PROPOSAL FOR A NEW MASTER'S DEGREE PROGRAM

University of Louisville
Institution Submitting Proposal

Master of Science in Materials and Energy Science & Engineering
Degree Designation as on Diploma

Master of Science in Materials and Energy Science & Engineering
Title of Proposed Degree Program

EEO Status	______________
CIP Code	______________
Academic Unit (e.g. Department, Division, School)	JB Speed School of Engineering
Name of Academic Unit	School of Engineering
Name of Program Directors	Mahendra K. Sunkara, PhD
Intended Date of Implementation	Fall 2020
Anticipated Date for Granting First Degrees	Fall 2021
Date of Governing Board Approval	______________
Name, Title and Information of Contact Person	Mahendra K. Sunkara, PhD Professor, Chemical Engineering Director, Conn Center for Renewable Energy Research mahendra@louisville.edu; 502.852.8574

Date of CPE Approval	______________

Evaluation Criteria

All actions in the approval of new programs for public institutions are subject to a stipulation regarding the program's ability to attain specified goals that have been established by the institution and approved by the Council on Postsecondary Education (the Council). At the conclusion of an appropriate period of time, the program's performance shall be reviewed by Council staff following criteria established in the Council's Academic Programs Policy.

A. Centrality to the Institution's Mission and Consistency with State's Goals

As part of former Governor Paul Patton's higher education initiative in 1998, the University of Louisville (UofL) began the *Challenge for Excellence* to expand and enhance research in order to "become a premier, nationally-recognized metropolitan research university." In addition, local businesses commissioned consultants to recommend the means to improve competitiveness and they found that the local infrastructure is in place for Louisville to be competitive in the materials and energy science and engineering industries. In response to these initiatives, UofL, and in particular the Speed School of Engineering, have made materials and energy science and engineering a top priority. Through the Conn Center for Renewable Energy Research, UofL has demonstrated its commitment to developing a nationally recognized materials and energy science and engineering program, one which will provide a formal structure for educating students and attracting faculty with the ability to establish multidisciplinary research programs.

The proposed Master of Science in Materials and Energy Science & Engineering (MS in MESE) represents an endeavor at UofL to create a degree enabling both UofL graduates and non-UofL graduates with Bachelor's degrees in engineering and sciences to enroll in a Master's degree program housed in the J.B. Speed School of Engineering. Currently, UofL does not offer any degrees in advanced materials and energy science and engineering. Thus, the proposed M.S degree provides a pathway for students to achieve specialization in advanced materials science and energy engineering.

This degree will offer advanced level training to provide students with in-depth knowledge in areas such as materials chemistry & physics, processing, energy conversion and storage devices and systems-level engineering. Student educational experiences will be enhanced by experimental experiences through classroom projects in laboratories such as solar energy conversion, energy storage, biofuels and biomass conversion, solar fuels, materials characterization, and advanced energy materials. The MS in MESE will prepare students for career tracks in industry such as semiconductor/opto-electronics (e.g., Intel; Micron; Applied Materials; Lam Research; etc.); catalysts (e.g., Clariant; BASF; etc.); and energy (e.g., EXXON MOBIL; First Solar; Panasonic, etc.). This degree track will allow them to pursue entrepreneurship, join government and corporate labs, and provides a strong foundation for those wishing to pursue doctoral studies in their respective disciplines.

1. List the objectives of the proposed program. These objectives should deal with the specific institutional and societal needs that this program will address.

The proposed MS in MESE degree program objectives are to:

1. Train highly motivated graduate students who demonstrate advanced level materials and energy science & engineering expertise and practical engineering experience necessary to function as professionals. *(Advanced Knowledge and Life-long Learning)*
2. Develop students with the materials and energy science & engineering expertise and practical experience necessary for employment in industry, academia or government, or further professional/graduate studies. *(Career Opportunities)*
3. Develop students with an understanding of the broad, social, ethical and professional issues of contemporary science and engineering practices. *(Awareness and Responsibility)*

Materials and Energy Science & Engineering is a multi-disciplinary degree program when compared to other engineering programs such as mechanical, civil, electrical, chemical, etc. A materials and energy scientist or engineer use traditional engineering skills and tools to analyze and solve problems specifically in materials and energy. MESEs collaborate with physicists, biologists, biochemists, chemists, chemical-, mechanical-, electrical & computer-, civil, and industrial engineers to design, develop and manufacture new materials and devices and assemble systems for applications at scale. Current programs offered in SREB states are listed in Section 4.

In 2012, the President's Council of Advisors on Science and Technology – an advisory group of the nation's leading scientists and engineers – set forth a goal, based on economic forecasts, to produce one million additional graduates with degrees in science, technology, engineering and mathematics. Employment opportunities for MESEs are predicted to continue growing faster than the average for all occupations through 2020 as reported by CNNMoney1 with a 10-year job growth of ~62%. Combined with a growing job market and attractive compensation (median pay: $87,0001), MESEs have the gratification that comes from working to meet the needs of society and improve quality of life, particularly in the energy sector. MESEs choose their field to be of service by applying engineering knowledge and skills to complex material systems and energy challenges faced worldwide.

With regards to societal impact, meeting rising energy demand is one of our civilization's greatest challenges affecting quality of life, education, and commerce across sectors and socio-economic strata. The MS in MESE supports the education of those who will design, produce and implement energy technologies into our current and developing infrastructure. Educational implications across the spectrum of fossil-fuel and renewable approaches support how energy is created, stored and distributed. The knowledge to create and refine new, advanced, earth-abundant materials and pioneer their scale-up and implementation into cost effective technologies lies at the heart of the MS in MESE. This mission includes redefining our reliance on fossil-based fuels and low energy efficiency systems, thus lowering our carbon impact on our environment. Likewise, the ability to tap into the immense potency of the sun as a primary source of energy requires materials innovations to overcome intermittency of sunlight and engineered solutions to store energy until needed. This essential aspect of attaining renewable energy generation requires a combined effort across themes of solar energy conversion, solar fuels, energy storage, biofuels & biomass conversion, and energy efficiency via advanced energy materials synthesis and characterization. The knowledge is not siloed within single disciplines, rather requiring the unique expertise across sciences (physics, chemistry, and biology) and engineering (chemical, electrical & computer, mechanical, civil & environmental, and industrial). Innovations in materials and energy science and engineering impact economic development, energy competitiveness, health, education and quality of life worldwide.

Currently, faculty, students and staff across science and engineering disciplines at UofL collaborate to address these energy-related challenges. However, creating a sustainable positive impact on the energy security and well-being of our culture is dependent upon effective capacity building in the field of materials and energy science and engineering. The proposed MS in MESE presents an opportunity to reach a new student population and increase our training of these students to become advanced-level materials and energy scientists and engineers who will have the capabilities to influence the quality of life worldwide. Students matriculating from this program will have a unique skill set with capabilities to design, develop and translate potential solutions and technologies to advance the way energy is generated, stored and distributed, thereby aiding our Commonwealth and nation in realizing improved productivity and economic gains.

2. Explain how the proposed program relates to the institutional mission and strategic plan.

Establishing a MS in MESE will address a number of goals of the University's Strategic 2020 Plan and the 21st Century Initiative. Specifically, as related to the relevant goals stated in these initiatives, the MS in MESE will:

2020 Plan

1. Implement STEM initiatives leading to more graduates with science, technology, engineering and mathematics majors
2. Increase the quality and quantity of graduates in the materials and energy sciences and engineering to improve energy infrastructure and economic development for the community
3. Increase the emphasis on translational research in materials and energy leading to both commercialization and entrepreneurship in the new energy economy.

21st Century Initiative

1. Revenue Enhancement: "Strategically grow enrollment in high demand fields."

In addition to these university-wide goals, this degree will also address several goals outlined the JB Speed School of Engineering 2020 Strategic Plan:

1. Establish areas of research excellence in materials and energy science and engineering
2. Attract motivated, prepared and talented students into all degree programs
3. Provide outstanding experiential learning experiences

3 Explain how the proposed program addresses the state's postsecondary education strategic agenda.

The MS in MESE is in alignment with the State of Kentucky's *Stronger by Degrees: 2016- 2021*[4] post-secondary education strategic agenda. A major goal of this plan is to raise Kentucky's educational attainment level to 58% by 2025, up from its current level of 45%. CPE's post- secondary education goals include "improving the readiness of employability of post-secondary education graduates" and to "advance Kentucky's STEM and S&T agendas…". The MS in MESE aligns with this agenda by providing a mechanism to enable Kentuckians to succeed in a global economy (Vision), delivering a world-class education to our students through the creation and application of new knowledge, and growing the economy of the Commonwealth (Mission). Moreover, the proposed degree program will prepare students for career paths in STEM and materials and energy fields.

Many STEM and advanced materials/energy jobs have relatively high salaries; CPE recognizes that "highly educated people create additional savings from lower costs in health, unemployment, public assistance and crime." Graduates from the MS in MESE who stay in Kentucky will also help to improve the energy infrastructure and economic revival with high tech industry involving various clean energy technologies and advanced materials.

The proposed program fulfills the *Research, Economic, and Community Development* criteria - Kentucky will be stronger by generating new knowledge, producing high-demand degrees, increasing the educational attainment of its workforce, and improving its communities. This program will increase educational attainment and quality of life in Kentucky communities through regional stewardship (Strategic Policy Objective 8). Additionally, by addressing the need for Efficiency and Innovation, Kentucky will be stronger by creating new ways of serving more postsecondary students at a high quality in a challenging resource environment by increasing academic productivity through innovation (Strategic Policy Objective 9) and maximizing postsecondary and adult education resources (Strategic Policy Objective 10).

4 Explain how the proposed program furthers the statewide implementation plan.

The statewide implementation plan has now been incorporated into a subsection of the newly established *Stronger by Degrees: 2016-2021*. The implementation plan promotes a legislative agenda, which supports post-secondary education through various funding initiatives, including a new Outcome-Based Funding Plan. UofL's Strategic Plan must address these outcome-based metrics once they are finalized. Our proposed MS in MESE aligns with goals of the UofL Strategic Plan, as well as the *Stronger by Degrees* plan (see items 2 and 3 above).

Participating Speed School of Engineering and Arts & Sciences faculty and the Program Director, listed in Appendix A, have demonstrated a nationally and internationally-recognized level of research productivity as evidenced by quality and placement of graduate BS and MEng students, presentations at national and international conferences, publications in high-impact peer refereed journals, and extramural funding. The success of these existing faculty will enable the delivery of high quality educational and research opportunities for students pursuing the thesis option, and will lead to graduates capable of translating their knowledge to address translational aspects of advanced materials and clean energy technologies. In summary, the proposed MS in MESE at UofL will exceed the requirements of our State's Strategic Agenda.

B. Program Quality and Student Success

The curriculum should be structured to meet the stated objectives and student learning outcomes of the program.

1. List all student learning outcomes of the program

a) demonstrated advanced level knowledge of materials and energy science & engineering
b) an understanding of contemporary materials and energy science & engineering topics
c) ability to effectively communicate advanced knowledge of materials and energy science & engineering orally and in writing
d) an understanding of the professional practice of materials and energy science & engineering

2. Explain how the curriculum achieves the program-level student learning outcomes by describing the relationship between the overall curriculum or the major curricular

components and the program objectives.

The program objectives are to train students with fundamental knowledge on materials and energy concepts, make them aware of contemporary topics or research, establish proficiency in communicating with peers about materials and energy science and engineering concepts, and enable success in their professional careers. To achieve these program objectives, the curriculum is divided into four parts. In the first part, core fundamental courses instruct students about structure, properties and techniques for measurements for energy materials, fundamental energy conversion, and energy storage concepts and challenges. In the second part, courses teach students the fundamentals of processing of these materials and devices for developing energy conversion and storage systems. In the third part, courses teach in-depth concepts on various energy conversion and storage technologies. In the fourth part, several guided electives including project experience are designed to teach students on how to design, evaluate, and practice an engineering solution for addressing an energy problem or challenge, thus giving the student a practical experience to be successful in their profession.

Conn Center offers a seminar series and focused workshops (ex: Nanomaterials and RE3 workshops conducted since 2003 – See http://www.re3workshop.org) in which distinguished researchers from various universities and national laboratories deliver lectures on the latest advances with various concepts related to advanced materials and energy conversion and storage. Student educational experiences will be enhanced by research opportunities in laboratories conducting basic and translational research on solar energy conversion, energy storage, biofuels and biomass conversion, solar fuels, materials characterization, and advanced energy materials. Students matriculating from this program will have a unique skill set with capabilities to design, develop and translate potential materials and energy science & engineering solutions and technologies that will advance their ability to affect quality of life. Through their project or guided electives in systems engineering type courses on energy science & engineering, students will gain important experiential learning necessary to be successful in their professional career. Student progress will be recorded and reviewed by the program director and faculty subcommittee for the program. A listing of the faculty subcommittee is given in Appendix B.

3. Highlight any distinctive qualities of this proposed program.

There is a strong materials and energy science & engineering research community at the UofL. This community is built upon established collaborations between Conn Center for Renewable Energy Research staff and associated faculty in the College of Arts and Sciences' Departments of Chemistry and Physics, along with associated faculty in other departments within the Speed School of Engineering, including Chemical Engineering, Mechanical Engineering, Electrical and Computer Engineering, Civil and Environmental Engineering, and Industrial Engineering. These multidisciplinary collaborations have led to extensive federal and private foundation research funding targeting the development of materials and energy science & engineering solutions to transform energy use. To best activate this community and keep the degree program responsive to the state-of-the-science, the program director will be the Conn Center Director.

The extensive materials and energy science & engineering community at UofL will provide a rich multidisciplinary training environment for students in the proposed program, enabling them to receive extraordinary hands-on experience in laboratories directed by materials and energy science & engineering faculty. Students in the program will have a unique opportunity to conduct their research while functioning on multidisciplinary teams that are based upon established engineer-scientist collaborations and an associated track record of successful development and translation of materials and energy science & engineering innovations.

4. **Will this program replace or enhance any existing program(s) or concentration(s) within an existing program?**

   This program will not replace any existing programs. The program will enable graduates with non-UofL ABET-accredited engineering degrees to pursue a MS in MESE at UofL. This program will also serve as a potential feeder to our existing PhD programs in various sciences and engineering disciplines (Chemical; Mechanical; Electrical & Computer Engineering; Physics and Chemistry).

5. **Is there a specialized accrediting agency related to this program?**
   a. **If yes, identify the agency.**

      The Southern Association of Colleges and Schools (SACS) accredits this degree program.

   b. **Do you plan to seek accreditation?**

      Yes

   c. **If yes, explain your plans for accreditation. If no, explain your rationale for not seeking accreditation.**

      This degree program would adhere to the institutional process for validation. At the University of Louisville, every educational program for which academic credit is awarded has been approved by the faculty and administration. Student learning outcomes have been established and are regularly evaluated. All proposals for new degree programs are reviewed and approved by the Provost Office, unit faculty/dean, and Faculty Senate before they are recommended to the Board of Trustees. The university maintains processes for program approval, program review, curriculum and consortial agreements processes and Council on Postsecondary Education (CPE) guidelines.

      The Office of the Executive Vice President and Provost serves as the gatekeeper for the program proposal process above the unit level, and coordinates the required reviews with the university's Faculty Senate, Undergraduate and Graduate Council (if applicable), the UofL Board of Trustees, and the Kentucky Council on Postsecondary Education (CPE). All contact and interaction with CPE related to the program proposal process shall be coordinated through the Provost Office. Any additional approvals and reports to the Southern Association of Colleges and Schools Commission on Colleges (SACSCOC) are handled by Provost Office staff.

6. **Attach the SACS Faculty Roster Form. Faculty resources shall be demonstrated to be adequate and appropriate for the proposed program. The number of faculty should meet external standards where appropriate. The qualifications of faculty will support the objectives and curriculum of the proposed program.**

   The SACS Faculty Roster Form is attached in Appendix A.

7. **Access to the qualitative and quantitative library resources must be appropriate for the proposed program and should meet recognized standards for study at a particular level or in**

a particular field where such standards are available. Adequacy of electronic access, library facilities, and human resources to service the proposed program in terms of students and faculty will be considered. Physical facilities and instructional equipment must be adequate to support a high-quality program. The proposal must address the availability of classroom, laboratory, and office space as well as any equipment needs.

a. Describe the library resources available to support this program. You may attach any documentation provided to SACS.

This program will be supported by the Ekstrom (Main) and Kornhauser Libraries, which house over 2.1 million volumes, approximately 16,000 current journal subscriptions, special collections, media and microforms. In addition, the library has an on-line virtual library that provides faculty, staff and students access to over 20,000 full text electronic journals, inter-library loan services, electronic books and databases, reference materials and other library resources. The library resources are more than adequate to support the needs of the faculty and students in the proposed MS program.

A letter from the Dean, University Libraries is included in Appendix C, indicating that the University's collection of journals, electronic resources and special collections is adequate to support the MS in MESE program.

b. Describe the physical facilities and instructional equipment available to support this program.

This program is supported by facilities and instructional equipment available in the laboratories of the Conn Center for Renewable Energy Research, the Micro/Nano Technology Center, Huson Microtechnology Core Facility, and the Rapid Prototyping Center, all located on the Belknap Campus of the UofL.

Instructors will have access to these facilities to assign class projects and to demonstrate materials and energy science & engineering-centric concepts.

See Appendix E for a complete list of laboratories and equipment.

8. Clearly state the admission, retention, and completion standards designed to encourage high quality.

The Speed School of Engineering has rigorous standards for admission into graduate programs, and those standards will apply to the MS MESE program as well. Applicants must meet Speed School graduate admission requirements along with additional program requirements.

Applicants must, as a minimum, have completed an equivalent Bachelor's Degree in Engineering from an ABET accredited program or an equivalent Bachelor's Degree in Physics or Chemistry from an accredited program. Successful applicants will typically have a 3.00 cumulative GPA in their BS in Engineering or Sciences. Applicants with an undergraduate GPA of 2.75 will be considered for provisional acceptance; however, they must maintain a 3.00 GPA at a minimum in their first semester of study or they will not be allowed to continue in the program. Applicants must submit: 1) transcripts of all college-level courses; 2) at least two letters of recommendation; 3) a written statement by the applicant describing previous experience related to materials and energy science & engineering; 4) a statement as to how the MS MESE will allow them to fulfill their career goals; and, 5) GRE verbal, quantitative and writing assessment-analytical scores. Ideal applicants will have GRE scores at or above the 60th percentile on verbal and quantitative sections.

Students whose native language is non-English or degree is from a non-US accredited institution are required to submit TOEFL scores (administered by the Educational Testing Service). A minimum TOEFL score of 80 or higher on the internet-based test or 550 or higher on the paper-based test is required. Alternatively, a minimum of 6.5 on the International English Language Testing System will be accepted.

Student performance will be monitored and assessed throughout their program using the following metrics to assure students completing the program have an advanced level of competency in the field of materials and energy science & engineering.

- Course performance (GPA)
- MESE Design/ Project performance

a. *Indicate expected faculty to student ratio:*

There are 29 participating faculty who are listed on the SACS Faculty Roster Form. By the 5th year, we anticipate 30 students will be in the program, yielding faculty to student ratio of approximately 1:1.

9. Clearly state the degree completion requirements for the program.

Students must meet degree requirements established by the Speed School of Engineering, in addition to Program requirements. The program must be completed with a 3.00 GPA or higher in all graduate courses used to satisfy degree requirements. MS MESE students must complete 30 credits, including an optional project in lieu of one systems engineering course. All degree requirements must be completed within six years from admission into the program.

10. Provide the following information for the program and for each concentration (some categories may not apply to all programs):

a. Total number of hours required for degree	30
b. Number of hours in degree program core	15
c. Number of hours in concentration	12
d. Number of hours in guided electives	3
e. Number of hours in free electives	0

11. Describe how the proposed program will articulate with related programs in the state. It should describe the extent to which student transfer has been explored and coordinated with other institutions. Attach all draft articulation agreements related to this proposed program.

Transfer of credits from a Master's Degree in engineering from an accredited institution is permitted. However, the number of transfer credits (up to a maximum of 6 credit hours) will be evaluated on a case-by-case basis by the Program Director, which will forward the petition to the Dean of the Speed

School of Engineering for final approval. Sufficient course descriptions and a transcript must accompany the petition so that the request can be evaluated.

The program can admit students with B.S degrees in Chemistry, Physics, Mechanical Engineering, Chemical Engineering, Civil Engineering, Chemical Engineering and Electrical Engineering disciplines. In addition, students graduating with M.S degrees in materials science and engineering from UK and other US institutions are also allowed. No special discussions are necessary to allow for transfer of two related courses (up to six credit hours) as this is consistent with UofL general policy.

12. List courses under the appropriate curricular headings.

Working with their advisor, students must complete a Plan of Study identifying each course to be taken by the student and its associated term. The Plan of Study must be reviewed and approved each term by the student's advisor. The Plan of Study may be modified with approval from the student's advisor. A list of course descriptions is shown in Appendix D.

A. Basic Fundamental Courses (Two core courses + three electives required)

MESE 510 (CHE 698) Energy Science and Engineering (Core Fundamentals Course)
MESE 520 (CHE 532) (Advanced Materials Science & Engineering (Core Fundamentals Course)
MESE 525 (ME675) Advanced Materials Characterization (Elective-Fundamentals Course)
CHEM 659 Solid State Chemistry or Materials Chemistry (Elective-Fundamentals Course)
PHYS 575 Solid State Physics or ECE 542 Physical Electronics (Elective-Fundamentals Course)
CHEM 621 Analytical Electrochemistry & Spectroscopy (Elective-Fundamentals Course)
ME 575 Computational Modeling of Nanomaterials or Computational Materials Science (Elective-Fundamentals Course)

B. Processing Courses (Two required)

CHE 581 Chemical Vapor Processing
MESE 522 Roll to Roll Processing
CHE 694 (IE 601) Additive Manufacturing
ECE 543/544 MEMS or Multi-scale Integration

C. Energy Conversion Fundamentals (Two required)

MESE 512 (CHE 694) Solar Cells and Fuels
MESE 514 (CHE 694) Biomass and Biofuels
ME 572 Electrochemical Energy Storage
ECE 531 Power Electronics
CHE 694 Industrial Catalysis

D. Systems Engineering (One course or Project)

MESE 610 Systems Integration & Entrepreneurship in Renewable Energy Sector
MESE 620 Techno-economic Analysis and Energy Policy
MESE 630 (IE 694) Smart Manufacturing
MESE 690 Project

13. Describe planned alternative methods of program delivery involving greater use of technology, distance education, and/or accelerated degree designs, to increase efficiency, better address student educational and workforce needs, and maximize student success, for both traditional and non-traditional students.

Most courses will be delivered in a face-to-face classroom setting style lecture or laboratory setting. However, some technical elective courses are available online via distance learning, with increased online course offerings anticipated in the future. Our goal is to offer a complete on-line degree program within two years of the start of this on-campus degree program.

C. Program Demand/Unnecessary Duplication

Proposed programs must respond to the needs of the academy and to larger economic and social environments. Thus, the institution must demonstrate demand for the proposed program. All proposed programs must address student demand. Programs must also address either employer demand or academic disciplinary needs.

1. Student Demand: Clearly describe all evidence of student demand, typically in the form of surveys of potential students and/or enrollments in related programs at the institution.

a. Provide evidence of student demand at the regional, state, and national levels

According to the US Dept. of Labor, in 2010, there were about 24,400 materials engineers in the USA [6]; this is 1.6% of the 1.5 million engineering jobs in the USA. The US Dept. of Labor predicts growth in materials science to be about the same as for the average of all engineering jobs through 2014, at about 8 to 9% per year. This job growth is projected to result from increased use of composite and other nontraditional materials developed through nanotechnology and biotechnology research.

To give an idea of the magnitude of employment opportunity in the field, data from the US Dept. of Labor for year 2010 is reported at https://www.careercornerstone.org. It can be seen that the Materials field holds a significant portion of the US workforce. It has more practitioners than Bioengineering, Mining, Nuclear, and Petroleum Engineering careers and it is close in employment to Chemical Engineering, with traditional disciplines (Electrical, Civil, Mechanical, Industrial) holding the bulk of the employment. Note, however, that due to the high ratio of advanced degrees to BS degrees in the materials science field (1:1.8 in materials science; 1:9 in engineering overall), a greater proportion of the Materials Science and Engineering workforce would be expected to work in the research and development fields of materials science. These jobs requiring advanced degrees typically have higher salaries than those at the BS level.

Aerospace engineers 71,600, 4.6% of the 1.56 million engineering jobs in the USA for 2010,
Agricultural engineers 2,700, 0.2% of all US engineering jobs,
Biomedical engineers 16,000, 1%
Chemical engineers 31,700, 2%
Civil engineers 278,400, 17.9%
Computer hardware engineers 74,700, 4.8%
Electrical engineers 157,800, 10%

Electronics engineers	143,700, 9.2%
Environmental engineers	54,300, 3.5%
Health and safety engineers	25,700, 1.6%
Industrial engineers	214,800, 13.8%
Materials engineers	**24,400**, **1.6%**
Mechanical engineers	238,700, 15.3%
Marine engineers	8,500, 0.5%
Mining/geological engineers	7,100, 0.5%
Nuclear engineers	16,900, 1.1%
Petroleum engineers	21,900, 1.4%
Engineers, all other	183,200, 11.8%

Regarding graduate education, https://www.careercornerstone.org states that "Many students continue their studies to earn an advanced degree, a master's (M.S.) degree or a doctoral (Ph.D./D.Sc.) degree. They do this either directly after earning the BS degree or after some work experience. An M.S. degree generally can be earned within two years after the BS degree.

https://www.asee.org/papers-and-publications/publications/collegeprofiles/15EngineeringbytheNumbersPart1.pdf

https://www.asee.org/papers-and-publications/publications/collegeprofiles/15EngineeringbytheNumbersPart1.pdf

b. Identify the applicant pool and how they will be reached.

Prospective students will be those who have completed a Bachelor's degree in engineering from an ABET accredited school or an equivalent Bachelor's Degree in Physics or Chemistry from an accredited program.

c. Describe the student recruitment and selection process.

Students will be recruited through web-based marketing of the program, along with advertisement of the program at regional, national and international materials and energy science & engineering society conferences. Program announcements will be sent to top- ranked engineering schools and materials and energy science & engineering focused companies throughout the world. It is also our intention to advertise heavily through our Conn Center's partner schools in India, China, Colombia, Nigeria and Europe.

d. Identify the primary feeders for the program

Accredited engineering schools across the US, including UofL, will serve as feeders for the program. In addition, we also expect to see applications from several students graduating with Physics and Chemistry majors from regional universities within Kentucky and neighboring states. Furthermore, we currently have International Memoranda of Understanding with Indian Institutes of Technology (Banaras; Delhi); Universidad Del Valley in Cali, Colombia; International Renewable Energy Research Center at Xian Jiang Tong University in Xian, China; Federal University of Technology, Akure, Nigeria; Universities of Loughborough/Northampton in England with their newly approved PhD in Energy Science; and the University of Dubai, etc.

Given the national and international reputation of our MESE faculty, it is reasonable to expect that engineering graduates from across the nation and worldwide will find our program attractive.

e. Provide any evidence of a projected net increase in total student enrollments to the campus as a result of the proposed program.

According to an *American Society of Engineering Education* report, 702 students enrolled for a Master's degree in materials engineering in 2006 in the US. This number increased to 1,119 students in 2015; nearly a 60% increase over 9 years, demonstrating significant student demand.

6 https://www.asee.org/papers-and-publications/publications/collegeprofiles/15EngineeringbytheNumbersPart1.pdf

f. Project estimated student demand for the first five years of the program.

Based on similar programs across the country and faculty resources during the first five years of the program, we project 10-12 applicants per year with a projected enrollment of 6-8 new students admitted and enrolled annually. The first graduates of the program are expected by the 2nd year of the program.

Table 1. Estimate of number of students in MS MESE program on an annual basis.

Academic Year	**Degrees Conferred**	**Majors (Headcount) – Spring Semester**
2019-20	0	8
2020-2021	8	8
2021-2022	8	16
2022-2023	16	20
2023-2024	20	28

2. **Employer Demand: Clearly describe evidence of employer demand. Such evidence may include employer surveys, current labor market analyses, and future human resources projections. Where appropriate, evidence should demonstrate employers' preferences for graduates of the proposed program over persons having alternative existing credentials and employers' willingness to pay higher salaries to graduates of the proposed program.**

a. Describe the types of jobs available for graduates, average wages for these jobs, and the number of anticipated openings for each type of jobs at the regional, state, and national levels.

In 2018, there were 2,324,866 energy efficiency jobs and 242,343 solar jobs nationally, with cumulative solar installations expected to double by 2024. Current market demand for a workforce with advanced training in energy materials sector is greater than average, with 7 to 9% growth in 2019. This is especially true for the solar energy and energy efficiency sectors. In Kentucky, there are 1,410 solar jobs with projected growth at 10%. These include installation (1044), manufacturing(162), wholesale trade and distribution (102), operation and maintenance (66), and others (37).

https://www.seia.org/solar-industry-research-data
https://www.thesolarfoundation.org/national/
https://www.usenergyjobs.org/
https://solarstates.org/#state/kentucky/counties/solar-jobs/2018

Established and announced corporate ventures in the region are speculated to provide an additional 100 – 200 jobs for MESE graduates in the next 5 years, including EnerBlu (Battery mfg; Announced but status unknown), Clariant Corporation (catalysts), Kentucky Advanced Materials Manufacturing (industrial diamonds), Braidy Industries (aluminum), and Nucor (steel). An additional 10 regional startup companies in the materials and energy sector are estimated to provide between 25 and 50 jobs over the next 5 years as well, including Pyrochem Catalyst Company (catalysts), Advanced Energy Materials, LLC (energy materials), Bert Thin Films, LLC (solar), and BioProducts, LLC (biofuels). In recent times, KY Cabinet for Economic Development (CED) aimed at recruiting companies that are involved with energy materials and systems recently. PhD students graduating with dissertation research performed in materials and energy research within Conn Center and associated faculty labs are finding great industrial positions at companies such as Intel, Applied Materials etc. In fact, we have not been able to produce enough graduates for their needs. Recently, companies such as Intel have started hiring master's level graduates into entry level positions due to scarcity with PhD graduates with related educational experience. The proposed MS graduates would acquire the necessary educational experience and will be appropriately positioned to be hired by companies such as Intel.

Employer Demand

If the program is designed for students to enter the workforce immediately upon graduation, please complete the following table.

Most of the current Bureau of Labor Statistics projections are for 2016-2026. Other sources include; but are not limited to:

- Georgetown University Center on Education and the Workforce
- Bureau of Labor Statistics' Occupational Outlook Handbook
- Kentucky Center for Statistics
- KY Chamber, "Kentucky's Workforce, Progress and Challenges," January 2018
- https://www.kychamber.com/sites/default/files/Kentuckys%20Workforce%20Progress%20and%20Challenges%202018%20Final%20NEW.pdf
- Kentucky, Bridging the Talent Gap
- Document - https://www.bridgingthetalentgap.org/wp-content/uploads/2017/05/KY-Statewide.pdf
- Interactive website: https://bridgingthetalentgap.org/dashboards/
- SolarStates.org

Occupation	Regional Average Wage	Regional # of Openings	Regional Growth Projections (%)	State Average Wage	State # of Openings	State Growth Projections (%)	National Average Wage	National # of Openings	National Growth Projections (%)
Materials Engineer	$92,961	5,070		$81,173	67	4.5%	$96,930	26,930	2.7%
Materials Scientist	$ 93,176	1,010		$78,692	34	5.7%	$102,450	7,730	5.2%
Environmental Scientist				$51,645	972	4.8%	$89,590	1,160	8%
Careers in Renewable Energy Industry								>234,000	>7% per year
Solar Installation, Manufacturing, Distribution, and Operations/Maint					1,410	9.1%		242,343	

Sources: Most of the current Bureau of Labor Statistics projections are for 2016-2026. Other sources include; but are not limited to, Georgetown University Center on Education and the Workforce

Bureau of Labor Statistics' Occupational Outlook Handbook

Kentucky Center for Statistics

KY Chamber, "Kentucky's Workforce, Progress and Challenges," January 2018
https://www.kychamber.com/sites/default/files/Kentuckys%20Workforce%20Progress%20and% 20Challenges%202018%20Final%20NEW.pdf

Kentucky, Bridging the Talent Gap
Document https://www.bridgingthetalentgap.org/wp-content/uploads/2017/05/KY- Statewide.pdf
Interactive website: https://bridgingthetalentgap.org/dashboards/

Timeframe for Growth Projections: Five years

3. Academic Disciplinary Needs: Clearly describe all evidence justifying a new program based on changes in the academic discipline or other academic reasons.

This degree will offer advanced level training to provide students with in-depth knowledge of materials and energy science and engineering in areas such as materials science and engineering, materials chemistry & physics, processing, energy conversion and storage devices and systems-level engineering. Student educational experiences will be enhanced by research opportunities in laboratories conducting basic and translational research on solar energy conversion, energy storage, biofuels and biomass conversion, solar fuels, materials characterization, and advanced energy materials. This degree track provides a strong foundation for those wishing to pursue doctoral studies in their respective disciplines.

Faculty listed under MESE program (about 29 of them) mentor PhD students with research activities dealing with advanced concepts in materials and energy science and engineering. Students graduating from the proposed MS degree in MESE will be prepared for pursuing research in renewable energy research. The demand for PhD students in energy research at UofL and other institutions worldwide increased tremendously with increased research funding. The employment prospects for PhDs in sciences and engineering with materials, processing and energy device concepts have grown tremendously with growing industry sectors in electronics, LED, battery cell and solar cell manufacturing in US and worldwide. We expect to see much larger demand for such growth.

4. Similar programs: A new program may serve the same potential student population, the proposed program must be sufficiently different from existing programs in the state or access to existing programs must be sufficiently limited to warrant initiation of a new program.

a. *Identify similar programs in other Southern Regional Education Board (SREB) states and in the nation.*

There are many programs on Materials Science & Engineering in SREB states. They include the following institutions. As stated below for the program at University of Kentucky, these programs do not address energy science and engineering aspects and differ in their curricula.

- **Alabama** - Univ of Alabama, Auburn Univ, Univ of Alabama at Birmingham, Univ of Alabama in Huntsville, Tuskegee Univ, Alabama A&M Univ
- **Arkansas** – Univ of Arkansas, Arkansas State Univ, Univ of Arkansas at Little Rock, Arkansas Tech Univ
- **Delaware** – Univ of Delaware

- **Florida** – Univ of Florida, Univ of Central Florida, Univ of South Florida, Florida International Univ, Florida State Univ, Embry-Riddle Aeronautical Univ, Florida Polytechnic Univ, and Polytechnic Univ of Puerto Rico – Miami
- **Georgia** – Georgia Institute of Technology, Emory Univ, Univ of Georgia, Mercer Univ
- **Kentucky** – Univ of Kentucky
- **Louisiana** – Louisiana Tech Univ, Univ of Louisiana at Lafayette, Southern Univ & A&M College, McNeese State Univ
- **Maryland** – Johns Hopkins Univ, Univ of Maryland – College Park, Morgan State Univ, Loyola Univ
- **Mississippi** – Mississippi State Univ, Univ of Mississippi, Jackson State Univ
- **North Carolina** – Duke Univ, Univ of North Carolina at Chapel Hill, North Carolina State Univ at Raleigh, Univ of North Carolina at Charlotte, North Carolina A&T State Univ
- **Oklahoma** – Univ of Oklahoma – Norman, Oklahoma State Univ, Oklahoma Christian Univ
- **South Carolina** – Clemson Univ
- **Tennessee** – Vanderbilt Univ, Univ of Tennessee – Knoxville, Univ of Memphis, Tennessee Technical Univ, Univ of Tennessee – Chattanooga, Christian Brothers Univ, Tennessee State Univ
- **Texas** – Rice Univ, Univ of Texas at Austin, Southern Methodist Univ, Univ of Texas at Dallas, Texas A&M Univ – College Station, Baylor Univ, Letourneau Univ, Texas Tech Univ, Univ of Houston, Univ of North Texas, etc.
- **Virginia** – Univ of Virginia, Virginia Polytechnic Institute & State Univ, Virginia Commonwealth Univ, Old Dominion Univ, Norfolk State Univ
- **West Virginia** – West Virginia Univ, Marshall Univ

There are energy science and engineering programs being offered at West Virginia University and Texas A&M University with slightly different names. MS degree programs on energy sciences & engineering or energy systems engineering are being established more recently. The list may increase in the next five years.

b. *If similar programs exist in Kentucky,*

i. *Does the proposed program differ from existing programs? If yes, please explain.*

University of Kentucky is the only university in the state of Kentucky to offer Master's and PhD in Materials Science & Engineering. All other listed programs are undergraduate or certificate programs only. The curriculum for UK's M.S. degree in materials science and engineering involves graduate courses on metallurgy; mechanical design; metals processing; polymers; electronic packaging systems; metal cutting operations; dislocation theory; mechanical metallurgy; etc.

There are only a few courses specifically related to our core on materials science & engineering that are potentially common, such as advanced materials science & engineering; computational materials science; opto-electronic properties & devices; and advanced materials characterization. We have collaborated and shared the course on advanced materials characterization and offered the course together at both UofL and UK campuses via Network/TV. We do plan to collaborate on offering such courses together and continue to develop curriculum.

Our proposed curriculum gives in-depth training with various aspects related and focused entirely on energy materials science and engineering. Our program could potentially be offered to UK students as well via TV and online.

Does the proposed program serve a different student population (i.e., students in a different geographic area) from existing programs? If yes, please explain.

This degree program will serve students from the existing programs, including the metropolitan Louisville area as well as the greater population of Kentucky and Indiana and SREB states. The online degree initiated in Y3 of the program will reach national and international audiences.

ii. Is access to existing programs limited? If yes, please explain.

There is no evidence that access to existing programs is limited.

iii. Is there excess demand for existing similar programs? If yes, please explain.

We believe the demand in existing programs is robust, and we expect increasing demand given the documented need for materials and energy science & engineering in the workforce. Moreover, the statewide STEM initiative to improve Kentucky's position for success in the knowledge-based economy by expanding and strengthening educational and economic development opportunities in science, technology, engineering, and mathematics should increase the demand for programs such as the MS MESE. The Kentucky General Assembly has the goal of substantially increasing number of mathematicians, scientists, and engineers in the Kentucky workforce to foster economic growth and provide high quality jobs for Kentuckians.

iv. *Will there be collaboration between the proposed program and existing programs?*
   i. *If yes, please explain the collaborative arrangements with existing programs.*
   ii. *If no, please explain why there is no proposed collaboration with existing programs.*

There will be some collaboration in sharing some specialized courses with students taking the curses on both campuses (UofL and UK). These courses will be used to fulfill respective degree requirements on campuses.

D. Cost and Funding of the Proposed Program

The resource requirements and planned sources of funding of the proposed program must be detailed in order to assess the adequacy of the resources to support a quality program. This assessment is to ensure that the program will be efficient in its resource utilization and to assess the impact of this proposed program on the institution's overall need for funds.

1. Will this program require additional resources?

Existing courses have been identified as well as a large number of existing faculty mentors. Conn Center for Renewable Energy Research's core facilities and associated faculty labs will be used for training students for classroom and longer-term project experience requiring nominal fees, detailed below.

a. If yes, provide a brief summary of additional resources that will be needed to implement

this program over the next five years.

New resources are required for one administrative staff person at 50% FTE including annual base salary at $50K and fringe at 28.5%per year.

Funds for Other Professional (Existing) include 1-month base salary each at $10K and fringe at 28.5% with a 3% annual raise for 3 theme leaders in Y1-2 and 4 theme leaders in Y3-5. *

Funds for Faculty (Existing) include 1-month base salary each at $10K each and fringe at 28.5% with a 3% annual raise for 3 faculty in Y1-2 and 6 faculty in Y3-5. *

*If a greater number of faculty than proposed are actually used in Y1-2, the theme leader salary costs can be shifted to Conn Center so that these faculty salary costs are paid from this program.

Funds for GTA lines include a stipend ($22,008/yr), health insurance ($254.07/month), and 12 months full-time graduate tuition charged at the resident rate. There are one GTA in Y1-2, two GTAs in Y3, three GTAs in Y4, and four GTAs in Y5.

Funds for supplies are allocated at 5K per year and for facilities access to Conn Center laboratories at 10K per year in lieu of equipment charges to carry our curricular assignments and experiments.

Funds are allocated for new subscriptions to journals focused on materials and energy science and engineering, such as "Advanced Energy Materials" by Wiley starting in Y3.

Funds for curriculum development are allocated at 10K per year starting in Y3.

Institutional overhead on the tuition revenue is calculated at 25% annually.

2. **Will this program impact existing programs and/or organizational units within your institution?**

   a. If yes, please describe the impact.

   The impact is positive. This program will strengthen the existing degree programs at UofL. The curriculum proposed here will be used for offering graduate certificates in materials & energy to students pursuing Master's and doctoral degrees in all disciplines – Chemical Engineering; Mechanical Engineering; Physics and Chemistry. Students from other disciplines such as Civil, Electrical & Computer Engineering and Industrial Engineering will also benefit from the offering of courses within the proposed program. Students can obtain specialization through graduate certificates while pursuing the respective disciplinary degrees. Also, the graduates from this one-year M.S degree will be adequately trained and motivated to pursue PhD degrees from their respective disciplines. We expect to see improvement in our attraction and recruitment of students into the existing PhD programs in sciences and engineering if the proposed MS degree program is successful.

3. **Provide adequate documentation to demonstrate sufficient return on investment to the state to offset new costs and justify approval for the proposed program.**

In addition to advancing Kentucky's STEM initiatives by producing highly trained materials and energy scientists & engineers, this program is expected to grow overall enrollment at UofL. We project an enrollment of approximately 30 students by Year 5, yielding annual tuition revenue of roughly $763,471. This revenue will offset the investment cost of 2 new GTA's ($119,419) needed to deliver the program. Less tangible benefits will also potentially include attracting graduates of the MS MESE program into PhD programs. Those who join the workforce following graduation from the MS MESE program and choose to remain in Kentucky will contribute to growth of Kentucky's economy and will contribute to improvements in the quality of life of Kentuckians.

Cost/Funding Explanation

Complete the following table for the first five years of the proposed program and provide an explanation of how the institution will sustain funding needs. *The total funding and expenses in the table should be the same or explain sources(s) of additional funding for the proposed program.

A. Funding Sources, by year of Program	**1st Year**	**2nd Year**	**3rd Year**	**4th Year**	**5th Year**
Total Resources Available from Federal Sources New Existing					
Narrative Explanation/Justification					
Total Resources Available from Other Non-State Sources New Existing					
Narrative Explanation/Justification:					
State Resources New Existing					
Narrative Explanation/Justification:					
Internal Allocation Internal Reallocati on					
Narrative Explanation/Justification: The source and process of allocation and reallocation should be detailed, including an analysis of the impact of the reduction on existing programs and/or organization units.					
Student Tuition **New**	**$229,341**	**$235,074**	**$465,575**	**$610,810**	**$763,471**
Narrative Explanation/Justification: Projected tuition revenues are based upon full-time enrollment for matriculation in an average of 3 terms of 12 hours +12 hours + 6 hours. A resident/non-resident Master's student ratio of 60%/40% is used for tuition calculations based on the prior 3 years of Speed School graduate enrollment demographics. Note that Y0 (2019) full time tuition for resident = $6,500; full time tuition for non-resident = $13,557; graduate online tuition = $764/hr. Rate of increase per year is 2.5% on resident and non-resident tuition and 7% for online tuition. However, we believe this program has the potential to attract new non-resident students to the university from neighboring states and abroad which will increase tuition revenues beyond projected values.					
TOTAL	**$229,341**	**$235,074**	**$465,575**	**$610,810**	**$763,471**

B. Breakdown of Budget Expenses/Requirements	**1st Year**	**2nd Year**	**3rd Year**	**4th Year**	**5th Year**
Staff					
Executive, Administrative, Managerial **New**	$32,125.	$33,089	$34,081	$35,104	$36,157
Other Professional **Existing**	$38,550	$39,706	$54,530	$56,166	$57,851
Faculty **Existing**	$38,550	$39,706	$81,795	$84,249	$86,777
Graduate Assistants **New**	$45,136	$45,730	$92,678	$140,892	$190,420
Student Employees					
Narrative Explanation/Justification: Funds for 1 Administrative Staff person at 50% FTE include annual base salary at $50K and fringe at 28.5% with a 3% annual raise. Funds for Other Professional (Existing) include 1 month base salary each at $10K and fringe at 28.5% with a 3% annual raise for 3 theme leaders in Y1-2 and 4 theme leaders in Y3-5. Funds for Faculty (Existing) include 1 month base salary each at $10K each and fringe at 28.5% with a 3% annual raise for 3 faculty in Y1-2 and 6 faculty in Y3-5. Funds for GTA lines include a stipend ($22,008/yr), health insurance ($254.07/month), and 12 months full-time graduate tuition charged at the resident rate. 1 GTA in Y1-2, 2 GTAs in Y3, 3 GTAs in Y4, and 4 GTAs in Y5. A 3% annual inflation rate was applied to the health insurance cost and 2.5% to the tuition cost.					
Equipment and Instructional Materials **New Existing**	$5,000 $10,000	$5,000 $10,000	$5,000 $10,000	$5,000 $10,000	$5,000 $10,000
Narrative Explanation/Justification: Funds for supplies are allocated at 5K per year and for facilities access to Conn Center laboratories at 10K per year in lieu of equipment charges to carry our curricular assignments and experiments.					
Library **New**			$5,000	$5,000	$5,000
Narrative Explanation/Justification: Funds are allocated for new subscriptions to journals focused on materials and energy science and engineering, such as "Advanced Energy Materials" by Wiley starting in Y3.					
Contractual Services					
Narrative Explanation/Justification					
Academic and/or Student Services					

Narrative Explanation/Justification					
Other Support Services					
Narrative Explanation/Justification					
Faculty Development **New**			$10,000	$10,000	$10,000
Narrative Explanation/Justification Funds for curriculum development are allocated at 10K per year starting in Y3.					
Assessment					
Narrative Explanation/Justification					
Other Institutional overhead	$57,335	$58,769	$116,394	$152,703	$190,868
Narrative Explanation/Justification:	Institutional overhead is charged to the revenue from tuition at a rate of 25%.				
TOTAL EXPENSES	**$226,696.03**	**$232,000.05**	**$409,478.68**	**$499,113.35**	**$592,072.14**
	YEAR 1	***YEAR 2***	***YEAR 3***	***YEAR 4***	***YEAR 5***
TOTAL FUNDING SOURCE	$229,340.88	$235,074.40	$465,575.15	$610,810.12	$763,470.72
TOTAL EXPENSES	(226,696.03)	($232,000.05)	($409,478.68)	($499,113.35)	($592,072.14)
BALANCE SURPLUS/DEFICIT	**$2,644.85**	**$3,074.35**	**$56,096.46**	**$111,696.77**	**$171,398.59**

E. Program Review and Assessment

Describe program evaluation procedures for the proposed program. These procedures may include evaluation of courses and faculty by students, administrators, and school personnel as appropriate. Program review procedures shall include standards and guidelines for the assessment of student outcomes implied by the program objectives and consistent with the institutional mission.

a) demonstrated advanced level knowledge of materials and energy science & engineering
b) an understanding of contemporary materials and energy science & engineering topics
c) ability to effectively communicate advanced knowledge of materials and energy science & engineering orally and in writing
d) an understanding of the professional practice of materials and energy science & engineering

1) Mastery of basic graduate knowledge in the materials and energy science and engineering topics – This outcome will be measured through final exam grades in two core courses.
2) Thorough knowledge about contemporary topics on materials research for energy challenges. This outcome will be measured through literature review as part of a term paper in a course offered in Spring Semester.
3) Strong oral and written communication skills – This outcome will be measured through the quality of term paper presentations in one of the courses offered in Spring semester.
4) Gain knowledge about professional practice of materials and energy science and engineering. This will be measured through output in the systems engineering courses during Summer semester.

The programmatic outcomes and their major measures of success are defined briefly below as part of the expected assessment plans for the graduate programs in Material & Energy Science and Engineering.

1. **Fundamental knowledge of materials structure, properties, processing and their application to energy conversion and storage technologies.** Fundamental knowledge or basic content about materials and energy science and engineering is address in the following curricular components: structure-property-processing-application relationships for materials and energy devices. The student learning for this outcome will be measured through performance with final exams in two core courses – Advanced materials science & engineering and Advanced energy science & engineering. The target is to have at least 50% success rate for students passing two out of three questions in the final exams.

2. **Good understanding about energy challenges, contemporary research being done in the field of energy:** The courses on energy technologies and systems engineering courses will teach students with current and on-going research and will enable students to review prior research and on-going research on various concepts. This programmatic outcome will be assessed by surveying students in one of the energy conversion device courses on the student's term papers. The target is to ensure that over 50% of students will score good or better on the course term papers on any energy research topic.

3. **Ability to communicate scientific and engineering aspects on materials and energy to other**

peers, colleagues and community at large. Several courses offer opportunities to students for classroom discussions, written term papers, oral presentations and to attend seminars/workshops organized by Conn center, departmental seminars on materials and energy research. In addition, students will also get opportunities to submit written reports from either final project or from experiential learning in systems engineering course. This outcome will be assessed by evaluating written reports and oral presentations in one of the courses in the second semester. The target is to have at least 50% students receive good or better on term paper presentations both on the written part and oral part.

4. **Ability to think, design, evaluate and enable systems level approaches for enabling energy solutions for practical applications.** Systems engineering courses and project will provide culminating experience for the various concepts covered in the program. The culminating experience will include a detailed project that will involve a detailed analysis of techno-economics; integration of various systems; design and application of systems at scale for solving energy challenges. The outcome will be assessed by evaluations of all students that take any guided elective or the project. The target is to have at least two thirds of students receive good or better grade on the reports product from the systems engineering courses and the projects. Some of the products may involve a prototype or a detailed systems design or a techno-economic analysis of technological solution to a problem or a proposed technological solution to an energy challenge. Discussions during courses; written term papers; presentations, attend seminars/workshops organized by Conn Center on materials and energy research and final project write-ups.

1. For each assessment method, please provide direct indicators of achievement of program-level student learning outcomes and frequency of data collection:

a. When will the components be evaluated?
Components will be evaluated each semester.

b. When will the data be collected?
Data will be collected each term.

c. How will the data be collected?
Data will be collected in select courses in Fall, Spring and all systems engineering and project courses.

d. What will be the benchmarks and/or targets to be achieved?
Targets are already specified above.

e. What individuals or groups will be responsible for data collection?

MS MESE Program Director and faculty subcommittee will be responsible for data collection, but the course instructor will be responsible for submitting the data from their courses.

f. How will the data and findings be shared with faculty?
Results of data analysis will be shared with faculty at an annual MESE faculty and staff retreat to review MESE programs, as well as at faculty meetings as deemed appropriate.

i. How will the data be used for making programmatic improvements?

As a part of the annual MESE retreat or meeting, findings will be evaluated and as needed recommendations for improvement will be discussed.

2. What are the measures of teaching effectiveness?

The UofL Office of Institutional Effectiveness is working on implementing a short set of standardized course evaluation questions related to teaching effectiveness to be used across all student evaluations. These questions were developed in conjunction with a group of unit associate deans. Course evaluations provide direct student feedback to course instructors who are then able to address areas needing improvement. In addition, course evaluations are measured outcomes of teaching performance. As a result, the Program Director will discuss and address any identified weaknesses with instructors.

3. What efforts to improve teaching effectiveness will be pursued based on these measures?

Course instructors have access to the Delphi Learning Center's monthly workshops designed to improve teaching effectiveness. Typically, these one-hour training workshops are designed to present new teaching approaches, education paradigms, and instruction of emerging technology to improve teaching effectiveness.

4. What are the plans to evaluate students' post-graduate success?

Short-term post-graduate success will be defined based upon placement in industry, government agency and academic positions. Intermediate and long-term success will be characterized by contributions to the field of materials and energy science & engineering as evidenced by employment advancement, scientific publications, patents issued, honors, start-up companies established, and professional attainment by alumni (targets for these outcome measures are shown below in Table 3). The MS MESE program will survey alumni in parallel with the SIGS Alumni Tracking program in the first year following graduation and every 5 years thereafter.

Table 3. Program assessment: targets for post-graduate measures of success

F. Outcome measure	**G. Target within 5 years post-graduation**
Employment advancement	30% of alumni
Scientific publications (co-author on peer-reviewed journal paper or conference proceeding)	50% of alumni
Patents submitted or issued	20% of alumni
Honors	20% of alumni
Start-up companies established	10% of alumni

Appendix A
Faculty Roster Form
Qualifications of Full-Time and Part-Time Faculty

Name of Institution: **University of Louisville**

Name of Primary Department, Academic Program, or Discipline: **Conn Center for Renewable Energy Research**

Academic Term(s) Included: Date Form Completed: Sept 10, 2019

1	*2*	*3*	*4*
NAME (F, P)	**COURSES TAUGHT Including Term, Course Number & Title, Credit Hours (All courses are 3 credit hours unless specified)**	**ACADEMIC DEGREES & COURSEWORK Relevant to Courses Taught, Including Institution & Major List specific graduate coursework, if needed**	**OTHER QUALIFICATIONS & COMMENTS Related to Courses Taught**
Sunkara, Mahendra (F) ***PROGRAM DIRECTOR***	CHE 694 – Energy Challenges (Advanced Energy Science & Engineering) – 3 times CHE 581 – Chemical Vapor Processing – Taught 6 times ChE 532 – Advanced Materials Science – once	PhD, Chemical Engineering Case Western Reserve University	>25 years of experience with R&D in materials and energy science and engineering Developed course curriculum for both chemical vapor processing and energy science and engineering courses.
Starr, Tom (F)	ChE 694 – Processing for Additive Manufacturing (Taught > 5 times)	PhD, Chemical Engineering University of Louisville	Developed all curricular materials for the above course. Includes results from ongoing, Navy sponsored research program on Additive Manufacturing of Stainless Steel
Gupta, Gautam (F)	Have not taught graduate courses at UofL yet	PhD, Chemical Engineering University of New Mexico	CHE 351 physical chemistry, 3 times CHE 253 materials science 2 times
Sathitsuksanoah, Noppadon (F)	ChE 694 – Bioprocess Engineering; taught 2 times & ChE 502 – Biochemical Engineering; taught 1 time	PhD, Biosystems Engineering Virginia Polytechnic Institute and State University	
Amos, Delaina (F)	CHE 699 – Engineering Project Fundamentals II CHE 694 – Quantum Dots and Lighting	PhD, Chemical Engineering University of California Berkeley	Developed graduate level materials course on Quantum dots, PV cells and lighting materials. Also, coach students through business ideas related to new materials development and startups.
Willing, Gerold (F)	CHE 653 – Polymer Processing – Taught 13 times CHE 551 – Polymer Science – Taught 2 times CHE 532 – Advanced Materials Science – Taught 1 time	PhD, Chemical Engineering Auburn University	20 years experience with design, synthesis, and characterization of soft materials, nanomaterials, and complex fluids Developed the Undergraduate Teaching Assistant program in the Speed School as the engineering lead of 6-year NSF STEP grant.

Druffel, Thad (F)	ME475 – Engineering Entrepreneurship in Renewable Energy (3 times); ME497 Capstone Design (2 times); ME251 Thermodynamics I (2 times)	PhD, Chemical Engineering University of Louisville	>25 years of engineering experience with ~ 20 years in industry, includes 2 technology startups. Developed curriculum for entrepreneurship.
Spurgeon, Joshua (F)	CHE 694 – Photovoltaics and Solar Fuels – 4 times	PhD, Chemical Engineering California Institute of Technology	>15 years of experience with solar energy and photoelectrochemistry Previous Project Leader for DOE Joint Center for Artificial Photosynthesis Developed course curriculum for photovoltaics and solar fuels class.
Satyavolu, Jagannadh (F)	ChE 694 Biomass and Biofuels – 3 times	PhD, Chemical Engineering The Ohio State University	**<u>Georgia Tech</u>**: ChE/ME 4720 (related to biomass) Papermaking – 2 times Pulping – 2 times Bleaching – 2 times > 30 years of industrial and academic R&D related to bioprocessing, bioproducts, and novel separations. Commercialized multiple products starting from concept scale Developed curriculum for the biofuels class.
Jasinski, Jacek (F)	UofL: CHE 694-03 – Materials Characterization (2 times) ME 675-03 - Materials Characterization (1 time)	PhD, Physics of Semiconductors Warsaw University, Poland; MSc, Solid State Physics Warsaw University, Poland	25 years of experience with R&D in solid state physics and materials and energy science and engineering Developed materials science curriculum courses, including courses on electron microscopy, diffraction, and materials characterization
Paxton, William (F)	Have not taught at UofL L yet	PhD, Electrical Engineering Vanderbilt University	10+ Years in advanced chemical vapor deposition technologies. Primary focus has been diamond (reactor construction, synthesis, applications). Additional expertise in virtually all next-gen semiconductor fabrication technologies including MOCVD, HVPE, and countless plasma-based approaches
Thapa, Arjun (F)	Have not taught at U of L yet	PhD, Applied Chemistry Saga University, Japan	>15 years of R&D experience with battery systems
Grapperhaus, Craig (F)	CHEM 654 – Advanced Coordination Chemistry (8 times) CHEM – 656 Special Topics in Inorganic Chemistry - Crystal field theory, spectroscopy, magnetic methods, and electron transfer. (1 time) CHEM 529 – Synthesis and Analysis II (6 times) CHEM 515 – Inorganic Chemistry (8 times)	PhD, Chemistry Texas A&M University	25 years of experience of inorganic chemistry research focused synthesis, physical and spectroscopic characterization, and reactivity studies. Developed multiple graduate and undergraduate lecture and laboratory courses.
Zamborini, Frank (F)	CHEM 207-210: Introduction to Chemical Analysis (21 times) CHEM 425: Instrumental and Statistical Analysis (2 times) CHEM 529: Synthesis and Analysis II (12 times) CHEM 621:	PhD, Chemistry Texas A&M University	26 years of experience in Analytical Chemistry with a focus on electrochemistry, surface functionalization, surface analysis, nanomaterials, scanning probe microscopy, spectroscopy, and photovoltaics.

	Electroanalytical Chemistry (6 times) CHEM 622: Analytical Separations (1 time) CHEM 625: Advanced Analytical Chemistry (6 times) CHEM 629: Special Topics in Analytical Chemistry (1 time)		
Ramezanipour, Farshid (F)	CHEM 659: Solid State Chemistry – taught 2 times (first time under a different course ID, CHEM 691) CHEM 529: Synthesis and Analysis II – taught 2 times	PhD, Chemistry McMaster University	Active R&D in materials chemistry; property measurements and materials by design for energy applications
Liu, Jinjun (F)	Chem 661: Thermodynamics, Statistical Thermodynamics, and Kinetics Chem 665: Special Topics in Physical Chemistry: Molecular Spectroscopy Chem 672: Quantum Chemistry	PhD, Chemical Physics The Ohio State University	Award-winning laser scientist and molecular physicist with recognized success in leading a medium-sized research group; Two decades of hands-on experience with research lasers and spectroscopy systems; Demonstrated expertise in data analysis and computer simulation of complex systems; Effective communication and persuasion skills; Extensive work experience in China, Europe, and the U.S.
Sumanasekera, Gamini (F)	PHYS 575-Solid State Physics-4 times PHYS 650-Research Methods-2 times Taught modules in CHE 694 – Energy Challenges (Advanced Energy Science & Engineering) – 3 times	PhD, Physics Indiana University	Over 20 years of experience in materials research. Developed course modules for Research Methods in Physics.
Yu, Ming (F)	Phys 621-Quan. Mech I. (multiple times) Phys 622-Quan. Mech II. (multiple times) Phys 530-Therm. Phys (multiple times)	PhD, Condensed Matter Physics Hokkaido Institute of Technology, Japan	Over 15 years of research experience in theoretical and computational condensed matter physics on nanostructures and surfaces
Jayanthi, Chakram (F)	Phys. 650- Research Methods (> 5 times) Phys. 565- Computational Physics (> 5 times) Phys. 561 – Mathematical Methods in Physics (> 10 times)	PhD, Physics Indian Institute of Technology Delhi, India	35 years of research experience in theoretical and computational condensed matter physics, in particular nanoscience, surface science, etc. Developed the course curriculum for computational methods used in physics, in particular, materials modeling and simulations.
Smadici, Serban (F)	Phys 621-Quan. Mech I. (multiple times) Phys 622-Quan. Mech II. (multiple times) Phys 601 Quan. Mech. Lab	PhD, Physics Columbia University	Over 15 years of research experience in magnetism, superconductivity. Ultra-fast spectroscopy. Developed a lab course to investigate quantum phenomena.
McIntyre, Michael (F)	ECE 531: Power Electronics ECE 560/561: Control Systems & Lab ECE 581: Electric Machines and Drives ECE 600: Grid Connected Power Electronics ECE 665: Nonlinear Systems	PhD, Electrical Engineering Clemson University	Over 15 years of research and development experience in systems and controls of electrical energy systems. Developed courses and modules for courses in control systems, power electronics, and electric machinery.

	and Controls		
McNamara, Shamus (F)	ECE 542 Physical Electronics ECE 600: Advanced MEMS ECE 600: Semiconductor Power Devices ECE 632: Semiconductor Principles ECE 633: Microelectronic Device Design and Fabrication Lab ECE 636: MEMS Design and Fabrication Lab ECE 638: The MOSFET	PhD, Electrical Engineering University of Wisconsin - Madison	Wrote textbook for ECE 542
Cohn, Robert (F)	Survey of Nanotechnology (2000-date); ECE674 Laboratory Practice in Nanotechnology (2000,2002); Foundations of Polymer MEMS (2004-date); ECE676 ECE 675 Nanostructure Self-Assembly (since 2005) ECE 600 Nanostructure Self-Assembly II & III (2013-date)	PhD, Electrical Engineering Southern Methodist University	R&D interests are mostly represented by courses. Main interests are materials science and engineering including self-assembly driven fabrication methods, nanoimaging, nanomechanics
Wang, Hui (F)	ME 572 Energy Storage Systems; taught twice	PhD, Materials Science & Engineering Michigan Technological University	>10 years research experience on advanced materials for energy conversion and storage applications.
Narayanan, Badri (F)	ME575 Computational Modeling of Nanomaterials (taught once)	PhD, Materials Science & Engineering Colorado School of Mines	>10 years of R&D experience in computational modeling of materials applied to energy applications
Park, Sam (F)	ME572 Energy Storage System: taught three times	PhD, Mechanical Engineering Texas A&M University	- Developed course curriculum for ME 572 Energy Storage Systems - 15 years of experience with R&D in materials and energy science and engineering - Site director of NSF: I/UCRC: EVSTS (Efficient Vehicle and Sustainable Transportation Systems)
Robinson, Brian (F)	ME 560 – Introduction to Nuclear Engineering – 2 times taught each once ME 575 – Manufacturing Processes – taught once ME 618 – Heat Exchanger Design – 2 times	PhD, Mechanical Engineering University of Louisville	- Has become an integral member within SSoE's Department of Engineering Fundamentals; primarily focused on research and integration of engineering education - Was recently awarded a $600K NSF grant in engineering education focused on edifying local high-school district (JCPS) science teachers in engineering design and energy science - Was directly responsible for building "from scratch" the highly-successful *Engineering Methods, Tools, and Practice II* course (ENGR

			111) that all first-year SSoE students are required to take. ENGR 111 is a hands-on, makerspace-based course, culminating in the SSoE Cornerstone experience, that teaches application and integration of fundamental engineering skills.
Kate, Kunal (F)	No graduate courses taught yet	PhD, Materials Science Oregon State University	R&D in 3-D printing & advanced manufacturing
McGinley, Mark (F)	CEE 694 Green Engineering (3) three times AREN 639 – Integrated Building Design (3) – Twice	PhD, Civil Engineering University of Alberta	Member ACI 122 Energy Efficiency of Concrete and Masonry Systems Chairman of ASTM C 12 Mortar and grouts Committee , Chairman (elect) of ASTM C 15 Masonry Units and material
Alphenaar, Bruce (F)	ECE 600 Solar Cells (2 times Cells (2 times) ECE 600-01 VLSI Technology (3 times) ECE 600-02 Advanced Device Electronics (3 times)	PhD, Yale University, Applied Physics	>25 years of experience with semiconductors; novel materials; fundamental properties of nanoscale materials and energy applications

F, P: Full-time or Part-time;

Appendix B

Program Sub-committee

The faculty subcommittee (listed below) will be used for administering the student admissions, faculty mentor assignment; monitoring student progress and serve as ad hoc committee for case by case basis.

Brian Robinson, PhD
Assistant Professor, Engineering Fundamentals
J.B. Speed School of Engineering

Joshua Spurgeon, PhD
Theme Leader, Solar Fuels
Conn Center for Renewable Energy Research
J.B. Speed School of Engineering

Gautam Gupta, PhD
Associate Professor, Chemical Engineering
J.B. Speed School of Engineering

Farshid Ramezanipour, PhD
Assistant Professor, Chemistry
College of Arts & Sciences

Gamini Sumanasekera, PhD
Professor, Physics
College of Arts & Sciences

Mark McGinley, PhD
Professor, Civil & Environmental Engineering
J.B. Speed School of Engineering

Michael McIntyre, PhD
Associate Professor, Electrical & Computer Engineering
J.B. Speed School of Engineering

Hui Wang, PhD
Assistant Professor, Mechanical Engineering
J.B. Speed School of Engineering

Appendix C

Letters of Support

Emmanuel Collins, PhD
Dean, JB Speed School of Engineering

Kimberly Kempf-Leonard, PhD
Dean, College of Arts & Sciences

Joel Fried, PhD
Professor and Chair, Chemical Engineering
JB Speed School of Engineering

Chakram Jayanthi, PhD
Professor and Chair, Physics & Astronomy
College of Arts & Sciences

Craig Grapperhaus, PhD
Professor and Chair, Chemistry
College of Arts & Sciences

Paul DeMarco, PhD
Acting Dean of the Graduate School
Professor, Psychological & Brain Sciences

UNIVERSITY OF LOUISVILLE
J.B. SPEED SCHOOL OF ENGINEERING

Office of the Dean

August 23, 2019

Dr. Beth Boehm
Provost
University of Louisville
Louisville, KY 40292

Dear Provost Boehm,

I would like to express my complete support for the proposal of a Master of Science in Materials and Energy Science & Engineering (MS in MESE) program. Though this program is being proposed through the efforts of the Conn Center for Renewable Energy Research, it will be a Speed School of Engineering degree program. It is my belief that the proposed program will be a great addition to our current offerings. The addition of this Master of Science program will open the door to students with Bachelor's degrees across science and engineering disciplines from other institutions as well as the University of Louisville. According to market research, there is a demand for programs such as this.

The proposal submitted for this program has been well thought out and planned. It was unanimously approved by the participating faculty in July 2019 and unanimously recommended for approval by the J.B. Speed School of Engineering Graduate Education Committee in August 2019. Implementation of this program will be possible without any major disruption to other degree programs, and this new offering will also further the goals of the University in both enrollment growth and research. In addition, students in this new MS in MESE program will benefit from the Conn Center's world-class laboratory facilities, research endeavors, researchers, and associated faculty.

I would like to offer my strongest support for this proposal to add a Master of Science in Materials and Energy Science & Engineering degree program here at the Speed School of Engineering.

Sincerely,

Emmanuel G. Collins

Emmanuel G. Collins
Dean, Speed School of Engineering

University of Louisville • Louisville, KY 40292
P: 502.852.6281 F: 502.852.7033 E: speed@louisville.edu W: louisville.edu/speed

UNIVERSITY OF LOUISVILLE
COLLEGE OF ARTS & SCIENCES

August 23, 2019

Dr. Beth Boehm
Provost
University of Louisville
Louisville, KY 40292

Dear Provost Boehm,

I would like to express my support for the proposal of a Master of Science in Materials and Energy Science & Engineering (MS in MESE) program in the Conn Center for Renewable Energy Research. The proposed program will be unique in Kentucky and will strengthen the educational opportunities for UofL students interested in careers in the multi-disciplinary fields related to materials and energy science. The addition of this Master of Science program will open the door to students with Bachelor's degrees across science and engineering disciplines from other institutions. According to market research, there is a demand for programs such as this. We believe that this degree will have significant positive impact on the academic and research goals of the College of Arts and Sciences through increased interactions of the faculty and students from the Departments of Chemistry and Physics & Astronomy with other affiliates of the Conn Center.

Implementation of this program will be possible without any major disruption to other degree programs in Physics & Astronomy or Chemistry. The growth potential associated with this new program will also further University goals including enrollment growth, increased research funding and outcomes, and enhanced career training of the STEM workforce in the Commonwealth. Students in this new M.S. in MESE program will benefit from the Conn Center's world-class laboratory facilities, research endeavors, researchers, and associated faculty.

I recommend that the proposed new Master of Science in Materials and Energy Science & Engineering degree program, working across the Speed School of Engineering and the College of Arts & Sciences, be added to the University of Louisville curricula.

Sincerely,

Kimberly Kempf-Leonard, PhD
Dean, College of Arts & Sciences

UNIVERSITY OF
LOUISVILLE.

Department of Chemical Engineering

August 22, 2019

RE: MS Degree in Materials and Energy Science and Engineering (MESE) Proposal
Departmental Letter of Support – Chemical Engineering

Dear Dr. Sunkara:

It is with great enthusiasm that I am writing in full support of the Master of Science (MS) program in Conn Center for Renewable Energy Research in conjunction with faculty from Chemical Engineering. The departmental faculty and I have reviewed the proposal and we look forward to MS students enrolling in our courses. In addition, our faculty are committed to working with MS students to serve as mentors and thesis advisors.

This program will create excellent opportunities for collaborations within the current academic and research programs in the schools of engineering, chemistry, physics and more. Currently, our MEng students can only enroll from within the Speed School at UofL. The MS program will enable students from other universities, both nationally and internationally, to enroll in our Master's program.

The overall outcomes of the program will certainly yield tremendous benefits to the students and faculty, and to the university as a whole. I look forward to working with you to assist in any way I can to make sure the program is successful. Best of luck as this moves forward!

Sincerely,

Joel R. Fried

Joel Fried, PhD
Professor and Chair of Chemical Engineering

University of Louisville • Louisville, KY 40292
P: 502.852.6347 **F:** 502.852.6355

August 22, 2019

RE: MS Degree in Materials and Energy Science and Engineering (MESE) Proposal
Departmental Letter of Support - *Physics*

Dear Professor Sunkara:

It is a pleasure to support the new proposed Master of Science degree program in Materials and Energy Science and Engineering by the Conn Center of Renewable Energy, JB Speed School of Engineering.

This program aims to seamlessly integrate the curriculum from fundamental studies of physics and chemistry of solids to materials engineering applications. Students graduating from the program will have well-rounded education and training in materials science and engineering and can pursue careers in academia after obtaining their PhD degree or they can become entrepreneurs. Furthermore, the strong ongoing materials & energy science research program of the Conn Center will attract students to this program.

The faculty members belonging to the Condensed Matter Physics sector of the Department of Physics and Astronomy will be happy to teach Solid State Physics (Phys. 575) and Research Methods appropriate for Experimental and Computational studies of Materials (Phys. 650), and will be willing to serve as mentors for MS students in the program.

I strongly believe this program will serve as feeder to the PhD programs in Physics, Chemistry, and many engineering disciplines.

The overall outcomes of the program will certainly yield tremendous benefits to the students and faculty, and to the university as a whole. I look forward to working with you to assist in any way I can to make sure the program is successful. Best of luck as this moves forward!

Please do not hesitate to contact me for any information.

Sincerely,

C. S. Jayanthi

Chakram Jayanthi, PhD
Professor and Chair of Physics and Astronomy

UNIVERSITY OF
LOUISVILLE.
COLLEGE OF ARTS & SCIENCES

Department of Chemistry

August 20, 2019

RE: M.S. Degree in Materials and Energy Science and Engineering (MESE) Proposal
Departmental Letter of Support - *Chemistry*

Dear Dr. Sunkara:

It is with great enthusiasm that I am writing in full support of the M.S. Degree in Materials and Energy Science and Engineering program in the Conn Center for Renewable Energy Research in conjunction with faculty from the Department of Chemistry in the College of Arts and Sciences. I have reviewed the proposal in consultation with departmental faculty and we look forward to M.S. students enrolling in our graduate courses. In addition, our faculty are committed to working with M.S. students to serve as mentors and theses advisors.

This program will create excellent opportunities for collaborations within the current academic and research programs in the Speed School of Engineering and A&S departments such as Chemistry, Physics, and more. Further, it will enable graduates of our Chemistry Bachelor's program and Bachelor's graduates from other universities, nationally and internationally, to pursue a degree through the proposed M.S. program as they prepare for employment or entrance into our Ph.D. programs.

The M.S. program will also help us implement collaborative projects with international universities. The overall outcomes of the program will certainly yield tremendous benefits to the students and faculty, and to the university as a whole. I look forward to working with you to assist in any way I can to make sure the program is successful. Best of luck as this moves forward!

Please do not hesitate to contact me for any information.

Sincerely,

Craig A. Grapperhaus

Craig Grapperhaus, Ph.D.
Professor and Chair of Chemistry

UNIVERSITY OF
LOUISVILLE
GRADUATE SCHOOL

August 29, 2019

Mahendra K. Sunkara, PhD
Professor, Chemical Engineering
Director, Conn Center for Renewable Energy Research
Speed School of Engineering
University of Louisville

Dear Dr. Sunkara:

The Graduate School is eager see growth in new and innovative graduate programs at the University of Louisville, and we are pleased to support this proposal for a Master of Science in Materials and Energy Science & Engineering. This is a critical area of training for master's students, and I'm confident that there will be high interest in this program as well as a strong job market for its graduates. We are also happy that this program will support doctoral students to serve as graduate teaching assistants for the program through assistantships, and I want to remind you of our standing policy that non-resident graduate students who are fully supported by these assistantships will be eligible to be billed at the resident tuition rate as long as they remain on scholarship funding and are in good academic standing.

Students enrolled in this program will also be eligible to benefit from the Graduate School's PLAN professional development program (http://louisville.edu/graduate/plan). This program supports graduate students by offering guidance, consultation, workshops and seminars to foster graduate student success by helping students take charge of their own learning and development through opportunities and resources related to professional and academic development.

We look forward to partnering with you and your colleagues on this exciting new degree program, and I fully support this proposal.

Sincerely,

Paul DeMarco

Paul DeMarco, Ph.D.
Acting Vice Provost for Academic Affairs
Acting Dean of the Graduate School
Professor of Psychological and Brain Sciences

Graduate School ● 105 Houchens ● University of Louisville ● Louisville, KY 40292
P: 502.852.6495 **F**: 502.852.2365 **W**: www.louisville.edu/graduate

Appendix D

Course Descriptions

MESE 510 (CHE 698) Advanced Energy Science and Engineering
This course presents overview of global challenges associated with energy/environment nexus, energy demand, generation and storage. The course will cover fundamental science underlying various energy conversion and storage through thermodynamics and kinetics and understand efficiency.

MESE 520 (CHE532) Provides a background in materials for students coming from various majors in engineering and science. The course will review fundamental crystal structures, structure, bonding relations and defects in crystals. Thermodynamics of solids, phase diagrams, structure-property relationships, microstructure control, lattice dynamics and fundamental electrical, magnetic and optical properties.

MESE 525 (ME675) Advanced Materials Characterization
This course provides graduate students fundamental understanding of some of the most important materials characterization techniques. Special focus is placed on fundamental aspects and practical applications of electron microscopy and diffraction methods to phase identification and structure determination for crystalline material. Following this course, students will (1) learn and understand fundamental concepts of materials structure, with the emphasis on crystals structure, (2) understand fundamentals of electron microscopy and diffraction techniques, and (3) apply theoretical methods and software tools to analyze and interpret various types of microscopic and diffraction data.

ME 575 Computational Modeling of Nanomaterials or Computational Materials Science
Introduction to crystal structures and chemical bonding in solids; basic of statistical thermodynamics; introduction to different materials modeling techniques at nano- to meso-scopic scales, namely, Molecular Dynamics, Monte-Carlo, and Density Functional Theory; Energy models from first-principles theory to classical potentials; Approximation associated with each technique, and their expected level of accuracy; modeling of surface diffusion processes, elastic constants, mechanical strengths, thermal conductivity and defect properties; “Hands-on” sessions on how to set-up simulations using available open-source packages, visualize and analyze output; introduction to emerging techniques like machine learning and materials informatics to design materials tailor-made for a specific functionality

PHY 575 Solid State Physics or ECE 542 Physical Electronics
This course will cover the optical properties of solid-state materials including metals, semiconductors, and insulator starting with the classical description of optical propagation and extending to quantum theory in the treatment of absorption, luminescence, and excitonic effects. Interaction of light with matter will be discussed with the aid of optical spectroscopies and characterization techniques such as UV-VIS spectroscopy, Fourier transform infrared spectroscopy, Raman spectroscopy, X-ray/UV photoelectron spectroscopy etc. An overview of the forms of electrical conduction in solid state materials will be given starting with the free electron theory. Then fundamental concepts in quantum theory and the theory of electron bands in solids will be introduced to interpret the electrical, magnetic and thermal properties of various classes of materials. A special emphasis of electrical behaviors of metals and semiconductors will be given by introducing key

electronic devices based on homo p-n junctions and hetero-junctions. A brief review of thermal and phonon properties will also be discussed.

CHEM 659 Solid State Chemistry

Course content will include the synthesis methods, characterization and properties of solid-state materials. Various techniques of preparation of solid-state materials as well as advantages and disadvantages of each method are discussed. The main properties of interest are structural properties, magnetism and charge transport in solid state. Basic principles as well as methods of investigation and characterization of these properties will be discussed in this course.

CHEM 621 Electroanalytical Chemistry

Principles of modern voltammetric and potentiometric methods of chemical analysis including fundamental theory, instrumentation, and applications.

II. FUNDAMENTAL PROCESSING COURSES

CHE 581 Chemical Vapor Deposition and Processing

This course presents a detailed understanding about science and technology of chemical vapor deposition and related methods and reactors used for making thin films, single crystals, powders. This process is popular for semiconductor materials manufacturing and manufacturing of materials for addressing global challenges associated with energy/environment nexus, energy demand, generation and storage. In particular, the course will focus on practical applications of CVD reactors, processes, electronic & amorphous materials and **educates and trains graduates with the academic and practical background necessary to function as chemical engineering professionals in several modern, state of the art industrial enterprises such as electronics manufacturing, advanced materials, energy, nanotechnology and bio-medical engineering. The course provides our graduates with the foundation for a successful career and enables life-long learning. Course will use CHEMKIN software to understand and model** chemical kinetics & transport processes to vapor phase deposition and processing of materials.

MESE 522 Roll to Roll Processing

Continuous manufacturing through roll-to-roll processes has been a staple within several industries over the past century including film, newspaper and other traditional low-cost high-volume products. As the renewable energy industry begins to scale, roll-to-roll processes can play an extremely important role in reducing costs at high volumes. This course will explore the roll-to-roll manufacturing processes through fundamental engineering principals including economics, heat and mass transfer, thermodynamics and materials. The course will consider the manufacturing of solar modules, batteries and fuel cell membranes.

CHE 694 (IE 601) Additive Manufacturing

This course focuses on the principal, commercially-realized AM processes and on the processing and materials science underlying them.

ECE 543/544 MEMS or Multiscale Integration

Microfabrication techniques including cleanroom technology, lithography, thermal oxidation, diffusion, ion implantation, film deposition, etching, micromachining, wafer-level bonding/polishing, and packaging yield. Microtechnology measurement and analysis techniques. Process simulation. CAD device-layout. MEMS (microelectromechanical systems) and microelectric technology and applications. Material issues for MEMS/microelectronics.

III. ENERGY CONVERSION AND STORAGE

MESE 512 (CHE 694) Photovoltaics and Solar Fuels

This course develops the fundamentals of semiconductor physics specific to solar energy and uses these key concepts to understand solar cell behavior. The various photovoltaic technologies, including both commercial and research-stage approaches, are described in detail. In addition, electrochemical and catalysis concepts are introduced and integrated with semiconductor behavior to understand the myriad criteria necessary to leverage solar energy in electrochemical fuel production processes such as water-splitting via artificial photosynthesis.

MESE 514 (CHE 694) Biomass and Biofuels
Manufacturing of “bioproducts or bio-based products” (materials, chemicals and energy produced using sustainable resources such as agricultural biomass) offers socio-economic, environmental, and health benefits. In order to be a part of this emerging bioeconomy, it is essential to learn the fundamental skills of managing biorenewable resources for the effective development of the rapidly evolving bioenergy and biofuels industries. This course integrates the biorenewable knowledge base of academic disciplines that include agriculture, chemistry, engineering, environmental sciences, and economics to provide the student with a broader perspective of this field. This course intends to assist senior level undergraduate and all graduate students in developing skills valued by prospective employers and providing a solid foundation for manufacturing, research and development of bioproducts.

ECE 531 Power Electronics
We cover power switching devices, AC to DC conversion of electric energy, DC to DC conversion, with and with magnetic isolation (transformers); DC to AC conversion (Inverters) of various forms. Also cover concepts related to grid connected power electronics; This is an advanced course that considers the circuits and control topics for integration of renewables to the power grid. We look at the circuits, systems and controls for grid connected PV applications. The course also covers material about grid connection of wind mills. There is also discussion about Micro-grids.

ME 572 Electrochemical Energy Storage
This course will cover functional knowledges of various energy storage modes with emphasis on electrochemical energy storage. It will introduce the fundamental principles of different energy storage systems such as mechanical energy storage, thermal energy storage, chemical energy storage, and electrochemical energy storage. The practical applications for each energy storage system will be discussed. This course will also focus on the chemistry and materials science behind these energy storage systems. In addition, the basis performance analysis of different types of batteries will be

introduced and compared.

CHE 694 Industrial Catalysis
This course will teach concepts involved with industrial catalysis involved in many chemical processing applications.

IV. EXPERIENTIAL AND PROJECT BASED COURSES – ENERGY SYSTEMS DESIGN, ENGINEERING AND ENERGY POLICY

MESE 610 Systems Integration & Entrepreneurship in Renewable Energy
The renewables market will continue to grow as the world seeks and finds cleaner and more sustainable techniques to produce energy. This project-based course guides student teams through the ideation to prototype development to test the commercial relevance of renewable energy products. At the end of the course each student team will have developed a prototype design supported by a business plan

MESE 620 Techno-economic Analysis and Energy Policy
While many novel scientific ideas are being explored for renewable energy generation and energy storage, a successful technology will require more than a proof-of-concept and an efficient prototype. Process economics, markets, and national and international energy policies will be critical to distinguishing which technologies can advance from laboratory feasibility to real-world commercialization. This course will introduce methods for conducting a technoeconomic analysis on an energy technology, determining the levelized cost of product over the facility lifetime, and modeling a sensitivity analysis to determine key performance metrics required to reach possible profitability. The development and current status of US and certain international energy policies will be addressed as well and incorporated to inform ideal markets for a prospective energy technology. Student teams will conduct their own project analysis as the core component of their grade for the course.

MESE 630 Smart Manufacturing
Smart Manufacturing are systems that are “fully-integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs”. NIST This directed reading and project-based course will address the key principals of Smart manufacturing with an emphasis on Energy efficiency, sustainability, and advanced sensors and control systems.

MESE 690 - Project: Students will work with a faculty/theme leader on a renewable energy systems topic and develop an in-depth understanding and provide a written report that includes problem definition, literature review, studies/analysis conducted and conclusions. The written report will be graded. This project will be substituted for the required systems engineering course.

Appendix E

8d. The physical facilities and instructional equipment available to support this program.

Offices – All of the faculty offices are located on Belknap campus: Lutz Hall; Sackett Hall; Ernst Hall; Shumaker building; Chemistry building and Natural Sciences building.

Classrooms and Instructional Laboratories – The proposed MESE-specific courses are offered primarily in Ernst and Sackett Halls, but the additional program courses are offered in classrooms across the Belknap Campus including Duthie Center. All classrooms have adequate lighting, climate control and acoustic characteristics, and are equipped with computers that interface with overhead LCD projectors. All buildings on the Belknap Campus are equipped with wireless internet access.

Computing Resources - The UofL central research computing or Cardinal Research Cluster (CRC) is housed in the UofL Information Technology Data Center located in the Miller IT Center on the university's Belknap campus. This facility provides over 5000 square feet of secure, environmentally controlled data center space including a FM200 fire suppression system. The data center is fed by 1000kVA electrical service with backup power provided by a large UPS and an 1125 kVA diesel generator. The research cluster is equipped with its own dedicated in- row cooling systems, and utilizes cold aisle containment to improve cooling efficiency. The facility is physically secure with limited keycard access and is monitored 24 hours a day. The UofL CRC infrastructure became available in spring 2009 and was upgraded in spring 2011. This infrastructure includes multiple systems serving the research needs of the entire university, including a general- purpose high-performance distributed-memory computation cluster, a high-memory SMP system and several general-purpose web and software servers. The general-purpose compute cluster is composed of 312 IBM iDatplex nodes each equipped with two Intel Xeon L5420 2.5 GHz quad-core processors for a total of 2496 processor cores. Each node has 16 or 32 GB of memory, and the node interconnects are a mixture of Gigabit Ethernet (1Gbps) and InfiniBand (16 Gbps) technology. The cluster is estimated to have a peak performance rating of 20+ TFLOPS. The UofL's campuses are served by a 40 Gigabit per second (Gpbs) campus backbone network. This backbone is comprised of over 80 miles of fiber in a dual ring configuration. The wired network can provide 100Mbps and 1Gbps Ethernet service for faculty and staff communications needs. With the recently completed Pervasive Wireless Project, the UofL campus wireless network provides 802.11n wireless connectivity to wireless devices at speeds up to 300Mbps. This wireless connectivity is available across all of UofL's campuses, classrooms and buildings. UofL is connected to the Internet2 node via dedicated 10Gbps optical fiber backbone network. The Internet2 connection gives UofL direct, high bandwidth, access to national research and education networks such as XSEDE/Teragrid. UofL is also a member of the Kentucky Regional Optical Network (KyRON). This regional optical network is managed and operated through a consortium including UofL, the University of Kentucky and the Kentucky Council on Postsecondary Education. Participating universities are interconnected using 10Gbps optical links. The Kentucky RON extends the research data sharing capabilities of UofL with other participating universities throughout the state, and provides new opportunities for collaboration.

Multi-Disciplinary & Core Research Facilities - To support the training of students in state-of-the-art research methodologies and techniques, MS MESE students will have access to a number of multidisciplinary and core research facilities (described below), as well as to individual faculty laboratories. Specifically, students will have access to the following multi-disciplinary facilities.

CONN CENTER FOR RENEWABLE ENERGY RESEARCH

The UofL is answering Kentucky's call to lead research efforts in renewable energy research issues. UofL established the Conn Center for Renewable Energy Research at the J.B. Speed School of Engineering in 2009. The Conn Center provides leadership, research, support and policy development in renewable energy; advances the goal of renewable energy; and promotes technologies, practices, and programs that increase efficiency for energy utilization. To accomplish these objectives, the Conn Center conducts and facilitates R&D on potentially commercializable renewable energy and energy efficiency technologies. The Center promotes partnerships among colleges and universities, private industries, and non-profit organizations to actively pursue federally and privately funded research and development resources that are dedicated to renewable energy solutions.

Conn Center research themes and facilities include: Solar Manufacturing; Solar Fuels; Biofuels & Biomass Conversions; Energy Storage; Advanced Energy Materials; Materials Characterization; and Energy Efficiency & Conservation.

The Conn Center houses instrumentation in 12 laboratories to support research in its core themes, as follows: Advanced Energy Materials; Biomass & Biofuels; Device Fabrication & Characterization; Energy Storage; Materials Characterization; Power Electronics; Solar Fuels; Solar Manufacturing; and Ultrafast Spectroscopy.

Conn Center: Advanced Energy Materials (EH 308)

Advanced Energy Materials lab maintains various capabilities to discover and develop new materials and processes. The lab allows for several different materials systems in various forms: nanoparticles, nanowires, polycrystalline thin films, single crystal thin films and large single crystals. The lab is specifically setup for discovery to scalable process development for materials used in various energy conversion and storage technologies.

Atmospheric Plasma Discharges: Equipped with a microwave plasma flame for fast bulk production of nanowires. Also has a microwave system with upward flame with auto matcher for foil oxidation. In addition, there are two custom-built, atmospheric plasma jet reactors for bulk production of nanowires. A custom-designed/developed atmospheric microwave plasma jet reactor for bulk production of various metal oxide nanowire powders (gram qty).

Plasma Assisted Chemical Vapor Deposition: Equipped with several custom designed plasma assisted chemical vapor deposition systems. ASTeX 5010 1.5 kW Microwave Chemical Vapor Deposition Reactor; ASTeX 250W ECR Chemical Vapor Deposition Reactor with RF bias and substrate heating/cooling capabilities. Custom built MOCVD precursor delivery system that operates at 150 C.; A 3 in. rotating/heated stage (up to 3000 rpm at 950 C) for use in any reactor; Plasmatherm Radio Frequency (RF) Plasma CVD reactor; Seki-Technotron 2.5 KW MW/ECR

Plasma with dual chambers for 4 inch and 10-inch substrates along with RF induction heating for stages & applied bias capability and for operation from mTorr to hundred Torr pressure range.

Hot-filament Chemical Vapor Deposition (HFCVD): Custom-built HFCVD reactor (3ft x 40 mm ID quartz tube) equipped with resistively heated refractory metal sources (Mo, Nb, W, Ta). Reactor is fitted with a 1-zone tube furnace for external heating with automated temperature control up to 1400 C. This reactor is used for deposition of thin films and nanostructured layers of refractory metals, refractory metal oxides and nitrides with filament operating temperatures up to 2500ºC, at pressures between 30 mTorr – 100 Torr, in H_2, N_2, O_2 and/or Ar atmospheres. In addition, this equipment can be used for pyrolysis, annealing, oxidation, reduction, and nitridation of materials.

Halide Vapor Phase Epitaxy (HVPE): A custom designed HVPE reactor with three zones for different temperatures and precursor delivery system. The system is capable of creating III-V and their alloys as epitaxial films and powders.

Metalorganic Chemical Vapor Deposition (MOCVD): A home built system for metal organic chemical deposition of III-V materials with precursor delivery system; shower head; resistive heated 2-inch stage; bubblers; pressure and flow controls.

Lab is also equipped with pyrometers; gas cabinets; leak testing equipment and optical emission spectroscopy for safety and in-situ monitoring.

Conn Center: Materials Characterization Facility (Lutz 009/010)

Advanced Materials Characterization facility, located in Lutz Hall at Belknap Campus is one of the UofL's core user facilities. Established in ~2500 ft^2 space, the facility serves dozens of UofL's Engineering and Natural Sciences faculty and students, as well as a number of external academic and industry users. The facility houses advanced instrumentation and capabilities for comprehensive structural, chemical, and spectroscopic analysis of a wide range of energy, nanoscale, and other functional materials. Available techniques include electron microscopy, x-ray diffraction (XRD), surface science techniques, optical and thermal analysis methods. In particular, the microstructure and samples morphology (particle size and shape, surface faceting, etc.) can be analyzed using a conventional Tescan Vega3 or a field emission gun (FEG) FEI Nova600 scanning electron microscope (SEM). The morphology and nanostructure can also be analyzed with the great detail using a 200-kV FEG FEI Tecnai F20 transmission electron microscope (TEM). With its sub-2.0 Å spatial resolution, this microscope allows for high-resolution crystal lattice imaging. Additionally, nanoscale electron diffraction as well as EDS or EELS chemical analysis, including line profiles and mapping of elemental distributions can be obtained using nanoprobe capabilities. TEM accessories include several dedicated sample holders, which expanding research capabilities on *in situ* experiments. For instance, the existing *in situ* TEM heating stage, enables nanoscale dynamical studies of thermally-driven phase transitions and materials transformations at temperatures up to 1300ºC. On the other hand, the recently acquired *in situ* liquid cell holder allows for dynamic TEM studies of materials synthesis and transformation in liquid environment. *In situ* capabilities, are invaluable as they provide a direct real-time insight into processes crucial for the synthesis, processing, and operation of energy and other functional materials. Among other unique capabilities is *in situ* XRD at temperatures up to 1100°C using a DHS 1100 Dome Heating Stage with gas injection system and a high-resolution Bruker Discover D8 XRD system. The system is equipped with a dynamic scintillation, a LynxEye(TM) detector and EVA software that employs the ICCD PDF-4 database for phase identification and allows for detail crystal structure, grain/domain size, and phase composition analysis. The facility houses also a VG Scientific MultiLab3000 ultrahigh vacuum (UHV) surface science system. With techniques such as XPS and UPS, the system allows for surface composition and chemistry analysis, including quantification of oxidation states and functional groups, as well as measurements of electronic structure parameters such as work function or valence band maximum position. The facility has also optical spectroscopy equipment including UV-Vis PL and Raman as well as thermal analysis instrumentation such as a TA Q20 with modulated differential scanning calorimetry (DSC) capability in the -40 °C to 600 °C to measure the heat flow and phase transitions and a TA Q600 system from a simultaneous DSC and thermo-gravimetric analysis (TGA) in temperatures up to 1500 °C. The facility has also a Micromeritics TriStar 3000 Brunauer-Emmett-Teller (BET) system for specific surface area and pore size distribution analysis of high surface area materials.

Conn Center: Solar Manufacturing R&D (EH300)

The Solar Manufacturing R&D Lab at the Conn Center is able to assist researchers in implementing designs, materials, and processes into scalable manufacturing platforms with demonstration devices. The facility maintains the capabilities to design and manufacture large-area solar cells over multiple platforms, including first- and second-generation technologies with an emphasis on the breakthrough of third generation technologies. The facilities include the capabilities for continuous (roll-to-roll) production of photovoltaics. The roll-to-roll manufacturing is also adaptable to other technologies such as electrochromics, OLEDs, thin film batteries, and fuel cells. In addition to fabrication, the lab is also equipped with solar cell testing equipment for AM1.5 light sources; J-V testing; IPCE and transient photocarrier dynamics.

Conn Center: Solar Fuels (EH 301)

The photoelectrochemistry laboratory is set up for state-of-the-art electrochemical testing, optical characterization, and electrochemical reaction product quantification.

Three BioLogic potentiostats (two SP-200s and one SP-150) with 12 V compliance and up to 5 electrode measurements and a Metrohm PGSTAT100 with 100 V compliance are available for general purpose electrochemistry. This includes electrochemical impedance spectroscopy (EIS) capability for AC measurement techniques with frequencies from 10 μHz to 7 MHz. The lab also has a Pine Research rotating disk electrode (RDE) system, including a ChangeDisk tip for incorporating thin film samples on a glassy carbon disk for characterization under rotating conditions. This system allows for measurements under minimal mass-transport limitations, making it an ideal system for the characterization of electrocatalysts.

Optical characterization equipment in the solar fuels lab includes a Newport 300 W Xe arc lamp system with variable intensity and an AM1.5 global filter and calibrated photodiode for simulating solar illumination conditions. Available accessories include an optical chopper for conducting transient illumination experiments, and an IR water filter to prevent heating of the illuminated samples. The lab has several 3 port and 4 port electrochemical cells outfitted with quartz glass windows for use in illuminated electrochemical experiments. The solar fuels lab also has a spectral response, or incidentphoton-to-current-efficiency (IPCE), system for measuring the quantum efficiency of electrodes at wavelengths ranging from 200 nm to 1000 nm. The system has a monochromator, optical chopper, calibrated photodiode for reference, and two lock-in amplifiers. A potentiostat is incorporated into the system allowing full three-electrode electrochemical control of the sample during IPCE measurements.

Direct product identification and quantification of volatile species can be achieved in the solar fuels lab using an SRI gas chromatograph (GC) system with both a thermal conductivity detector (TCD) and a flame ionization detector (FID) coupled with a methanizer. This system is particularly suited to measuring light weight hydrocarbon products, such as those resulting from electrochemical carbon dioxide reduction. Additionally, the lab has a differential electrochemical mass spectrometry (DEMS) system from Hiden Analytical (HPR-40 MS, up to 200 amu) that allows for the simultaneous electrochemical testing and product quantification of volatile products generated in a liquid electrolyte. This cutting-edge technique is an invaluable tool for the mechanistic study of heterogeneous electrocatalysts.

Conn Center: Biofuels & Biomass Conversion (Lutz 3rd floor; Basement; 2929 S. Floyd)

The facilities described below represent lab, pilot, and analytical labs for collaborative work on development, characterization, and deconstruction of various biomass types; selective separation of hemicellulose, cellulose and lignin; as well as synthesis and conversion to biofuels, biochemicals, and other bioproducts.

Biomass Development: In collaboration with our collaborators, Drs. Paul Himes, Mark Running, and David Schultz from Biology Department at UofL, our researchers conduct studies on improving biomass yield, early flowering for oilseed yield, oil quality for biodiesel conversion, etc. Dr. Paul Himes's microbiology and molecular biology lab has smaller accessory rooms for media preparation, glassware washing, imaging, and microscopy. The lab is equipped with Class II Biosafety Cabinets, upright incubators, shaker incubators, and cold incubators (-70°C, -20°C, 4°C). Dr Mark Running's lab is thoroughly equipped for biochemistry, cell biology, cytology, and microscopy experiments, and includes standard and ultralow temperature freezers, SDS-page and agarose gel electrophoresis equipment, incubators, thermal cyclers, water baths, dissecting scopes, a wax microtome, etc. The lab has four large Percival reach-in plant growth chambers and tissue culture experiments, along with several light racks in a separate room for seedling growth. In addition, the biology department has 12 Conviron growth chambers and an 800 sq. ft. rooftop greenhouse in the same building for shared use.

Biomass Deconstruction and Conversion: A dedicated 700 Ft2 space and 25' ceiling facility is available for biomass deconstruction work. Various capacity lab and pilot pressure reactors including 8-liter Scraped Surface high solids Bioreactor (SSBR), 10-liter recirculating and 25-liter mixed are available for hydrolysis of various biomass types. Novel plasma and microwave reactors are also available. A Schlenk line for organic synthesis and air-free organometallic synthesis, stainless steel gas manifold for catalysis studies at both low (glass vessels) and high (stainless steel vessels) pressures, fixed bed catalyst reactors are also available. Aerobic and anaerobic fermentation reactors for lab and pilot testing are also available. The lab also has lab and pilot scale centrifuges for solids removal from the hydrolyzates prior to their further processing.

Anaerobic Digestion for biogas and biofuels production: The Conn Center currently has two advanced anaerobic digestion systems to perform initial /pilot scale analysis.

60-liter continuous UASB reactor: The continuous reactor utilizes sludge retention technology to allow for higher flow and lower residence times compared to conventional AD's, and has a target COD concentration loading of 20g/L/day. Testing with the continuous unit allows for monitoring and analysis of: Gas production; Gas production rate; COD removal efficiency; Volatile Fatty Acid (VFA) concentration; Total suspended solids (TSS); Sulfate concentration; Phosphorous concentration; Nitrogen concentration over a period of 30 to 45 days.

1-Liter Batch Anaerobic Respirometry Reactor: Respirometers measure "respiration" of living organisms. The respirometry system is used here to continuously monitor methane generation of methanogenic bacteria in real time. Two examples of tests performed with the batch respirometry system are: 1- Biochemical Methane Potential (BMP) Test***;*** 2- Anaerobic Toxicity Assay (ATA) Test***.*** BMP tests measure methane or total gas production over periods ranging from 3 to 60 days to assess the ability for sustained biodegradation. Example BMP test data are shown in Figure 3. ATA tests determine the dose at which the organic substrate becomes toxic. Example ATA test results are shown in Figure 4 in which the effect of a sanitizing agent on anaerobic activity is determined.

Liquid Analysis: Characteristics of the liquid stream, such as concentrations of COD, sulfate, phosphorous, and nitrogen will be analyzed using a colorimetric methodology Characteristics of the gas stream, such as concentrations of methane, carbon dioxide, and hydrogen sulfide will be analyzed using gas chromatography.

Biomass and Torrefied Biomass Densification for Solid Fuels Production: A fully equipped facility for densification of biomass and torrefied biomass at 300 lb/hour capacity is available at Conn Center (Figure 7). A bench top Carver press with heating platens is available for lab scale evaluations. Associated equipment for grinding, mixing, and conveying is available at the facility. Various biomass types such as forest residue, wood waste, bagasse, agricultural cereal straws, etc are being evaluated for torrefaction and densification. Some examples of the produced briquettes are shown in Figure 8. The facility has the analytical equipment to measure BTU content, durability, and hydrophobicity of the produced briquettes. Scanning electron microscopy (SEM), Fourier Transform Infra-Red (FTIR), spectroscopy, and controlled environment burning and carbonization capabilities are also available.

Natural Fiber Composites: In collaboration with Dr. Kunal Kate and Material Innovation Guild (MIG), Conn Center has been developing technologies to produced engineered bast fibers from hemp, kenaf, and flax as well as agricultural fibers such as corn fiber, soy hulls, etc., and utilizing them in light weight composites (LWC) such as Natural Fiber Composites (NFC). The end applications are in molded as well as 3-D printed objects for automotive and construction markets. MIG focuses on research related to sintered materials and powder processing including powder injection molding and additive manufacturing.

Researchers working on NFC have access to simulations and software design tools such as SolidWorks, Moldex3D, etc. Characterization Tools for density, rheological properties, powder characteristics (size, packing, density and flow), thermal analysis (heat capacity, thermosgravimetric analysis) PVT-thermal conductivity are also available. Lab scale Process Equipment such as torque rheometer for identifying suitable powder-polymer compositions and making filaments for Fused Deposition Modeling (FDM) based printing, twin-screw extruder for producing powder-polymer mixtures and making filaments for FDM, a fully instrumented injection molding machine, several molds, tube and box furnaces to 1700oC in air, nitrogen, or hydrogen for debinding and sintering, Concept Laser – Metal 3D printer, EOS-M270, M290, PROX-300 , FDM 3D printers (Meakergear M2, Z-Morph), etc., are available.

For scale-up and piloting, we have access to a Killion pilot extruder and cast filming line.

Conn Center: Electrochemical Energy Storage R&D (2929 S. Floyd St)

The UofL, Conn center is operating a battery facility which includes Lithium ions, Sodium-Ion, Lithium-Sulfur, and Capacitors, in coin cell, pouch cell and Swagelok cells format in oxygen free glove boxes in Science & Innovation Garage for Materials Advancement at 2929 S. Floyd Street. Electrochemical test includes galvanostatic charge-discharge curves, cycles, C-rate tests in 2 Arbin battery testers with 16-channels each. Cyclic voltammetry and impedance measurements were carried in SP-200 Bio-Logic Instrument. The cathode and anode materials for Li-ion, Li-S, and Na-Ion synthesis include high temperatures sintering from (250-1700 °C) using different muffle furnace in argon, nitrogen, oxygen, and air atmosphere. The fabrication facilities include *in-situ* and *ex-situ* XRD for charge-discharge cell. It also has facility for depositing/coatings (doctor blade etc.) of materials on metal foils for electrodes, ball Milling machine, Electrode annealing furnace, vacuum oven, electrode punching tool etc.

The pouch cell fabrication facilities include all the facilities require for pouch cell fabrications like milling, ball milling machine, deposit/coating (doctor blade) of materials on Al, Cu foil, winding machine, semi-auto stacking, electric rolling press, ultrasonic metal welder, compact vacuum sealer, pouch cell case/cup forming machine, compact heating sealer, precise die cutter, aluminum laminated films and automatic bottle dispenser for electrolytes.

Coin cell fabrication:

- Arbin battery tester : Battery assembly (Coin cell, Pouch cell, Swagelok cell) multiple channels tester for charge-discharge curves, cycles, C-rate tests, cyclic voltammetry,
- SP-200 Bio-Logic Instrument: It is used for measuring cyclic voltammetry, Impedance of cathode, anode electrode and electrolyte for Li-ion battery oxidation and reduction potential.
- Argon glove box: Argon glove boxes are used for coin cell, pouch cell fabrications as well as electrolyte preparations.
- Mixer: Mixture milling is used for mixing battery powder with binder to make slurries for cathode and anode electrode to coat on Al and Cu foils.
- Automatic film coater: are used for coating slurries of cathode and anode electrode on aluminum and copper foil using Dr. Blade.
- Vacuum oven: are used for drying coated cathode and anode electrode on Al and Cu foils to remove the moisture before assembly of cell.
- Muffle furnace: are used for sintering lithiated transition metal oxides and anode powders (in the range of 250-1700°C) for using Li-ion, Li-S, Li-Air, Na-ion batteries.

Electrode fabrication:

- Roll to Roll electrode coater: Roll to Roll coater are used for battery electrode sheets with a small footprint of **2.2'**× 3.3' for battery research. This system integrates the functions/ features of reeling in & out, slurry feeder, coating blade, baking oven, and final electrode winding (reeling in). It can coat electrode sheets up to 160mm in width and 500 meters in length automatically.
- Vacuum Mixer with a 2-liter container and PLC Touch Panel Control: A vacuum mixer incorporates the unique tri-shaft stirring design to ensure a gas-bubble free blending of complex materials under vacuum with extreme uniformity. Furthermore, an observation window on the mixing tank provides a better way to monitor the entire mixing process.

Pouch Cell Fabrication:

- Cup forming machine: is used to prepare polymer cases made of Aluminum Laminated Films for pouch cell.
- Hot rolling cylinder press: with working temperature of 100°C, this is designed for preparing battery electrode for both inside and outside glove-box.
- Semi-automatic winder: winder is used for winding electrode and separator together in the research of Li-ion pouch batteries
- Metal welder: Metal Welder with Touch-Screen Digital Controller welding stacked electrode sheets (Copper & Aluminum) and tabs onto current collectors to prepare Li-ion pouch cells in laboratories.
- Compact vacuum sealer: for sealing aluminum-laminated pouch cell in glove box after injection of electrolyte into the cell or after formation of the final seal (Li-Ion cell).

We also have all necessary capabilities for fabrication, complete electrochemical characterization, and performance tests for both PEM fuel cells and solid oxide fuel cells.

Conn Center: Ultra-fast Transient Spectroscopy Facility (Ernst Hall 102A)

The Conn Center maintains expertise and a comprehensive array of equipment for characterizing both inorganic and soft materials using a variety of microscopy, spectroscopy and diffraction tools and femtosecond transient spectroscopy facilities. In our ultrafast spectroscopy lab, an experimental system for transient absorption spectroscopy has been set up to study the dynamics that contribute to the energy transfer and charge separation in solar cells. A laser pulse with ultrashort time duration (~30 fs) is used to pump the system, while a second ultrashort laser pulse with either a continuous wavelength distribution (so-called "white light") or a narrow wavelength range is used to "probe" the photoinduced dynamics. Our investigations include transient absorption spectroscopy of both dye-sensitized solar cells based on nanoparticles and nanowires, and organic solar cells.

THE UOFL MICRO/NANO TECHNOLOGY CENTER

The MNTC occupies approximately 12,000 sq ft and includes laboratories focused on the development of MEMS/NEMS-based devices using: 1) Computer-aided design; 2) testing and packaging; 3) microfabrication cleanroom; and, 4) micromechanical machining. The UofL Micro/NanoTechnology Center conducts and facilitates R&D on MEMS/NEMS- based technologies including those with high commercialization potential. The Center promotes partnerships among the state's colleges and universities, private industries, and non-profit organizations to actively pursue federally and privately funded research and development resources that are dedicated to MEMS/NEMS solutions.

Micro/Nano Technology Cleanroom Facility

The Micro/Nano Technology Cleanroom (MNTC) is a $30M class 100/1000 cleanroom facility established to support a wide range of research and academic initiatives in the growing areas of micro/nanotechnology, advanced materials, biotechnology, MEMS at the UofL and throughout the state of Kentucky. This 10,000 ft2 Abbie Gregg, Inc. designed cleanroom opened in the Summer of 2006 and is located on the 1st floor of the new $60M Shumaker Research Building. The cleanroom is strategically divided into 7 bays – two for photolithograghy and mask generation, one for wet processing (etching/cleaning/plating), one for dry etching, one for thin film deposition, one for high temperature processing, and one for PDMS processing. The Micro/NanoTechnology Core Facility is utilized for the fabrication of MEMS (microelectromechanical) devices and structures, bioMEMS devices, nano-scale devices and structures, microelectronic devices, and electro-optic devices. It is utilized by a wide variety of disciplines, including ECE, ME, BE, ChE, Chemistry, Physics and Medicine. Due to stringent processing requirements, the lab is designed to meet class 1000 cleanroom specifications within five of the processing bays and class 100 specifications in its two lithography bays. Activities performed in the MNTC Cleanroom include: photolithography with back side alignment, e-beam lithography, oxidation, thermal diffusion and annealing, rapid thermal processing, thermal and electron beam evaporation, plasma enhanced chemical vapor deposition (PECVD), Molecular Vapor Deposition (MVD), Atomic Layer Deposition (ALD), RF/DC sputtering, spinning, parylene deposition, RCA substrate cleaning, anisotropic and isotropic dry and wet etching, XeF2 isotropic dry etching reactive ion etching (RIE), deep reactive ion etching (DRIE), bulk micromachining, anodic bonding with wafer bond alignment, silicon fusion bonding (SFB), low temperature glass bonding, electroplating, photomask generation with greyscale capabilities, maskless lithography or direct write, wirebonding, metrology and material characterization.

MEMS Computer-aided Design Laboratory

This lab includes four high end workstations located in the Belknap Research Building are dedicated to running CoventorWare©, a MEMS finite element modeling software which has modules for simulation of mechanical, electrical, thermal, and fluidic phenomenon in the micro regime. Both preprocessing (model design and generation) and postprocessing (simulation and data extraction) is accomplished on the workstations. The workstations are also equipped with LUEDIT, Athena and T-Spice software for MEMS layout generation, semiconductor fabrication process simulation and circuit modeling, respectively. In addition, the licensing configuration for the software effectively allows anyone on campus to run the software, which is particularly advantageous for inspecting results at locations away from the more powerful systems.

MEMS Testing & Packaging Laboratory

This is a 1200 sq. ft. laboratory for the packaging and testing of MEMS devices fabricated in the Micro/Nanotechnology Facility. The lab includes two fume hoods and a full complement of utilities, including DI water. This research and instructional facility contains numerous backend and post-processing pieces of equipment appropriate for the packaging and assembly of MEMS and microelectronic devices. Additionally, it contains many electronic instruments for device testing and characterization.

Micromechanical Machining Laboratory

This lab is dedicated to the development of micro mechanical machining methodologies to produce MEMS-based devices fabricated out of non-silicon materials as well as silicon. The lab includes a full complement of utilities including nitrogen, air, water, a sink, and electrical outlets. This facility contains multiple pieces micromechanical machining equipment.

HUSON NANOTECHNOLOGY CORE FACILITY

This analytical imaging facility was established in 1998 with the partial support of an NSF MRI grant. It is housed in the new Belknap Research Building, which opened in December 2005 and consists of ~1800 sq. ft. of space which contains microscopes that can measure the three-dimensional shapes of ultrasmall objects with precision up to 5000X finer than that of conventional light microscopes. The Three-Dimensional Nanoscale Imaging Facility features several complementary instruments that can measure three-dimensional topography and other related physical properties of nanoscale and atomic surfaces. These instruments are the first of their kind at a Kentucky university or business. All instruments are PC controlled and attached via TCP/IP to a local Microsoft Windows NT domain, and the university's main network. The 3D Nanoscale Imaging Facility is actively used by various research groups for diverse projects that require ultra-precise three-dimensional profiling, and even nanoscale- sculpting of small surfaces.

RAPID PROTOTYPING CENTER

The UofL (UofL) has one of the best-equipped facilities with world class capabilities for 3D Printing/Additive Manufacturing (AM) of metals and polymers. The industrial/academic consortium known as the Rapid Prototyping Center (RPC) has been performing federally-funded basic and applied research, technology transfer and industry-funded projects in AM since starting with polymer Laser Sintering (LS) in 1993. Today the UofL has over 20 people focused on AM applications and research. The UofL is a partner of leading AM users such as Boeing, GE, EWI, Nike, Emerson, Northrop- Grumman, Burton, Integra, and several service bureaus. There are over 70 industrial/academic consortium member organizations in the Rapid Prototyping Center. The UofL Rapid Prototyping Center (RPC) was formed in 1993 as a consortium between the university and five local companies to investigate the new technology of rapid prototyping via laser sintering and its impact on the design cycle. Today the RPC’s 70+ members have access to world-leading capabilities in Additive Manufacturing (AM) via laser and electron beam powder bed processes for metals, plastics, and ceramics; ultrasonic additive sheet lamination; plus many ancillary processes and techniques. The assistance available to joint academic/industrial consortium partners has grown from helping companies to understand rapid prototyping to aiding members in the entire product development process: conceptual design, material selection, prototyping, tooling, production, applied and basic research. The RPC has the latest software for solid modeling and part design of new components and the capability for reverse engineering of existing parts. The RPC combines the expertise of its professional staff and faculty with strategic partnerships to assist in all aspects of product and process development. The RPC supports research and development programs in Additive Manufacturing and provides student instruction in the application of these new technologies. The role of technology transfer and new business development is fueled by interaction with the industrial consortium members and emphasizes the utilization of University resources to enhance job growth. Users gain access to the problem-solving technology as well as continuing research in Additive Manufacturing. Benefits also include access to UofL’s Speed School of Engineering graduates, engineers of the future with training in this state-of-the-art technology.

The UofL Rapid Prototyping Center (RPC) is capable of producing prototypes and end use, low volume component parts utilizing the following additive manufacturing systems: Laser Sintering (LS), Direct Metal Laser Sintering (DMLS), Electron Beam Melting (EBM), Ultrasonic Consolidation (UC), Fused Deposition Modeling (FDM), and Stereolithography (SLA). The RPC has become an industry leader in Additive Manufacturing applications with expertise and funded research in all areas of Additive Manufacturing. This includes the fundamental understanding of the effect of process variables and properties, material development, design for AM, and testing. AM research areas include the following: 1) Laser Sintering of Polymers - Process control and optimization; Mechanical properties; Hardware improvements; Materials research and development; and, High temperature materials; 2) Additive Metals Processing - Evaluation of process variable on mechanical properties; High performance alloys; and, Post processing parameters e.g. – annealing or heat treating; 3) Advanced Additive Manufacturing Techniques; Multi-material and gradient structures; Embedded electronics; Controllable microstructures; and Parts consolidation, internal features, as built mechanisms; and, 4) Testing - Mechanical and Fatigue Testing; Physical properties; and, Particle size characterization. The RPC and its associated personnel and faculty are recognized as international leaders in Additive Manufacturing. They are heavily involved in growing and promoting the technology through technical organizations as officers, presenters, and featured speakers.

APPENDIX F

Budget form pages

Cost/Funding Explanation

A. Funding Sources, by year of program:	1st Year	2nd Year	3rd Year	4th Year	5th Year
Total Resources Available from Federal Sources					
~ New	$ -	$ -	$ -	$ -	$ -
~ Existing					
Narrative Explanation/Justification:					

Funding Sources, by year of program *(continued)*	1st Year	2nd Year	3rd Year	4th Year	5th Year
Total Resources Available from Other Non-State Sources					
~ New	-	-	-	-	-
~ Existing					
Narrative Explanation/Justification:					

Funding Sources, by year of program *(continued)*	1st Year	2nd Year	3rd Year	4th Year	5th Year
State Resources					
~ New	$ -	$ -	$ -	$ -	$ -
~ Existing					
Narrative Explanation/Justification:					

Funding Sources, by year of program *(continued)*	1st Year	2nd Year	3rd Year	4th Year	5th Year
Internal Allocation					
Internal Reallocation					

Narrative Explanation/Justification: *The sources and process of allocation and reallocation should be detailed, including an analysis of the impact of the reduction on existing programs and/or organization units.*

Funding Sources, by year of program *(continued)*	1st Year	2nd Year	3rd Year	4th Year	5th Year
Student Tuition					
~ New	$ 229,340.88	$ 235,074.40	$ 465,575.15	$ 610,810.12	$ 763,470.72
~ Existing					

Narrative Explanation/Justification: *Describe the impact of this program on enrollment, tuition, and fees.*

Cost/Funding Explanation

Projected revenues are based upon full-time enrollment for matriculation in an average of 4 terms for onsite students and 5 terms for online students (starting in Y3), but with only 3 terms calculated per year at 24 credit hours/year for onsite students and 18 credit hours/year for online students. Resident/non-resident Master's student ratios of 60%/40% are used for tuition calculations based on the prior 3 years of Speed School graduate enrollment demographics. Online degree starts in Y3. Note: Y0 (2019) full time tuition for resident = $6,500; full time tuition for non-resident = $13,557; graduate online tuition = $764/hr. Rate of increase per year is 2.5% on resident and non-resident tuition and 7% for online tuition. **Calculations by Year:** In **Y1**, the program takes 8 new onsite students at 60/40 residency for 3 terms earning 30 credit hours each at 12 hrs + 12 hrs + 6 hrs. In **Y2**, the program takes 8 new onsite students at 60/40 residency for 3 terms earning 30 credit hours each. In **Y3**, the program takes on 8 new onsite students at 60/40 residency for 3 terms earning 30 credit hours each and 8 new online degree students for 3 terms earning 30 credit hours each. In **Y4**, the program takes on 12 new onsite students at 60/40 residency for 3 terms earning 30 credit hours each and 8 new online degree students for 3 terms earning 30 credit hours each. In **Y5**, the program takes on 16 new onsite students at 60/40 residency for 3 terms earning 30 credit hours each and 12 new online degree students for 3 terms earning 30 credit hours each.

		1st Year	2nd Year	3rd Year	4th Year	5th Year
A.	**TOTAL - Funding Sources** (REVENUES)	$ 229,340.88	$ 235,074.40	$ 465,575.15	$ 610,810.12	$ 763,470.72

Cost/Funding Explanation

B. Breakdown of Budget Expenses/Requirements	1st Year	2nd Year	3rd Year	4th Year	5th Year
Staff					
Executive, Administrative, Managerial					
~ New	$ 32,125.00	$ 33,088.75	$ 34,081.41	$ 35,103.85	$ 36,156.97
~ Existing	-				
Other Professional					
~ New	-				
~ Existing	38,550.00	39,706.50	54,530.26	56,166.17	57,851.15
Faculty					
~ New	-				
~ Existing	38,550.00	39,706.50	81,795.39	84,249.25	86,776.73
Graduate Assistants					
~ New	$45,135.81	$45,729.70	$92,677.83	$140,891.54	$190,419.61
~ Existing	-				
Student Employees					
~ New	-				
~ Existing	-				

Narrative Explanation/Justification: *Includes salaries or all listed above. Identify the number of new faculty required and whether the new hires will be part-time or full-time. Identify the number of assistantships/stipends that will be provided. Include the level of support for each assistantship/stipend.*

Funds for 1 Administrative Staff person at 50% FTE include annual base salary at $50K and fringe at 28.5% with a 3% annual raise. Funds for Other Professional (Existing) include 1 month base salary each at $10K and fringe at 28.5% with a 3% annual raise for 3 theme leaders in Y1-2 and 4 theme leaders in Y3-5. Funds for Faculty (Existing) include 1 month base salary each at $10K each and fringe at 28.5% with a 3% annual raise for 3 faculty in Y1-2 and 6 faculty in Y3-5. Funds for GTA lines include a stipend ($22,008/yr), health insurance ($254.07/month), and 12 months full-time graduate tuition charged at the resident rate. 1 GTA in Y1-2, 2 GTAs in Y3, 3 GTAs in Y4, and 4 GTAs in Y5. A 3% annual inflation rate was applied to the health insurance cost and 2.5% to the tuition cost.

Breakdown of Budget Expenses/Requirements *(continued)*	*1st Year*	*2nd Year*	*3rd Year*	*4th Year*	*5th Year*
Equipment and Instructional Materials					
~ New	$ 5,000.00	$ 5,000.00	$ 5,000.00	$ 5,000.00	$ 5,000.00
~ Existing	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00

Narrative Explanation/Justification:

Funds for supplies are allocated at 5K per year and for facilities access to Conn Center laboratories at 10K per year in lieu of equipment charges to carry our curricular assignments and experiments.

Breakdown of Budget Expenses/Requirements *(continued)*	*1st Year*	*2nd Year*	*3rd Year*	*4th Year*	*5th Year*
Library					
~ New	-		5,000.00	5,000.00	5,000.00
~ Existing					

Narrative Explanation/Justification:

Funds are allocated for new subscriptions to journals focused on materials and energy science and engineering, such as "Advanced Energy Materials" by Wiley starting in Y3.

Breakdown of Budget Expenses/Requirements *(continued)*	*1st Year*	*2nd Year*	*3rd Year*	*4th Year*	*5th Year*
Contractual Services					
~ New	$ -	$ -	$ -	$ -	$ -
~ Existing					

Narrative Explanation/Justification:

Funding Sources, by year of program *(continued)*	*1st Year*	*2nd Year*	*3rd Year*	*4th Year*	*5th Year*
Academic and/or Student Support Services					
~ New	-	-	-	-	-
~ Existing					

Narrative Explanation/Justification:

Breakdown of Budget Expenses/Requirements *(continued)*	1st Year	2nd Year	3rd Year	4th Year	5th Year
Other Support Services					
~ New	$ -	$ -	$ -	$ -	$ -
~ Existing					

Narrative Explanation/Justification:

Funding Sources, by year of program *(continued)*	1st Year	2nd Year	3rd Year	4th Year	5th Year
Faculty Development					
~ New			10,000.00	10,000.00	10,000.00
~ Existing					

Narrative Explanation/Justification:

Funds for curriculum development are allocated at 10K per year starting in Y3.

Breakdown of Budget Expenses/Requirements *(continued)*	1st Year	2nd Year	3rd Year	4th Year	5th Year
Assessment					
~ New	$ -	$ -	$ -	$ -	$ -
~ Existing					

Narrative Explanation/Justification:

Funding Sources, by year of program *(continued)*	1st Year	2nd Year	3rd Year	4th Year	5th Year
Other					
~ New - Institutional overhead	57,335.22	58,768.60	116,393.79	152,702.53	190,867.68
~ Existing					

Narrative Explanation/Justification:

Institutional overhead is charged to the revenue from tuition at a rate of 25%

		1st Year	2nd Year	3rd Year	4th Year	5th Year
B.	**TOTAL - Expenses/Requirements** (EXPENDITURES)	$ 226,696.03	$ 232,000.05	$ 409,478.68	$ 499,113.35	$ 592,072.14

		1st Year	2nd Year	3rd Year	4th Year	5th Year
A.	TOTAL - Funding Sources (REVENUES)	$ 229,340.88	$ 235,074.40	$ 465,575.15	$ 610,810.12	$ 763,470.72
		1st Year	2nd Year	3rd Year	4th Year	5th Year
B.	TOTAL - Expenses/Requirements (EXPENDITURES)	(226,696.03)	(232,000.05)	(409,478.68)	(499,113.35)	(592,072.14)
	BALANCE - (SURPLUS/DEFICIT)	$2,644.85	$3,074.35	$56,096.46	$111,696.77	$171,398.59