TRI-CEA: Harnessing Controlled Environment Agriculture to Secure Sustainability and Economic Growth

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PI (Lead): Jingjing Wang, Award 2418345
Co-PI: Yolanda Lin
Co-PI: David Hanson
University of New Mexico (NM)
Co-PI: Stephen Gomez, Subawardee (Award 2418345)
Santa Fe Community College (NM)

PI: Kevin Lombard, Award 2418348
New Mexico State University (NM)

PI: Meghann Jarchow, Award 2418346
University of South Dakota (SD)

PI: Carmela Guadagno, 2418347
University of Wyoming (WY)

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1. Overview

The TRI-CEA project (NSF Award ID: 2418345) is a Focused EPSCoR Collaboration (FEC) designed to advance Controlled Environment Agriculture (CEA) as a pathway toward secure food systems, enhanced community resilience, and economic development, especially in rural communities.

Our vision is to advance the scientific understanding and socioeconomic application of CEA as a transformative strategy to foster long-term community resilience. By exploring different dimensions of CEA —from community gardens to precision-controlled greenhouses—we strive to develop scalable solutions that empower rural communities to adapt to diverse challenges while ensuring food security and economic growth. Through cutting-edge research and innovative technology, we aim to identify best management practices, create innovative educational pathways to train a skilled CEA workforce, and equip rural communities with the tools needed to thrive in the face of unpredictable events.

TRI-CEA brings together cross-disciplinary teams from the University of New Mexico (UNM), University of South Dakota (USD), University of Wyoming (UW), New Mexico State University (NMSU), and Santa Fe Community College (SFCC), collaborating on three interrelated research thrusts:

- Objective 1: Advancing Fundamental Science of CEA – Deepening our understanding of the fundamental biological and environmental dynamics that drive successful CEA systems.
- Objective 2: Assessing Socioeconomic Impacts of CEA – Investigating how CEA systems are perceived by rural communities and evaluating their potential social, economic, and environmental impacts.
- Objective 3: Workforce Development – Designing and implementing curricula and pathways that equip a highly skilled workforce to advance CEA practices, particularly in ways that create business and employment opportunities for rural populations.

Together, these goals position TRI-CEA to make contributions to the national field of CEA research while directly benefiting the EPSCoR jurisdictions involved. The team's convergent approach integrates natural science, engineering, and socioeconomics to improve system performance, community alignment, and workforce readiness. TRI-CEA will be both a research catalyst and an innovation engine rooted in local priorities.

2. Executive Summary

Year 1 of TRI-CEA laid the groundwork for a cross-institutional and cross-disciplinary collaborative research program, focused on expanding controlled environment agriculture (CEA) across three EPSCoR jurisdictions. Despite delays tied to hiring freezes, funding uncertainty, and institutional processes, the project progressed meaningfully toward nearly all Year 1 goals across its biophysics, socioeconomics, and workforce development threads.

Figure 1 Hydroponic System Demonstration, All Hands Meeting, February 2025. Michael Baldwin, a GrowBig consultant contracted by University of Wyoming, demonstrates a Deep Water Culture (DWC) system for participants at the All Hands Meeting. The hydroponic system is being demonstrated at the greenhouse testbed of the Controlled Environment Agriculture program in the School of Trades, Advanced Technologies and Sustainability, Santa Fe Community College (NM).

A major milestone was the successful in-person All-Hands Meeting held February 13–14, 2025, at Santa Fe Community College, with 22 attendees: 10 faculty/researchers, 7 students, and 5 other staff members from the five collaborating institutions. The event supported critical relationship-building, project clarification, and planning for Year 2. According to the external evaluator, 83% of participants rated the meeting 5 stars, and all attendees reported meaningful new connections, especially around student internships, local engagement, and shared modeling tools.

Across the project, more than a dozen undergraduate and graduate students were directly engaged in research, internships, or initial micro-credential programing. These included interns at NMSU's Farmington site, students developing optimization models at UNM and SFCC, students helping draft survey instruments and conduct literature reviews at UW and USD, and SFCC CEA students evaluated for Bioscience Core Skills Institute (BCSI) micro-credentials.

Collaboration and community engagement were also core strengths in Year 1. EDOCS records show at least 15 formally logged external collaborations, including rural organizations (e.g., Sinte Gleska University, Wind River Food Sovereignty Project), high schools, and technical colleges. These relationships supported listening sessions, articulation discussions, and local system planning.

TRI-CEA's Advisory Board, composed of six experts in traditional agriculture, commercial hydroponics, plant science, epidemiology, and technical education, is scheduled to convene for the first time on June 2, 2025. Their insights will inform Year 2 planning, including priorities for student support and external engagement.

To ensure engaged collaboration, TRI-CEA:

- Built systems at SFCC and initiated procurement at UW, NMSU, and UNM for hydroponics research.
- Held informal and semi-structured listening sessions with partners in SD, NM, and WY.
- Integrated traditional food systems and sustainability perspectives into research framing.
- Developed microcredentials, training SOPs, and credential evaluator capacity.
- Coordinated cross-institutional internship and mentorship activities.
- Hosted the All-Hands Meeting for demonstration, planning, and team building.

For example, in South Dakota, the team worked with the Sicangu Lakota community to conduct a listening session that identified affordability, access, and traditional food values as top food system concerns. These findings are now informing socio-economic modeling and outreach planning.

At SFCC, faculty created a microcredential pathway embedded in its AAS degree and piloted laboratory-based assessments, while staff at NMSU will supervise interns through the Farmington greenhouse site—including a senior from Navajo Prep and a student through the Shiprock Workforce Development Center.

The All-Hands Meeting provided a venue for cross-site demonstration and training, helping new staff and students understand the vision and tools of the program and generating new cross-jurisdictional partnerships.

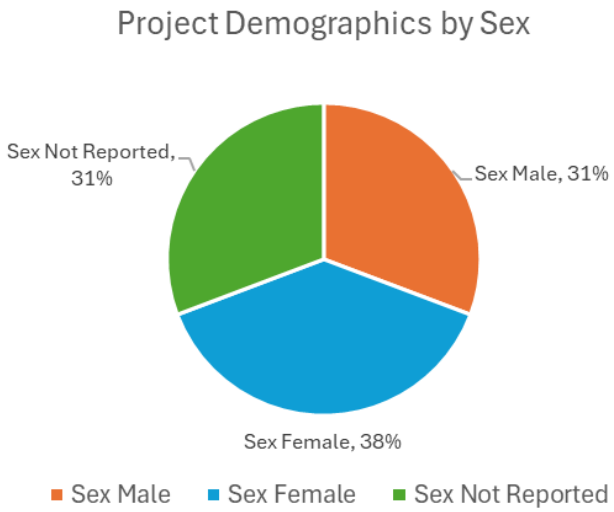
Looking ahead to the summer months (within the current program year), two TRI-CEA institutions—University of New Mexico and University of Wyoming—will launch coordinated summer programs to extend hands-on training and research opportunities for student participants.

At UNM, a free Introduction to CEA Workshop will offer student participants stipends and the opportunity to learn hydroponics techniques, build environmental sensors, and contribute to installations at TRI-CEA sites. The workshop includes both classroom and field-based activities, with sessions held at UNM and regional farm sites.

At UW, the AGRI4990 Principles and Applications of Controlled Environment Agriculture course will serve as a cross-disciplinary summer program for students from UW and regional community colleges. The course combines lectures from UW faculty and industry professionals with lab-based training in CEA deployment and management. Participants will earn academic credit and a stipend, with access to internships and future project involvement.

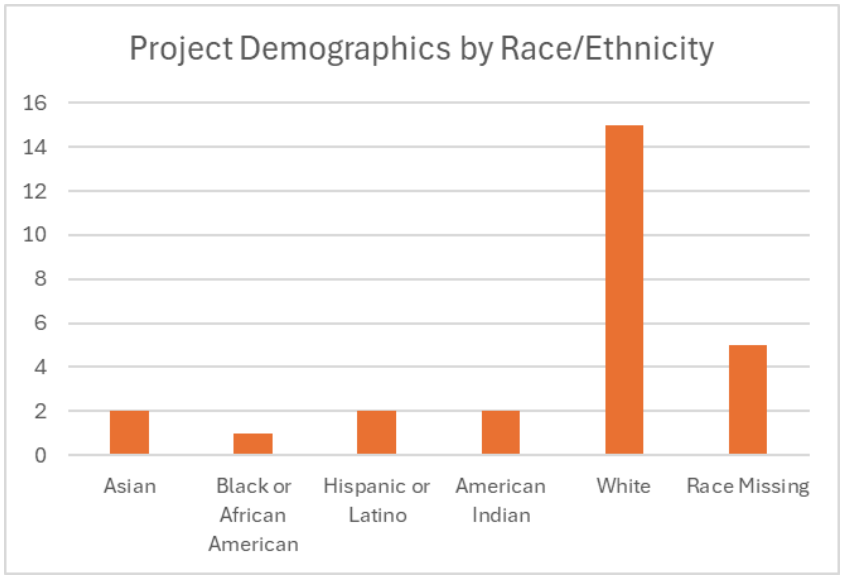
At SFCC during the summer semester, 2 student employees and 4 student interns will be operating and maintaining the TRI-CEA systems in the greenhouse and a visiting graduate student is collecting data for his Master's thesis. SFCC Faculty will deliver and assemble up to 3 replicate hydroponic systems for NMSU's Farmington campus.

Figure 2. Project Demographics by Sex



Note: Demographic data are self-reported in the EDOCS system. Where there were fewer than 2 participants in a role at an institution, demographic information is not available. For instance, project PIs are not reflected in the chart above.

Figure 3. Project Demographics by Race/Ethnicity



Note: Demographic data are self-reported in the EDOCS system. Where there were fewer than 2 participants in a role at an institution, demographic information is not available so totals will not equal total participants in TRI-CEA.

3. Research

The TRI-CEA research threads reflect a comprehensive, interdisciplinary approach to designing and scaling controlled environment agriculture solutions in and with rural

communities. While each research objective has specific institutional leads and deliverables, the project has prioritized coordination across threads. This integration ensures that technology deployment is both socioeconomically relevant and workforce-supported.

The first year of project activity also unfolded under an unusual degree of uncertainty around the continuation of federal research funding. This uncertainty directly impacted hiring timelines at every participating institution, resulting in delayed staff onboarding and slowed progress on several planned system developments and deployments. Despite these disruptions, collaborating teams worked diligently to maintain continuity of effort. Nearly all Year 1 activities—across research, workforce development, and socio-economic integration—are expected to be completed by the end of the program year (August 31, 2025).

3.1 Objective 1: Advancing Fundamental Science of CEA

The Biophysics thread in Year 1 emphasized coordinated infrastructure deployment, SOP development, and early experimental design across jurisdictions. The team focused on standardizing growing conditions and system protocols to enable collaborative pilot trials comparing deep water culture (DWC) and nutrient film technique (NFT) hydroponics systems, with red Russian kale (*Brassica napus* var. pabularia) selected as the common research crop.

Strategic Activities and Progress:

- **1.1.1 Feasibility Assessment:** Assessment is ongoing; systems built at SFCC and procurement supported at UW, NMSU, and UNM.
- **1.1.2 System Deployment:** SFCC systems operational; other sites have systems ordered or partially deployed. Seeding has started.
- **1.2.3 / 1.3.1 Pilot Experiments:** SOPs for seedling production are in progress. Initial NFT experiments launched to generate data and finalize protocols.
- **1.1.2 Training & Support:** Training support planned by SFCC; inter-site SOP coordination under development.

Table 1. Objective 1 Strategic Activities and Progress

Objective / Activity	Strategic Plan Task	Year 1 Progress

1.1.1 Feasibility assessment	Conduct feasibility assessment and market analysis for hydroponic systems	Assessment is ongoing; systems built at SFCC and procurement supported at UW, NMSU, and UNM.
1.1.2 System deployment	Procure, build, and pilot NFT and DWC systems	SFCC systems operational; other sites have systems ordered or partially deployed. Seeding has started.
1.2.3/1.3.1 Pilot experiments	Develop SOPs and run pilot experiments	Seedling production SOP in progress. Initial NFT experiments launched to generate data and finalize protocols.
1.1.2 Training & support	Coordinate training and deployment across institutions	Training support planned by SFCC and others; inter-site collaboration under development.

At SFCC, four systems were assembled early in the year, enabling the first trials and SOP pilots for seedling production, nutrient monitoring, and training video development. Faculty worked with a GrowBig consultant (Michael Baldwin) to troubleshoot design issues, ensure consistent environmental parameters, and develop reproducible processes for deployment. Charlie Shultz and his team at SFCC are now preparing to train other institutional partners in setup and system management.

Procurement and shipping continued into spring at UW, NMSU, and UNM. UW purchased five systems—four for their own use and one for NMSU—while SFCC and Shultz coordinated parts purchases for faculty at UNM. All institutions agreed to only use natural sunlight for these experiments, avoiding artificial lighting due to potential effects on microbial communities. Seeding began at SFCC in late spring with projected harvest and data collection to begin by June. UW, SFCC, and NMSU will seed shortly thereafter, aiming to generate cross-site comparative data on yield, morphology, and nutrient content.

Environmental sensor monitoring, coordinated by faculty at UNM and UW, was a major focus of preliminary planning. Institutions compiled greenhouse environment profiles (temperature, pH, light, airflow), and began developing a shared plan for integrating canopy-level and water-quality sensors. These include Bluelab controllers and

open-source microcontrollers (e.g., for pH, EC, temperature, DO), with data collection standardized across sites. Each greenhouse site is recording environmental constraints and will use the data to contextualize yield and microbe analyses.

In parallel, UW began developing a multimodal plant phenotyping platform (oQulus), which will deploy in 2025 as part of the long-term collaboration. This platform includes fluorescence imaging, thermal sensing, and 3D canopy reconstruction. It will support downstream CEA studies in productivity, stress detection, and plant response modeling. UW also conducted trials on substrate performance, comparing peat-based media and calcined clay, and supported student-led studies on light spectra and photosynthetic efficiency.

Figure 4. Carmela Guadagno (UW) and Dave Hanson (UNM) met in person for the first time at the All Hands Meeting (February, Santa Fe, NM). Touring and discussing research plans at the indoor CEA facilities at Desert Verde Farms (founded by SFCC CEA alumni) deepened their collaboration.

While microbial community work was deferred to Years 2–4, several institutions began outlining protocols for microbial sampling, in partnership with Dr. Weinig's lab at UW. The team expects to pilot those protocols in late summer alongside plant harvests. Ultimately, the biophysics group aims to generate a shared dataset on growth, nutrient yield, and environmental context to inform both plant physiology models and socioeconomic system dynamics models across threads.

3.2 Objective 2: Improve the socio-environmental-economic understanding of CEA

The Socioeconomics thread advanced stakeholder engagement, community-informed research design, and planning for modeling and focus groups. Several institutions initiated literature reviews and informal listening sessions. UW and NMSU engaged with partners through ongoing collaborations.

Strategic Activities and Progress:

- **2.1.1 Listening Sessions:** Conducted informally at UW; formal IRB planning ongoing.
- **2.3.1 Modeling Framework:** Initial system dynamics model introduced; interdisciplinary integration discussions began.
- **2.3.2 / 2.4.1 Data & Policy Review:** Ongoing across institutions; focused on Navajo Nation and existing public data.
- **2.4.1 Regulatory Scan:** Initial documentation started; formal processes to continue into Year 2.

Table 2. Objective 2 Strategic Activities and Progress

Objective / Activity	Strategic Plan Task	Year 1 Progress
2.1.1 Listening sessions	Hold listening sessions and informal conversations with partners	Conducted informally at UW and NMSU; formal IRB planning ongoing.
2.3.1 Modeling framework	Develop general modeling framework	Initial framework presented and discussed; integration with other thrusts in planning.
2.3.2/2.4.1 Data & Policy Review	Conduct literature review and data compilation	Ongoing across institutions; focused on Navajo Nation and existing public data.
2.4.1 Regulatory scan	Document regulatory and policy frameworks	Initial documentation started; formal processes to continue into Year 2.

Stakeholder Engagement and Listening Sessions:

Multiple informal community engagement efforts took place across jurisdictions,

particularly through the University of South Dakota (USD), and the University of Wyoming (UW). USD held a listening session on the Rosebud Reservation in collaboration with the Boys and Girls Club of Rosebud, where project staff and graduate student Glen Marshall gathered insights on community food preferences, barriers to access, and values related to local food production. Affordability, traditional knowledge, distance to suppliers, and youth engagement emerged as key themes. Mr. Marshall's project received IRB approval from the Rosebud Higher Education Research Review Board (HERRB) board in March 2025.

At UW, faculty including Jill Keith participated in ongoing community conversations with the Wind River Food Sovereignty Project, the Tribal Buffalo Initiative, and the High Plains American Indian Research Institute. While not formal listening sessions, these engagements helped align TRI-CEA goals with local values and informed future research directions. Across sites, traditional agricultural community outreach helped identify opportunities for future CEA partnerships, especially with schools, food system nonprofits, and extension agents.

Interdisciplinary Modeling Framework:
UNM graduate student Meirah Williamson presented a system dynamics modeling framework to the Socioeconomics working group in Spring 2025. The model integrates variables related to community preferences, economic conditions, and food access within CEA adoption scenarios. This launch marked the beginning of interdisciplinary planning across teams: modelers began discussing integration with plant science and infrastructure threads to support cross-cutting analysis.

Faculty and students at UNM and UW are collaborating to develop a shared modeling diagram. Graduate students are leading the development of conceptual models that combine system dynamics, machine learning, and policy constraints. This interdisciplinary process includes crosswalks between biophysical yield functions and community-informed decision rules, supporting long-term integrated assessments.

Literature Review and Data Analysis:
To support the model structure and community engagements, the team launched a systematic literature review using Web of Science and Scopus. Student researchers (Ziqing Xie, Meirah Williamson, Jane Sawerengera, and Galen Osten) developed workflows to categorize existing modeling frameworks, regulatory barriers, and social determinants of food access. This included mapping gaps in the literature relevant to

rural and traditional agricultural community CEA adoption, with structured analysis led by UNM faculty Jingjing Wang and Yolanda Lin.

Additionally, undergraduate student Galen Osten produced a time-series decomposition of kale prices in the Los Angeles wholesale market, separating trends, seasonal components, and residuals. These findings provide foundational economic insights on volatility, seasonality, and pricing patterns—inputs that are feeding into modeling work on consumer preferences and production viability.

Collaborative Synthesis and Knowledge Integration:
Faculty from USD, UNM, and UW met regularly to align research approaches and ensure knowledge transfer across institutional boundaries. These sessions highlighted the importance of representing both quantitative and qualitative insights within the socioeconomic thread. For example, modeling leads from UNM emphasized the need for parameter estimates rooted in lived experience—like those captured through USD's interviews with rural consumers and entrepreneurs.

Ultimately, the Year 1 activities of the Socioeconomics team have set the stage for integrated, participatory modeling that centers community values, local barriers, and market dynamics in future CEA planning. Work on IRB applications, focus group question design, and community-based participatory research protocols will continue into Year 2, guided by the interdisciplinary framework developed this year.

3.3 Objective 3: Workforce Development

The Workforce thread of TRI-CEA initiated a wide array of activity in Year 1, leveraging faculty expertise, local workforce centers, and community and technical college partnerships to build sustainable career pathways in controlled environment agriculture. Recognizing the complex and jurisdiction-specific nature of workforce development ecosystems, this thread emphasized foundational work in credential design, industry alignment, and early-stage internships, all with a focus on rural community inclusion.

Strategic Activities and Progress:

- **3.1.1 Credentialing Structure:** SFCC developed skill-based credential structure; assessments in use for several competencies.
- **3.1.2 Evaluator Training:** Bioscience Core Skills Institute (BCSI) evaluator training completed by faculty including Stephen Gómez and colleagues at SFCC

and the Master's Program (TMP) Charter High School. Evaluated 1st cohort of SFCC and TMP students for BCSI micro-credentials in May 2025.

- **3.2.1 Articulation Agreements:** Initial outreach and collaboration with Navajo Technical University (NTU), UNM, and NMSU ongoing. Curriculum mapping of CEA courses between SFCC and NMSU underway.
- **3.3.4 Internships:** Tionna Tapaha (NMSU) managing three student interns; Farmington site active in training. Charlie Shultz (SFCC) managing four student interns; working to create two more CEA internships through the college and one in collaboration with Los Alamos National Laboratory (LANL).

Table 3. Objective 3 Strategic Activities and Progress

Objective / Activity	Strategic Plan Task	Year 1 Progress
3.1.1 Credentialing structure	Design and assess CEA micro-credentials	SFCC developed skill-based credential structure; assessments in use for several competencies.
3.1.2 Evaluator training	Train micro-credential evaluators	BCSI evaluator training completed by faculty including Stephen Gómez and colleagues.
3.2.1 Articulation agreements	Develop articulation agreements	Initial outreach and collaboration with NTU, UNM, and NMSU ongoing; progress slowed by structural hurdles.
3.3.4 Internships	Support internship coordination and workforce training	Tionna Tapaha (NMSU) managing three student interns; workforce exposure integrated into farm operations. Charlie Shultz (SFCC) managing four student interns; collaborating with LANL to create internship.

Credentialing System Design and Evaluator Training

Santa Fe Community College (SFCC) emerged as a lead institution in credential development. Led by Stephen Gómez and Ondine Frauenglass, SFCC finalized a

lab-based micro-credential evaluation structure embedded within its existing AAS programs based on existing Dept. of Energy supported micro-credentials developed for the Algae Cultivation certification embedded in the CEA program. Several of these microcredentials—such as lab safety, microscopy, small volume metrology and hand-held instrumentation—were piloted using in-house assessments that allow students to earn stackable badges upon demonstrating mastery at or above 80% competency.

Crucially, SFCC faculty also completed evaluator training through the Bioscience Core Skills Institute (BCSI), equipping them to assess and validate skills in ways that are portable and recognized across the biosciences industry. This “train-the-trainer” model, completed by five faculty and staff, across two schools and three departments, increased collaboration across schools in the college, and ensures a broader reach across TRI-CEA institutions as evaluator capacity expands in future years.

Industry Listening and Validation Mechanisms

Recognizing that microcredentials must align with industry needs, the Workforce group launched survey planning efforts in spring 2025. Under the leadership of Jill Keith (UW), Margo Chavez-Charles (UNM), and Lina Guadagno (UW), the team crafted an IRB-ready industry survey to validate a proposed list of core competencies. Stakeholder engagement included outreach to aquaponics and vertical farming firms, with particular attention to companies operating in or near rural and traditional agricultural communities.

At the All-Hands Meeting and in subsequent planning calls, partners identified industry leaders—such as CropKing and RAYN Growing Systems—as collaborators willing to provide feedback on credential design, equipment selection, and internship potential. UW also began formalizing a Memorandum of Understanding (MOU) to create a CEA network of business partners across Wyoming and adjacent states, supported by the Wyoming Innovation Partnership.

Notably, UNM and SFCC partners consulted with First Ignite, a workforce-matching platform, to explore data-driven strategies for identifying additional employers in need of CEA-trained workers.

Apprenticeship Pathways and State-Level Workforce Engagement

In meetings held throughout Year 1, team members emphasized the importance of integrating credentialing with subsidized workforce initiatives like registered apprenticeships. Lina Guadagno (UW) and Margo Chavez-Charles (UNM) highlighted how New Mexico and Wyoming already have active programs that can be leveraged for this purpose. In South Dakota, USD partners began exploring the StartTodaySD program as a potential mechanism for workforce integration.

UNM collaborators also reviewed the broader landscape of state, regional, and federal workforce agencies that could support program alignment and future participant recruitment. These include New Mexico's Department of Agriculture Workforce Development Program, the Pueblo of Acoma's Workforce Development Program, the Mescalero Apache Tribe's WIOA program, and the Tesuque Pueblo Tribal Farm among others.

Internships and Community Engagement

NMSU's Farmington Agricultural Science Center, under Kevin Lombard and Tionna Tapaha, successfully onboarded three student interns during the spring and summer of Year 1. These included high school and early college students from Navajo Prep, Shiprock Workforce Development, and Fort Lewis College. Ms. Tapaha served as their site mentor, integrating their work with the Farmington greenhouse and emerging hydroponic systems. A field day is planned for July 24, 2025. This event routinely attracts about 300 participants, many from the Navajo Nation.

Figure 5 NMSU Greenhouse complex in 2023, Farmington, NM. Community members and students tour the greenhouse complex on NMSU's field day in 2023. Photo by Josh Bachman from "NMSU Agricultural

Science Center to host annual Field Day"
(https://www.tricityrecordnm.com/articles/nmsu-agricultural-science-center-to-host-annual-field-day/)

At the University of Wyoming, the WIP-funded summer course (AGRI4990) explicitly incorporated workforce development by engaging community college students in classroom and laboratory instruction, supported by CEA industry guests and hands-on training in lighting, sensors, and water systems. This course is now being promoted for recurring implementation, with support from TRI-CEA and external partners.

SFCC also collaborated with contacts in the Southwest and Great Plains to support potential CEA system installations and curriculum partnerships. An existing MOU with Tesuque Pueblo (NM) and connections with the Three Affiliated Tribes (ND) were explored and with plans for evaluator training, system demos, and future outreach events.

3.4 Research Conclusion

Together, the research activities across TRI-CEA's three objectives demonstrate the power of interdisciplinary coordination to advance both fundamental science and community-centered innovation. The biophysics team built infrastructure, developed shared SOPs, and launched pilot trials that will generate comparative data on yield and environmental conditions across jurisdictions. The socioeconomics group advanced stakeholder engagement, dynamic modeling, and food systems research rooted in traditional agricultural community perspectives. The workforce thread launched badge-based credentialing, evaluator training, and pilot internship placements while laying the groundwork for statewide and industry-linked workforce pathways.

Despite early-year delays due to hiring and funding constraints, the project remains broadly on track. Cross-thread integration—visible in the connections between modeling, biophysical trials, and credential-aligned student training—positions TRI-CEA to scale and deepen its impact in Year 2. The research activities to date are already informing the field of CEA by linking controlled system performance with the economic, social, and workforce ecosystems necessary for sustainable adoption in traditional agriculture communities.

4. Education

TRI-CEA's education strategy bridges technical training, research mentorship, and curricular innovation across institutions and learning levels. The project aims to create seamless pipelines for students to engage meaningfully with controlled environment agriculture. These efforts are reinforced through co-mentorship, articulation agreements, paid internships, and interdisciplinary graduate-level research opportunities.

Figure 6. Sarah Doyle and Isaiah Spiegelberg (University of Wyoming) harvest deep water culture lettuce

Figure 6 Sarah Doyle and Isaiah Spiegelberg (University of Wyoming) harvest deep water culture lettuce. Sarah Doyle holds up lettuce roots during harvest from a Deep Water Culture hydroponic system. Isaiah Spiegelberg pauses in the background before harvesting the next grouping. Photo by Carmela Guadagno.

Education and training have been central to TRI-CEA's cross-cutting efforts in Year 1. Beyond institutional coursework and research involvement, students shaped the collaborative structure and culture of the project itself. Graduate students Glen Marshall (USD) and Ziqing Xie (UNM) co-designed a student-only session at the All-Hands Meeting, where they facilitated cross-institutional conversation around research interests, collaboration tools, and communication strategies. Ms. Xie also led the TRI-CEA logo design process, collecting survey responses from staff and students across institutions and iterating on feedback to produce a shared visual identity that now appears on all project materials. Undergraduate student Galen Osten (UNM) helped establish the TRI-CEA website, translating project goals into a public-facing resource for partners and stakeholders.

TRI-CEA graduate students also achieved early professional success tied to their engagement with the project. Ziqing Xie and Jane Sawerengera, both mentored by Dr. Jingjing Wang, received 2025 ARID Interdisciplinary Research Grants to extend their work on CEA economic modeling and aquaponic systems with Regen Aquaculture. Further, TRI-CEA faculty mentorship is not limited to their own campuses as Dr. Wang serves on University of Wyoming's Isaiah Spiegelberg's master's thesis committee.

Undergraduate student Galen Osten took the lead on developing and launching TRI-CEA's initial web presence, supporting broader outreach and science communication goals. These creative contributions reflect an educational strategy rooted not only in coursework but in participatory, intergenerational research culture.

Formal mentoring structures evolved through monthly graduate student coordination meetings, supported by program leadership and the program manager. These meetings allowed students from different disciplines and institutions to align literature review approaches, troubleshoot modeling challenges, and reflect on research implementation. Several students—Ziqing Xie, Meirah Williamson, Jane Sawangera, and Glen Marshall—actively contributed to literature synthesis, modeling framework development, and conference preparation.

A core structure supporting these achievements has been TRI-CEA's cross-institutional mentorship network. Graduate students from multiple campuses meet monthly in facilitated sessions led by program manager Dr. Margo Gustina, where they share progress on literature reviews, collaborate on modeling design, and refine their research communications. These calls provide space for peer mentoring,

interdisciplinary brainstorming, and timely guidance from faculty advisors. Students also share a Zotero library for organizing their systematic literature review and use a collaborative feedback structure for refining presentation materials, with several co-authoring slides or posters for institutional research days.

Hands-on education also played a central role in program activities, with field-based training emerging as a bridge between system deployment and workforce readiness. At the All-Hands Meeting in February 2025, students joined system installation and monitoring demos facilitated by technical faculty and the GrowBig consultant. These sessions introduced students to the basics of NFT and DWC hydroponics, environmental sensing, and seedling SOPs, reinforcing the project's commitment to integrating training with research implementation.

Across campuses, articulation agreements were discussed as a strategy to extend the reach of TRI-CEA credentialing. SFCC's work with NTU and early-stage discussions between UW and regional community colleges support this momentum. Students involved in coursework at SFCC, UNM, and UW will have access to shared instructional materials, summer research opportunities, and microcredential pilots aligned with workforce development plans.

- SFCC developed microcredential-aligned course materials and hosted technical demonstrations at the All-Hands Meeting.
- UW and NMSU engaged rural high school and college students in research internships.
- SFCC, UNM, and NMSU advanced articulation pathways that would allow students to begin in technical training and continue through research-oriented degrees.
- EDOCS records indicate more than a dozen students were formally engaged in research, internships, or training programs.
- Graduate students coordinated across institutions to support literature reviews, modeling, and research dissemination.
- At UNM, a 5-week Introduction to CEA Workshop will provide hydroponics training, environmental sensor kits, and student stipends in summer 2025.
- At the University of Wyoming, a credited CEA summer course (AGRI4990) will integrate classroom, laboratory, and industry-based training on topics including lighting, water systems, robotics, and data visualization.

In preparation for summer activities, Tionna Tapaha at NMSU coordinated with Kevin Lombard and Lois Standford the onboarding of four student interns to begin placements at the Farmington Agricultural Science Center. These interns—drawn from Navajo Prep High School, the Shiprock Workforce Development Center, NMSU main campus and Fort Lewis College—will participate in TRI-CEA activities in Summer 2025, gaining hands-on experience with hydroponics systems and greenhouse operations. Their engagement reflects the project's broader emphasis on recruiting and supporting students from and building bridges between secondary education, technical training, and applied research.

As TRI-CEA prepares for expanded summer workshops and internships, its educational model continues to evolve through student leadership, inter-institutional mentorship, and community-based placements. The work completed in Year 1 lays a strong foundation for scaling student participation, refining instructional tools, and deepening alignment between research, credentialing, and long-term workforce engagement. Education in TRI-CEA is not a parallel effort—it is integrated at every level of project design, and driven forward by the students it serves.

5. Solicitation-Specific Project Elements

5a. Research Capacity and Infrastructure
Significant investments were made in system procurement (NFT, DWC systems), sensors, and greenhouse renovations across all five institutions. SOPs for system operation and environmental monitoring were collaboratively developed.

5b. Interjurisdictional Collaboration
Cross-campus collaboration was integrated across all threads: UNM, UW, and SFCC co-developed credentialing tools; UNM and NMSU aligned hydroponics implementation; and PI meeting notes reflect multi-institution authorship planning.

5c. Workforce Development
Credentialing, evaluator training, articulation agreements, and three internship pathways launched this year. Multiple students were engaged in educational and research roles.

5d. Jurisdictional Impacts
Each jurisdiction brought distinct strengths and activities to the TRI-CEA collaboration:

New Mexico (SFCC, UNM, NMSU):
New Mexico's institutions worked closely on education and system infrastructure. SFCC led the development of microcredential-aligned curriculum and hosted early system demonstration activities, including tours during the All-Hands Meeting. UNM spearheaded system modeling efforts and contributed to credentialing survey design and REU site coordination. NMSU served as a key field deployment hub, supervising multiple interns at the Farmington greenhouse and supporting workforce partnerships with rural communities.

Wyoming (UW):
UW contributed heavily to literature reviews and traditional agricultural community engagement through its socioeconomics and education work. Faculty and graduate students helped advance the modeling framework and planned a for credit summer CEA course. UW also played a lead role in building articulation pathways with community colleges and technical institutions.

South Dakota (USD):
USD provided critical program administration and strategic planning, including cross-thread coordination and proposal development. Staff facilitated rural outreach and supported EPSCoR and INBRE collaboration across jurisdictions. Listening sessions and planning with Sinte Gleska University and the Sicangu Lakota community provided foundational input for modeling and system alignment.

5e. Overall Project Integration
Bi-weekly meetings of subgroup leads, regular PI coordination, and the February All-Hands meeting contributed to high levels of coordination. Evaluation data indicates increased clarity, morale, and role alignment post-gathering.

5f. Broadening Participation
Involvement of high schools and colleges, rural researchers, and first-generation college students was evident throughout Year 1. Partnerships with organizations, workforce centers, and advisory members strengthened this focus.

6. Development or Recruitment of Early Career Faculty
Year 1 progress was notably shaped by delays in hiring across all participating institutions, largely driven by uncertainty in federal funding continuity and institutional restrictions on long-term commitments. The delay in onboarding new faculty and staff

impacted momentum for planned system deployments and slowed capacity for student supervision, curriculum design, and interdisciplinary coordination.

For example, New Mexico State University reported that multiple searches yielded applicant pools with limited alignment to the rural location or project focus areas, which led to position reconfiguration and delay. Similar barriers were echoed at UW, SFCC, and USD, where collaborators reported long review cycles for new hires and constraints on staff time that limited early training and evaluation activities.

Despite these setbacks, team leads coordinated interim strategies to keep project work moving—pairing graduate students with PIs and leaning on existing staff to maintain core activities. Institutions are now positioned to proceed with delayed appointments in Year 2 and integrate new personnel into ongoing activities more rapidly.

University of New Mexico's Dr. Yolanda Lin, is an early career faculty member who has been a part of the leadership team from project inception. Lin is actively engaged in receiving mentorship support from other project faculty and professional development in transdisciplinary collaboration. Her first graduate student works on this project and is co-advised with Wang. Through TRI-CEA's first project year, Lin has had expanded opportunities to build leadership and management skills.

7. Evaluation

The TRI-CEA evaluation process in Year 1 was anchored by external feedback gathered during and after the February 2025 All-Hands Meeting. A formal evaluator report highlighted the success of the event in promoting collaboration, participant morale, and clarity of roles. Attendees praised the structure, interactivity, and value of in-person demonstrations and cross-institutional dialogue.

Key findings included:

- Participants felt the meeting improved their understanding of project goals and the role of their institution.
- Student involvement was widely appreciated, and attendees recommended even more structured opportunities for graduate and undergraduate engagement in future events.
- Stakeholders expressed high interest in developing more systems-level communication tools, like shared modeling language and collaborative project dashboards.

In response, the leadership team has begun:

- Expanding shared meeting infrastructure (e.g., working groups, breakout sessions, and resource sharing via EDOCS).
- Planning for earlier and more student-centered components in future convenings.
- Encouraging subgroup leads to incorporate evaluation reflections into regular work planning.

As the team continued their work after the All Hands meeting, the evaluator noted that without the strength of in-person communication, projects participants struggled to feel fully informed about the work conducted in sub-groups of which they are not a part. An important component of the leadership team's communication design work going forward will be leveraging monthly Full Team meetings to clearer strategic effect to improve whole group inclusion in all research threads.

The external evaluator also pointed out numerous areas of success from project year 1. Importantly for EPSCoR jurisdictional goals, student progress was a key highlight of TRI-CEA progress. Specifically, the evaluator noted that undergraduate, masters, and doctoral students all described their growth beyond technical science to include areas important for their future success as professionals and researchers, including the development of listening session strategies, collaborations with external partners, and the construction of publications from literature review and journal selection to final draft submission.

8. Expenditures and Unobligated Funds

Over the collaborator sites, funding uncertainties shifted institutional processes leading to delayed spending. New Mexico State University and University of New Mexico will be able to hit programmatic spending targets by the end of year 1, August 31, 2025. Because both UNM and NMSU incorporated their heaviest program spending as part of summer education and experiment implementation, spending won't be reflected in account reporting until August.

University of South Dakota

The University of South Dakota will have greater than 20% of year 1 funding unobligated on September 1, 2025 and will request a carry over accompanied with a

detailed spend down plan. Unobligated expenditure is driven by a new faculty position in Life Cycle Assessment written into this project which USD has been unable to fill. USD PI Meghann Jarchow held a search and conducted on-campus interviews. When moving to hire selected candidates, Jarchow was required by USD administration to include the clause that if NSF funding was terminated/revoked/removed, the position contract would be rescinded or revoked. No qualified candidate was willing to accept the offered position with the clause intact. USD considers this a failed search and will reopen the search in Fall 2026. Jarchow hopes that by fall the contract-revoking clause will be unnecessary.

Further, increased uncertainty about job security for federal grant funded positions has increased attrition at some subawardees. Jarchow's partner at Sicangu Co, a USD subawardee, has left their position leaving all of the subaward budget unspent. Sicangu Co has undergone structural reorganization, which has resulted in changes in positions. Some of Sicangu Co's (awarded) federal funding has also been terminated/revoked (in areas (food systems) related to this grant), which has also reduced their capacity as they have had to determine how to continue those efforts in spite of changes to the funding plan. This rural non-profit is struggling to attract qualified candidates to work on the TRI-CEA project given the general sense of funding and employment precarity.

USD anticipates having spending on track by the end of programmatic year 3 given that the LCA faculty search won't begin again until Fall 2025 for a Fall 2026 appointment.

University of Wyoming

The Wyoming Research Office, facing uncertainty in funding during the early part of the year, chose to delay advertising the position and proceed cautiously with new hiring until the situation became clearer.

UW expects to reach between 50 and 60% of direct costs for Year 1 by August 31st, equal to $315,200. So far, we have spent 30%, equal to $91,800. A breakdown of summer expenses looks like: $60k instrumentation (until the hydroponic systems are in place we could not buy the cameras/systems); $19k faculty summer salaries; $9k undergraduates' salaries; $10k summer salaries for grad students; $30k Postdoc (3 months & moving expenses); $40k in materials and supplies for summer experiments. The missing 20% was allotted to the postdoc salary that was supposed to be spent during the beginning of the year. This amount will be spread over the future salaries'

months for the same personnel to ensure that the workload from year one will be achieved without delays.