122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #13733

CREST Bioenergy Center

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Abstract

Biomass ranks fourth in world-wide resources for energy following oil, coal, and natural gas. The production of energy from biomass has been recognized as an important step towards sustainable energy development. In recent years, most of the attention for renewable hydrocarbon biofuels has focused on cellulosic ethanol.[1] However, thermochemically derived biofuels have a number of advantages over cellulosic ethanol including flexibility in choice of feedstock, use of whole biomass, and the ability to produce drop-in transportation fuels. As a consequence of the lower investment in thermochemical biofuels than in cellulosic ethanol, research on thermochemical routes to produce biofuels is greatly needed for the widespread implementation of the next generation of hydrocarbon biorefineries.[2,3] The NSF funded CREST Bioenergy Center at North Carolina A&T State University is an educational and research resource in the field of thermochemical conversion of biomass to bioenergy that is preparing students to meet this global challenge. In addition to three core research thrust areas, the Center has an economics cross-cutting research and education initiative.

The educational program of the Center emphasizes mentoring to develop underrepresented students in core science and engineering areas relevant to bioenergy. The degree programs associated with the Center are the interdisciplinary energy and environmental systems PhD (sustainable bioproducts concentration); nanoengineering PhD; and BS and MS programs in chemistry, chemical engineering, biological engineering, and mathematics. The objectives of the center's educational and outreach activities include to: 1) establish scholarships in bioenergy for graduate and undergraduate students; 2) establish a sustainable educational and research program in sciences and engineering related to bioenergy that is integrated into undergraduate research and graduate theses and dissertation projects; 3) partner with current K-12 summer camps; 4) develop and implement a coordinated program for recruiting students; 5) provide opportunities for faculty members and students to spend time at industrial and government labs; and 6) create an interdisciplinary community of learning, discovery, and engagement that will promote excellence and internal and external collaboration in the bioenergy area.

This paper will present an overview of the Center along with survey and focus group assessment and evaluation of Bioenergy Center activities impacting student skill development needed to address current and future engineering challenges.

Introduction

Fig. 1 summarizes the Center's research thrusts and themes. Alcohols, Fisher-Tropsch fuels, and hydrogen have established markets or are considered to be promising alternative transportation fuels. However, these alternative fuels have not been commercially produced from abundant sources of lignocellulosic biomass such as crop residues, forest residues, and food processing wastes due to the low conversion efficiency and high production costs of the processes to produce them.[4] The thermochemical conversion of lignocellulosic biomass into second-generation biofuels integrates the processes of biomass gasification and biofuel synthesis. However, this promising, combined process remains far from commercialization because it still requires optimization.[5] Gasification has been identified as an energy-efficient, environmentally-friendly and economically feasible technology to convert biomass into syngas consisting of H_2, CO, CH_4 and CO_2 by partially oxidizing biomass.[6] Processes for biomass gasification are notoriously convoluted due to the complexity of reactions for gasification and the variability in the composition of biomass. Thus, an increased understanding of the chemistry of gasification, interactions of gas-biomass particles, and comminution of biomass particles during gasification is necessary to advance the design and operation of a biomass gasifier in which the quality of the syngas can be precisely predicted and controlled.[7]

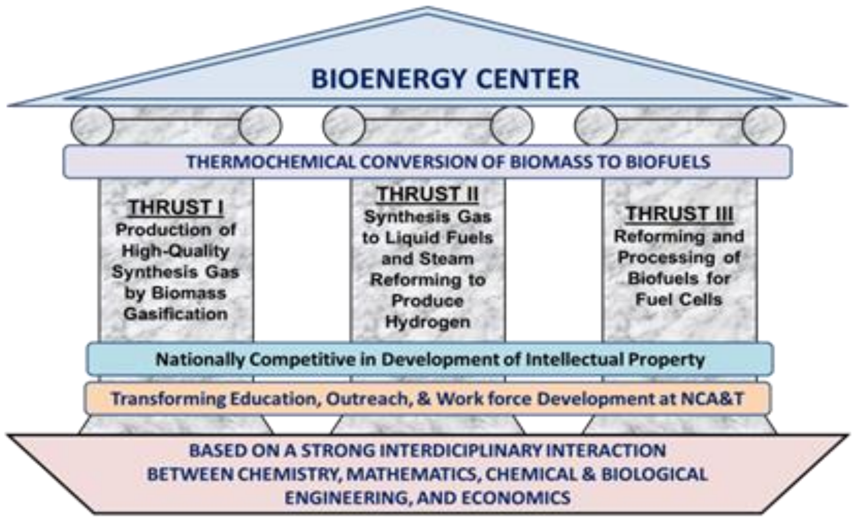

Fig. 1: Center thrust areas and themes

The syngas can be further used to synthesize liquid fuels or produce H_2 over catalysts made of transition metals.[6] Due to long-term high crude oil prices and new environmental requirements limiting residual sulfur (30-50 ppm) in diesel fuel, the Fisher-Tropsch synthetic (FTS) process ($2n\ H_2 + n\ CO \rightarrow C_nH_{2n+2} + n\ H_2O$) has recently gained increased interest for use in converting the H_2 and CO in syngas into liquid hydrocarbons. FTS fuel is of high purity with zero sulfur content and little or no aromatic contamination.[8,9] Catalysts play a pivotal role in the conversion of the syngas to hydrocarbon fuels via FTS.[10] FTS can also be used to produce liquid fuels such as methanol and ethanol.[11] Gasification of different types of biomass under different conditions can produce a wide range of compositions of syngas with H_2 to CO ratios varying between 0.45 and 2. Syngas produced by gasification of biomass contains a large amount of CH_4, CO_2, and tar. The molar ratio of H_2 to CO in syngas for the synthesis of liquid fuels via FTS should be close to 2. The carbon, hydrogen, and oxygen in biomass can be precisely converted into CO and H_2 in the syngas by using a proper amount of steam and recycling any CO_2 produced from the biomass as oxidant agents.[12]

Production of hydrocarbons from biomass is considered to be a leading option for supplying energy in the near- and mid-term future.[13,14] Steam reforming is a popular route to produce H_2 from syngas or from hydrocarbons and low-molecular weight alcohols produced in FTS. Of the different candidates for a source of H_2 fuel, methanol and ethanol are currently being investigated intensely.[15,16] The transition to an economy based on energy from H_2 demands a significant reduction in the cost of high purity H_2.[17] Separation of H_2 is a key technology in overall schemes for the production of H_2, whether it is from gasification of biomass or coal or steam reforming of hydrocarbons and/or alcohols. Membranes and techniques based on membranes are increasingly becoming key determinants of technical and economic efficiency in production and use of H_2. From the end-user's perspective, there has been a growing interest in Proton Exchange Membrane Fuel Cells (PEMFC) because of their high power density, high efficiency, and near-zero emissions to the environment. Reformed methanol and liquid hydrocarbons are expected to be major fuel sources in PEMFCs for use in terrestrial transportation.[18] The CO_2 generated during catalytic reforming can be removed from the H_2 using the membrane-based technology and then used as a gasifying agent. Co-feeding of CO_2 recycled from the downstream processing of syngas and H_2 from other sources can suppress the formation of CO_2 from biomass and, thus, increase the CO concentration in syngas during gasification.[19]

Methodology

Center directors identified the need to study how well the Center prepares graduate students to conduct research as part of formative evaluations of the Center in light of its mission. To answer this question and gather details of the perspectives of students and faculty related to student preparation, an external evaluator developed two parallel surveys. These surveys, administered online, asked students and faculty, independently, about the strategies to which students are exposed to develop their research skills, as well as the impact of these strategies and faculty mentoring on their preparation. A total of nine graduate students and nine faculty members who are actively engaged in the Center's research provided responses.

Student Responses

Strategies

Students were first asked to indicate from among a list in which strategies to improve students' research-related skills they had participated, and then to indicate which ones had most positively impacted them. As shown in **Table 1**, students participated in a variety of activities, with most indicating that the ones in which they had participated had positively impacted them. The most common experiences noted were research experiences with Center faculty, being mentored by them, and attending and/or presenting at seminars and conferences. Students provided ratings

Table 1.
Student Ratings of Strategies - Participation and Impact

	Participation		**Positive Impact**	
	n	**%**	**N**	**%**
Research experiences with CREST Bioenergy Center faculty	9	100%	7	78%
Mentoring by NSF CREST Bioenergy Center faculty	6	67%	3	50%
Attending seminars and/or conferences	5	56%	5	100%
Presenting at seminars and/or conferences	5	56%	5	100%
Industrial internship experiences	3	33%	0	---
STEM courses	3	33%	2	67%
Field study experiences	2	22%	2	100%
Web-based tutorials	2	22%	1	50%
Research experiences outside of CREST Bioenergy Center	0	---	0	---

above 4.0 (on a scale of 1 to 5) to the below areas, indicating that their skills and knowledge had increased in these areas:

- Ability to work independently in a lab (mean = 4.22)
- Knowledge of areas of research related to bioenergy (mean = 4.11)
- Data presentation skills (mean = 4.00)
- Ability to conduct thorough literature reviews (mean = 4.00)

Ratings were relatively neutral for the following areas, indicating that their research and mentoring had little impact on their knowledge and skills in these areas:

- Knowledge of careers related to bioenergy (mean = 3.22)
- Knowledge of other STEM careers (mean = 3.22)
- Technical writing skills (mean = 3.22)
- Teaching skills (mean = 3.11)
- Mentoring skills (mean = 3.11)

Suggestions students provided for improving strategies designed to increase their research-based skills and STEM knowledge included: 1) providing state-of-the art instrument accessibility and training; 2) providing internship opportunities; 3) emphasizing that students obtain work or teaching experience; and 4) providing mentoring on how to be a researcher or how to conduct independent research. Other comments included the following:

> *"I wish we had more interaction with the other CREST areas... maybe even some social events."*
>
> *"There is need for promotion and fostering of team work; especially in the complex projects that require the expertise of many individuals. It should not be left for a single individual."*
>
> *"Closer one-on-one in labs with mentors and advisors."*

Mentoring

Students indicated that mentoring most positively impacted them in terms of conducting literature reviews, increasing their knowledge of their research area, improving their independence, and improving their technical presentation and data analysis skills (see **Table 2**).

Thrust Areas

Students rated their knowledge of the areas of research in which the three thrust groups are engaged and the role of the overarching economic thrust group relatively low: 3.22 and 3.50, respectively, on a scale of 1 (Low) to 5 (High). Students reported that the benefits of meeting within their thrust group included the ability to discuss new ideas and hear what others are doing. On the benefits, one student wrote, "advice, different outlooks, troubleshooting ideas, encouragement/ motivation." Another student wrote, "It increases knowledge of bio-energy in the areas in which one's project is connected to others." Other comments suggested that these meetings support collaboration and improves analytical skills and presenting skills. According to

Table 2.
Positive Impacts of Being Mentored

	n	%
Literature review	7	78%
Knowledge of research area	6	67%
Independence	5	56%
Technical presentation	4	44%
Research ethics awareness	4	44%
Data analysis and presentation	4	44%
Networking	3	33%
Scientific method	3	33%
Creativity	3	33%
Knowledge of bioenergy	3	33%
Technical writing	2	22%
Computer software	2	22%
Knowledge of STEM careers	2	22%
Teaching	1	11%
Leadership / Mentoring	1	11%
Hardware troubleshooting	1	11%

one student, "It also helps advance the research because some of the questions asked lead the researcher to investigate other things that they themselves had not thought of."

Students reported meeting with members of the other thrust groups to hear about their research and/or collaborate less frequently (generally once a month) but found these meetings beneficial as it allowed them to hear about others' research work and their progress. Two comments were, "Meetings help build the researchers' knowledge of what is going on in other areas of bioenergy." and, "Gives me ideas of what they are working on, and the need to link my area to theirs."

Faculty Responses

Strategies

Faculty were first asked to indicate in which strategies to improve students' research-related skills they had participated and in which ones they believed had most positively impacted students. As shown in **Table 3**, faculty indicated that they had participated in a variety of activities, with most indicating that the ones in which they had participated had positively impacted students. The most common experiences noted were research experiences, mentoring, attending seminars and/or conferences, and presenting at seminars and/or conferences. Next faculty indicated which among a list of skills/knowledge areas their university most emphasizes

Table 3.
Faculty Identification of Strategies - Participation and Student Impact

	Participation		Positive Impact	
	n	**%**	**N**	**%**
Research experiences with CREST Bioenergy Center faculty	9	100%	7	78%
Mentoring by NSF CREST Bioenergy Center faculty	9	100%	6	67%
Attending seminars and/or conferences	2	22%	2	100%
Presenting at seminars and/or conferences	2	22%	1	50%
Industrial internship experiences	1	11%	1	100%
STEM courses	0	---	0	---
Field study experiences	6	67%	6	100%
Web-based tutorials	7	78%	6	86%
Research experiences outside of CREST Bioenergy Center	8	89%	7	88%

Table 4.
Skills and Knowledge Supported by the University and Faculty

	University	**Faculty**
Scientific method	9	8
Technical writing	8	8
Technical presentation	8	8
Literature review	8	7
Knowledge of research area	8	7
Data analysis and presentation	7	6
Research ethics awareness	6	4
Knowledge of bioenergy	6	7
Networking	5	2
Creativity	5	4
Knowledge of STEM careers	4	4
Independence	3	7
Computer software	2	1
Teaching	1	1
Leadership / Mentoring	1	1
Hardware troubleshooting	1	0

and the ones they, themselves, do. As can be seen in **Table 4**, the ones the university emphasizes map closely to the ones the faculty also emphasize. As shown in **Table 5**, faculty rated students' skills and knowledge as strongest in terms of their research ethics awareness, knowledge of STEM careers, technical presentation skills, knowledge of the scientific method, and networking. However, even these ratings were relatively neutral, with means ranging from 3.38 to 3.71 on a scale of 1 (Low) to 5 (High), with some large standard deviations (0.49 – 1.07).

Table 5.
Faculty Ratings of Students' Skills and Knowledge

	Mean	**sd**
Research ethics awareness	3.71	0.49
Knowledge of STEM careers	3.50	1.07
Technical presentation	3.40	0.70
Scientific method	3.40	0.70
Networking	3.38	0.74
Knowledge of bioenergy	3.25	1.04
Computer software	3.13	0.64
Knowledge of research area	3.11	0.78
Data analysis and presentation	3.11	0.60
Leadership / Mentoring	3.00	1.00
Literature review	3.00	0.47
Creativity	2.88	1.13
Independence	2.75	0.89
Teaching	2.71	0.95
Technical writing	2.70	0.67
Hardware troubleshooting	2.43	0.79

Strategies faculty use to emphasize the above include meeting with students every week to review data and discuss their research, encouraging students to do research independently and explore new ideas, and allowing them the “freedom to fail”. Eight respondents indicated that their strategies had been "somewhat successful" in improving students’ research-related skills whereas two indicated that their strategies had been "very successful." Suggestions to improve students’ research-related skills were two-fold: some were about providing more opportunities for students to present findings or supporting their understanding of fundamental concepts, while others were comments indicating that it is up to students to perform better (e.g., “hard work”, “increased expectations” and “more motivation” needed). One instructor commented, “Quality of the students matter. What we have at hand, we [are] doing great with these students.”

Mentoring
CREST Bioenergy Center Faculty reported mentoring both undergraduates and graduate students. Faculty members were asked to indicate in which skills/knowledge areas their mentoring had most impacted students. As shown in **Table 6**, most indicated that mentoring had impacted graduate students in terms of their knowledge and skills related to the scientific methods, technical writing, and their research areas. In comparison, for undergraduate students, the impacts were more in making technical presentations.

Table 6.
Mentoring Impacts on Graduate and Undergraduate Students

Skills and Knowledge	Grads	Undergrads
Scientific method	8	4
Technical writing	6	4
Knowledge of research area	6	4
Technical presentation	5	5
Literature review	5	4
Data analysis and presentation	5	3
Independence	5	2
Knowledge of STEM careers	5	3
Research ethics awareness	4	2
Knowledge of bioenergy	4	4
Networking	3	1
Creativity	3	1
Computer software	2	1
Leadership / Mentoring	1	1
Teaching	0	0
Hardware troubleshooting	0	0

Thrust Areas
Most faculty indicated that their research students formally meet to hear about research and/or to collaborate with other members of their own thrust group on a weekly basis and with members of the other thrust groups less frequently, generally once a month. Faculty view the benefits of having their students meet within and across thrust groups to include; "[the] exchange [of] ideas and share research results to update other members of the group," helping students understand the project in its entirety, and "accountability for making progress and planning for the future."

Summary
Student and faculty survey responses indicate that both groups view as effective strategies to increase graduate students' research knowledge and skills. The most common experiences noted were research experiences with Center faculty, being mentored by them, and attending and/or

presenting at seminars and conferences. Student ratings (on a scale of 1 to 5) indicated that their skills and knowledge had increased most in terms of their ability to work independently in a lab (mean = 4.22); knowledge of areas of research related to bioenergy (mean = 4.11); data presentation skills (mean = 4.00); and ability to conduct thorough literature reviews (mean = 4.00). Faculty ratings of students' skills and knowledge indicated that they believe that overall, students are strongest in terms of their research ethics awareness, knowledge of STEM careers, technical presentation skills, knowledge of the scientific method, and networking. However, ratings by faculty were relatively neutral (means = 3.38 - 3.71) with some large standard deviations (0.49 – 1.07).

When asked what they liked best about their research experiences with the NSF CREST Bioenergy Center, students reported they like the people they work with, that the Center promotes the ability to do independent research and “helps to enrich students in their quest for research knowledge”, and that the Center significantly “improves” technical writing and presentation skills. Suggestions students provided for improving their research experiences included increasing their access to instruments and equipment, ensuring more opportunities to present at conferences, emphasizing the need for students obtaining work or teaching experience, and providing more mentoring by faculty.

Mentoring was recognized by both faculty and students as a critical way to develop graduate students' research knowledge and skills. Benefits noted by students and faculty on meeting within and across thrust areas include "cross-pollination" of ideas, general awareness of research, feedback and group discussion, and peer pressure to produce work, as well as an opportunity for them to practice and improve their presentation skills.

Conclusion

Well-trained engineers are needed to advance the thermochemical bioenergy industry. The CREST Bioenergy Center provides a model for this training with a focus on underrepresented students. Assessment data indicate that the Bioenergy Center training model is a promising one for developing the critical professional skills.

Acknowledgement

This work was supported by NSF award #HRD-1242152, Centers of Research Excellence in Science and Technology (CREST) Bioenergy Center.

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