ERC for Advancing Sustainable and Distributed Fertilizer Production (CASFER)

Texas Tech University (lead institution)

Striving Toward a Nitrogen Circular Economy

CASFER
Center for Advancing Sustainable and Distributed Fertilizer Production

A National Science Foundation Engineering Research Center since 2022

Partner Institutions:

- ***Case Western Reserve University***
- ***Florida Agricultural and Mechanical University***
- ***Georgia Institute of Technology***
- ***Massachusetts Institute of Technology***

The National Science Foundation (NSF) Engineering Research Center for Advancing Sustainable and Distributed Fertilizer Production (CASFER) strives to solve one of the most pressing problems facing humankind: *How do we feed the growing world population while protecting and sustaining our environment?* By 2050, the world population will exceed 10.5 billion, increasing the demand for food by 70%, with only an additional 10% land available for agriculture. To meet this demand, nitrogen-based fertilizers (NBFs) are required for the formation of plant proteins. Currently, more than 50% of the world population is supported by synthetic NBFs, produced via the Haber-Bosch process (HB), an energy- and carbon-intensive process. In addition, NBFs produced via the HB suffer high volatility of prices in the US and developing countries. Moreover, only 20% of NBFs produced translate into food, with 80% lost to the environment creating significant environmental, health, and socioeconomic impact. Therefore, society requires new cost effective, resilient, and secure ways to produce NBFs with minimum environmental and socioeconomic impact.

CASFER's vision is to enable resilient and sustainable food production by developing next-generation, modular, distributed, and efficient technologies for capturing, recycling, and producing decarbonized nitrogen-based fertilizers. CASFER will also leverage its platform technologies to optimize the recovery of phosphorous (phosphorous-based fertilizers, PBF), nutrients and other resources from waste streams while maximizing nitrogen (N) circularity (i.e., recycling of nitrogen). Through CASFER research (CR), its engineering workforce development program (EWD), a diversity and culture of inclusion (DCI), and its innovation ecosystem (IE), CASFER will lead the US toward a Nitrogen Circular Economy (NCE), fertilizer independence, and an affordable and resilient price range for NBF, while sustaining and preserving the environment.

The CASFER vision addresses human, social, economic, and environmental sustainability. CASFER will develop precise, commercial grade-like NBFs from waste streams and transform standard practices of applying manure waste to fields (which creates environmental emissions due to lack of predictability and composition required for precise dosing to crops). CASFER employs an Organic but Synthetic Approach (OSA) to NBF, with ingredients, predictability, and reliability designed to stimulate plant growth. CASFER technologies require convergence of nanotechnology, electrochemical science, data science (for modularity, synthesis, and separations), biology, chemistry, environmental and agricultural science and will confront economic pressures, logistics issues, public and industry acceptance, regulatory, and safety issues.

Dr. Mbuya and a CASFER scholar from FAMU examining plant growth in the field. (Credit: Florida Agricultural and Mechanical University)

Current NBF prices (produced via the HB process) are based on centralized facilities, are highly volatile, and are affected by externalities such as food demand, energy costs, transportation costs, foreign policies, natural hazards, and exchange rates. CASFER's mission is to transform the agricultural and fertilizer industries into a nitrogen circular economy (simultaneously lowering world pollution and overall fertilizer costs), through the integration of fundamental and systems-level research, workforce development, and innovation ecosystems, in measurable and quantifiable areas of NFB recycling/production, energy reduction, and emissions footprint reduction; to translate fundamental academic research encompassing nanotechnology, electrochemical and data science into innovative technologies that the U.S. fertilizer industry can bring to commercial realization; and to establish a diverse and inclusive world leadership with emphasis in the NCE encompassing engineers, scientists, systems integrators, economists, legislators, and policy makers.

In the process, CASFER will transform agricultural industry practices in the U.S. CASFER will capture and recycle N from waste to reach over 50% of the U.S. NBF consumption. Instead of expending resources, energy, and money to deactivate diluted reactive N from waste streams, N from waste will be captured and recycled for crop production. CASFER will make NBFs affordable for American agriculture by targeting resilient and sustainable N prices.

Goals: CASFER has three goals:

1. Increase recycling of nitrogen in agriculture by 50%, decrease reactive nitrogen emissions by 50%, and achieve cost-efficient decarbonization of NBF by developing transformational solutions for the NCE that will demonstrate continuing U.S. global leadership of the agricultural and fertilizer industries.
2. Develop and implement a platform for the next generation of diverse engineers and technical workforce with the skill sets needed to advance the NCE.
3. Develop guidance and metrics to catalyze investment to support the bridge of innovation for commercialization of NCE technologies and processes.

Outcomes

CASFER has established **major outcomes needed to create** a nitrogen circular economy:

- Over 50% recycling of N in agriculture and reduction in emissions footprint
- Decarbonization of NBF production
- Diverse and inclusive leadership for NCE
- EWD programs and training tools towards NCE
- Business models for NCE infrastructure
- Policy and legal infrastructure for NCE

Behnaz (CASFER student from Texas Tech) and Dr. Botte (CASFER Director) working on the synthesis of smart fabrics for efficient recovery of NBF. (Credit: Texas Tech University)

RESEARCH

CASFER's engineering system is a *modular, distributed, decarbonized NBF production process*. CASFER will produce NBF by capturing N from concentrated animal feeding operations (CAFOs), wastewater treatment plants (WWTPs), agricultural runoff, and air integrating electrified technologies for separations, conversion, sensing, and control algorithms to deliver NBF to farmers. This system integrates technologies and components from three Center-coordinated research thrusts:

T1. Geospatial Data Science Models for Social, Environmental, and Economic (SEE) Growth: CASFER researchers are developing multidimensional models (social, economic, environmental, and policy) to support the nitrogen circular economy, and to create the advanced monitoring network and control algorithms to support the distributed nitrogen-based fertilizer technologies and phosphorus circularity. Projects in T1 are cross-cutting and will enable assessing the SEE impact of CASFER technologies.

T2. Capture and Resource Recovery for Nitrogen-Based Fertilizer Production: CASFER is creating modular, electrified, and distributed separation technologies to enable circular use and delivery of nitrogen-based fertilizer while optimizing phosphorus-based fertilizer circularity. **T2** researchers are working on developing multiple separations approaches for the recovery of all nutrients (N, P), with initial focus on point-sources (i.e., WWTP and CAFO) because of the high concentrations and ease of collection of starting materials. The resulting technologies, models, and techno-economic analysis from **T1** will give CASFER a guidebook for implementing the right technology at the right location, such as big vs. small city, and expanding applications to non-point sources.

T3. Modular and Distributed Nitrogen Based Fertilizer Production: CASFER researchers are developing catalytic technologies to synthesize nitrogen and phosphorus-based fertilizer from recovered and alternative resources using distributed, modular reactors powered with renewable electricity. **T3** researchers are working on catalytic routes for the conversion of waste streams containing N and P into fertilizer. Solid waste streams in the form of sludge generated from both WTTPs and CAFOs are considered critical for both N and P circularity. This sludge contains N and P both in organic form. **T3** and **T2** researchers work in concert toward the regeneration of specific nitrogen-based nutrients because nitrogen compounds are mobile and can require change in oxidation state.

Systems Level Testbeds

CASFER's engineering research is geared toward developing testbeds, such as: (1) NBF/PBF production from CAFOs, (2) NBF/PBF production from WWTPs, (3) Next-generation NBF production, and (4) NBF/PBF field testing with crops at farms.

EDUCATION

CASFER's goal is training the next generation of engineers and technical workforce with the skills to advance the NCE while considering sustainability within their own and global communities. This means equipping engineers with skill sets including the intersection of technical and soft skills in engineering, agricultural sciences, and environmental science. CASFER is creating agents of change and influencers targeting formal and informal education along the K-gray spectrum. Engagement at each level is based on theoretical foundations and evidence-based practices. CASFER is developing, refining, and implementing a holistic curricular platform that includes sustainability across the entire spectrum of learners in three areas: *expanded sustainability (pre-college), educated sustainability (academic), and social sustainability (broader community)*.

DIVERSITY AND CULTURE OF INCLUSION

CASFER activities implemented as part of our Diversity and Culture of Inclusion program will ensure our diverse group of participants is valued and can contribute to their fullest potential throughout CASFER. CASFER will engage a diverse range of underrepresented participants in STEM by leveraging and championing the varied backgrounds and experiences of each participant and facilitating their engagement in CASFER disciplines and the community despite historic socioeconomic and cultural barriers.

CASFER will support all participants regardless of gender, race, ethnicity, physical ability, and socioeconomic status. CASFER will maintain diversity at 50%, will capitalize in the resources of partners, and will implement **l00% of CASFER testbeds in agricultural regions and communities underrepresented in STEM** (Hispanic-Serving Institution Texas Tech [TTU] and HBCU FAMU) to increase participation of underrepresented minorities. Technology training at the communities will be translated into Spanish to enable access and equity and to broaden the participation of the workforce.

INNOVATION ECOSYSTEM (IE)

CASFER's IE aims to bridge the gap between research and commercialization in the field of nutrients recovery. It provides educational programs, technology development, and leadership to maximize the impact of its partners' assets. CASFER IE aims to enable successful transfer of processes and technologies to industry, secure investment for commercialization, and develop self-sustaining innovation alliances. Through its membership model, it connects NSF-funded research with various stakeholders, including government, businesses, and corporations. CASFER's industrial practitioner board (IPAB) provides training opportunities, industrial expertise, and input on research projects to ensure their relevance and viability. The IPAB also provides input on the selection of research proposals and technology commercialization pathways. The goal of CASFER IE is to unite diverse communities, maintain adaptiveness, and develop transformational Ag Waste Trading business models.

FACILITIES

CASFER headquarters is located in the Maddox Engineering Research Center (MERC), a 70,000 ft^2 building at TTU. CASFER laboratories and facilities within this building expand over 10,000 ft^2. CASFER also has access to the Materials Characterization Center, a 11,500 ft^2 facility located in MERC with state-of-the-art infrastructure to support materials studies (synthesis, characterization, applications). CASFER leverages other facilities at TTU and partner institutions such as: TTU Greenhouse facilities; TTU Quarter Avenue Research Farm (120 acres of farmland designed for testing fertilizer dosing and irrigation); New Deal Research Farm (40 acres with specialized irrigation and test zones); the swine farm and test field at Western Texas College; the City of Lubbock Municipal Wastewater treatment; Florida Agricultural and Mechanical University research and extension farms; Georgia Tech chemical sensor and characterization labs, Institute for Electronics and Nanotechnology, and The Georgia Tech Effective Team Dynamics Initiative; Case Western Reserve University SDLE Research Center and CRADLE distributed and high-performance computing; and MIT's Center for Materials Science and Engineering and its Synthetic Biology Center.

The Maddox Engineering Research Center on Texas Tech's campus, where the CASFER headquarters and labs are housed. (Credit: Texas Tech University)

CENTER CONFIGURATION, LEADERSHIP, TEAM STRUCTURE

The CASFER management structure facilitates a convergent approach and provides team formation across the foundational components of the Center. The Director of CASFER chairs a leadership team. The leadership includes experts in fundamental science and engineering (Center Director, thrust leaders, co-leaders, testbed leads), Innovation Ecosystem, Intellectual Property, Engineering Workforce Development, and Diversity and Culture of Inclusion.

CASFER's horizontal management structure is inclusive and encourages engagement from all participants by reducing silos found in hierarchical organizations and allows the Center to: select and direct research activities; manage relationships among participants and stakeholders; plan, implement, and evaluate educational and outreach programs and mentorship activities; evaluate diversity programs and instill a culture of inclusion; enhance industrial membership and technology transfer opportunities, including for small companies, farms, cooperatives, and state-managed facilities; and realize a culture of innovation and entrepreneurship. Foundational Components are each led by Directors, Thrust Leaders, and the Convergence Coordinator. CASFER operation is facilitated by program managers (CASFER's Research and Team Science Coordinator, ILO, Director of EWD Integration, and Director of DCI Integration) who help integrate the foundational components with the research portfolios of CASFER. An executive committee (EC) advises the Center Director on the direction and operation of the Center; ensures communication across Center components and CASFER partner institutions; performs analyses; makes approvals as laid out in Center governance; and reviews/updates research goals and milestones.

In addition, the Director consults periodically with the NSF ERC Program team as well as with the different advisory boards that have been established to support the vision and mission of CASFER, discuss progress, address challenges and opportunities, plan changes, and update CASFER's strategic plan.

CENTER HEADQUARTERS

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