The Post-Industrial Midwest and Appalachia (PIMA) Nuclear Alliance

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Abstract

Led by the Pennsylvania State University a coalition of academia, national laboratories and industry have formed the Post-Industrial Midwest and Appalachia (PIMA) Nuclear Alliance to harness firm carbon-free energy from nuclear while educating and training the future energy workforce. The PIMA Nuclear Alliance will facilitate nuclear research, critical infrastructure, policy, community engagement, education, and workforce development to augment the country's dependency on non-renewable energy resources to more resilient, sustainable, high-capacity sources of energy. Advanced nuclear technologies including microreactors (aka nuclear batteries), small modular reactors and fusion reactors are opening opportunities for non-carbon firm sources of energy that are dispatchable and versatile to meet difficult-to-decarbonize sectors of the economy. From the standpoint of sustainable economic development and a just clean energy transition, nuclear-based technologies offer safe, secure, and reliable energy while abating the impact of fossil fuels to our climate and local regional communities. The long-term vision of the PIMA Nuclear Alliance is the establishment of a technology corridor for manufacturing advanced nuclear microreactors at scale. The goal is to enable a future where 10's to 100's of thousands of reactors are manufactured in the region resulting in a "tera factory" (i.e. 100,000*10MWe = 1 TWe) transforming a high-tech supply chain for advanced reactors in the world. The PIMA Nuclear Alliance has a holistic approach with three primary aims: 1) to establish a research, develoment & deployment (RD&D) microreactor platform for end users and stakeholders to test energy conversion systems to their applications, 2) to engage communities and end users in participatory practices for the adoption of advanced nuclear technologies, and 3) to innovate enabling technologies (e.g. digital twin, advanced manufacturing, AIML,

doi: 10.18278/jcip.3.2.6

etc.), as well as regulatory and policy frameworks to accelerate and scale deployment of advanced reactors in the US and abroad.

Introduction

The impact of climate change and the geopolitical landscape placing greater emphasis on energy security and resilience, requires a broader multi-faceted approach than currently exists for the transition to a carbon-free energy economy. Energy markets are complex and dynamic with changes influenced by multiple factors including policy, global production trends, macro and microeconomic forces, geopolitical conflicts, and many more. One can look at some general trends regarding global energy and electricity consumption. For example, the global final electricity consumption in 2019 reached about 23,000 TWh or roughly a total of about 2.6 TW [1]. Roughly about 80 percent of this electricity is provided by fossil fuel-based sources such as coal and natural gas. Energy transition away from fossil fuels, however, not only consists of reducing carbon emissions from electricity. In the United States, electricity is only one third of total greenhouse gas emissions with the other two thirds coming from industrial processes and transportation [2]. Therefore, energy transition must examine versatile sources of energy that are not only resilient but can be adopted in sectors of the economy that demand large amounts of power such as manufacturing and heavy-duty transportation.

Multiple studies have examined energy transition pathways with many considering a diverse mix of energy sources including renewables (e.g. wind, solar) and nuclear. However, to reach an energy transition that is economically viable when transitioning from fossil fuels, a combination of firm energy sources such as nuclear and carbon capture and storage (CCS) must complement intermittent sources such as solar and wind [3]. In addition, challenges such as battery technology cost and lack of scale, land access, and resilience, make renewable technologies limited to specific energy transition scenarios and may not necessarily provide the firm and sustainable energy sources required for reliable low-cost decarbonization scenarios [4]. Transition strategies from fossil fuels must also consider the current pace of energy demand outpacing carbon-free sources such as renewables. For example, a recent report found a 5 percent rise in electricity demand in 2021 with almost half the increase met by fossil fuels [5]. By 2040, the energy demand in modern nations will grow on average between 20-30 percent. However, energy demand will also be driven by emerging and under-developed economies. This is due to the fact that close to about half of the world population lives in economically vulnerable conditions (e.g. living on average $12-120 per day). As they transition to emerging economies, faster development will be triggered, which, combined with climate change, will cause energy demand to continue growing at non-linear rates [6,7].

Given these factors we find that nuclear technology, would not only need be a part of the energy solution, but a significant one with the promise of a sustainable and resilient source of energy for electricity and other energy sectors, [4,8]. Roughly about 14 TW of reliable energy will be needed by end of this century to keep up with demand, and at the rate of current conventional nuclear fission reactor construction and aggressive renewable and CCS deployment, a shortage of about 8 TW is conceivable [4,9]. There are many examples where advanced nuclear technologies can address important gaps in energy transition towards reliable (e.g. base-load), resilient, and sustainable energy sources. For example, microreactors and small modular reactors could find opportunities in multiple energy sectors including hydrogen generation, water desalination, industrial process heat used in steel or concrete manufacturing, co-generation of district heat and electricity on microgrids, synthetic liquid fuel generation, thermal storage to complement intermittent energy sources such as solar and wind, transportable power units with applications in natural disaster and military applications, and as energy sources for mining and critical mineral extraction from brownfield and former coal sites [4]. These advances will result in a drastic reduction of carbon-free energy costs.

Microreactor technologies can vary from 1MWth (e.g. “MWth” means Megawatt of *thermal* power) to about 40 MWth and small modular reactors (SMRs) are currently being designed in the 60-80 MWe (e.g. “MWe” means Megawatt of *electrical* power) up to 300 MWe range. Similar to SMRs, nuclear fusion reactor technologies with large private capital investments in the last few years, can provide thermonuclear magnetic confinement energy reactors ranging from 100-500 MWe using hydrogen isotopes as fuel with self-sustaining breeding systems and low-level radioactive waste generation [10]. Both SMRs and fusion reactors are considered as options for baseload power to an electric grid with a larger footprint (~ 10 acres) but significantly smaller than conventional nuclear reactors (footprint ~ 640 acres). On the other hand, microreactors are small enough to be manufactured in a factory and transported by truck to the point of use. In fact, their footprint is less than an acre. They can be integrated with other renewable power sources, such as solar or wind power, in microgrids to support communities without access to reliable energy due to location or natural disaster. Their compact size has driven the use of the term of either “nuclear batteries” or “fission batteries” to refer to these small nuclear power reaction systems. They are highly mobile, reliable, with standardized designs that can be factory-produced, can be installed, and operated at any location with limited site development, secure and safe while unattended and autonomously operated, and economically competitive. These characteristics makes it easier to remove after use and can be replaced quickly and relatively cheaply, if needed [11].

PIMA Nuclear Alliance – The Vision

The Pennsylvania State University, a $7B economic powerhouse contributing more than $11.6 billion to the state's economy and supporting, directly and indirectly, more than 105,000 jobs across Pennsylvania in FY 2017 [12] is Pennsylvania's only land-grant university, with 24 commonwealth campuses providing access to training, education, and research to over 88,000 students. Penn State founded the PIMA Nuclear Alliance in May 2022 to address carbon emission reduction goals and energy transition at the regional scale, and bring forth economic development, innovation, and transformation to the region. Penn State has a long history with nuclear technology. Penn State is home to the Breazeale nuclear reactor, a 1MW TRIGA light-water research reactor, that provides a platform for neutron science and technology since the mid-1950's [13]. The PSBR, which first went critical in 1955, is the nation's longest continuously operating university research reactor.

The Alliance goal focuses on a multi-institutional collaboration to support the siting of a microreactor research, development, and deployment (RD&D) platform at the Penn State University Park campus in central Pennsylvania supporting nuclear technology and workforce development as well as maturing the technical and societal readiness levels of advanced nuclear reactors. The Alliance will actively include local and regional colleges and universities and make sure that they have prominent roles, not just from a research perspective, but also from training the next generation workforce in nuclear technology. Training will focus on the current and future workforce generation across the heartland of America providing new skills, high-paying jobs, and careers that can sustain the economic growth of these communities. The alliance will also engage with other green-tech initiatives and look for effective synergies.

The vision of the PIMA Nuclear Alliance is a transformational change to the region, mitigating the climate crisis and fostering economic development by introducing micronuclear reactors across difficult-to-decarbonize industrial sectors enabling a sustainable, just, and resilient clean energy transition in the PIMA region at scale. Penn State with its 24 commonwealth campuses throughout Pennsylvania serves as an important demonstration hub for advanced nuclear technology supporting research, development, deployment, and community economic development. With large and diverse urban centers in Philadelphia and Pittsburgh and a rural population in between, Pennsylvania is a microcosm of the US and an ideal setting to establish a holistic approach at research, development, and deployment of advanced nuclear with our strategic university partners across the Midwest and greater Appalachia in the PIMA Nuclear Alliance. These partnerships will be supported with strategic National Laboratory and industrial partners providing for an advanced nuclear battery development ecosystem.

In addition, this initiative is envisioned to seed and nurture a robust domestic supply chain of nuclear and advanced materials technology in the greater Appalachia region and the post-industrial Midwest. The PIMA Nuclear Alliance will bring emergent technologies in additive and advanced manufacturing of conventional and novel materials, digital innovation, advanced computing, and combine multi-disciplinary and transdisciplinary collaborations leveraging initiatives in law, policy, and technology interfaces. The vision of the PIMA Nuclear Alliance is a collective effort with rural, micro-urban, and urban communities in the region empowered to support the energy transition with the goal to drastically reduce carbon-free energy costs in difficult to decarbonize sectors, helping support advanced manufacturing of microreactors at scale, leading to a truly transformative change for how we power society.

The PIMA Nuclear Alliance has strong support from the leadership at Penn State. For example, Lora Weiss, Senor Vice President for Research, recently stated that "The breadth of the PIMA Nuclear Alliance speaks to the critical role it is filling as we explore how to efficiently power our future — literally and figuratively." She went on to state "With trailblazing experts, state-of-the-art facilities and a strong community in varied environments across the Commonwealth, Penn State is well situated to both understand the challenges of developing sustainable energy and lead the innovations needed to solve them [14]." In addition to support from the Penn State University leadership, the PIMA Nuclear Alliance receives support from a diverse and broad collective of departments, colleges, and institutes, including the College of Engineering; Smeal College of Business; the College of Earth and Mineral Sciences; the Materials Research Institute; the Institute of Computational and Data Sciences; the Social Science Research Institute; the Center for Energy Law and Policy; the Law, Policy and Engineering initiative; the Radiation Science and Engineering Center which houses the Breazeale Nuclear Reactor; Pennsylvania Technical Assistance Program; the Office of the Senior Vice President for Research, and the Office of Physical Plant, which recently supported a Carbon Emissions Reduction Task Force and published a report in December 2021 on carbon net zero strategies for Penn State University [15].

PIMA Nuclear Alliance is also a diverse collective of institutions and organizations. Alliance members include foundational partners University of Michigan Nuclear Engineering and Radiological Sciences, University of Tennessee at Knoxville, and the Westinghouse Electric Company. Additional partners include Pennsylvania College of Technology, Idaho National Laboratory, Los Alamos National Laboratory, Argonne National Laboratory, Sandia National Laboratories, Oak Ridge National Laboratory, Morgan Advanced Materials, Pittsburgh Technical, Energy Driven Technologies, and Reuter Stokes. Faculty from University of Central Florida, California Polytechnic State University, West Virginia State University, and Cornell University are also participating.

These collective efforts are anticipated to accelerate technology adoption and provide the framework for similar transitions across the U.S. and the world. Transformation of these regions means leveraging nuclear technology with microreactors to generate hydrogen, decarbonize steel and concrete factories, food processing, and innovate ways to provide green energy to high-value critical mineral extraction from coal [16]. In addition, microreactors will be designed to innovatively couple to renewal or other advanced reactor technologies (e.g. small modular reactors, compact fusion reactors, etc..) for optimum resilience and an environmentally just energy transition.

Recent developments from both the federal and private sectors are providing opportunities for initiatives that support advanced nuclear reactor development and deployment. For example, the Department of Energy's Advanced Reactor Demonstration Program and the privately funded Breakthrough Energy Ventures are both investing hundreds of millions of dollars into advanced nuclear development and energy innovation at scale. Penn State University is in a unique position with several potential venture firms and industry partners that have interest in advanced nuclear technology and deployment in the PIMA region.

A result of a strategic private-public partnership has been the Penn State and Westinghouse collaboration on research and development efforts focused on exploring and applying nuclear engineering and science innovations to societal needs. A memorandum of understanding detailing the partnership — the first one between Westinghouse and a university in the United States — was signed at Westinghouse's headquarters in Cranberry on May 18, 2022. The partnership entails exploring the siting of Westinghouse's eVinci micro-reactor, a next-generation, small modular reactor designed to address sustainable power needs from immediate use in large communities to decentralized remote applications, at University Park. The current focus is a RD&D platform as discussed earlier with the long-term goal of supporting Westinghouse in deployment of first-of-a-kind (FOAK) units that could be adopted as an alternate energy source of heat to the campus.

Both Penn State and Westinghouse have a long history and significant experience in the realm of nuclear energy: Penn State houses the Penn State Breazeale Reactor — the longest continuously operating research nuclear reactor in the United States — and Westinghouse established the first commercial nuclear reactor in the country. Both are uniquely positioned to cultivate microreactor technology to provide safe and sustainable energy. Westinghouse, with a 130-year history distributing electricity, produced the country's first commercial reactor in Shippingport in 1957, just two years after Breazeale reached full power. Now, Westinghouse has established and helps oversee more than 430 nuclear reactors around the world.

Penn State and Westinghouse share a common vision for the potential of micro-reactors to revolutionize industry and energy globally, micro-reactors are smaller and safer than conventional reactors (note: conventional nuclear reactors are extremely safe) since they produce less power, require less fuel, and have fewer moveable parts. The eVinci micro-reactor can produce sustainable carbon-free energy and integrate with other renewable power sources, such as solar or wind power. It is also small enough for factory fabrication and truck transportation, meaning it can be built and implemented to support communities without access to reliable energy due to location or natural disaster. Its compact size minimizes the physical footprint and allows for construction and installation in as few as 30 days. "eVinci is a game-changing nuclear battery that can play a critical role in reducing the carbon intensity of the global energy sector," said Mike Shaqqo, Senior Vice President of Advanced Reactors at Westinghouse. "Westinghouse and Penn State share a long history of leadership in the nuclear industry and will build on that legacy through this program."

Penn State will leverage its established nuclear capabilities — such as the Breazeale reactor, multi- and interdisciplinary experts in power conversion systems, thermal hydraulics, detection and safeguards, high-temperature nuclear materials, advanced manufacturing, nuclear energy policy, nuclear safety, technology adoption and community engagement, and more. The aim is to support basic and translational research development to establish a micro nuclear reactor prototype platform to drive technology advances and support wide adoption and deployment of advanced nuclear technologies in the PIMA region and across the country in a safe and sustainable way. In addition to advancing the eVinci micro-reactor for broad applications, the team plans to explore how the platform can contribute to displacing carbon-generating energy sources at Penn State.

"Such a platform for research and development would help establish a clean technology corridor in Pennsylvania and beyond, as well as help strategically position our teams to partner with experts across the University in multi- and interdisciplinary scientific fields, as well as in social sciences, business and law on focused projects supporting micro nuclear reactor study and deployment," said Geanie Umberger, associate vice president for research and director of industry research collaborations at Penn State,

The Penn State College of Engineering, Office of the Senior Vice President for Research, the Office of the Physical Plant, among others, will be deeply involved in preliminary discussions with Westinghouse about the feasibility of siting the eVinci micro-reactor at University Park, including potential locations. The micro-reactor platform would be subject to all federal safety rules and reviews by the U.S. Nuclear Regulatory Commission, from approving the safety and operations plans and design to conducting regular inspections. The Penn State Breazeale Nuclear Reactor, which has been in operation at University Park since 1955, underwent the same initial approval process — although the regulations have evolved over the last 67 years — and now receives regular reviews to ensure compliance with modern standards.

The role universities can play in the deployment and adoption of advanced nuclear technologies cannot be overstated. Universities such as Penn State have significant expertise in many of the emerging technologies supporting advanced nuclear such as novel materials, advanced manufacturing, and digital innovation. Land grant universities also have beyond their mission of education and research, their role in economic development of the region. It is on this premise that the PIMA Nuclear Alliance was established.

Recently multiple efforts are aimed at establish R&D platforms and the siting of advanced nuclear (i.e. microreactors or small modular reactors either on campus or in the region) including University of Illinois, Purdue University, Abilene Christian University, and several others [17]. The collective efforts of these universities is of critical importance to regional deployment of advanced nuclear technology, its adoption, and public acceptance as efforts to continue to communicate the benefits of microreactors to energy transition demands. The hope of the PIMA Nuclear Alliance is that multiple consortia support deployment of microreactor technologies. The ingalliance is focused on an overall strategy and plan summarized in the next section.

PIMA Nuclear Alliance – The Plan

The first phase of the initiative will focus on: (1) energy market evaluation in the region for microreactors from industrial processes to other applications, (2) engagement with community, nonprofits, and local government stakeholders, (3) expanding industry and academia partners to our alliance and, (4) flesh out the details of the research platform at Penn State addressing the needs of all our partners. These activities will also help to establish strategic partnerships with key players leveraging major government and private sector financing to establish the RD&D platform, technology deployment strategies, and ultimately help support the establishment of a global technology corridor supply chain for advanced reactor high-volume manufacturing in the PIMA region. Penn State along with their academic partners will also help establish new nuclear engineering programs in the region and collaboratively support workforce development jointly with industry and local governments. This will help sustain a resilient microreactor "Tera" factory (i.e. 100,000*10Mwe ~ 1 TWe) vision for the PIMA region described earlier.

The plan is illustrated in Fig. 1 showing a technology roadmap supporting development of a FOAK design collaborating with Westinghouse and in parallel supporting the design of a RD&D platform. Collaborations among PIMA Nuclear Alliance members would focus on de-risking RD&D platform design and certain aspects of a FOAK. Ultimately the RD&D platform will benefit NOAK (nth-of-a-kind) microreactor designs when cost and scale play a critical role in market adoption. The roadmap in Fig. 1 also illustrates collaborative translational research by alliance members across multiple technical areas including but not limited to advanced power conversion systems, molten salt reactor technology, advanced detection and safeguards, high-temperature nuclear materials, advanced manufacturing of high-temperature components, nuclear energy policy and regulatory innovation, social adoption of nuclear technology and many more.

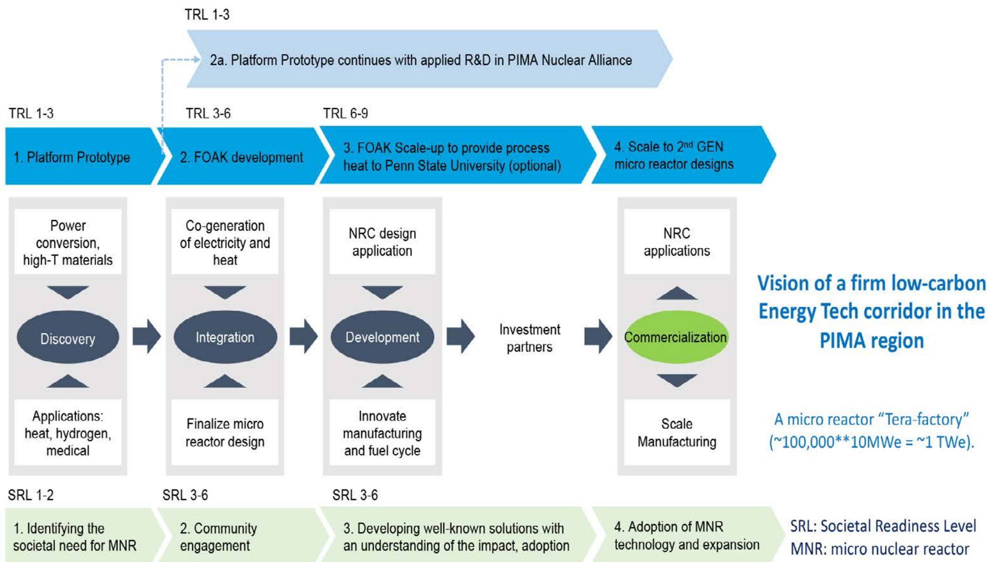

Figure 1: Vision for strategy of a microreactor RD&D platform at Penn State University. A technology roadmap that links enabling technologies such as advanced manufacturing to scale microreactor deployment.

Fig. 2 illustrates the diversity of expertise leveraged at Penn State University from its multi-disciplinary institutes. For example, scientists from the Social Sciences Research Institute (SSRI) would work closely with those from the Institute of Computing and Data Sciences (ICDS) developing enabling technologies such as virtual reality tools to communicate how microreactors work to regional communities.

The PIMA Nuclear Alliance plan has three major goals:

1. To support basic and translational research development in a nuclear battery prototype platform enabling use for licensing, testing, and validation. The prototype platform will provide modular connections to enable study of applications of process heat (e.g., hydrogen generation and low-carbon concrete) and neutron irradiation (e.g., medical isotope production and high temperature materials testing). It will bring both technical and non-technical experts to study all aspects of advanced nuclear technology adoption in the Midwest and greater Appalachia region. Focus areas will include supporting a resilient and "green" mining value chain, high-value critical mineral extraction from coal, carbon-based advanced materials, co-generation, hydrogen generation, medical radioisotope fabrication, industrial and district heating, and renewable energy resilience.

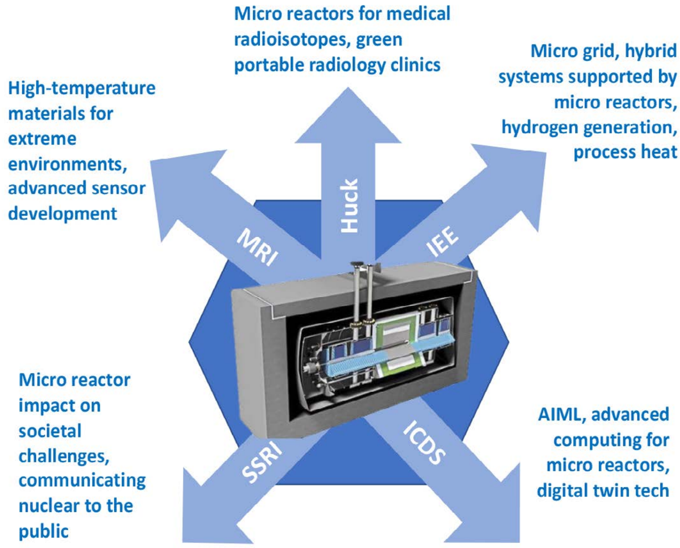

Figure 2: Research areas enabled by microreactor RD&D technology platform at Penn State leveraging PSU multi-disciplinary institutes.

2. To support development and siting of eVinci micronuclear reactor First-of-a-kind (FOAK) deployed on the Penn State University campus that can supply district heating; and other advanced nuclear technologies in the long-term.

3. To leverage development and innovation in #1 and #2 to develop n-th generation nuclear battery technologies that can scale massively with innovative manufacturing for a variety of energy-intense applications (e.g. terawatt-factory).

The alliance also supports bridge programs to provide K-12 and beyond students an affordable, achievable path to obtain education and training in nuclear engineering and science, such as non-traditional models for students unable to reside at University Park to still obtain their degrees in nuclear engineering. This initiative is supported via the Nuclear Sustainability Fund, which was established by the Penn State Nuclear Engineering Alumni Society.

Although the PIMA Nuclear Alliance was established in October 2020 during the pandemic, the collective work of collaborating members began in June 2022 (see the PIMA NA website: https://sites.psu.edu/pima/). The PIMA Nuclear Alliance kickoff workshop took place at the University Park campus in the Invent Penn State Innovation hub, which more than 60 participants from multiple universities and national laboratories attended. The PIMA Nuclear Alliance was highlighted at the Clean Energy Ministerial in Pittsburgh, PA in September 2022 The second workshop was held Oct. 4-5, 2022 in Pittsburgh at the Westinghouse headquarters and included a tour of the eVinci microreactor facilities at Waltz Mill. Attendees included several potential microreactor end users, including oil and gas company NOV and the Saskatchewan Research Council, among others.

Engaging PIMA Communities

The PIMA Nuclear Alliance strategically positions technology teams to collaborate with experts in social sciences, business, policy, and law on focused projects supporting microreactor study and deployment. These teams are organized in working group committees as shown in Fig. 3 and engage together at the PIMA NA series of workshops. Through the Law, Policy, and Engineering initiative at Penn State, a collaborative effort between the College of Engineering, Penn State Law, and the School of International Affairs, the regulatory and policy frameworks of advanced nuclear, as well as the societal effects of technology adoption and impact on communities, are explored.

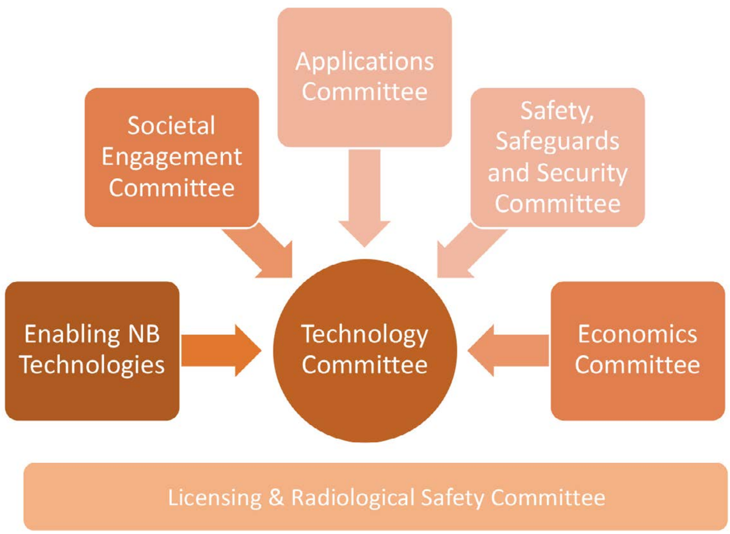

Figure 3: The PIMA Nuclear Alliance plan includes working group committees made up of faculty experts from multiple universities and national laboratories developing working project plans.

"There is a growing interest in engineering amongst young people in disenfranchised communities across this region that are looking for ways to address the urban-rural divide that has been a reality in their lives for a long time," said Aditi Verma, Assistant Professor of Nuclear Engineering and Radiological Sciences at the University of Michigan and PIMA member. "They have seen how many places in Appalachia and the Midwest have been adversely impacted by resource extraction to satisfy the energy appetite of urban America. There is now an opportunity to pursue firm, low-carbon energy generation with nuclear as a potentially viable, scalable, and reliable source of energy. Through the work of the PIMA Nuclear Alliance, we will seek to explore and demonstrate not just the technical but also the social and environmental viability of nuclear as a source of energy for this region through direct engagement with communities. This collaboration with the University of Michigan also leverages their initiative known as Fastest Path to Zero.

Developing better understanding of industries in the region that can benefit from advanced nuclear technology, such as nuclear batteries, and the needs of the region's communities is just as important as developing the technology, Community participation and engagement are at the forefront of the PIMA Nuclear Alliance. Microreactors have the potential to transform communities and spur job creation and economic development in the region. For microreactors to succeed, the regulatory and policy frameworks must evolve in tandem with the technological advancements. Comprehensive outreach and participatory frameworks in all these realms, accompanied by effective communication channels and supporting social infrastructure, is critical for communities to adopt these technologies and reap the benefits.

A great example of the impact micronuclear technology could have on a community is the city of New Kensington, PA. New Kensington in Westmoreland County is 15 miles NE of Pittsburgh, and the city is considered part of the Pittsburgh metropolitan area. It was founded in 1891 and has a population of 12,052 of which 23% live below poverty level according to the 2017 US Census Bureau. New Kensington is witnessing a resurgence in manufacturing and digital innovation that is transforming the community. In 2022 Penn State New Kensington's Digital Foundry was named one of four new Smart Manufacturing Innovation Centers (SMICs) by the U.S. Department of Energy (DOE) in partnership with the CESMII, the Smart Manufacturing Institute. One goal of the Alliance is to immerse itself in community action in the PIMA regions to find out how micronuclear reactors and advanced nuclear, as well as its supply chain, can transform industries and create not only jobs, but sustained, equitable, and resilient economic development and environmental justice. This is the reason the Alliance chose to have their third and most recent workshop on December 8-9, 2022, at the PSU New Kensington's Digital Foundry innovation space directed by Sherri McCleary. The PIMA workshop in New Kensington was impactful to see and learn about the history of the city that went from steel glory to abandoned town and is now on the rise gaining traction as a manufacturing hub.

New Kensington is witnessing a resurgence in manufacturing and digital innovation that is transforming the community. The desire of the PIMA Nuclear Alliance is immersed in community action in the PIMA regions to find out how micro nuclear reactors and advanced nuclear engineering can transform industries and create not only jobs, but sustained and resilient economic development. "We are excited to welcome PIMA and our University colleagues to New Kensington," said Kevin Snider, chancellor of Penn State New Kensington. "The goals and mission of PIMA in relation to workforce development, sustainability, education and use of cutting-edge technologies align with the vision of our future-ready initiatives, including the Digital Foundry, and we look forward to learning more during the event and being part of discussions on continued partnership." Working closely with partners such as PSU New Kensington, engaging and listening to communities, and working with potential local end users of advanced nuclear technology is precisely what the PIMA Nuclear Alliance is all about. Enabling pathways for adoption of nuclear technology as their manufacturing will create more resilient and sustainable jobs that support energy transition.

Author Capsule Bios

Jean-Paul Allain is Professor and Department Head of the Ken and Mary Alice Lindquist Department of Nuclear Engineering at Pennsylvania State University. He was Professor and Associate Head of Graduate Programs in the Department of Nuclear, Plasma and Radiological Engineering at the University of Illinois at Urbana-Champaign (UIUC) from 2013 until 2019 and was Assistant and Associate Professor in Nuclear Engineering at Purdue University from 2007 to 2013. Dr. Allain was also a staff scientist at Argonne National Laboratory from 2003 to 2007. He received a master's and a doctorate in Nuclear Engineering from UIUC and a B.S. degree in Mechanical Engineering from Cal Poly Pomona. He works in areas of surface science and plasma-material interactions with applications in nuclear fusion, plasma medicine, and advanced nanomaterials. Dr. Allain is the recipient of Argonne National Laboratory's Distinguished Award from 2003 to 2006, Best Teacher Awards in 2008 at Purdue and 2013 at Illinois, Department of Energy Early Career Award in 2010, Purdue Research Excellence Award in 2011, the Fulbright Scholar Award in 2015, Faculty Entrepreneurial Fellow in 2016, Grainger Engineering Dean's Excellence in Research Award in 2017 at Illinois, and the 2018 American Nuclear Society Fusion Energy Division Technology Accomplishment Award.

Sandra Allain is Professor of Practice in the Penn State School of Engineering Design, Technology and Professional Programs (SEDTAPP) in the College of Engineering and the School of International Affairs, Lecturer in Law at Penn State Law, and an affiliate of the Sustainability Institute at Penn State. She is Inaugural Director of the Law, Policy, and Engineering initiative (LPE), and the Design, Justice, & Sustainable Development Lab (DJSD). She has worked in higher education since 2007 in various roles including in-house counsel, tech transfer and innovation, global programs, international partnerships and business development. She has over 15 years experience as a practicing attorney in intellectual property and technology transfer in both private practice and as in-house counsel, including in the Office of University Counsel at the University of Illinois. Her research interests include innovation ecosystems, interdisciplinarity, the UN Sustainable Development Goals, public interest technology, legal design, civic tech, and participatory policy-making. She holds a LL.B. Law Degree form Universidad del Rosario, Colombia; an M.Ed. from the University of Illinois at Urbana-Champaign.

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