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Engaging Minority Students in Sustainable Bioenergy and Water Quality through an Education and Research Network

Krystel Castillo

Mauricio Cabrera-Rios

Michael W. Persans
The University of Texas Rio Grande Valley

Hudson R. DeYoe
The University of Texas Rio Grande Valley

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Dr. Krystel Castillo P.E., The University of Texas - San Antonio

Dr. Krystel Castillo is currently the GreenStar Endowed Assistant Professor in Energy in the Department of Mechanical Engineering and co-Director of the Manufacturing Systems and Automation Laboratory at The University of Texas at San Antonio (UTSA). Dr. Castillo's research expertise is in two primary areas. The first is mathematical programming and optimization techniques for analyzing large-scale, complex systems under uncertainty. The second is in big data analytics, which has applications to renewable energy, aerospace/defense industry, and logistics. Dr. Castillo has received more than $2 million in grant funding from agencies including: USDA, AFRL, CONACyT, NSF, among others. She is among the core faculty of the Center for Advanced Manufacturing and Lean Systems as well as of the Center for Simulation, Visualization, and Real Time Prediction at UTSA.

Prof. Mauricio Cabrera-Rios, University of Puerto Rico - Mayaguez

Mauricio Cabrera-Ríos obtained his doctoral degree in Industrial and Systems Engineering from The Ohio State University in 2002. He currently holds an appointment as Associate Professor in the Department of Industrial Engineering at University of Puerto Rico at Mayagüez. He also co-leads the Applied Optimization Group. https://www.facebook.com/AppliedOptUPRM

Dr. Michael W. Persans, University of Texas Rio Grande Valley

1987-1991 B.S. in Biotechnology, Rochester Institute of Technology 1991-1998 Ph.D. in Plant Biology, University of Illinois at Urbana-Champaign 1998-2001 Postdoc in Plant Biology, Northern Arizona University 2001-2002 Postdoc in Plant Biology, Purdue University 2002-2008 Assistant Professor, Biotechnology, University of Texas Pan American 2008-2015 Associate Professor, Biotechnology, University of Texas Pan American 2015-Present Professor, Biotechnology, University of Texas Rio Grande Valley

Dr. Hudson R. DeYoe, University of Texas Rio Grande Valley

Expertise in water quality and algal physiology and culture. Interest in use of algae as biofuel.

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Krystel K. Castillo-Villar[1], Mauricio Cabrera-Rios[2], Michael Persans[3], Hudson Deyoe[3]

[1] Department of Mechanical Engineering, The University of Texas at San Antonio, One UTSA Circle, San Antonio, TX 78249
[2] Department of Industrial Engineering, The University of Puerto Rico Mayaguez, PO BOX 9000, Mayaguez, PR 00681
[3] Department of Biology, The University of Texas Rio Grande Valley, 1201 West University Drive, Edinburg TX 78539

Abstract

Growing energy demand is connected to water availability and climate change and it places additional stress on the environment. Thereby, It is critical to prepare the next generation of engineers and professionals to face the challenges in bioenergy, expand sustainable alternatives to fossil fuels[1] and enable climate-smart agriculture[2,3]. To address this challenge, a career-oriented multidisciplinary educational model is being implemented at three minority-serving institutions.

This paper discusses the foundation of this educational program, which provides a robust response to the current sustainability issues by conducting multidisciplinary coordinated education, mentoring, research and extension activities among multiple universities and laboratories. This educational program aims to accomplish the ultimate goal of increasing minority participation in pursuing advanced degrees in STEM and attaining a diverse highly trained and skillful workforce with a strong pragmatic, experimental, analytical and computational background as well as scientific literacy in sustainable energy and the energy-water nexus.

In this model, students are expected to gain knowledge and understanding of the operational complexity of sustainable energy systems from source-to-use. Students will be able to conduct research and discovery from the feedstock properties passing through the conversion technologies to the mathematical modeling and optimization of the whole bioenergy value chain. In addition, students will be able to translate their findings in the laboratory regarding water quality and treatment into operational parameters to be included in comprehensive water systems models.

1.0 Introduction

Traditional education programs often lack the multidisciplinary curriculum to provide students with the competences needed to face challenges in sustainability. The majority of the educational techniques are based on proving proficiency of fundamental concepts (commonly following unrealistic assumptions) with little or null pragmatic knowledge and hands-on experiences. The students are expected to specialize in one particular major and the career aspirations and preferences of students are usually not considered in academic programs, which are rigid and only aim to provide fundamental technical skills. A valley of death (i.e., gap or disconnection) exists between the students' competencies and the needs of industry, government and the emerging green sectors, which often place more emphasis on pragmatic knowledge and soft skills instead of on highly specialized theoretical training (hard skills).

A major reason for low retention in STEM programs is that students are exposed to core courses for more than half of their program with no exposure to experiential learning related to their majors. The traditional education model is significantly lacking in the development of competences such as interdisciplinary training. Students usually take core classes related to their field of specialization with minimum involvement in research projects that address national priorities. Slow progress towards getting involved in meaningful basic and applied research projects may easily lead to a rapid declining interest in STEM and an eventual drop-out from the program[4].

In particular, numerous first-generation in college, economically disadvantaged and minority students have difficulties navigating the college or graduate school system. Some of the proposed initiatives that can aid in reducing the drop-outs from STEM careers are: (1) establishing a fellowship program to reduce the student's financial burden; (2) enhancing the faculty mentorship of minority students and creating research oriented cohorts; (3) assigning real-life multi-disciplinary projects that require collaboration with other students and researchers from national laboratories; (4) providing students with the opportunity to produce tangible outcomes from their projects such as decision support or expert systems along with posters, presentations, papers and/or webcasts to disseminate in their own words the significance of their research work.

In the next section, the proposed multi-institutional program is presented, in which many of the activities mentioned previously are integrated into a holistic model.

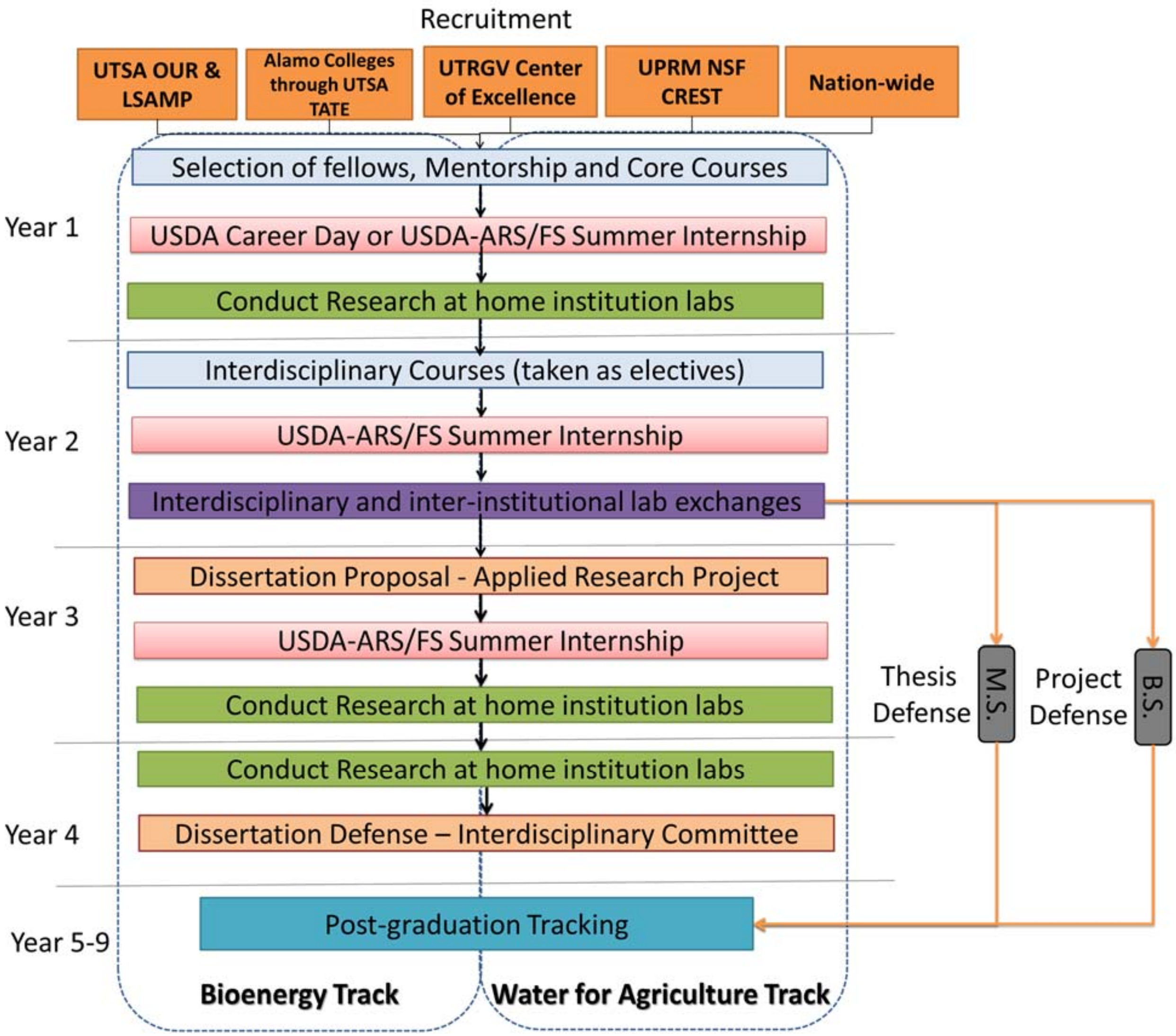
2.0 Overview of the Research and Education Network

We propose a unique educational model that aims to close the gap between rigorous science, math, and engineering competencies and the team work, communication, soft and systems skills needed to transcend disciplinary boundaries in sustainability. The proposed model aims to facilitate a smooth transition from a traditional course delivery model of lectures to a student-centered active learning model that allows students to connect scientific concepts to our two priority areas: bioenergy and water for agriculture.

The fellows are trained in ***systems principles*** and acquire engineering, mathematics and biological sciences knowledge to discover, model, design, evaluate and optimize bioenergy and water for agriculture systems. The fellows are trained to have knowledge and understanding of the operational complexity of sustainable energy systems from source-to-use.

The pillars of our innovative flexible educational model consist of: ***(1) outreach & active minority recruitment;*** (2) ***early mentorship & flexible career-oriented program of study; (3) experiential learning at national laboratories; (4) inter-institutional/interdisciplinary lab exchange; and (5) interdisciplinary training with emphasis on systems thinking***.

As illustrated in Figure 1, recruitment activities start early with the support of institutional outreach centers in the participating universities. These centers expose elementary and high school students to sustainability majors. Moreover, well-established relationships with community colleges provide this program with a sturdy foundation to advance the education of community college minority students. This initiative aims to support at least 20 undergraduates and 20 graduates from three different minority serving institutions located in Texas and Puerto Rico. Moreover, 76 community college students will be reached through summer research immersion camps.



The pair-to-learn technique is used to pair students with faculty mentors during their first semester in the program and meet on a monthly basis. A mentorship record is filled out with the purpose of identifying the student's career interest. Students are incorporated into research projects at their home institutions laboratories for the first year and are provided with the opportunity to conduct summer internships at partnering laboratories. A requirement for all the fellows is to attend to the systems thinking workshop. A distinctive characteristic of this model is that students receive workshops on intellectual property and technology commercialization. Under the supervision of their mentors, students develop a poster, thesis or dissertation proposal (for undergraduate, master and Ph.D. fellows, respectively) centered on a current research challenge (co-advised by researchers in national laboratories). The next sections discuss in more detail the unique aspects of this initiative.

3.0 Student-centered inquiry-learning program.

The proposed program is based on John Dewey's philosophy that education should be centered on the learner [5]. John Dewey is a major proponent of pragmatism, which is based on the idea that learning requires experience and testing of hypothesis to better align them with the real-world. In the last two decades, the National Research Council has encouraged the use of "student-centered inquiry-learning" teaching methods in secondary and postsecondary curricula[6,7]. These strategies have been widely incorporated into classes such as anatomy and physiology[8], biology [9,10], mathematics[11], business marketing[12], among many others. Applications of these techniques in interdisciplinary programs spanning from science to engineering are still lacking. The student-centered inquiry-learning educational theory and best practices serves as the educational framework of the proposed program.

As illustrated in Figure 1, the process starts with a background evaluation for each trainee and the follow-up coursework, seminars and workshops that accommodate their educational, research training, and career placement needs. The fellows have to attend an introductory panel discussion with several faculty members, researchers at national lab, industry professionals, and current graduate students to help new fellows identify their interest.

With successful completion of background knowledge and core research skill training, students *start working in their home institution's research laboratories* for the first year. Faculty and external mentors help trainees in developing his/her applied research project (i.e., thesis, dissertation or undergraduate project depending on the student's level) that addresses a sustainability priority track.

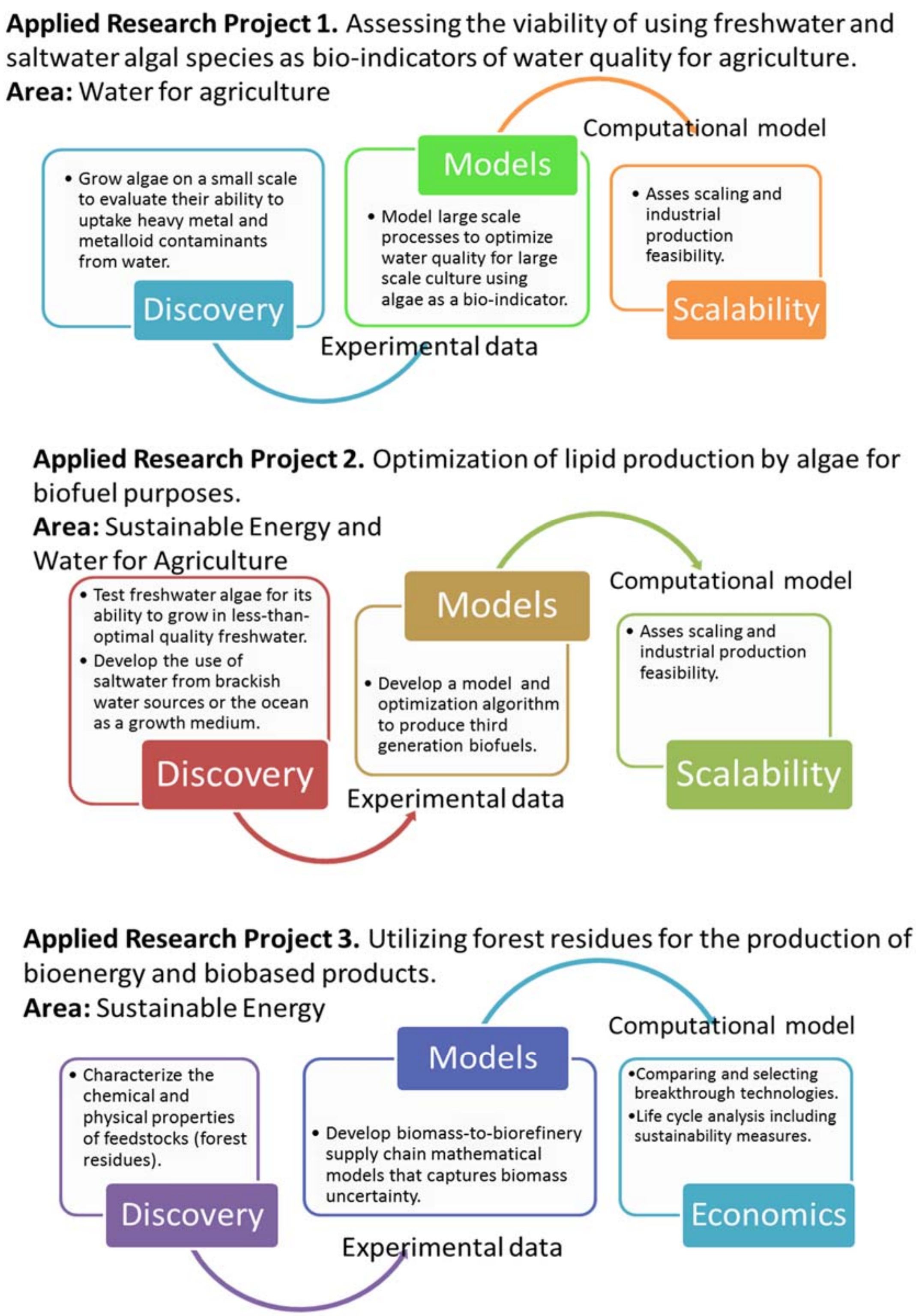
3.1 Integration of Educational and Research Thrusts

The interdisciplinary program of study covers three core thrusts: (1) ***biology topics*** such as plant biology, feedstock development and quality of water for agriculture, (2) ***quantitative techniques*** such as big data analytics, mathematical modeling, simulation, visualization, and optimization techniques for solving complex integrated bioenergy/water systems; and (3) ***engineering economics and life cycle analysis techniques*** to evaluate economic feasibility and commercialization of designs/emerging agriculture technologies.

This unique interdisciplinary approach fosters cross-core joint training and synergistic collaborations from research activities across the participating universities, which facilitates inter-institutional thesis/dissertation advisory committees.

This cross-disciplinary systems training is needed to address sustainability challenges. The trainees are expected to possess not only a strong experimental and science background but also a mathematical and systems engineering knowledge to excel in the solution of pragmatic problems in bioenergy and water systems. Some of the sample applied research projects are shown in Figure 2.

Figure 2. Sample research projects proposed in the BE AWARE Network.



3.2 Cross-institutional and multi-disciplinary exchanges.

Due to the interdisciplinary nature of the priority sustainability areas, laboratory rotations are implemented after the second year of the program to expose students to interdisciplinary environments and new research groups and facilitate open communication and exchange of information and experimental data among the participant institutions located in Texas and Puerto Rico. Lab rotations broaden the exposure of the students participating in this program to a different culture in a professional and academic setting. This lab rotation will enhance students' English proficiency for the fellows in Puerto Rico, professional communication skills and effectiveness working across cultures through delivering multiple presentations to the lab members and receiving feedback.

Remarkably, one of the universities in this network is the only institution in South Texas offering post-M.S. engineering programs and has served as an essential bridge to advanced higher education for under-represented students. This initiative provides students from other partnering institutions with opportunities to continue their formation at the masters and doctoral degree.

Importantly, minority students, located in noncontiguous United States, interested in pursuing a doctoral degree outside the island benefit from laboratory rotations as well as dynamic participation in technical and professional conferences so that the cultural shock does not become a deterrent. The other two institutions provide the academic opportunities to pursue doctoral degrees and the cultural compatibility (all the universities are Hispanic-serving institutions) to successfully sustain a STEM pipeline.

3.3 Experiential Learning Program

A survey conducted by the National Research Council showed that 60% or more interviewed students were not satisfied with their community involvement and students graduated with limited pragmatic/soft skills [4,13]. To overcome this issue, this program provides *paid summer internships* at federal national laboratories and local government agencies each summer. The outcomes of the internships are documented through student's final report and/or posters. Trainee's joint mentorship between an academic faculty mentor and an external mentor is continued throughout the academic year. This joint-mentorship program exposes the trainees to the current challenges in the agricultural systems, role models for counseling, network opportunities outside of academia, and community involvement. Within the February-April timeframe, summer internship workshops for students are conducted to raise awareness of these opportunities.

4.0 Tangible Outcomes and Knowledge Dissemination

It is expected that the graduate fellows develop and test decision-support tools, case studies and computational models as part of their research during the program. Due to the holistic and interdisciplinary nature of the proposed effort, technology transfer will take place by making available the computer codes, simulations and decision-making tools to the public. The fellows are furnished with the knowledge and training to develop computational and theoretical schemes to model and optimize bioenergy/water systems/designs. The Decision Support System (DSS) will cover the broad range of activities (i.e., cradle-to-grave) in the bioenergy business and will greatly benefit institutions at the national and international settings. This DSS will be developed by faculty and students and would have user friendly interfaces to communicate and share inputs/outputs with the existing computational tools developed by federal laboratories.

The undergraduate fellows, with assistance from graduate students and faculty, create at least short videos that present energy-water nexus challenges *in their own words*, and make them available to the public through the project's website and institutional social media to increase awareness of bioenergy and water for agriculture challenges.

5.0 Discussion and Conclusion

This paper describes an innovative and flexible educational and research model that possesses unique features such as an early faculty mentorship and career-oriented traineeship program, experiential learning in national laboratories, inter-institutional/interdisciplinary lab exchange in support of the development of comprehensive projects addressed from a systems-thinking perspective.

Even though this multi-disciplinary career-oriented education and research model is an on-going effort, the first year of its implementation has attracted minority students and provided valuable lessons. The minority recruitment activities were leveraged with existing programs and institutional resources at the participating institutions. The Office of Undergraduate Research (OUR) provides institutional support for cross-campus and cross-discipline impact. As a centralized facilitator of undergraduate research participation, the OUR will ensure inclusion of students of diverse backgrounds underrepresented in STEM fields.

The assessment for this first cycle consists of two mechanisms. The first evaluation process evaluates students' progress towards obtaining their degree. Trainees are evaluated based on GPA, academic progress, thesis/dissertation proposal and defense presentation (for graduate students), and publications (posters, conference papers and journal papers). The second evaluation process focuses on the efficacy of the program and faculty/external advisors. Each trainee completes an annual anonymous electronic survey, which will be modified from Murphy et al.[14] while in the program. Survey results and follow-up activities are discussed by the leadership team.

As this project progresses and students graduate from this program, two more evaluation processes will be conducted. The third evaluation process consists of tracking the career placement of trainees. Each student participating in the program will be asked to set up a Google Scholar account, ResearcherID and a LinkedIn profile. The Google Scholar and ResearcherID will be used to track the impact of the students' publications by monitoring citations to their published work. This project will create a LinkedIn account to which all students will be connected. The fourth evaluation process will assess the impact of the instructional material developed by requesting the users to open an account and provide contact information. This will provide information regarding the number of students/teachers/researchers using the material.

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