Graduate Learning at the Interface of Science, Engineering, and Business – The Energy and Environmental Studies Program at North Carolina Agricultural and Technical State University

Keith Schimmel, Derrek Dunn, Vereda King, Stephanie Luster-Teasley, Stephen McCary-Henderson, G.B. Reddy, Abolghasem Shahbazi, Harmohindar Singh, Valmi Sousa, Guoqing Tang, Godfrey Uzochukwu, Kenneth Murray
North Carolina A&T State University

Through its FUTURES planning process, North Carolina A&T State University has developed a vision to become a "learner-centered community that develops and preserves intellectual capital through interdisciplinary learning, discovery, engagement, and operational excellence." Toward achieving this vision, a new interdisciplinary doctoral program in Energy and Environmental Studies has been created in which the program office is in the School of Graduate Studies instead of a traditional engineering department. The program is designed to produce graduates able to: conceive, develop, and conduct original research leading to useful applications in energy and environmental systems; incorporate into their professional work considerations relating to scientific, technical, managerial, and social aspects of energy and environmental systems, and contribute to societal understanding of global energy and environmental issues through development of interdisciplinary educational materials and participation in international exchanges. To accomplish its objectives, the program uses core courses that integrate the technical, economic, legal, and ethical considerations involved in solving energy and environmental problems. The courses utilize case study and hands-on laboratory pedagogy for effective and deep learning. An internship is provided in an environment that fosters the development of leadership skills in solving energy and environmental problems. Dissertation requirements include an analysis of the potential economic and environmental impacts of the technology investigated.

I. Introduction

One of the most important technical challenges of the twenty-first century is the discovery of breakthroughs that are required to allow the world to shift civilization from dependence on energy derived from fossil fuels to energy from, first, nuclear power and, ultimately, sunlight. Many groups have begun to recognize the need to consider an interdisciplinary skill mix as well as the way work is accomplished to meet the challenges of this new century. The NSF (Environmental Science and Engineering for the 21st Century, February, 2000) has stated that "Environmental challenges are often exceedingly complex, requiring strengthened disciplinary inquiry as well as broadly interdisciplinary approaches that draw upon, integrate, and invigorate virtually all fields of science and engineering." Others have stated that a case for a new paradigm in engineering education can be made as follows: "Education strategies are being considered now that prepare a new professional to feel comfortable in a multidisciplinary framework. Individuals cannot have all the specialized knowledge relevant to decisions they make in their private, work, or civic life. They must realize through the education process, however, that such information is relevant and available. Even if they are not experts in everything, they can appreciate the work of others, and they can collaborate with others to achieve integrated solutions. Such an approach would enable graduates to apply their learning to the needs of real world problems and real people. Cross disciplinary education enlarges students' awareness of issues and methods beyond their own disciplinary inquiry, enabling them to explore the relationships among these issues and encouraging students to view their studies from a broader social and ecological perspective that takes into account human values and environmental, social, and economic sustainability." [1]

To respond to this need an interdisciplinary Doctor of Philosophy (Ph.D.) program in Energy and Environmental Studies has been established at North Carolina A&T State University to produce the experts needed to help meet this challenge (http://www.eng.ncat.edu/idp/ees). To be considered for admission to the Energy and Environmental Studies Program an applicant must satisfy the following requirement: Master's degree in Agriculture, Business and Economics, Engineering, Public Health and Policy, Science, or Technology. Consistent with the diversity of student disciplinary backgrounds reflected in this requirement (see Figure 1), the program will commence in fall 2005 with the first group of students consisting of eight students whose backgrounds include biology, biochemical engineering, chemical engineering (2 students), civil engineering, environmental engineering/computer science, food and nutrition, and mathematics/mechanical engineering.

Figure 1: Program graphic that emphasizes the interdisciplinary nature of the problems on which students will be working.

The need for the proposed program that provides an integrated approach to energy and environmental systems education and research has been highlighted in recent policy statements emanating from a variety of sources. In his 2003 State of the Union address, President Bush announced a $1.2 billion hydrogen initiative to reverse America's growing dependence on foreign oil and reduce greenhouse gas emissions:

With a new national commitment, our scientists and engineers will overcome the obstacles … so that the first car driven by a child born today could be powered by hydrogen, and pollution-free. Join me in this important innovation to make our air significantly cleaner, and our country much less dependent on foreign sources of energy.
-President Bush, State of the Union Address, January 28, 2003

A 2004 report National Academies report on the Department of Energy's hydrogen program concludes that:

A transition to hydrogen as a major fuel in the next 50 years could fundamentally transform the U.S. energy system, creating opportunities to increase energy security through the use of a variety of domestic energy resources for hydrogen production while reducing environmental impacts, including atmospheric CO_2 emissions and criteria pollutants.
-The National Academies, Committee on Alternatives and Strategies for Future Hydrogen Production and Use, February 2004

The importance of these policy initiatives is highlighted in a 2004 Department of Energy report:

Energy is the life-blood of our Nation. It is the mainstay of our standard of living, economy, and national security. In the United States demand for oil is projected to increase by nearly 50 percent by 2025. Petroleum imports already supply more than 55 percent of U.S. domestic needs, and those imports are projected to increase to more than 68 percent by 2025. Our growing dependence on foreign sources of energy threatens our national security. As a Nation, we must work to reduce our dependence on foreign sources of energy in a manner that is affordable and preserves environmental quality. Clean forms of energy are needed to support sustainable global economic growth while mitigating impacts on air quality and the potential effects of greenhouse gas emissions.

In the same report, the need for the broad approach to energy and environmental systems that is encompassed in the proposed Ph.D. program is highlighted:

Technical challenges to achieving a hydrogen economy include lowering the cost of hydrogen production, delivery, storage, conversion, and end-use applications. Additional needs include effective building codes and equipment standards to address safety issues as well as outreach and education campaigns to raise awareness, accelerate technology transfer, and increase public understanding of hydrogen energy systems.
-United States Department of Energy, Hydrogen Posture Plan: An Integrated Research, Development, and Demonstration Plan, February 2004

Finally, this report highlighted the need for an international effort to meet these challenges. The report lists the members of the International Partnership for the Hydrogen Economy – Australia, Brazil, Canada, China, European Community, France, Germany, Iceland, India, Italy, Japan, Norway, Republic of Korea, Russia, United Kingdom, and United States. The Energy and Environmental Studies Program is designed to provide students with the skills and expertise necessary to operate in such a global research effort.

II. Special Features of the Program

To reach its educational objectives, the Energy and Environmental Studies program employs the following features:

- ***Innovative core courses that integrate the technical, economic, legal, and ethical considerations involved in solving energy and environmental problems***
  The courses utilize case study and hands-on laboratory pedagogy for effective and deep learning. This emphasis will include the development and use of unique energy and

environment related remote experiments to be shared with K-12 schools and other universities.

- ***Elective sequences of courses that provide students depth of technical knowledge in their research area***
  Distance education courses from government agencies and other universities will be utilized as needed to maximize elective choices for students and provide courses on cutting edge technologies.

- ***An optional semester long internship***
  The internship occurs in an industry, consulting, or government environment that fosters the development of leadership skills in solving energy and environmental problems.

- ***Dissertation requirements include an analysis of the potential economic and environmental impacts of the technology investigated***

- ***Core campus-wide analytical facilities with well-maintained energy and environmental analytical equipment on which students are trained by lab managers***

III. Program Organizational Structure

Figure 2 provides an overview of the organizational structure that has been developed to meet the needs of interdisciplinary graduate programs at North Carolina A&T State University. The key feature of the structure is that the Energy and Environmental Studies Program is housed in the graduate school, and as such, it interfaces with disciplinary programs from across campus to stimulate interdisciplinary approaches to problems of common interest. Recognizing that the success of the program depends on faculty researchers and graduate students being productive, the intent of the structure is to be highly responsive to the needs of faculty and students.

IV. Program Options and Degree Requirements

The program requires 51 credit hours beyond the M.S. degree distributed as follows:

27 credit hours for course work,
3 credit hours for seminars,
3 credit hours for professional practice/development, and
18 credit hours for dissertation research.

Students progress through the program by passing a written qualifying exam over the four core courses and a preliminary exam over their proposed research. As an indicator of their research competency, all students will be required to submit at least two refereed journal articles that have been approved by their dissertation committee before graduation. The program requirements are summarized in Table I.

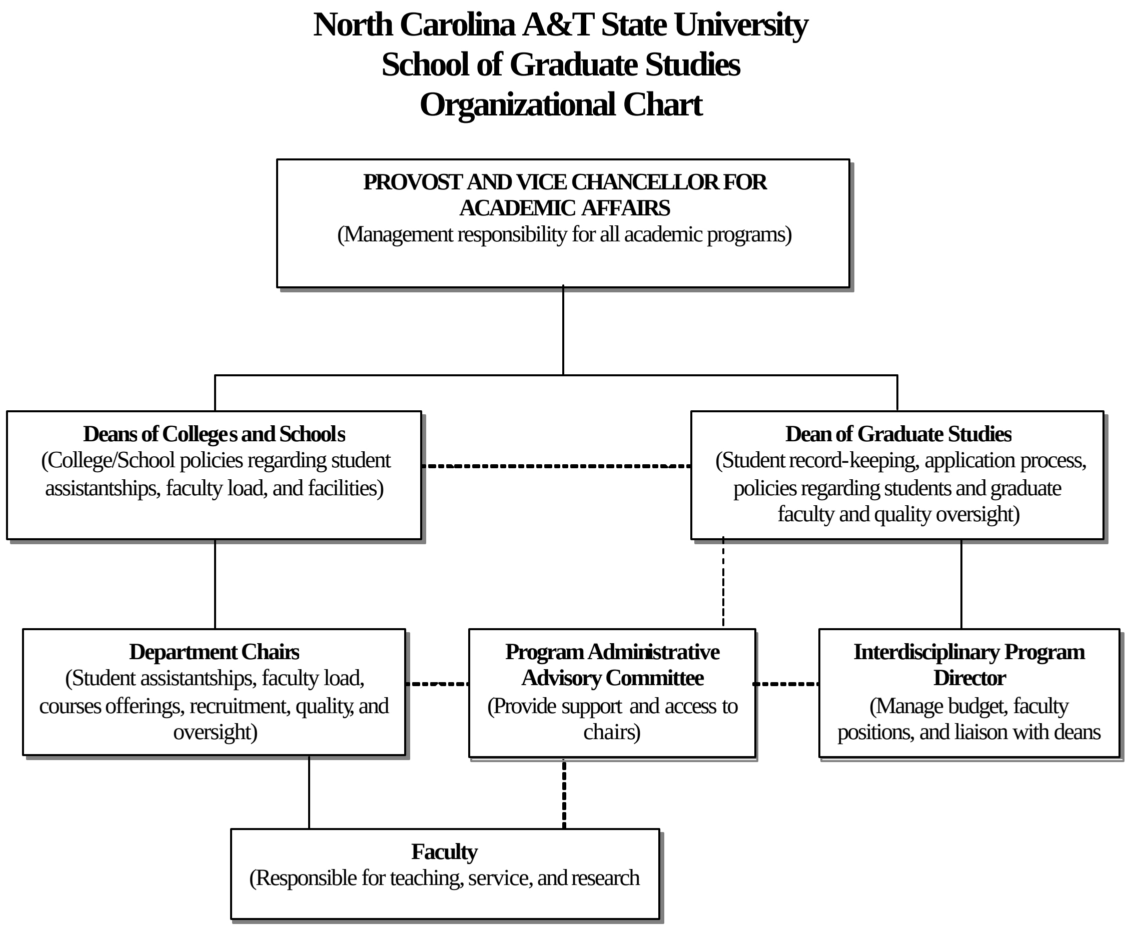

Figure 2: Interdisciplinary graduate program organizational chart.

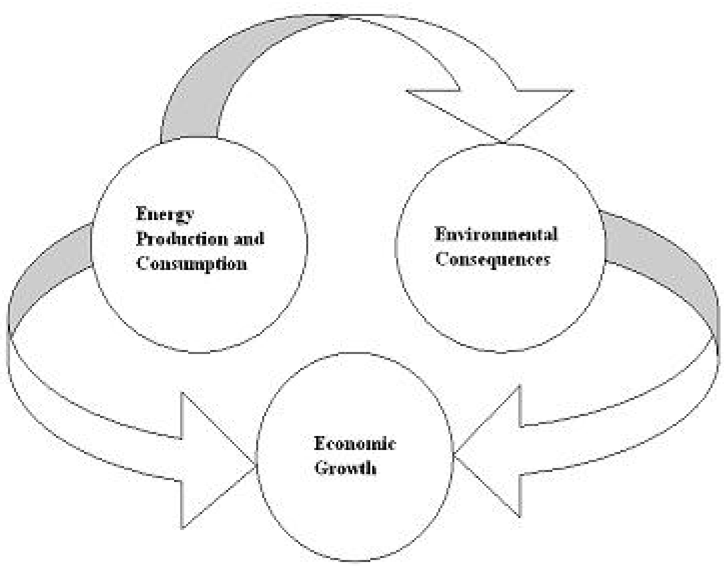

Figure 3: Integration strategy that is employed throughout the core courses.

Table I: Energy and Environmental Studies Program Requirements

Requirement Category	Credits	Courses
Core Courses	12	EES 720, 810, 811, 820.
Written Qualifying Examination	0	EES 991. Covers core courses only.
Elective Track	9	Courses at the 700-level or 800-level. Options are presented below.
Supervised Teaching/Practicum	3	EES 990 or EES 993
Seminar Requirement	3	EES 992
Technical Electives	6	Courses at the 700-level or 800-level. Subject to advisor approval.*
Preliminary Examination	3	EES 995
Dissertation	15	EES 997
TOTAL	**51**	

*EES 710 (Theory and Practice of Energy and Environmental Science) required as a core course only for students who have not previously had undergraduate or graduate courses in the biological or chemical aspects of energy and environmental science.

The program seeks to provide the students the proper balance of breadth and depth in their area of research expertise. The learning objectives and pedagogy for the core courses have been carefully designed to provide the students with experience integrating energy, environmental, and economic topics. Through an elective track sequence of at least three courses, students gain content depth in their research area. Most of these courses are expected to be developed by existing disciplinary departments with the Energy and Environmental Studies Director responsible for the development and assessment of only the core group of courses. Descriptions of the primary program courses are as follows:

EES-710. Theory and Practice of Energy and Environmental Science
This course presents both the biological and chemical aspects of energy and environmental science. The biological aspects involve the role of microbes in the environment, remediation processes, and energy production, while the chemical aspects deal with the chemistries of air, water, and soil systems.

EES-720. Theory and Practice of Alternative Energy Technologies

The course will cover the thermodynamic, mass and energy balance, economic, and environmental considerations of alternative energy technologies. Alternative energy technologies and conventional energy technologies will be compared.

EES-810. Economic and Legal Aspects of Energy and Environmental Management I

This course is a study of economic and legal concepts that affect the decision-making process in the management of energy and the environment. Policy case studies that emphasize environmental management are used to allow a variety of perspectives to be examined.

EES-811. Economic and Legal Aspects of Energy and Environmental Management II

This course is a continuation of EES 810 with an emphasis on energy management.

EES-820. Acquisition and Management of Energy and Environmental Data

This course is a study of theories and techniques for acquiring and managing scientific data and information related to the analysis, design, and management of energy and environmental systems.

EES-990. Doctoral Supervised Practicum

This course represents the supervised internship for the doctoral student that satisfies the 3 credits of required professional development. Oral and written presentations on the experience will be provided to the faculty. Grading is pass/fail evaluation only.

EES-991. Doctoral Qualifying Examination

This course will guide the student to take the qualifying examination. The qualifying examination will consist of a written examination over the Energy and Environmental Studies program core courses. Prerequisites: EES 720 and EES 810. Corequisites: EES 811 and EES 820.

EES-992. Doctoral Seminar

This course includes presentations delivered by the doctoral student, faculty, and invited speakers. Each registered student will present at least one seminar and provide at least one formal critique of a presentation.

EES-993. Doctoral Supervised Teaching

This course represents the supervised teaching for the doctoral student that satisfies the 3 credits of required professional development. This course introduces the doctoral student to classroom or laboratory teaching under the supervision of a faculty mentor. Doctoral students who serve as teaching assistants or as instructors are required to take this course during the first semester they teach.

EES-995. Doctoral Preliminary Examination

In this course dissertation advisors will guide their students towards completing the preliminary examination. The preliminary examination will consist of a written proposal and oral defense of the student's dissertation proposal. Prerequisite: EES 991.

EES-997. Doctoral Dissertation

This course represents the supervised research leading to the dissertation for the doctoral student who has passed the preliminary exam. Doctoral dissertation research will be conducted under the supervision of the dissertation committee chairperson and include regular meetings with the dissertation committee to evaluate progress on the dissertation. Prerequisite: EES 995.

Core Research Areas/Elective Tracks

Current energy and environmental related research funding at North Carolina A&T State University is about $4 million per year and is focused in the following areas:

- Renewable Energy Technologies
  (Biomass, Solar, Wind, Energy Storage, Fuel Cells, Hydrogen Fuel Infrastructure)
- Biotechnology
- Energy and Environmental Education
- Energy and Environmental Information Technology
- Energy and Environmental System Modeling
- Environmental Health
- Environmental Justice
- Environmental Sciences
- Fate and Transport of Contaminants
- Materials
- Nanotechnology
- Power Electronics System
- Sensors and Controls
- Separations and Reactions
- Solid and Hazardous Waste Management
- Sustainable Manufacturing
- Sustainable Technologies for Built Environments
- Systems Management and Economics
- Transportation and Logistics

This list reflects both areas of emphasis for development of research projects as well as elective course areas that will be supported. The foundation for building additional research capacity is the following current group of research centers:

NSF Center for Advanced Materials and Smart Structures (http://camss.meen.ncat.edu/camss/)
NSF Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (http://www.nano-cemms.uiuc.edu)
NSF Center for Power Electronics Systems (http://www.cpes.vt.edu)
NSF STC for Environmentally Responsible Solvents and Processes (http://www.nsfstc.unc.edu)

Additional information on Energy and Environmental related centers at North Carolina A&T State University is available at http://dor.ncat.edu/ under/center/ and http://www.ag.ncat.edu/research/.

V. Pedagogy Employed – Problem Based Learning/Case Studies/Inquiry Learning
To enhance the depth of student learning of energy and environmental topics in the core courses, more active learning strategies will be employed than is typically the case at the graduate level. An example area in which such course materials have been developed is biodegradable polymers. Following is some information that gives a flavor for how such an area will be presented in the core courses.

Polymers are used widely in modern society because they are light in weight, low in cost, and easy to process materials. However, there is an increasing and global-scale concern over the environmental consequences of products made of polymers when they eventually end up in landfills after their intended uses. Polymers derived from agricultural feedstock can be biodegradable and play a role in helping alleviate the environmental concerns. Biodegradable polymers have a wide range of potential applications in markets currently dominated by petroleum-based materials such as drug delivery systems, flushable diapers, controlled release systems for agricultural chemicals, disposable nonwovens, horticultural containers, washable paints, and lubricants.[2]

Most natural polymers, such as starch, cellulose, and proteins are readily biodegradable through hydrolysis followed by oxidation with the aid of enzymes. Synthetic polymers may attain biodegradability by incorporating hydrolyzable linkages in their backbones. Aliphatic polyesters have been known to be the most easily biodegradable synthetic polymers. Important examples of synthetic biodegradable polymers of industrial scale include polyvinyl alcohols, polycaprolactones (such as Tone polymer by former Union Carbide)[3], and polylactic acid (pioneered by Argonne National Laboratories). Although there are issues related to both cost and monomer supplies, development of lactic acid based biodegradable polymers appears to be most active, and a number of commercial projects are under way.

Laboratory units have been designed to provide an inquiry-based educational experience to students by exposing a variety of polymer samples to simulated biomass environments and characterizing the samples against the exposure time. It is known that molecular properties of polymers, such as molecular weight distribution, crystallinity, and morphology, will dictate the physical properties of the final products made from these polymers. When a polymer sample undergoes biodegradation, many chemical and physical properties will change.[4-6] The following chemical and physical properties are measured at various exposure times:

(1) Melt Index (MI), which indirectly measures the average molecular weight of the polymer;
(2) Molecular Weight Distribution (MWD) by gel-permeation chromatography (GPC), which gives detailed molecular information regarding the degree to which the degradation proceeds;
(3) Thermogravimetric analysis (TGA), which indicate the characteristics of the low molecular weight degradation products;
(4) Tensile stress-strain curve, which reflects physical weakening of the polymer due to degradation.

Finally, the degradation kinetics are determined through the use of a respirometer that measures the gas-phase oxygen concentration.

These biodegradable polymer laboratory units will be utilized in EES 710. Groups of students will be presented with a product development scenario that they might encounter if they worked for a company involved with the development of biodegradable polymers. This activity will provide students opportunity to:

1) Work in groups with people of diverse expertise,
2) Learn environmental science concepts in the context of real problems,
3) Develop literature, patent, and vendor search skills,
4) Integrate content from science, engineering, and business,

5) Gain experience with analytical and data analysis techniques relevant to environmental science.

VI. Development Plan/Program Challenges

Provided below is an outline of some of the key factors involved in successfully working at the interface of science, engineering, and business development in a new interdisciplinary graduate program such as the Energy and Environmental Studies Ph.D. Program. Consistent with principles described in the 2005 National Academies Press report entitled "Facilitating Interdisciplinary Research" [7], strategies are presented for addressing the challenges.

1) **Hardworking, productive, interdisciplinary faculty who feel ownership of the program and a desire to collaborate with colleagues**
   (a) Consistent recruitment of high-quality, new faculty with fresh ideas and experience with cutting-edge technologies is needed. This requires open communication between faculty search committees in different departments, schools, and colleges at to determine which research specialties are needed to complement existing strengths. To successfully recruit high-quality candidates, the program will need to garner resources for start-up packages, easier access to quality lab space, competitive salaries, university supported sabbaticals, and appropriate teaching loads.
   (b) University supported sabbaticals are needed to allow established faculty to maintain research efforts on the cutting-edge of technology. Faculty professional growth needs to be encouraged through facilitating workshops and meetings with investigators at other universities, government agencies, and companies.
   (c) A significant barrier to interdisciplinary collaboration is the physical separation of faculty and students on campus. Creative ways of maximizing the opportunities for faculty from different areas to engage in conversations about their research interests are being experimented with.
   (d) Good communication in a campus-wide program is important and challenging. Dissemination of information by members of the program advisory committee to colleagues in their academic units is one important element of good communication. Regular input on program decisions and direction is solicited from faculty via Blackboard delivered surveys and other means.

2) **Hardworking, productive, interdisciplinary students who feel ownership of the program and are successful in obtaining attractive jobs**
   (a) There is keen, global competition today for quality graduate students. To be successful in recruiting the students needed to sustain the program will require offering competitive stipends to U.S. citizens and international students, an aggressive marketing campaign, an innovative curriculum, and graduate success stories.
   (b) The EES program has been designed with a number of features geared to prepare students for successful careers – internship opportunities, management training, etc. Additionally, the program has a focus on the development of good technical communication skills and networking with colleagues outside of North Carolina A&T.

3) **Adequate lab space that is well maintained, equipped, and staffed**

Recruitment of new faculty and students and research productivity are aided by quality facilities. The program leadership is aggressively working with others across campus to minimize inefficient use of facilities, staff analytical labs with the technician support that is needed to enhance research productivity, and provide strong support for key Energy and Environmental analytical facilities across campus.

4) **Identification of significant common research problems for which either we have or can attract the resources necessary to make a worthwhile contribution to solving**
A true interdisciplinary research program is focused on research problems instead of disciplines. One of the fundamental challenges to the Energy and Environmental Studies Program will be to be inclusive of new research areas without spreading resources too thin. The program leadership is working with the campus community to identify the few research areas (common problems to solve) that should be of highest priority and strongly support these areas while being open to discussing new areas with faculty and helping them to identify possible new sources of funding.

5) **Ability to overcome institutional barriers to interdisciplinary research**
Budget control, indirect cost recovery distribution, compatibility with college/department strategic plans, promotion and tenure criteria, unit reporting relationships, space allocation, and honoring award agreements are institutional issues that are being addressed for a successful interdisciplinary program.

6) **Regular program assessment**
A comprehensive assessment plan is being developed for the program that will provide data on whether the goals of the interdisciplinary program are being accomplished and to provide a rationale basis for changes in the program. Whether or not students are developing a sense of what it means to integrate more than one discipline in addressing a complex research question is one key aspect of the program that will be regularly assessed.

VII. Conclusion

The challenge for interdisciplinary graduate programs working at the interface of science, engineering, and business is succinctly presented in the following quote attributed to Albert Einstein: "The problems that exist in the world today cannot be solved by the level of thinking that created them." The solution to this challenge is presented in a quote from George Washington Carver who helped revolutionize agriculture in the southern U.S in the early 20th century: "Since new developments are the products of a creative mind, we must therefore stimulate and encourage that type of mind in every way possible." It is hoped that features that have been incorporated into the new Energy and Environmental Studies Ph.D. Program at North Carolina A&T State University will help to produce graduates with creative minds that can contribute to innovations in energy and environmental problems that are at the interface of science, engineering, and business.

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KEITH SCHIMMEL
Keith Schimmel is Associate Professor of chemical engineering in the College of Engineering at North Carolina A&T State University, Director of the energy and environmental studies Ph.D. program, and a registered professional engineer in North Carolina. He received a B.S. degree in chemical engineering from Purdue University. He also holds M.S. and Ph.D. degrees in chemical engineering from Northwestern University.

DERREK DUNN
Derrek Dunn is Associate Professor of electronics-computer technology in the School of Technology at North Carolina A&T State University, Chair of the electronics-computer technology department, and member of the energy and environmental studies Ph.D. program advisory committee. Dr. Dunn received his B.S. degrees in electrical engineering and math from the North Carolina A&T State University. He holds M.S. degrees in mathematics and electrical engineering from the Virginia Polytechnic Institute and State University. His Ph.D. is in electrical engineering from the Virginia Polytechnic Institute and State University.

VEREDA KING
Vereda King is Associate Professor of economics in the School of Business and Economica at North Carolina A&T State University and member of the energy and environmental studies Ph.D. program advisory committee. Dr. King received her B.A. degree in economics and math from Johnson C. Smith University. She holds M.B.A. and Ph.D. degrees from North Carolina Central University and Duke University, respectively.

STEPHANIE LUSTER-TEASLEY
Stephanie Luster-Teasley is Assistant Professor of civil/chemical engineering in the College of Engineering at North Carolina A&T State University and member of the energy and environmental studies Ph.D. program advisory committee. Dr. Luster-Teasley received her B.S. degree in chemical engineering from North Carolina A&T State University. She holds M.S. and Ph.D. degrees in environmental engineering from Michigan State University.

STEPHEN MCCARY-HENDERSON
Stephen McCary-Henerson is Assistant Professor of curriculum and instruction in the School of Education at North Carolina A&T State University and member of the energy and environmental studies Ph.D. program advisory committee. McCary Henderson received his B.S. degree from North Carolina A&T State University. He holds M.S. and Ph.D. degrees in education from the University of Southern Mississippi and Union Institute and University, respectively.

G.B. REDDY
G.B. Reddy is Professor of natural resources and environmental design in the School of Agriculture and Environmental Sciences at North Carolina A&T State University, Chair of the natural resources and environmental design department, and member of the energy and environmental studies Ph.D. program advisory committee. Dr. Reddy received his B.S. and M.S. degrees in agriculture from A.P.A.U. (India). His Ph.D. degree is in Soil Microbiology from the University of Georgia.

ABOLGHASEM SHAHBAZI
Ghasem Shahbazi is Professor of agricultural and biosystems engineering in the College of Engineering at North Carolina A&T State University, Director of the agricultural and biosystems engineering department, and member of the energy and environmental studies Ph.D. program advisory committee. Dr. Shahbazi received his B.S. degree in agricultural engineering from the University of Tabriz. He holds M.S. and Ph.D. degrees in agricultural engineering from the University of California, Davis and Pennsylvania State University, respectively.

HARMOHINDAR SINGH
Harmohindar Singh is Professor of architectural engineering in the College of Engineering at North Carolina A&T State University, Director of the Center for Energy Research and Technology, a registered professional engineer in North Carolina, and member of the energy and environmental studies Ph.D. program advisory committee. Dr. Singh received his B.S. degree from Punjab University. He holds M.S. and Ph.D. degrees from Wayne State University.

VALMI SOUSA
Valmi Sousa is Assistant Professor of nursing in the School of Nursing at North Carolina A&T State University, a registered nurse, and member of the energy and environmental studies Ph.D. program advisory committee. Dr. Sousa received his B.S.N. degree from the Faculty of Nursing and Obstetrics of Guarulhos, Guarulhos, BZ. He holds C.S. and M.S.N. degrees from the Federal University of Sao Paulo, Sao Paulo, BZ. His Ph.D. degree is from Case Western Reserve University.

GUOQING TANG
Guoqing Tang is Associate Professor of mathematics in the College of Arts and Sciences at North Carolina A&T State University and member of the energy and environmental studies Ph.D. program advisory committee. Dr. Tang received his B.S. degree in applied mathematics from Anhui University. He holds M.S. and Ph.D. degrees in mathematics from the Nanjing University of Science and Technology and Rutgers University, respectively.

GODFREY UZOCHUKWU
Godfrey Uzochukwu is Professor of natural resources and environmental design in the School of Agriculture and Environmental Sciences at North Carolina A&T State University, Director of the Waste Management Institute, and member of the energy and environmental studies Ph.D. program advisory committee. Dr. Uzochukwu received his B.S. and M.S. degrees from Oklahoma State University. His Ph.D. degree is from the University of Nebraska.

KENNETH MURRAY
Kenneth Murray is Professor of civil engineering at North Carolina A&T State University, Associate Vice Chancellor for Academic Affairs and Interim Graduate Dean, a registered professional engineer in North Carolina, and member of the energy and environmental studies Ph.D. program advisory committee. Dr. Murray received his B.S., M.S., and Ph.D. degrees in civil engineering from the Virginia Polytechnic Institute and State University.