. Two additional TTU faculty recently joined the curriculum effort, and work is underway on an "Introduction to Molten Salts for Fusion Reactors" module.

Technical approach

To assess the internship's effectiveness, we administered a pre-survey at the onset and a post-survey at the conclusion of the program. These anonymous surveys collected information on students' baseline and post-internship familiarity with fusion research topics, and their interest in pursuing a career in fusion engineering. We analyzed the responses to assess shifts in knowledge and career orientation as a result of the internship.

For curriculum development, the PI reviewed course modules with collaborators at ORNL and private fusion companies. Based on their feedback, he revised the lecture materials to ensure alignment with current practice. At the time of this report, deployment of the fusion-focused modules at TTU is underway. To assess the modules' effectiveness, PI Zhang will design targeted surveys to evaluate students' knowledge gains in fusion, interest in fusion career, and transfer of prior knowledge to fusion. Results will be analyzed and used to refine the modules for future deployment.

Progress and key outcomes

Progress outcomes are evidenced in student involvement, internship training outcomes, and survey results. Two TTU students successfully completed Summer 2025 internships at ORNL, gaining experience with modeling tools and scientific communication skills. Pre- and post-survey responses by the cohort indicate increased familiarity with core fusion-engineering domains. Interest in a fusion-engineering career remained high: the post-survey showed 60% "Extremely interested" and 40% "Interested," with no responses in "Somewhat interested" or lower. On perceived impact of the internship experience, 80% "Strongly agree" and 20% "Agree" that the internship helped them develop new knowledge, skills, or perspectives useful for their careers; no negative responses were recorded. The survey identified several benefits of the internship: networking with fusion professionals, growth in fusion-domain knowledge, mentorship, career development, and computational skills. These findings are consistent with the project's targeted objective to provide training that improves students' career perspectives in fusion engineering.

Training and professional development for participants

The project delivered substantive training and professional development for student and faculty. Two TTU students completed a 10-week, full-time internship at ORNL. Their training emphasized hands-on technical skills, research practices, and scientific communication. Both interns expanded their professional networks through regular interactions with national lab researchers.

Fusion-focused course modules developed for ME2210 (Thermodynamics), ME6040 (Intermediate Fluid Mechanics), and ME6360 (Introduction to Continuum Mechanics) courses at TTU created classroom-based training that translates core mechanical-engineering knowledge into fusion applications. A one-hour "Ethics and Safety in Nuclear Fusion" session in ME2910 further supported professional development by emphasizing safe and ethical decision-making.

Preparing and iteratively reviewing the modules with ORNL and private-sector collaborators expanded the research scope of the faculty in liquid-metal/molten-salt MHD and radiation interaction with materials. This interaction not only aligned instructional content with current practice but also promoted future research collaborations between faculty and fusion professionals.

Dissemination

To disseminate our early project outcomes with the professional and student community, the PI presented a poster co-authored with ORNL and TTU collaborators at the 2025 Symposium on Fusion Engineering in Boston. This presentation facilitated discussions with national-lab, industry, and academic professionals and generated interest in curriculum development and student mentoring.

We established a dedicated project website for the general public with news updates, basic description of project goals, internship opportunities, and the planned FIB, thereby broadening awareness among potential applicants and collaborators. Additionally, a TTU intern will present her Summer 2025 research at the 67th Annual Meeting of the APS Division of Plasma Physics, further disseminating technical outcomes as a result of student training. We had also scheduled an outreach at ORNL's "Nuclear for All" career expo on TTU's campus in November 2025 to inform students about pathways into fusion via internships, fusion-focused courses, and bootcamp participation; however, this event has been cancelled due to the government shutdown.

Plan for the next reporting period

In the next reporting period, we will continue enhancing student mentorship and fusion curriculum at TTU. For student mentorship, we will complete recruitment for Summer 2026 ORNL internship, ensure full financial support, and encourage Summer 2025 interns to pursue internship with private companies. We will administer pre/post surveys to assess the internship's impact.

For curriculum development, we plan to deploy the Nuclear Fusion Power Plants module in ME2210 in Spring 2026 and to deploy the MHD and Radiation Interactions with Materials modules again in ME6040 and ME6360 in Fall 2026. Student feedback and further reviews will help us improve the lectures and homework problems for this second-round deployment. The Ethics and Safety in Nuclear Fusion session in ME2910 will be offered during 2026, and we anticipate finalizing and deploying the Introduction to Molten Salts for Fusion Reactors module in 2026. Beyond modules, we will begin developing full-semester graduate courses in MHD and Radiation Interactions with Materials, aiming to get both courses ready for review and the planned deployment in 2027.

In summary, TTU made steady progress toward the project's three objectives. We selected and supported students for high-quality internships, developed and refined fusion-focused course modules, and disseminated outcomes to professional and student communities. Survey results show strong perceived career impact and broadened familiarity with key fusion topics. From this initial cycle, we learned that early engagement and clear communication with ORNL mentors greatly improve student preparedness and project matching. The positive outcomes from the internship and module deployment highlight the value of structured feedback loops (pre/post surveys and collaborator reviews), which we plan to expand in the next cycle. These lessons will guide refinements to recruitment, mentorship coordination, and module assessment, ensuring stronger student outcomes and smoother implementation moving forward.

PRODUCTS

The products shown below include only Publications with a 'Published' status and Intellectual Properties with a 'Granted' status. Products with other statuses are not included in this report. The Revision Type indicates whether a product is New (newly added), Updated (existing product modified), or No Change (existing product reported without modifications) during the current budget period. Note that 'Updated' statuses may appear more frequently as products progress through the publishing process. All products listed have been reported for the current project period of this award.

PUBLICATIONS

Conference Paper/Presentation (New):
Zhang, Peng; Fan, Yuqiao; Rao, Mohan; Lumsdaine, Arnold, "Initiatives to Grow New Innovate Talent to Enable Fusion Energy (IGNITE Fusion Energy)", *2025 Symposium on Fusion Engineering (SOFE)*, Published, 2025.

Website (New):
"IGNITE Fusion Energy", *https://sites.tntech.edu/ignite-fusion-energy/*.

INTELLECTUAL PROPERTIES

There are no intellectual properties to report.

PARTICIPANTS AND OTHER COLLABORATING ORGANIZATIONS

The table below only contains participants who have identified an affiliation with the Awardee Institution. Participants from any associated subawards may not be included in this count.

PARTICIPANTS DETAIL

Project Role	Number of People	Total Person Months Worked
Co-Project Director	1	2
Faculty	2	2
Principal Investigator/Project Director	1	2
Undergraduate Student	2	4
Total Responses	**6**	**10**

PARTNERS DETAIL

Partner: Missouri University of Science and Technology, Rolla, MO, USA
Partner: Oak Ridge National Laboratory, Oak Ridge, TN, USA
Partner: Southern Adventist University, Collegedale, TN, USA
Partner: Tennessee State University, Nashville, TN, USA
Partner: Tuskegee University, Tuskegee, AL, USA
Partner: University of Tennessee - Knoxville, Knoxville, TN, USA

IMPACT

Impact on the development of principal disciplines

Our project advances pedagogical methods by demonstrating how fusion engineering curriculum can be integrated into the standard mechanical engineering (ME) curriculum through short, modular courses. Each two-week module (Nuclear Fusion Power Plants, Magnetohydrodynamics, and Radiation Interactions with Materials) is organized with explicit learning objectives, lecture slide decks, and homework problem sets that connect core ME knowledge (thermodynamics, fluid mechanics, and continuum mechanics) to realistic fusion applications (first wall and blankets, liquid-metal flows in magnetic fields, and radiation-induced material behavior). These materials were iteratively reviewed with national lab and industry collaborators, which ensured fusion-relevance and consistency with current practice. Additionally, the targeted Ethics and Safety in Nuclear Fusion session introduces safety and professional responsibility in fusion, which can be readily integrated in any engineering professionalism and ethics course through a single class meeting.

Tennessee Tech University's approach represents a replicable model for integrating emerging disciplines like fusion engineering into traditional mechanical engineering programs without requiring new degree tracks or major curriculum revisions. By embedding short, self-contained fusion modules directly into core ME courses such as Thermodynamics, Fluid Mechanics, Continuum Mechanics, and Engineering Ethics, TTU demonstrated that foundational mechanical concepts can serve as natural gateways to advanced fusion topics. This modular framework allows students to explore fusion energy applications within familiar coursework while maintaining ABET alignment and manageable faculty workload. The strategy is particularly effective for institutions that lack dedicated nuclear engineering programs but wish to expose students to clean energy and next-generation reactor technologies. TTU's implementation thus offers a scalable, low-barrier pathway that can be adopted nationally to expand the fusion-ready engineering workforce.

Impact on the development of human resources

During this reporting period, the project advanced human resource development in science and engineering by creating mentored internship opportunities, developing and deploying fusion-relevant course modules, and supporting professional development of faculty members at TTU.

First, we enhanced students' involvement in science and technology through 10-week, full-time summer internships at ORNL. Two TTU students were selected from a pool of 20 applicants and were matched with ORNL mentors for day-to-day guidance. Interns gained practical research experience in fusion engineering, including literature review and analysis using commercial codes and software. Both interns concluded the program with a poster presentation at ORNL. Pre- and post-surveys registered uniformly positive perceived career impact and increased familiarity with core fusion topics, indicating that the internship experience strengthened students' technical competence, professional connections, and career pathways in fusion engineering and technology. Importantly, the project provided financial support for daily expenses and housing, reducing barriers to participation for students who might otherwise be excluded.

Second, we developed new educational materials by creating three two-week, fusion-focused modules that connect core mechanical engineering theories with realistic fusion applications: Nuclear Fusion Power Plants (ME2210 Thermodynamics), Magnetohydrodynamics (ME6040 Intermediate Fluid Mechanics), and Radiation Interactions with Materials (ME6360 Introduction to Continuum Mechanics). These modules were organized with explicit learning outcomes, lecture slide decks, and problem sets. Instructors of key ME courses can readily adopt these self-contained two-week modules to introduce fusion fundamentals and applications into their existing courses. Additionally, we designed a one-hour Ethics and Safety in Nuclear Fusion session for ME2910 to emphasize safety and responsibility in fusion industry. Two additional TTU faculty recently joined the curriculum effort, and a new module on Introduction to Molten Salts for Fusion Reactors is under development. Overall, we put together a team of instructors prepared to teach fusion-relevant content.

Third, this project fostered professional development for faculty at TTU. Course materials underwent iterative review with ORNL researchers and private-sector collaborators, exposing faculty members to up-to-date research directions and practices. This process expanded faculty expertise in liquid-metal and molten-salt magnetohydrodynamics and in radiation-materials mechanics.

Finally, we advanced dissemination and recognition of trainee's work. This project is supporting a Summer 2025 intern from TTU to present her research at the 67th APS Division of Plasma Physics Annual Meeting. This will expose the student trainee to professional standards and help expand networking with fusion professionals.

Impact on information resources that form infrastructure

This project made significant infrastructure impacts on information resources. The project produced a suite of fusion-focused instructional modules designed for integration into existing mechanical engineering courses: Nuclear Fusion Power Plants (ME2210), Magnetohydrodynamics (ME6040), Radiation Interactions with Materials (ME6360), and a one-hour Ethics and Safety in Nuclear Fusion session (ME2910). Each module includes clear learning outcomes, lecture slide decks, and homework problem sets that connect mechanical-engineering theories to realistic fusion applications. Following our ongoing classroom deployment and review of student feedback, we will revise and release the course materials via a public data repository to facilitate reuse and adaptation by other institutions – digital object identifiers (DOIs) and uniform resource locators (URLs) to the repository will be shared on the project website. In addition, we will post survey questions and summary statistics documenting learning and interest shifts, so that other programs can adopt the evaluation approach. The existing project website will continue to function as a centralized venue for opportunities (internships, bootcamp), instructional resources, and new updates, thereby improving electronic access and supporting scientific communication across partner institutions and the broader fusion community.

Impact on society beyond science and technology

Although the project is primarily education-focused within science and engineering, it brings several impacts beyond the research community. By creating a publicly accessible project website, the project improves general understanding of fusion as part of the clean-energy landscape and clarifies concrete career entry pathways for students and community members who are unfamiliar with the field.

The project lowers barriers to participation through paid, mentored internships (including support for daily expenses and housing), which broadens access to high-quality training and can positively influence retention in STEM among students who might otherwise be excluded. As we share the fusion-focused course modules and evaluation summaries with the public, other institutions will be able to adapt these resources without new expenditures, thereby extending our course development outcomes and benefits to additional campuses and communities. Collectively, these outcomes bring impact on society that complement the project's main accomplishments in academia.