Inertial Fusion Energy (IFE) Workforce Development:
Development of a New National IFE Research Consortium (IRC)

Raspberry Simpson[1,2] and G. Jackson Williams[2]

[1]Department of Nuclear Science and Engineering, Massachusetts Institute of Technology, Cambridge USA
[2]Lawrence Livermore National Laboratory, Livermore CA USA

Executive Summary

The record-breaking fusion shot at the National Ignition Facility in August 2021, which was able to produce 1.3 MJ of fusion yield, represents a pivotal moment on our path towards inertial fusion energy and we must invest in innovative educational infrastructure now to harness this excitement for the purpose of recruiting and training the next generation of students, postdoctoral researchers, and early-career scientists. Realizing an inertial fusion energy (IFE) power-plant is a many decades-long project, therefore creating and establishing a pipeline is critical to staff an effort lasting multiple career-generations. In addition, IFE concepts have not yet been down-selected, thus we need a "big tent" of disciplines to capture all the necessary expertise to achieve this enduring goal of net-zero carbon emission fusion energy. Towards this goal, this white paper presents a proposal for a new IFE Research Consortium, which allows for the formal partnerships of universities, private industry and national laboratories including Lawrence Livermore National Laboratory (LLNL). This consortium will aim to address the need of a wider area of disciplines beyond traditional High-Energy-Density Science (HED) and Inertial Confinement Fusion (ICF) education.

Introduction

High-Energy-Density Physics is already a deeply interdisciplinary field, however the inertial fusion energy scientists and engineers of the next generation will need an even wider and more diverse toolbox to meet the challenge of realizing a future IFE power plant. These specific mission needs include:

- Driver Physics (e.g. High-Repetition Laser Development, Pulsed Power, Heavy Ion and Laser-Driven Secondary Sources)
- Targets (e.g. Additive Manufacturing, Manufacturing at Scale, Novel Fabrication)
- Engineering (e.g. Energy Balance of Plant and Materials)
- Public Policy (e.g. Nuclear Non-Proliferation, Climate Initiatives, and Licensing)
- Machine Learning and Artificial Intelligence for Optimization

To address this need, this white paper proposes the formation of an **IFE Research Consortium** that would link together universities, national laboratories and industry in a common goal of promoting research and innovative pedagogy for our evolving work force needs. This proposed IFE Research Consortium is modeled after and inspired by many existing research alliances including the Research University Alliance (RUA), the Nuclear Science and National Security Consortium (NSSC) led by UC Berkeley and the HED Science Center at Lawrence Livermore National Laboratory and Consortium for High Energy Density Science led by UC Merced. In the following sections, we describe central features of the proposed IFE Research Consortium that borrow from these previously mentioned consortia, while adding new dimensions to that are specific to the needs of a robust IFE program.

Research Exchange

The need for diverse skillsets motivates a new approach to graduate and postdoctoral education pertaining to IFE. Currently, each university that comprises core HED educational institutions have expertise typically in 1-2 subject areas relevant to IFE. Therefore, students become experts in this area and may only get exposure to fields outside of their subject-focus through conferences and summer schools. Our community has done a wonderful job creating many HED educational tools and workshops through the University of Michigan HED summer school, HED summer school through University of California, San Diego and HED Courses through LLNL and the University of Rochester. However, the research alliance allows us to take this work one step forward by proposing a formal program for students and postdocs to spend up to 6 months at another university or lab/industry partner to learn an additional research skill. The RUA already implemented a similar program successfully to ensure that students and postdocs can broaden their skillsets and be more effective leaders in their respective fields. The financial support of participating students is a requirement to the success of the IFE consortium. Providing such things as prepaid travel, cost-of-living adjustments, and administrative support reduces personal burdens and facilitates a more inclusionary system to draw a wider pool of applicants. Furthermore, having representation from universities from a variety of states within the Research Consortium, helps demonstrate a national commitment to an IFE program and therefore provide more impetus to provide funding for IFE at higher levels.

Recruitment and Outreach

Outreach, recruitment, and retention must be an essential part of this consortium. Leveraging existing graduate fellowship programs, such as the GEM Fellowship, allows a mechanism to support students to conduct summer internships at national laboratories, universities or in industry. Using the consortium to establish a pool of IFE-related summer projects appropriate for undergraduates and graduate students will be crucial to expose students to this subject area and provide them with the technical skills to pursue enduring careers in the field. There are also a number of student engineering and science conferences that are aimed at undergraduates, including the: Physics Congress Conference, Conferences for Undergraduate Women in Physics, National Society of Black Engineers Convention, Society of Hispanic Professional Engineers Convention, and the Society for Advancement of Chicanos/Hispanics and Native Americans in Science Conference. Coordinating efforts to give talks, expos or staging recruitment booths at these conferences, will be extremely valuable for socializing the concept of IFE among talented junior scientists and engineers and also committing to include students from currently underrepresented backgrounds in HED. To this point, including more community colleges and teaching-focused colleges such as the excellent California State University (CSU) System, in this consortium should also be a key thrust area.

This consortium also allows the ability to be creative in recruitment strategies. For example, the pivot to more virtual work due to the COVID-19 pandemic, potentially allows for these recruitment strategies to reach a broader audience. For example, the implementation of an all-virtual summer school on IFE led by this IFE consortium would be an excellent means to familiarize and recruit students. Furthermore, this ensures that we prioritize access of this type of resource to a wide pool of students that wouldn't otherwise be able to physically attend. In addition, investing in many of the best practices that have been established by APS Division of Plasma Physics Diversity Equity and Inclusion Organizing Committee will be important such that students and early-career researchers feel excited about pursuing long careers within IFE, minimize attrition and demonstrate serious investment in creating a diverse workforce where scientists feel included and like equal stakeholders in our fusion future.

Introduction of New Subject Areas into IFE Education

Chemistry, Material Science, and Engineering - In addition, this new research alliance allows the engagement of new departments and universities that haven't historically been involved in the HED academic community. For instance, since IFE targetry will have to be a major initiative in this field, departments in universities that have strong programs in chemistry, additive manufacturing, nanofabrication and material science, but not necessarily HED or plasma physics, should be invited into this research alliance. Northwestern University is one example since this institution has a strong department in advanced manufacturing, which includes in-house additive manufacturing and nanofabrication laboratories. The consortium should also engage early with industrial leaders with experience in mass production and economies of scale to drive down target costs.

Science Policy and Licensing- Public policy and public engagement will also need to be a key research area for IFE. The magnetic confinement fusion community has begun to look at questions of the regulatory structures needed to bring a real fusion power plant to the grid [1] and the nuclear proliferation implications and safeguard requirements of fusion power plants [2]. Building on this foundation, the IFE community through this alliance can add universities that focus on climate equity, climate action, public policy and energy policy. In this way, this alliance aims to broaden the definition of an IFE scientist and engineer, to include skills that center science communication, science advocacy and lobbying. Some institutions that have robust technology and policy programs that address this need include the Technology and Policy Program (TPP) at the Massachusetts Institute of Technology, the Science, Technology and Public Policy Program at the Belfer Center at Harvard University and the Energy Science and Public Policy Program at Carnegie Mellon University. The science policy subject area also allows for an opportunity to engage LLNL's Center for Global Security Research group, which is already a world leader in technical and public policy work in areas including nuclear non-proliferation.

Machine Learning and Artificial Intelligence – IFE power plants will need to fire at high-repetition rates (~10 Hz) in order to provide the energy output necessary to meet energy demand. This presents the need for a means to distill the copious amounts of data from these types of devices to provide active feedback for power control. Machine learning is a tool poised to both process this large amount of data and optimize the automation of an IFE power plant. Therefore, engaging universities with strong programs in computer science and machine learning will also be important.

Faculty Appointments and Cluster Hiring

One mission of the consortium should be to promote the creation of dedicated IFE programs at universities to support the educational and workforce development needs by committing to hiring a new cohort of junior and mid-career faculty across the universities within the alliance. This portion of the alliance could model existing programs such as the Presidential Postdoctoral Fellowship Program (PPFP), which invites senior graduate students to apply for postdoctoral fellowships at partner universities with the intention that they will be hired on as tenure-track faculty at the end of their postdoctoral appointment. Exchange programs could also be extended to faculty and national lab staff scientists where scientists are able to complete sabbaticals within industry/other national labs or universities. This research exchange program also incentivizes collaboration between multiple institutions rather than competing for similar funding pools. Sponsored programs could be another useful tool, similar to Department of Energy's Research Centers program, guaranteeing long-term (5+ years) funding devoted to kickstarting activities at universities that have historically not participated in IFE research.

Industry Partnerships

This IFE research consortium would be unique among the other research alliances mentioned since there would also be a component to encourage industry partnerships. There are already a number of fusion startups and those may be natural areas for collaboration. However, there are also additional collaborations possible for the complementary technologies that are needed to support an IFE market. For example, to support the need for machine learning algorithms to optimize IFE operation, accelerated hardware will need to be customized for fast inference of models built to optimize fusion production. Companies like Nvidia and Intel are leaders in the development of specialized hardware for machine learning and thus partnership with these companies in this consortium would be tremendously useful for training students. As noted previously, there are many fusion startups in both laser-fusion and magnetic confinement, which presents a landscape where many companies will be competing for students. A primary goal of the IFE consortium is to train students for jobs in for all job classes within the IFE enterprise in government, university, or industry. Close partnership with industry will be key to stay agile and provide students with the skills they need most and can take the form of internships or public-private collaborations. This flexibility in training may allow for more retention in IFE and prevent loss of talent to opportunities outside the field.

Here too, the GEM fellowship stands out as an important model since as part of that program students are funded to complete summer internships at either research institutions or industry. Some examples of industry partners with the GEM fellowship include Intel and therefore this allows an ability to leverage this existing program such that students can engage in industry summer internships involving high-synergy projects that benefit the IFE program. In addition, LLNL's proximity to the Bay Area and Silicon Valley provides a unique opportunity to engage the private technology sector which has familiarity with successfully shepherding high-risk/high-reward technologies. Thus, LLNL is a clear leader in helping bridge this gap between industry and national lab/academic spaces in this proposed IFE Research Consortium.

Building Systemic Equity into our IFE Future

For the last sixty years, the pursuit of fusion energy has provided enduring and complex challenges for the international scientific community. In addition to the technical hurdles involved, an IFE community will be required to address questions of equity in economic and socio-political contexts, such as: how the cost of a fusion reactor may exacerbate existing global energy stratification, how fusion will fit into the global energy market while not engaging in exploitative resource extraction and where fusion power plants are built. These are all impactful questions and are rich research avenues that require dedicated investigation by experts in fields like global security, economics, and energy policy. Therefore, this is a great opportunity to invest in novel research areas in IFE where these socio-political questions are investigated ***in parallel*** to technical endeavors. This may happen by inviting new universities into the research alliance as previously mentioned or connecting with research think-tanks such as the Carnegie Endowment for International Peace and the Women of Color Advancing Peace and Security Collective (WCAPS). In addition, this could also occur by leveraging existing postdoctoral programs that focus on nuclear policy including the Stanton Nuclear Security Fellowship, which allows young leaders to study key nuclear security questions at a host institution. Adding an IFE Consortium member university as a host for the Stanton Nuclear Security Fellowship could be a small first-step towards creating a new IFE Science Equity Research Program.

The nuclear fission community has struggled to reckon with the environmental impacts of the field and how those impacts disproportionally impact communities of color [3]. In this way, that community is assessing the true impact of the industry on Indigenous land use [4], nuclear waste management [5], resource extraction and other issues of environmental racism [6]. In some ways, this history has created some public distrust in nuclear fission technology and therefore has partially impeded new investment in this energy resource [7]. In contrast, the IFE community has the opportunity to lead in this area, by engaging thought leaders now in these key research questions to ensure that systemic equity is *built into* the designs of the IFE plant of our future rather than poorly addressed after the fact. As an example, targets will be a key component of technical research in realizing a new IFE power plant and these targets will need to be utilized in large volumes (~10Hz). A parallel question might be: how does our community design targets to minimize waste, and ensure that the design of these targets take into account the full life-cycle of the product. Another example of a public policy question that might drive the technical side of IFE research is: are microgrids or large-scale traditional power plants better at ensuring the equitable distribution of fusion technology for the global energy market? This too is an area where these types of research questions need to be investigated concurrently to technical pursuits. In fact, there is precedent for this type of work. For example, there is the Space Enabled Research Group at the Massachusetts Institute of Technology led by Professor Danielle Wood, which aims to advance economic and socio-political justice through using the United Nations Sustainable Development Goals to guide technical research questions on the development of space and satellite technology. This also includes investigating the interaction of space-enabled technology and society through an economic justice lens. Making the leap to bring forth a commercial IFE device necessitates the inclusion of a similar research lens.

Summary and Conclusions

The growing excitement in IFE from this record-breaking experiment and the many years of high-quality science by generations of scientists and engineers has generated a unique opportunity for increased momentum for an IFE program in the United States. This moment calls for a paradigm shift in educational infrastructure to support the workforce needs to realize an IFE power plant in the future. This proposed IFE Consortium leverages the existing expertise within the HED community to ensure that sustained investment is made into the next generation of our IFE workforce. It is also the hope that this highly interconnected research consortium will enable an enduring IFE program that is resilient to shifts in funding levels or shifting research priorities while also creating a workforce of highly trained leaders with a high level of diversification in skill sets.

References

[1] R. P. White and K. Shirvan, "Impact of Technology Hazards and Regulatory Methods on Commercial Fusion Development," in *IEEE Transactions on Plasma Science*, vol. 48, no. 6, pp. 1836-1841, June 2020
[2] A. Glaser et al. "Proliferation risks of magnetic fusion energy: clandestine production, covert production and breakout," in *Nuclear Fusion*, vol.52, no.4, pp.43004, 2012
[3] Gabrielle Hecht. Being Nuclear. The MIT Press, 2012.
[4] Traci Brynne Voyles. Wastelanding: Legacies of Uranium mining in Navajo Country. University of Minnesota Press, 2015.
[5] Danielle Endres (2012) Sacred Land or National Sacrifice Zone: The Role of Values in the Yucca Mountain Participation Process, Environmental Communication, 6:3, 328-345,
[6] Robert Bullard. Anatomy of environmental racism and the environmental justice movement. In Confronting Environmental Racism. South End Press, 1993.
[7] A. Abdulla, "Limits to deployment of nuclear power for decarbonization: Insights from public opinion" in *Energy Policy*, vol.129, pp.1339-1346, 2019.