Proposal for the Initiation of a Doctor of Philosophy of Energy Science and Engineering Program

Submitted by

The University of Tennessee, Knoxville

Center for Interdisciplinary Research and Graduate Education

A NEW PROGRAM LEADING TO THE DEGREE OF:

Doctor of Philosophy	**Energy Science and Engineering**
Title of degree as on diploma	**Title of major**
	ESE
CIP/THEC Code	**Formal degree abbreviation**

Doctor of Philosophy

Degree designation on student's transcript

August 2011

Proposed starting date

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Abstract

Institution: The University of Tennessee, Knoxville (UTK)

Division/Department: Center for Interdisciplinary Research and Graduate Education (CIRE)

Program leading to the degree of:
Doctor of Philosophy in Energy Science and Engineering (ESE)
This degree will be administered in CIRE but the degree will be awarded by the Graduate School of the University of Tennessee Knoxville.

Proposed startup date: August 2011

Number of anticipated students: 20 - 40 new doctoral students recruited and enrolled per year

Estimated headcount enrollment and graduates:

Year	Fall full-time Head count	Head count ESE degree students	Head count ESE concentration students	Graduates with ESE degree	Graduates with ESE concentration
1	20	15	5	0	0
2	45	34	11	0	0
3	70	53	17	0	0
4	95	72	23	0	0
5	120	91	29	15	5
6	125	95	30	19	6

The table above assumes that 20 new doctoral students will be recruited to the Energy Science and Engineering program for fall semester of 2011, followed by an additional 25 new students each year thereafter. In addition to the *interdisciplinary* PhD program in Energy Science and Engineering, various science and engineering departments will have a *concentration* in ESE as part of their own doctoral program. In this case, graduate students will take the ESE core curriculum courses, one course from the knowledge breadth curriculum, and perform research with one of the CIRE faculty, but will choose to get a PhD in the academic department that most relates to their primary area of study. Students of both types will be recruited to be part of the CIRE ESE program and work on dissertation research with CIRE faculty, but some will choose a conventional PhD rather than the new interdisciplinary PhD in energy science and engineering. It is difficult to know what percentage of recruited students will choose the conventional versus interdisciplinary PhD program. Of the students recruited into this joint program (first column in above table), it is estimated that 75% will choose to take the *interdisciplinary* degree, which is reflected in the table above. The assumption is that both kinds of students will require, on

average, five years after the bachelor's degree to receive the doctorate. All of these students over the average of five years will be supported on the $28K stipend. It is assumed that there will be no part-time students, so that column has been omitted from the above table.

No new faculty lines will be established. Instead, CIRE faculty will serve on a part-time unpaid basis and will be drawn from the ranks of existing UTK faculty and research staff at Oak Ridge National Laboratory (ORNL). Most of the courses offered will be existing ones, therefore costing the center and the program nothing in resources. A few new courses will be organized and offered, in which case some of the administrative funds for the center will be devoted to paying for course development and instruction.

New costs generated by the program:	Year 1	$1,318,900
	Year 2	$2,232,700
	Year 3	$3,400,000
	Year 4	$4,602,500
	Year 5	$5,873,200

All of these costs will be covered by three sources of income. ORNL or UTK research groups will pay for the full cost of the graduate student once the student joins that group for dissertation research - stipend, tuition, and insurance. Secondly, UTK will provide a Research Incentive Fund proportional to the volume of grants and contracts that come to the university by virtue of CIRE-related activity, e.g., ORNL support of ESE graduate students (in the interdisciplinary or the conventional PhD program). Thirdly, the Tennessee Legislature has appropriated $6.2M of one-time funds for support of CIRE.

Total credit hours required for degree: 72

Number of new courses proposed: 8 Number of new credit hours: 12 and up

New courses proposed:
ESE 502 Registration For Use of Facilities (1-15)
Required for the student not otherwise registered during any semester when student uses university facilities and/or faculty time before degree is completed.
Grading Restriction: Satisfactory/No Credit grading only.
Repeatability: May be repeated.
Credit Restriction: May not be used toward degree requirements.
Registration Restriction: Minimum student level – graduate.

ESE 511 Introduction to Energy Science and Technology I (3) Topics include: Energy basics, history of energy and society, current and future supply and demand, political and environmental

aspects of energy production, energy technologies (fossil fuels, biomass, nuclear fission, nuclear fusion, solar, wind, geothermal), energy conversion, storage, transportation, and distribution, energy efficiency, and innovation.

ESE 512 Introduction to Energy Science and Technology II (3) Topics include: Energy basics, history of energy and society, current and future supply and demand, political and environmental aspects of energy production, energy technologies (fossil fuels, biomass, nuclear fission, nuclear fusion, solar, wind, geothermal), energy conversion, storage, transportation, and distribution, energy efficiency, and innovation.

ESE 593 Independent Study (1-3)
Repeatability: May be repeated. Maximum 9 hours.
Credit Restriction: Only 6 hours may be applied toward degree requirements.

ESE 599 Seminar (1)
Grading Restriction: Satisfactory/No Credit grading only.
Repeatability: May be repeated. Maximum 15 hours.
Credit Restriction: Only 3 hours may be applied toward degree requirements.

ESE 600 Doctoral Research and Dissertation (3-15)
Grading Restriction: P/NP grading only.
Repeatability: May be repeated.

ESE 597 Special Topics (1-3)
Repeatability: May be repeated. Maximum 9 hours.

ESE 697 Special Topics (1-3)
Repeatability: May be repeated. Maximum 9 hours.

Overview

A new interdisciplinary doctoral degree in Energy Science and Engineering (ESE) is proposed in order to educate students in energy-related fields that are increasing in importance to the state and the country. Faculty formed from current researchers at the University of Tennessee Knoxville and Oak Ridge National Laboratory provide research opportunities in various fields relating to the scientific and engineering challenges in energy supply and usage, including impacts on the environment and climate. A few new courses are proposed at the 500 level and one at the 600 level, while existing 500 and 600 courses in various departments are utilized to provide the course component of the PhD, which differ depending on the specific area of specialization of the ESE student. This is a program that was initiated by Governor Bredesen and funded by the State Legislature. This degree will be administered by the newly created Center for Interdisciplinary Research and Graduate Education (CIRE), which has been established by University of Tennessee, Knoxville and Oak Ridge National Laboratory.

The details of this proposal have been shaped in part by the advice of two consultants with extensive experience in universities and national laboratories and with recognized expertise in the broad field of energy:

Dr. Phillip Parrish
Associate Vice President for Research
University of Virginia

Dr. Marilyn Brown
Professor of Energy Policy
Georgia Institute of Technology

Program Description

A. Program intent

A new model for graduate education
The Center for Interdisciplinary Research and Graduate Education (CIRE) has developed and proposes to offer one of the country's first interdisciplinary PhD programs in energy science and engineering. CIRE will combine the educational resources of a comprehensive research university and the research capabilities of a major national laboratory to provide expanded opportunities for graduate students in energy-related sciences and engineering, fostering multidisciplinary research, large-scale problem-oriented research projects, and innovation and entrepreneurship.

Expanding the graduate campus
CIRE will expand the graduate research campus of UTK to include ORNL, greatly increasing research opportunities and capacity.

Leveraging research capabilities
CIRE will leverage ORNL staff, facilities, and research programs to increase substantially the number of mentors and graduate students while contributing to ORNL research programs.

Vision for the Center
Multidisciplinary: CIRE will offer graduate students opportunities to engage in multidisciplinary research in energy-related sciences and engineering, while preserving the rigor and depth of a PhD program.

Entrepreneurial: CIRE will incorporate entrepreneurial experiences, including partnership opportunities with the UTK College of Business Administration in developing and implementing business plans to accelerate the deployment of new technologies.

Transformational: CIRE will be transformational in engaging graduate students in multidisciplinary projects, large-scale problem-oriented research programs, and science-to-applications research opportunities, enabling scientific breakthroughs and innovative solutions to energy-related challenges.

Mission
By combining the resources of a comprehensive research university and a major national laboratory, CIRE will provide expanded opportunities for graduate students in energy-related science and engineering, fostering scholarship and innovation, advancing multidisciplinary research, and accelerating development and deployment of new technologies.

Background

Energy science and engineering is an emerging field of study that builds on the conventional disciplines of science and engineering but is focused on the challenges and issues relating to the development and use of sources of energy. The issues of energy supply and use provide our country and the world with some of the grandest challenges that citizens and institutions face now and for coming decades. The overwhelming dependence of the world in getting energy from the burning of fossil fuels (over 80% of the supply) has led to many problems of a technical, political, and/or environmental nature. Petroleum is a limited resource that could begin to be limited in supply within 20 years, which would increase the cost of gasoline by a large factor and thus wreck many national economies if the dependence on conventional vehicles remains. Essentially all scientific leaders in the world now agree that the global climate is warming and that the huge dependence on burning fossil fuels is the dominant cause.

Developing and encouraging alternatives to the dependence on fossil fuels are emerging for the source of energy for the world. Electricity from nuclear power is a largely non-carbon based form of energy supply, but has been stalled for decades due to issues of safety, politics, and public acceptance. Electricity from solar or wind farms is increasing in volume, but is not close to being cost competitive and constant in output for mass adaptation. Long-term development of electricity from fusion reactors is proceeding but is still several decades away.

The careers of many current students will be shaped in the future by the complex issues related to the generation and use of energy - the technical R&D necessary for the more cost competitive alternative and sustainable forms of energy; pricing of future energy sources; regulation of carbon emissions; legal challenges to issues of climate and energy supply and ownership; development and marketing of electric vehicles; policies related to energy generation and use; government actions relating to energy and climate; and detailed understanding of climate change and the impact on regional weather, ocean level and acidity, etc.

It behooves universities to prepare students for this increasingly dominant role of issues of energy in so many future careers. Graduate degrees in the conventional fields of science, engineering, business, political science, and law will remain as important training for students to enter this field. However, the leaders in many energy-related fields in the future will need training not only in a prime area of concentration but also in a broad spectrum of disciplines that are somehow related to energy. It is time for our country to provide to students a broad training in the issues of energy in addition to a detailed 'deep dive' into one of the major fields related to energy. This is the reason for the proposal of one of the first (if not *the* first) *interdisciplinary* PhD in energy science and engineering. The issues of energy supply and use are extremely interdisciplinary in nature, thus the need to accordingly educate students in an interdisciplinary manner.

The proposed ESE PhD will offer coursework that serves two purposes - (a) a broadening education in the issues of energy generation and use from many aspects and (b) a deep dive into issues of energy in a given discipline. The students will work on doctoral research in one of six

initial areas relating to energy in multi-disciplinary teams of scientists and engineers working at the University of Tennessee and Oak Ridge National Laboratory (ORNL). Some students will choose to include entrepreneurial elements in their program of study, working with faculty from the College of Business Administration. All students will receive a broad foundation of coursework and doctoral research in teams working at the forefront of the science and engineering related to energy.

The University of Tennessee and Oak Ridge National Laboratory are well positioned to offer students forefront research opportunities in energy-related fields. ORNL has rapidly become the broadest national laboratory in energy-related research and development. Six areas of research have been chosen as the initial areas of emphasis in the ESE program, and these six areas together address 10 of the *grand challenges* that our country faces in the energy arena:

- Nuclear energy
  1. Close the nuclear fuel cycle
  2. Find an inexhaustible source of energy
- Bioenergy and biofuels
  3. Develop a new generation of ethanol
- Renewable energy
  4. Lower the cost of solar power
- Energy conversion and storage
  5. Store alternative energy
  6. Design high-mileage cars
- Distributed energy and grid management
  7. Modernize the electric grid
  8. Reduce energy consumption
- Environmental and climate sciences related to energy
  9. Respond to climate change
  10. Store carbon emissions

Future roles for ESE graduates

The Energy Science and Engineering degree will position graduates for leadership careers in various areas of professional life, including the following.

- Industry. New or expanding industries are rapidly emerging to address increasing marketplace demands for energy efficiency, alternative sources of energy, electric vehicles, advanced materials for next-generation batteries and fuel cells, etc. Graduates of this doctoral program will qualify to take initially R&D positions in a host of industries. For example, the era of consumer electric vehicles is about to begin with the imminent sale of the Nissan Leaf and the GM Volt. But, much R&D is needed to evolve the batteries to be robust enough in energy storage and cheap enough in cost to make these (and other electric vehicles) commonplace. Another example is the nuclear power industry, where the development of a new breed of small, modular, inherently safe reactors will hopefully spur the rebirth of this industry, very important in an increasingly

carbon-constrained world. ESE graduates will begin careers in R&D positions but rather rapidly advance to key leadership roles in these energy-related companies.

- National laboratories. These institutions are inherently interdisciplinary centers of research and development. Whereas the classical departments of academia largely remain unchanged in an organizational structure from era to era, national labs are constantly changing and reforming in order to effectively meet the interdisciplinary challenges of national areas of need. Graduates of the ESE program will be natural fits to national labs, which are less interested in a new PhD coming from a physics or a chemistry department, for example, and more interested in the training the student has acquired in the interdisciplinary landscape that defines the laboratory every day.
- Universities. Even universities change with the times, although not as rapidly as industry and national labs. Change in universities generally relates to the creation of new research centers and sometimes even degree programs, still rooted usually in the classical departmental and college structure. Today an increasing number of universities has formed research centers related to energy. New PhDs with an interdisciplinary ESE degree and with depth in a given classical discipline will be *very* attractive to a university increasingly focused on the energy challenges of the country and the research funding that is more and more focused on energy.
- Government. It is clear to many that the complicated issues of energy supply and use will play an increasing role in the policies of state and national government. Too often professionals with little technical background take important government policy positions, which can be a problem if the set of policies relate to highly technical issues. While it may be difficult for a person with doctorates in science and engineering to advance to positions of policy leadership in government (too specialized), a PhD in an interdisciplinary field as relevant as energy should be attractive for policy and leadership roles in agencies of government.

B. Curriculum

A graduate program is proposed leading to the Doctor of Philosophy (PhD) degree in Energy Science and Engineering (ESE). This interdisciplinary degree is a collaborative effort supported by selected faculty in the University of Tennessee College of Arts and Sciences, the College of Agricultural Sciences and Natural Resources, and the College of Engineering, in addition to research staff of Oak Ridge National Laboratory. These research and educational leaders are appointed as faculty members of the Center for Interdisciplinary Research and Graduate Education (CIRE). Members of the CIRE faculty determine the curriculum and serve as the primary resource for the teaching, research, and mentoring of the students admitted to the program. The CIRE Graduate Education Committee makes decisions on admissions, transfer, evaluation, and continuation of graduate students in the program.

Admission Requirements:

In order to be admitted to the PhD program in Energy Science and Engineering, student applicants must fulfill the general admission criteria for the Graduate School of the University of Tennessee Knoxville. In addition, the student must have a Bachelor of Science degree in either

engineering or a scientific field (physics, chemistry, biology, mathematics, computational science, etc.), or the equivalent. Students with other undergraduate degrees may also be admitted on a case-by-case basis by the CIRE Graduate Coordinating Committee. Dependent on the student's background, additional coursework may be required to satisfy co- and prerequisites.

A minimum of 72 hours is required beyond the bachelor's degree, exclusive of credit for a Master's degree, and completion of the core requirements, as outlined in the section on Course Requirements. Of this number, a minimum of 24 and up to 36 hours of 600 Doctoral Research and Dissertation and six hours of 600-level coursework at UTK will be required.

No later than one year after entering the program, each student must take a qualifying examination. A student must pass the qualifying examination to proceed in the PhD program.

No later than at the end of the second year following entrance into the PhD program, each student must take and pass a comprehensive examination that includes presentation and approval of the proposed dissertation research. After passing the comprehensive exam, the student should submit the Admission to Candidacy Application to the Graduate School. Admission to candidacy indicates that the student has demonstrated the ability to do acceptable work in the area of study and has made satisfactory progress toward the degree. This action usually connotes that all prerequisites to admission have been completed and the program of study/research has been approved (see details in a later section).

After completion of the dissertation, prior to graduation, each student must pass a dissertation defense examination administered by the student's doctoral committee.

Timeline

The academic level of the graduate student to be recruited is expected to be high, as a result of national recruiting and the unique nature of this program and the partnership between UT and ORNL in educating the student. Therefore, an aggressive timeline is assumed for most students that enroll. The table below shows this timeline, starting with the summer before graduate studies actually begin. It is assumed that many (most?) students will select an initial research mentor for the summer before coursework begins in the fall, and then continue working with this mentor (or perhaps another one) during the first year. This will guide the student to the intended choice of a dissertation research mentor in the second semester of the first year of graduate studies, resulting in a summer of research after the first year. This leads to the definition of a dissertation research topic and passing the *Comprehensive Exam* before the end of semester 6, spring of the second year.

Year	Semester	Semester	Expected course credit hours	Expected research credit hours	Exams	Activity
1	1	Summer				Full-time research
1	2	Fall	10	2		Part-time research
1	3	Spring	10	2	Qualifying	Choose dissertation research mentor; part-time research
1	4	Summer		3		Full-time research
2	5	Fall	10	3		Part-time research
2	6	Spring	9	3	Comprehensive	Part-time research
2	7	Summer		3		Full-time research
3	8	Fall		6		Full-time research
3	9	Spring		6		Full-time research
3	10	Summer		3		Full-time research
4	11	Fall		6		Full-time research
4	12	Spring		6		Full-time research
4	13	Summer		3		Full-time research
5	14	Fall		6		Full-time research
5	15	Spring		6		Full-time research
5	16	Summer		3	Dissertation defense	Full-time research
	Sum		39	61		

Course Requirements

A minimum of 72 hours is required for the ESE doctoral program, and of this total a minimum of 36 hours of coursework is required beyond the BS degree. The table above shows an expected *average* academic load for an ESE student, including 39 hours of coursework and 61 hours of research credit, totaling 100 credit hours. Of the 36 hours of required coursework, the following 30 hours of courses (or their equivalent) must be completed at a minimum, including the Core Curriculum, a Knowledge Breadth Curriculum, a Knowledge Specialization Curriculum, and Seminar Series, as summarized below.

A. *Core Curriculum (6 credits)*

ESE 511 and ESE 512 Introduction to Energy Science and Technology (3, 3 credits); (Lead instructor plus guest lecturers): Topics include: energy basics; history of energy and society; current and future supply and demand; political and environmental aspects of energy production; energy technologies (fossil fuels, biomass, nuclear fission, nuclear fusion, solar, wind, geothermal); energy conversion, storage, transportation, and distribution; energy efficiency; and innovation.

B. *Knowledge Breadth Curriculum (6 credits): select two courses from the three following areas*

1. Political, social, legal, ethical and security issues related to energy (3-4 courses, each 3 credits)
2. Entrepreneurship, leadership, and management (3-4 courses, each 3 credits).
3. Environmental and climate sciences related to energy (3-4 courses, each 3 credits)

C. *Knowledge Specialization Curriculum (15 credits)*

Choose five courses from participating departments as defined in the CIRE Graduate Student Handbook and listed in section VI of this document.

1. Nuclear energy
2. Bioenergy and biofuels
3. Renewable energy
4. Energy conversion and storage
5. Distributed energy and grid management
6. Environmental and climate sciences related to energy

D. *ESE 599 Seminar (3 credits; 1+1+1)*

Topical seminars in the focus areas of CIRE.

Specialty areas and courses

Almost all courses needed for each of the six specialty areas of the ESE degree exist in various departments. This section lists these courses by department. As discussed above, these courses are needed for the minimum of 15 credit hours for the Knowledge Specialization Curriculum.

A. Nuclear Energy

Fundamentals (9 credits)
Reactor Design and Modeling emphasis:
- NE 511, Transport Processes in Nuclear Engineering
- NE 571, Reactor Theory and Design
- NE 572, Nuclear Systems Design
- NE 583, Radiation Transport Methods
- NE 598, Nuclear Engineering practice
- ME 587, Dynamic Modeling and Simulation
- ECE 575, High Performance Computer Modeling and Visualization

Fuel Cycle Emphasis:
- Chem 511, Analytical Separations
- Chem 512, Electroanalytic Chemistry
- ESE /NE5xx, Reactor Fuel Modeling and Design
- ESE /Chem 5xx, Radiochemistry and Actinide Process Engineering

Structural Materials Emphasis:
- ME 559, Advanced Mechanics of Materials I
- MSE 511, Fundamentals of Materials Science and Engineering I
- MSE 512, Fundamentals of Materials Science and Engineering II
- MSE 515, Physical Metallurgy – Diffusion and Phase Transformations
- MSE 516, Mechanical Metallurgy
- MSE 525, Welding Metallurgy
- MSE 532, Metallurgy of Deformation and Fracture

Instrument and Controls Emphasis:
- NE 579, Advanced Monitoring and Diagnostic Techniques
- NE 521, Nuclear Systems Dynamics and Control
- ECE 505, Digital Signal Processing I
- ECE 506, Digital Signal Processing II
- ECE 551, Digital System Design I
- ECE 552, Digital System Design II

Advanced (6 credits)
Reactor Design and Modeling emphasis:
- NE 611, Selected Topics in Reactor Theory
- NE 640, Nuclear Cross Section Modeling
- NE 697 Special Topics in Nuclear Engineering

Fuel Cycle Emphasis:
- Chem 610, Selected Topics in Analytical Chemistry
- Chem 670, Selected Topics in Physical Chemistry

Structural Materials Emphasis:
- ME 659, Advanced Mechanics of Materials II
- MSE 610, Structure and Dynamics of Materials
- MSE 611, Phase Transform and Simulations at Small Length Scales
- MSE 650, Mechanical Behavior of Solids at Elevated Temperatures
- MSE 674, Materials Physics
- MSE 675, Advanced Structural Analysis

Instrument and Control Emphasis:
- NE 653, Theory of Information Processing
- ECE 631, Advanced Topics in Electronic Instrumentation I
- ECE 632, Advanced Topics in Electronic Instrumentation II
- NE 697 Special Topics in Nuclear Engineering

Nuclear Physics:
- PHYS 621 Nuclear Physics I
- PHYS 622 Nuclear Physics
- PHYS 642 Advanced Topics in Modern Physics

B. Energy Conversion and Storage

Fundamentals (9 credits)

CBE 547, Transport Phenomena
CBE 531, Thermodynamics
MABE 521 Thermodynamics 1
MABE 522 Thermodynamics 2
MABE 559 Advanced Mechanics of Materials I
MABE 587 Dynamic Modeling and Simulation
CBE 532, Statistical Mechanics
CBE 506, Engineering Analysis
Math 511 Methods in applied mathematics I
Math 512 Methods in applied mathematics II
CBE/CHEM 5XX Applied Electrochemistry
ECE 575 High Performance Computer Modeling and Visualization
MABE 527&528 Thermal Systems Analysis I& II
CBE/CHEM 5XX Solid-state ion conductors
MSE 540 Basic Polymer Chemistry
CHEM 570 Quantum Chemistry and Spectroscopy
CHEM 553 Spectropic Characterization of Organic Compounds
MSE 543 Basic Polymer Physics
PHYS 521 Quantum Mechanics I
PHYS 522 Quantum Mechanics II
PHYS 551 Statistical Mechanics
PHYS 555 Solid State Physics

Advanced (6 credits)

CBE 633 Multi scale Materials Modeling
CBE 631 Advanced Topics in Statistical Thermodynamics
MSE 672 Introduction to Transmission EM and Electron Diffraction
MSE 611 Fundamentals of Thermodynamics, Phase Transformation, and Material Simulation at Small Length Scales
MSE 666 Nanoindentation and Small-scale Contact Mechanics
MSE 673 Introduction to Scanned Probe Microscopies
MABE 656 Advanced Mechanics of Materials II
ESE/CBE 6xx Energy conversion systems
ESE/CBE/MSE/CHEM 6xx Advanced Materials for Energy conversion and Storage
CBE 691 Advanced Topics in Chemical Engineering
MSE 676 Advanced Topics in Materials Science and Engineering
CHEM 690 Selected topics in Polymer Chemistry; Polymers for Renewable Energy
CHEM 691 Selected Topics in Thermal Analysis of Polymeric
PHYS 671 Advanced Solid State Physics I
PHYS 672 Advanced Solid State Physics II

C. Bioenergy and Biofuels

Fundamentals (9 credits)

Biology emphasis:

PlSc 605 (1) Plant Genomics Journal Club: Bioenergy and Biofuels Literature
PlSc 465/5xx (2) Bioenergy Crop Ecology
BCMB 522 (3) Advanced Plant Physiology I
BCMB 523 (3) Advanced Plant Physiology II
BCMB 512 (3) Advanced Molecular Biology
PlSc 561 (3) Statistics for Biological Research
PlSc 571 (3) Design and Analysis of Biological Research
PlSc 545 (3) Advanced Plant Biotechnology

PlSc 5xx (3) Biotechnology and Genomics of Biofuels
PlSc 475/575 (3) Professional Issues in Bioenergy
BCMB 401 - Biochemistry-Molecular Biology I
BCMB 402 - Biochemistry-Molecular Biology II
BCMB 515 - Experimental Techniques I
CBE 576 - Applied Microbiology and Bioengineering
ENSC 586 - Green Engineering
BCMB 512 - Advanced Molecular Biology
ENVE 576 - Applied Microbiology and Bioengineering
MICR 410 - Microbial Physiology
MICR 411 - Microbial Genetics
MICR 601 - Journal Club in Microbial Physiology
MICR 605 - Journal Club in Microbial Genetics
MICR 609 - Journal Club in Microbial Genomics
MICR 680 - Foundations in Microbiology
ESS 516 - Soil Biology and Biochemistry
ESS 554 - Environmental Soil Biology
PLSC 532 - Environmental Plant Ecophysiology
EPP 550 - Molecular Epidemiology
EPP 612 - Soil Borne Plant Pathogens
EPP 613 - Fungal Epidemiology and Disease Control
EPP 615 - Physiology of Plant Disease

Chemistry and Materials emphasis:
CHEM 510 - Analytical Spectrometry
CHEM 511, Analytical Separations
CHEM 512, Electroanalytic Chemistry
ENSC 586 - Green Engineering
ME 559 - Advanced Mechanics of Materials I
MSE 511, Fundamentals of Materials Science and Engineering I
MSE 512, Fundamentals of Materials Science and Engineering II
CHEM 550 - Structure and Reactivity in Organic Chemistry
CHEM 551 - Organic Reactions
CHEM 552 - Applications of Organic Reactions
CHEM 590 - Polymer Chemistry
CHEM 594 - Organic Chemistry of Polymers
MSE 540 - Basic Polymer Chemistry
MSE 543 - Basic Polymer Physics
MSE 472 - Fundamental Principles of Composite Materials
MABE 526 - Mechanics of Composite Materials
Forestry FORS 521 - Composite Materials from Renewable Resources
STAT 572 – Applied Regression Analysis
MSE 552 - Laboratory Methods in Polymer Engineering
MSE 572 - X-Ray Diffraction
ENSC 551 - Finite Element Analysis
ENSC 539 - Continuum Mechanics

Advanced (6 credits)
PlSc 65x Advanced Plant Breeding and Genetics
PlSc 6xx Advanced Bioenergy Journal Club
FWF 6xx Life Cycle Analysis for Bioenergy
FWF 6xx Cellulose
Chem 610, Selected Topics in Analytical Chemistry
Chem 670, Selected Topics in Physical Chemistry
ME 659, Advanced Mechanics of Materials II

MSE 610, Structure and Dynamics of Materials
MSE 674, Materials Physics
MSE 675, Advanced Structural Analysis
CBE/MSE/CHEM 6xx Advanced Materials for Energy conversion and Storage
CBE 631 Advanced Topics in Statistical Thermodynamics
CBE 6xx Energy Conversion Systems
EPP 643 - DNA Analysis

D. Renewable Energy – Solar, Wind, Hydro, Geothermal

Fundamentals (9 credits)

CE/Geol 485, Principles of Hydrogeology (?)
GEOL 501, Fractal Models in Earth Sciences
AE 513, Experimental Methods in Fluid Mechanics
CBE 547, Transport Phenomena
CBE 531, Thermodynamics
MABE 521 Thermodynamics 1
MABE 522 Thermodynamics 2
MABE 559 Advanced Mechanics of Materials I
MABE 584 - Turbomachinery Systems I
MABE 587 Dynamic Modeling and Simulation
ENVE 535 Applied Ground Water Hydrology
CBE 532, Statistical Mechanics
CBE 506, Engineering Analysis
Math 511 Methods in applied mathematics I
Math 512 Methods in applied mathematics II
CHEM 512 Electroanalytical Chemistry
CBE/CHEM 5XX Applied Electrochemistry
ECE 525 Alternative Energy Sources
ECE 575 High Performance Computer Modeling and Visualization
MABE 541 & 542 Fluid Mechanics I & II
CHEM 570 Quantum Chemistry and Spectroscopy
CHEM 572 Thermodynamics and Statistical Mechanics
CHEM 573 Chemical Kinetics and Transport
PHYS 531 Classical Mechanics
PHYS 551 Statistical Mechanics

Advanced (6 credits)

CBE 633 Multi scale Materials Modeling
CBE 631 Advanced Topics in Statistical Thermodynamics
CBE 652 Sustainable Energy Production
MSE 672 Introduction to Transmission EM and Electron Diffraction
MSE 611 Fundamentals of Thermodynamics, Phase Transformation, and Material Simulation at Small Length Scales
AE 681 Advanced Viscous Flow Theory
MSE 644 Opto-electronic Processes in Polymeric Materials
MABE 656 Advanced Mechanics of Materials II
ESE/ CBE 6xx Energy Conversion Systems
ESE/CBE/MSE/CHEM 6xx Advanced Materials for Renewable Energy
CBE 691 Advanced Topics in Chemical Engineering
MSE 676 Advanced Topics in Materials Science and Engineering
CHEM 610 Selected Topics in Analytical Chemistry - Electrochemistry
CHEM 690 Selected Topics in Polymer Chemistry – Polymers for Renewable Energy
PHYS 671 Advanced Solid State Physics I
PHYS 621 Advanced Solid State Physics II

E. Environmental and Climate Sciences related to Energy

Fundamentals (9 credits)

Earth System Modeling Emphasis

EV 562 Three Dimensional Climate Modeling
EV 577 Air Pollution Climatology
MATH578 Numerical Methods for Partial Differential Equations

Carbon Cycle and Sustainable Energy Environments Emphasis

ESE 5xx Land-Atmosphere-Ocean-Ice biogeochemical processes
ESE 5xx Carbon management science, policy, and economics

Data Integration and Climate Informatics Emphasis

EV 561 Climate and Environmental Informatics
Geog 517 Geographic Information Management and Processing
Geol 525 Data Analysis
ESE 5xx Data management, uncertainty, dissemination, and integration

Climate Impacts and Consequences Emphasis

Geog 512 Environmental Modeling and Geospatial Analysis
EV 521Climate Impacts on Water Resources
EV 574 Air Pollution Engineering and Control

Advanced (6 credits)

Earth System Modeling Emphasis

EV 691 Special Topic on Environmental Engineering: Global Hydrology
EV 691 Special Topic on Environmental Engineering: Land Ecosystem Modeling

Carbon Cycle and Sustainable Energy Environments Emphasis

EV 691 Special Topic on Environmental Engineering: Environmental management for carbon sequestration
EV 691 Special Topic on Environmental Engineering: Environment, Energy and Sustainability
Geol 660 Advanced Environmental Geochemistry
Micro 670 Global Medicine and Emerging Infectious Disease
Micro 670 Microbial Ecology
Micro 670 Advanced Topics in Environmental Microbiology

Data Integration and Climate Informatics Emphasis

EV 691 Special Topic on Environmental Engineering: Model Uncertainty and Climate Extremes
CS 691 Visualization and Analysis of Large Datasets

Climate Impacts and Consequences Emphasis

EV 672 Air Pollution Dispersion Modeling
EV 691 Special Topic on Environmental Engineering: Regional Air Quality Impacts of Climate Change
EV/CE 691 Special Topic on Environmental Engineering: Transportation and Climate Change
EV 691 Special Topic on Environmental Engineering: Ecological Consequences of Climate Change
EV 691 Special Topic on Environmental Engineering: Energy and Climate Policy

F. Distributed Energy/Grid Management

Fundamentals (9 credits)

ECE 507 Application of Linear Algebra in Engineering Systems
ECE 511 Linear Systems Theory
ECE 512 Multivariable Linear Control System Design
ECE 521 Power Systems Analysis I
ECE 522 Power Systems Analysis II
ECE 523 Power Electronics and Drives

ECE 525 Alternative Energy Sources
ECE 553 Computer Networks
ECE 571 Pattern Recognition
ECE 575 High Performance Computer Modeling and Visualization
CS 541 Database Management Systems
CS 581 Algorithms
PHYS 573 Numerical Methods in Physics

Advanced (6 credits)

ECE 613 Nonlinear Systems Theory
ECE 615 Control of Electric Machines
ECE 617 Special Topics in Systems Theory I
ECE 621 Computational Methods for Power System Analysis
ECE 622 Power System Economics
ECE 623 Advanced Power Electronics and Drives
ECE 625 Utility Applications of Power Electronics
CS 670 Advanced Topics in Scientific Computing

Faculty Committee

Advisor/Major Professor

Each graduate student must have an advisor/major professor from the CIRE faculty, who can be either an ORNL or UT based employee. This professor advises the student about course selection, supervises the student's research, and facilitates communication within the degree program and/or student's major department, to other departments, and with the Graduate School relative to requirements. A temporary advisor may be assigned to direct the entering student's work during the period in which the student is becoming acquainted with the institutions and determining the focus of research interests. Once the major professor is determined, the major professor and the student together select a doctoral committee. The student is expected to maintain close consultation with the major professor and other members of the graduate committee with regard to progress in the program.

Doctoral Committee

The major professor (from the CIRE faculty) directs the student's dissertation research and chairs the doctoral committee. The student and major professor identify a doctoral committee composed of at least four faculty members holding the rank of assistant professor or above, three of whom, including the chair, must be approved by the Graduate Council to direct doctoral research. At least one member must be outside the CIRE faculty. Committee members should be chosen to insure multidisciplinary breadth. The Center Director has oversight responsibility to insure the multidisciplinary nature of the committee. A doctoral student, in collaboration with the major professor, should begin to form the doctoral committee during the first year of study. Once formed, the doctoral committee, by request of the major professor, will meet annually, at the minimum, with the student to insure timely progress toward the degree.

Admission to Candidacy

Admission to candidacy indicates that the student has demonstrated ability to do acceptable graduate work and that satisfactory progress has been made toward the degree. This action

usually connotes that all prerequisites to admission have been completed and a program of study has been approved.

A student may be admitted to candidacy for the doctoral degree after passing the comprehensive examination and maintaining at least a B average in all graduate coursework. Each student is responsible for filing the Admission to Candidacy form, which lists all graduate courses to be used for the degree, including courses taken at the University of Tennessee or at other institutions prior to admission to the doctoral program. The Admission to Candidacy form is signed by the doctoral committee.

Graduate Student Examinations

This section provides a description of the graduate student examination requirements for the PhD degree program. Three examinations are required as part of the doctoral program: qualifying examination, comprehensive examination, and defense of dissertation examination.

Qualifying Examination

The qualifying examination is developed, administered, and graded by the CIRE faculty (or designated subset of the faculty) of the PhD program under the coordination of the CIRE Director and tests the student's general knowledge related to the course requirements. In case of failure, the candidate may appeal to retake the examination through the CIRE Graduate Education Committee within 30 days of notification of the result. If the appeal is granted, the student must retake the examination at the next offering. The result of the second examination is final. This examination must be taken no later than the end of the first year of ESE graduate studies.

Comprehensive Examination

Timing: the Comprehensive Examination must be taken no later than the end of the second year following entrance into the PhD program and prior to admission to candidacy. The timing is late enough in a student's academic program to permit most of his/her graduate course work to be covered on the examination, and early enough to permit modification of the student's program based on the results of the exam.

Prerequisites for the exam: two requirements must be satisfied before a student takes the Comprehensive Examination.

1. A written Dissertation Proposal, approved by the major professor, must be submitted to each member of the student's Doctoral Committee two weeks prior to the examination.
2. Each member of the student's Doctoral committee must agree that the student is ready to take the Comprehensive Exam. In order to satisfy each member of the committee that he/she is ready for the exam, the student may be required to perform satisfactorily on either written or oral tests as prescribed by the committee member. The committee member will communicate to the major professor when they are satisfied that the student is ready to take the Comprehensive Exam.

The Comprehensive Examination will consist of two parts.

1. A one-day to two-day open book written examination will be given at an agreed upon date. This exam will be composed by the members of the Doctoral Committee at the request of the student's major professor, and the exam will be administered by the major professor.
2. Approximately three to six weeks after the written examination, the student will be required to defend his/her dissertation research proposal to the committee. An oral examination will be given. In addition, the student may be further examined in an oral examination on subject matter similar to that covered on the written exam.

Once the Comprehensive Examination is passed, the student should file for and be admitted to candidacy. At the discretion of the Doctoral Committee, supplemental reexaminations for the Comprehensive Examination and/or proposed dissertation research may be required. In case of failure, the candidate may not apply for reexamination until the following semester. The result of the second examination is final.

Defense of Dissertation Examination
A doctoral candidate must pass an oral examination on the dissertation. The dissertation, in the form approved by the major professor, must be distributed to the committee at least two weeks before the examination. The examination must be scheduled through the Office of the University Registrar at least one week prior to the examination and must be conducted in university-approved facilities. The examination is announced publicly and is open to all students and faculty members. The defense of dissertation will be administered by all members of the doctoral committee after completion of the dissertation and all course requirements. This examination must be passed at least two weeks before the date of submission and acceptance of the dissertation by Graduate Student Services. The major professor must submit the results of the defense by the dissertation deadline.

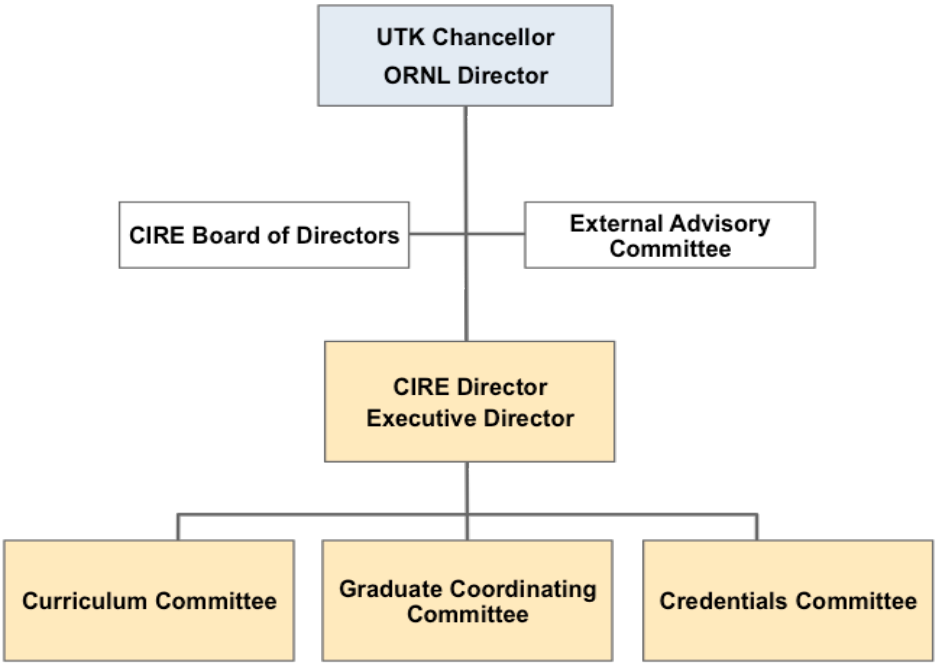
C. Organization

In January 2010 the General Assembly of the State of Tennessee passed legislation authorizing The University of Tennessee to establish an academic unit of The University of Tennessee, Knoxville (UTK) for interdisciplinary research and graduate education in collaboration with Oak Ridge National Laboratory (ORNL). This academic unit, known as the Center for Interdisciplinary Research and Graduate Education (CIRE), brings together extensive and complementary resources at UTK and ORNL to increase science, technology, engineering, and mathematics (STEM) academic and research activities of national significance focused on energy-related science and engineering. CIRE will enhance collaborations between UTK and ORNL, increase the number of STEM graduate students, advance multi-disciplinary research in energy-related science and engineering, and accelerate the translation of research results into beneficial technologies.

CIRE has developed and proposes to offer one of the first interdisciplinary PhD programs in energy science and engineering. This new degree will provide breadth while preserving the depth and rigor of a PhD program. Topical areas have been chosen to align with unique ORNL capabilities and programs. The Energy Science and Engineering (ESE) PhD will be complemented by a concentration in ESE for students who prefer pursuing doctoral studies through existing programs. Both the ESE degree and the concentration will include an emphasis on entrepreneurship and innovation, including opportunities for interested students to develop and implement business plans with the UTK business school.

CIRE is led by a Director (UTK employee, initially full time) and Executive Director (ORNL employee, part time) appointed jointly by the UTK Chancellor and ORNL Director. The Director is responsible for day-to-day operations, finances, personnel, appointment of CIRE faculty committees, appointment of CIRE faculty, performance appraisals of CIRE faculty, recruiting and admissions, student life, and relationships with UTK departments and administration. The Executive Director assists the Director and is the primary interface with ORNL, including ORNL research programs, staff, management, operations and safety, security, and financial systems. The Director will appoint a Credentials Committee, Curriculum Committee, and Graduate Coordinating Committee to assist in administering CIRE programs. An organization chart is provided in the figure below. Lee Riedinger, Professor of Physics, was appointed to this position effective September 1, 2010.

Center for Interdisciplinary Research and Education



A Board of Directors composed of senior officials at UTK and ORNL oversees the operation of CIRE. An external advisory board will provide independent advice and strengthen relationships with industry and other universities. CIRE faculty are drawn from UTK and ORNL, with common eligibility criteria and appointment processes. CIRE faculty will mentor graduate students, develop and teach courses, develop and submit research and other funding proposals, and serve on CIRE committees including Curriculum, Graduate Coordinating, and Credentials committees.

Chancellor Cheek has appointed the first Board of Directors to be composed of the Task Force that he and Laboratory Director Mason established in February of 2010 to develop the preliminary structure of CIRE and the ESE degree program. This initial Board of Directors is shown below and is chaired by Dr. Davis (UTK) and Dr. Roberto (ORNL).

Name	Affiliation	Title
Beierschmitt, Kelly	ORNL	Associate Laboratory Director, Nuclear Science and Engineering
Daverman, Bob	UT	Professor, Department of Mathematics
Davis, Wayne	UT	Dean, College of Engineering Professor, Department of Civil & Environmental Engineering
Hodges, Carolyn	UT	Vice Provost & Dean of the Graduate School
Keller, Martin	ORNL	Associate Laboratory Director, Biological & Environmental Sciences
Khomami, Bamin	UT	Professor & Head, Department of Chemical & Biomolecular Engineering
Liu, Yilu	UT	Governor's Chair Professor, Department of Electrical Engineering and Computer Science
Miller, Alex	UT	Associate Dean of Academic Programs, College of Business William B. Stokely Professor of Management
Nichols, Jeff	ORNL	Associate Laboratory Director, Computing & Computational Sciences Directorate
Parang, Masood	UT	Associate Dean & Professor, Academic & Student Affairs, College of Engineering
Roberto, Jim	ORNL	Associate Laboratory Director, Graduate Education and University Partnerships
Sorensen, Soren	UT	Professor & Head, Department of Physics
Stewart, Neal	UT	Professor & Ivan Racheff Chair of Excellence, Department of Plant Sciences

CIRE graduate students will join interdisciplinary research teams at ORNL that will expose them to large-scale problem-oriented research and development, foster their ability to work across disciplinary boundaries, encourage them to approach research problems from new directions, and strengthen their ability to work in teams. Students will be encouraged to develop their research in the context of potential solutions to important national problems, and will be given the tools and support to follow an entrepreneurial path consistent with their interests.

CIRE is being initiated with startup funds from the State of Tennessee. Competitively selected students will be supported jointly by UTK and ORNL, with UTK supporting students primarily during coursework, and ORNL supporting students during research. Additional research support and other funding will be actively sought from federal and industry sponsors. Financial projections demonstrate sustainability for at least five years with reasonable levels of additional external funding required thereafter.

D. Evaluation

A CIRE Board of Directors is appointed by the UTK Chancellor and ORNL Director to oversee the development and operation of CIRE. The Board will have equal representation from UTK and ORNL. The CIRE Director and Executive Director will be ex-officio on the Board. A CIRE External Advisory Committee will be appointed by the UTK Chancellor and ORNL Director to provide advice to the CIRE Director and strengthen relationships with industry and universities. The composition of the initial Board of Directors is shown in the previous section.

It is these two bodies, the Board of Directors and the External Advisory Committee, that will perform regular evaluation of the progress of the center and the PhD program. The Board of Directors will evaluate performance relative to established goals on a yearly basis, and an in-depth evaluation of the center and the graduate program will be performed every five years. In this major review, the UTK Provost will appoint a Program Review Committee in a manner that is consistent with regular reviews performed by that office on all UTK departments and programs. A program review committee will be composed of a combination of UTK and outside experts that will be commissioned to study CIRE and the PhD program in detail, reporting their findings to the Provost. This process includes follow-up to be sure that recommendations are adopted and a mid-term update on the progress of the unit before the next major review.

E. Accreditation

This degree will not be subject to accreditation, as there is no accreditation process or body for such an interdisciplinary program.

F. Related undergraduate programs

Related undergraduate programs are any major in the College of Engineering or College of Agriculture and Natural Resources and any science or math major in the College of Arts and Sciences. Any of these specific disciplines will be able to provide students that can apply for admission to this interdisciplinary doctoral program.

G. Need for the program

Our country is facing an energy crisis of massive proportion and broad impact. A supply for an expanded energy need for our citizens and industries must be made with the issues of climate change being understood and remedied. The U.S. government is putting great emphasis on R&D to generate a new set of sustainable strategies for energy supply, while stressing also energy efficiency and solutions to climate change. Many students entering the workforce in the next 50 years will face in their careers the complex and inter-related issues of energy supply, policy, pricing, control, regulation, and impact on the climate. It is very important for the university to prepare students for this national and international energy emphasis that will only grow stronger in coming decades.

A key objective of the academic unit (CIRE) is to expand the number and quality of UTK doctoral students carrying out dissertation research at ORNL. This academic unit will position UTK to play a major role in facilitating the collaboration between UTK and ORNL in graduate

education including support, through funded research activities, for students. It will also position UTK to increase the number and quality of enrolled graduate students. Through this new interdisciplinary graduate program in energy science and engineering, UTK will be innovative in its approach and attractive to students seeking to work in transformative energy research and development that cut across traditional disciplinary boundaries.

The CIRE Task Force conducted phone interviews with leaders of energy-related industries and university energy research and education centers between February and May 2010. The purpose of these interviews was to solicit their input and recommendations on energy-related research and education initiatives, interdisciplinary programs, and university/national laboratory centers.

The industry interviews were conducted with corporate level senior management from Chevron, DuPont, Exxon Mobil, GE Global Research, and Siemens Energy. Industry hires PhDs for depth and expertise, with a preference for traditional science or engineering degrees with a solid grounding in fundamentals. Students should have the breadth to apply fundamentals across disciplines (industry assembles disciplines into multidisciplinary teams). Industry prefers that new employees learn details of the energy business from their employers. The large-scale project experience and problem-oriented interdisciplinary research typical of national laboratories is highly valued. Communication skills and the ability to work in teams are essential. Interdisciplinary degrees without a "deep dive" are not well received. The proposed doctoral program has been constructed with these imperatives in mind.

University interviews were conducted with Stanford, MIT, and the University of Southern California. All of these universities have energy-related research and education centers. These centers provide both research and educational opportunities. They are effective at interfacing with industry and developing large funded projects (the MIT Energy Initiative exceeds $200M). The centers promote interdisciplinary research and education by bringing together multidisciplinary teams and encouraging interdisciplinary dissertation topics. They typically offer traditional PhD programs and do not offer an interdisciplinary energy degree. However, there is a clear need identified for a truly interdisciplinary program and degree.

Role in economic development

There is a need for the ESE degree program in terms of economic development in the State of Tennessee. In many ways, Tennessee is a microcosm of the country with respect to the challenges and the opportunities in energy-related areas. Issues of climate certainly affect our state, as the Great Smoky Mountains are a national treasure that needs to be protected from the harmful effects of extensive burning of coal in the region. Tennessee is heavily dependent on private transportation with the absence of much public transportation, and thus is very susceptible to the cost of gasoline for cars and trucks. Tennessee through TVA has had a nuclear power industry that has been on hold and static for 35 years.

But, the opportunities for Tennessee are profound. The presence of ORNL, TVA, and UTK has led to discussion of designing and building a new generation of small modular nuclear reactors,

which could become a workhorse of an expanded nuclear power industry in the country, very important as we look for ways to move away from the burning of fossil fuels as the primary source of our electricity. Nissan will begin building the new all-electric Leaf in Tennessee, along with the all-important battery that can potentially provide up to 100 miles of careful driving before a full recharge is needed. A huge amount of R&D is needed to develop a far more robust and far cheaper battery that can provide the real opportunity for the Leaf (and other electric vehicles) to become a vehicle of choice. This HAS to be done in the next 10 to 20 years, as the supply of petroleum is likely to start to decease, which will cause the cost of gasoline to skyrocket.

The presence of ORNL, UTK, TVA, and some of the formative nuclear and electric vehicle industries in Tennessee, and the generation of ESE graduates from UTK, should be a huge incentive for other energy-related industries to locate in Tennessee. For example, a new Volunteer State Solar Initiative has begun in the past year, utilizing in part the solar-energy R&D assets of ORNL and UT. Two important parts of this initiative are the West Tennessee Solar Farm being constructed near Brownsville ($31M) and the Tennessee Solar Institute at UTK and ORNL, including solar opportunity funds of $29.2M. This new program should give Tennessee the chance to take a leadership role in the development of solar energy, initially for small niche markets but eventually for use by large companies, utilities, and municipalities. ESE graduates will be a source of talent to attract these industries and contribute to the workforce.

The regional and national scene will be similar to that in Tennessee. Energy supply and use are huge challenges that face the United States. Solutions to these extreme problems provide profound opportunities for economic development - new industries, new jobs, and new careers. There will be big opportunities in the electric vehicle and/or fuel-cell powered vehicle industries in the next one to three decades, and this will accelerate as the cost of petroleum once again goes to $140/barrel and then rockets past that high-water mark when the supply of petroleum is *perceived* to be soon limited. Other advanced countries will migrate to the point of taxing carbon emissions to the atmosphere in the next decade, and even our country will be dragged along in this direction. This will then lead to a cry for more nuclear energy and increased electricity from solar and wind resources. Industries and people that have been working in these technologies will be huge sources of economic development.

H. Diversity and access

Graduate students will be nationally recruited for this new doctoral program in a large annual campaign led by Oak Ridge National Laboratory. Recruiters from ORNL have visited in this first year 30 top universities across the U.S., to attend job fairs to advertise this ESE doctoral program and to talk to undergraduates at some of the top universities in the country. Diversity will be a strong consideration in this recruitment process. After the first year, depending on the achieved level of diversity in the first class of new students, CIRE leadership will decide how to expand this aggressive recruiting campaign to include high quality minority institutions, especially Historically Black Colleges and Universities.

I. Estimated size of program

Year	Fall full-time Head count	Head count ESE degree students	Head count ESE concentration students	Graduates with ESE degree	Graduates with ESE concentration
1	20	15	5	0	0
2	45	34	11	0	0
3	70	53	17	0	0
4	95	72	23	0	0
5	120	91	29	15	5
6	125	95	30	19	6

The goal is to recruit 20 new students for year 1, 25 for year 2 and each year thereafter. It is assumed that all students will receive their doctorate after five years, and that 75% of the students will choose to take the *interdisciplinary* ESE degree as opposed to a conventional PhD with an ESE concentration.

J. No unnecessary duplication

There are no comparable programs at the University of Tennessee or in the state of Tennessee, and apparently no where else in the country of a form like this (interdisciplinary energy doctorate done jointly with a national laboratory).

K. Faculty

CIRE will have no dedicated faculty lines. All faculty will be appointed as part-time from the ranks of current UTK faculty and existing research staff at ORNL. All ORNL research staff members and UTK and UTIA faculty who fulfill the following criteria are eligible to apply for membership to the CIRE faculty.

- Their appointment will substantially benefit CIRE and CIRE's mission.
- They have a strong record of research and leadership accomplishments in CIRE's mission areas.
- They are willing to commit the required resources (time, student support, expertise, etc.) to the ESE program or other CIRE projects.

High professional standards will be applied in appointing CIRE faculty. Membership of the CIRE faculty is time limited but renewable. The initial appointment is made for three years and renewal appointments are made for five years.

Responsibilities of CIRE faculty

- They should be actively engaged in CIRE activities, which include mentoring, recruiting, teaching, course development, and committee service.

- They should commit to supervising and supporting at least one graduate student at any given time, ensuring timely completion of the PhD.
- They should provide descriptions of research opportunities, dissertation topics, and shorter research projects available in their groups on an annual basis. CIRE will provide a Doctoral Research Clearing House web site describing the research of all CIRE faculty as well as a current list of research groups with doctoral research opportunities.

CIRE faculty who are not fulfilling these requirements will in general not have their appointment renewed, and can in severe cases be terminated as CIRE faculty prior to the end of their term.

Academic titles of CIRE faculty

CIRE faculty with ORNL as their home institution will hold one of the following three UTK titles of Joint Faculty: Joint Professor, Joint Associate Professor, or Joint Assistant Professor. CIRE Faculty with UTK as their home institution will also hold an ORNL title (examples are Research Associate, Senior Research Associate, etc.). The initial title is determined at the time of the first appointment following the process for appointment of CIRE faculty described below. CIRE faculty can request promotions at the time of renewal. Promotion of CIRE faculty requires a vote by the CIRE faculty, recommendation of the CIRE Director, and approval of the Provost. In cases where a faculty member has an appointment within CIRE and within another degree program, the CIRE director will coordinate any change in title with the other degree program(s). The criteria for the use of the Joint Faculty titles within CIRE are given below.

CIRE Joint Faculty Professors are expected to

1. hold the doctorate or other terminal degree of the discipline, or present equivalent training and experience appropriate to the particular appointment,
2. be accomplished teachers or mentors of graduate students,
3. have achieved and then maintain a nationally recognized record in disciplinary research, scholarship, and/or creative activity,
4. have achieved and then maintain a record of significant institutional, disciplinary, and/or professional service,
5. serve as mentors to junior colleagues,
6. have normally served as an associate professor for at least five years,
7. have shown beyond doubt that they work well with colleagues, staff, and students in performing their professional responsibilities.

CIRE Joint Faculty Associate Professors are expected to

1. hold a doctorate or other terminal degree of the discipline, or to present equivalent training and experience as appropriate to the particular appointment,
2. be good teachers or mentors of graduate students.
3. have achieved and then maintain a recognized record in disciplinary research, scholarship, and/or creative activity,
4. have achieved and then maintain a record of institutional, disciplinary, and/or professional service,
5. have normally served as an assistant professor for at least five years,

6. have demonstrated that they work well with colleagues, staff, and students in performing their professional responsibilities.

CIRE Joint Assistant Professors are expected to

1. hold a doctorate or other terminal degree of the discipline, or to present equivalent training and experience as appropriate to the particular appointment,
2. show promise as teachers or mentors of graduate students,
3. show promise of developing a program in disciplinary research, scholarship, and/or creative activity that is gaining external recognition,
4. have a developing record of institutional, disciplinary, and/or professional service,
5. show evidence that they work well with colleagues, staff, and students in performing their professional responsibilities.

CIRE faculty appointment process

Requests for initial and renewal appointment as CIRE faculty are submitted to CIRE's Director.

- ORNL applicants who do not currently have a base appointment within an existing UTK degree-granting unit should submit their application through the ORNL division director, who will then forward the application to the CIRE Director.
- Faculty applicants whose base faculty appointment is with an existing UTK degree granting unit should submit their application through the department head, who will then forward the application to the CIRE Director.
- All applications will be reviewed by the CIRE Faculty Credentials Committee. The Credentials Committee will provide a brief written recommendation concerning the decision of membership application and the proposed appointment level to the Director.
- If a positive recommendation is made by the Credentials Committee, the application is brought to the CIRE faculty for discussion and recommendation, which will require a simple majority of the votes with a quorum of at least half the faculty required. The recommendation of the Credentials Committee and of the current faculty are considered by the CIRE director in forming his/her recommendation, and all three, as well as the appointment level, are forwarded to the Provost for approval by the university.
- The appointment request is required to contain the following elements:
    - A current curriculum vita describing all the professional accomplishments of the applicant.
        - Full education history
        - Full employment history
        - Refereed publications
        - Invited and contributed talks
        - External research funding record
        - Teaching experience
        - Student supervision experience
        - Awards and recognition
    - A brief description (one page or less) of the reason(s) for the request and how the applicant fulfills the eligibility criteria.

    - For the initial appointment a letter of nomination from a current CIRE faculty member or a unit leader at UTK or ORNL.
- The CIRE Director will be responsible for an annual evaluation of all CIRE faculty, shared with appropriate UTK department heads and ORNL division directors.
- The UTK Chancellor and the Laboratory Director will appoint an interim Credentials Committee for the purpose of approving the initial CIRE faculty. Four of these committee members will be senior and accomplished faculty from UTK and four will be senior and accomplished ORNL researchers. After this initial step, members of the CIRE faculty will staff the Credentials Committee, in equal numbers from each institution.

Appointment of initial CIRE faculty
On November 3, the CIRE director initiated the process to recruit and appoint a CIRE faculty from the current faculty at UT and research staff at ORNL. University department heads and laboratory division directors were asked to distribute the request for applications to all interested people.

Following the process described above, Chancellor Cheek and Laboratory Director Mason appointed an Interim Credentials Committee to review applications and make recommendations on which have the best credentials for appointment. Members of this committee are shown in the table below.

ORNL	**Division**	**Area**
Robin Graham	Environmental Sciences	biosystems
Steve Zinkle	Materials Science and Technology	materials
John Wagner	Nuclear Science and Technology	nuclear energy and computing
Ricky Kendall	Center for Computational Sciences	computing
UT	**Department**	**Area**
Mike Guidry	Physics	general
David Mandrus	Materials Science and Engineering	materials
Larry Townsend	Nuclear Engineering	nuclear energy
Tim Rials	Center for Renewable Carbon	bioenergy

A total of 80 applications were received - 34 from ORNL, 33 from UTK, 4 Governor's Chairs (joint between ORNL and UTK), and 9 from UT Institute of Agriculture. The Interim Credentials Committee reviewed all applications, as did the CIRE Board of Directors. These two independent bodies came to a uniform recommendation of 38 of these applicants to be appointed to the CIRE faculty, which Provost Martin did on December 20. These initial CIRE faculty are shown in the table below.

	Last name	First name	Energy area Primary	Unit	
1	Besmann	Ted	1	Materials Science and Technology Division	ORNL
2	Williams	Mark	1	Reactor and Nuclear Systems Division	ORNL
3	Hall	Howard	1	Departmentof Nuclear Engineering	UTK
4	Wirth	Brian	1	Departmentof Nuclear Engineering	UTK
5	Nazarewicz	Witek	1	Physics Department	UTK
6	Chen	Jay	2	Bioscienes Division	ORNL
7	Davison	Brian	2	Bioscienes Division	ORNL
8	Bozell	Joe	2	Department of Forestry, Wildlife and Fisheries	UTIA
9	Stewart	Neal	2	Department of Plant Sciences	UTIA
10	Bruce	Barry	2	Department of Biochemistry and Cellular and Molecular Biology	UTK
11	Sayler	Gary	2	Department of Microbiology	UTK
12	Paranthaman	Parans	3	Chemical Sciences Division	ORNL
13	Narula	Chaitanya	3	Materials Science and Technology Division	ORNL
14	Khomami	Bamin	3	Department of Chemical and Biomolecular Engineering	UTK
15	Kalinin	Sergei	4	Center for Nanophase Material Sciences	ORNL
16	Van Berkel	Gary	4	Chemical Sciences Division	ORNL
17	Daniel	Claus	4	Materials Science and Technology Division	ORNL
18	Paddison	Stephen	4	Department of Chemical and Biomolecular Engineering	UTK
19	Zawodzinski	Tom	4	Department of Chemical and Biomolecular Engineering	UTK
20	Mench	Matthew	4	Depart. of Mechanical, Aerospace and Biomedical Engineering	UTK
21	Shankar	Arjun	5	Computational Sciences and Engineering Division	ORNL
22	Gleason	Shaun	5	Measurement Science and Systems Engineering Division	ORNL
23	Liu	Yilu	5	Department of Electrical Engineering and Computer Science	UTK
24	Tolbert	Leon	5	Department of Electrical Engineering and Computer Science	UTK
25	Wang	Fred	5	Department of Electrical Engineering and Computer Science	UTK
26	Tomsovic	Kevin	5	Department of Electrical Engineering and Computer Science	UTK
27	Norby	Rich	6	Environmental Sciences Division	ORNL
28	Hack	Jim	6	National Center for Computational Sciences	ORNL
29	Fu	Joshua	6	Department of Civil and Environmental Engineering	UTK
30	Parker	Jack	6	Department of Civil and Environmental Engineering	UTK
31	Doktycz	Mitch	7	Bioscienes Division	ORNL
32	Simpson	Mike	7	Center for Nanophase Material Sciences	ORNL
33	Bhaduri	Budhu	7	Computational Sciences and Engineering Division	ORNL
34	Datskos	Panos	7	Measurement Science and Systems Engineering Division	ORNL
35	Nagler	Steve	7	Neutron Scattering Science Division	ORNL
36	Pharr	George	7	Department of Materials Science and Engineering	UTK
37	Liaw	Peter	7	Department of Materials Science and Engineering	UTK
38	Sawhney	Rupy	7	Department of Industrial Engineering	UTK

The primary area of energy research for each faculty member is listed in the table above, and the distribution by area is summarized in the table below.

Research area	**Code**	**Number of faculty**
Nuclear energy	1	5
Bioenergy and biofuels	2	6
Renewable energy	3	3
Energy conversion and storage	4	6
Distributed energy and grid management	5	6
Environmental and climate sciences related to energy	6	4
Cross cutting over several energy areas	7	8

These 38 represent the first set of CIRE faculty, those with perhaps the highest credentials and closest attachment to the initially defined areas of energy-related research. More faculty will be added from the group of those that have already applied and those that will apply. A Credentials Committee will be appointed from this first set of 38 and it will be this committee that considers the needs for an expanded faculty and the credentials of those that apply.

Approval to Direct Doctoral Dissertations

- All CIRE faculty members, prior to serving as major professors of PhD students, must be approved by the UTK Graduate Council to direct doctoral dissertations.
- All CIRE faculty members, who do not already have this approval and have no prior experience in supervising doctoral thesis research, can initially request a one-time approval or approval to co-direct doctoral dissertations with an approved faculty member.

L. Library resources

No new library resources are needed. The library resources of UTK and ORNL will serve the needs of this program.

M. Support resources

The ESE doctoral program has been developed as a close partnership between UTK/UTIA and ORNL. Both institutions have committed resources to make this program a success, and in addition the Tennessee Legislature has appropriated $6.2M of one-time funds for CIRE. The university has assigned the fourth floor of Greve Hall as the on-campus space for CIRE - its administration, students, and part-time faculty. ORNL and UTK have assigned space in the Joint Institute for Computational Sciences for the administrative functions of CIRE at ORNL. A few support personnel will be hired to help operate CIRE, using the state allocation.

ORNL Director Thom Mason has pledged strong support for this new partnership in the letter shown below. The university and the laboratory have signed an MOU concerning this new partnership, as also shown below.

OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

P.O. Box 2008
Oak Ridge, TN 37831-6255
Phone: (865) 576-2900
Fax: (865) 241-2867
E-mail: masontr@ornl.gov

June 22, 2010

Dr. Brad Fenwick
Vice Chancellor for Research and Engagement
The University of Tennessee
535 Andy Holt Tower
Knoxville, Tennessee 37996-0152

Dear Dr. Fenwick:

Proposal to Establish the UTK–ORNL Center for Interdisciplinary Research and Graduate Education

I am writing to express my full support for the proposal to create and implement the Center for Interdisciplinary Research and Graduate Education (CIRE) as an academic unit of The University of Tennessee, Knoxville (UTK), for interdisciplinary research and education in collaboration with Oak Ridge National Laboratory (ORNL). The task force that Dr. Jimmy Cheek and I jointly appointed to develop this proposal has completed its work and delivered a comprehensive plan that provides a solid foundation for CIRE.

The creation of CIRE offers an extraordinary opportunity to enhance the partnership between UTK and ORNL, a partnership that dates from the earliest years of ORNL and has brought substantial benefits to both institutions. CIRE represents a new model for graduate education, bringing together the resources of a comprehensive research university and a major national laboratory to provide expanded opportunities for graduate students to participate in large-scale, multidisciplinary research projects focused on energy-related challenges, with an emphasis on entrepreneurship and innovation. The engagement of CIRE graduate students in ORNL's research programs will open new avenues for collaboration between UTK and ORNL and will enhance our capacity to deliver solutions to compelling challenges in energy-related fields.

I am strongly committed to the success of CIRE as the next step in strengthening the partnership between ORNL and UTK, and I look forward to working together with UTK to deliver one of the first interdisciplinary PhD programs in energy science and engineering. If you have questions or need additional information, please do not hesitate to contact me.

Sincerely,

Thomas Mason

Thomas E. Mason
Director

TEM:kfr

MEMORANDUM OF UNDERSTANDING
No. MOU-UTB-2010014
BETWEEN
UT-BATTELLE, LLC
AND
THE UNIVERSITY OF TENNESSEE

REGARDING

DEVELOPMENT OF AN ACADEMIC UNIT OF THE UNIVERSITY OF TENNESSEE, KNOXVILLE FOR INTERDISCIPLINARY RESEARCH AND EDUCATION
and an
INTERDISCIPLINARY PH.D. PROGRAM IN ENERGY SCIENCE AND ENGINEERING

The Parties to this Memorandum of Understanding are The University of Tennessee, on behalf of The University of Tennessee, Knoxville (UTK), and UT-Battelle, LLC (UT-Battelle), which manages and operates the Oak Ridge National Laboratory (ORNL) under its contract with the Department of Energy, DE-AC05-00OR22725.

WHEREAS, UTK and UT-Battelle share the goal of developing solutions to climate, energy, and environmental problems, the Parties desire to bring together extensive and complementary resources for the purpose of increasing academic and research activities in science, technology, engineering, and mathematics to foster an interdisciplinary focus on energy science; and

WHEREAS, the General Assembly of the State of Tennessee has authorized The University of Tennessee to establish an academic unit of UTK for interdisciplinary research and education in collaboration with ORNL; and

WHEREAS, the General Assembly has further authorized the Chancellor of UTK and the Director of ORNL to enter in an agreement concerning collaboration in interdisciplinary research and education designed to accomplish the purposes of Tennessee Code Annotated, Title 49, Chapter 9, Part 15.

NOW, THEREFORE, the Parties enter into this Memorandum of Understanding (MOU) to memorialize their understandings concerning development of an academic unit of UTK for interdisciplinary research and education in collaboration with ORNL and a related interdisciplinary Ph.D. program in Energy Science and Engineering (Program).

1. The Parties' current understandings with respect to the academic unit of UTK and the Program are outlined in the Proposal attached as Exhibit 1 and incorporated herein by reference.

Memorandum of Understanding No. MOU-UTB-2010014
UT-Battelle, LLC and The University of Tennessee

2. Development of the academic unit of UTK and implementation of the Program are subject to all required governing board and state and federal government approvals.

3. No funds are committed, no intellectual property rights are created or affected, and except as provided in paragraph 7 below, no legal obligations are created by this MOU.

4. This MOU may be transferred from UT-Battelle to DOE or to its designee.

5. This MOU, including the Proposal attached as Exhibit 1 and incorporated herein by reference, may be amended by written amendment signed by authorized representatives of the Parties.

6. Each Party acknowledges that it is responsible for its own compliance with all U.S. export control laws and regulations; and each Party acknowledges that it will not knowingly export directly or indirectly, through its affiliates, licensees, or subsidiaries, any export controlled hardware, software, or technical data in the performance of this MOU without a required license/authority which will be obtained by the responsible Party from the appropriate U.S. authority.

7. This MOU will become effective upon the date of the last signature and shall remain in effect until terminated by either Party by giving at least 180 days' written notice to the other Party. If this MOU is terminated, the Parties will satisfy their respective funding commitments to graduate students and will take appropriate steps to allow students enrolled in the Program to complete their degree within a reasonable time.

SIGNED:

Thom Mason — 5/21/2010
Thom Mason — Date
Director, Oak Ridge National Laboratory

Jimmy Cheek — 5/21/2010
Jimmy Cheek — Date
Chancellor, The University of Tennessee, Knoxville

Attachment (Exhibit 1)

N. Cost/benefit

The costs of this proposed program are included in the table at the end of this document. Costs have been escalated at 3% per year. The one-time allocation of $6.2M from the Tennessee Legislature is shown in Revenues.

O. Costs/productivity of recently initiated programs

The 2004-2005 through 2008-2009 Productivity Report indicates that UT Knoxville currently offers 42 active PhD programs. Of this total, 35 of the programs produce at a rate at or above the productivity goal set by THEC (an average of three degrees over a five-year period). Although the Energy Science and Engineering program being proposed is unique and cannot be compared with extant UT Knoxville programs, below are the productivity rates for other engineering PhD programs.

Program	Total Graduates 04-05 thru 08-09
Engineering Science	5
Biosystems Engineering	5
Polymer Engineering	7
Chemical Engineering	12

The recommended action for these programs was that they be retained.

P. Consultants

Two consultants have been engaged to study the ESE doctoral program. They are:

Dr. Phillip Parrish
Associate Vice President for Research
University of Virginia
Charlottesville, VA 22901
parrish@virginia.edu

Dr. Marilyn Brown
Professor, School of Public Policy
Georgia Institute of Technology
Atlanta, GA 30332-0345
Marilyn.Brown@pubpolicy.gatech.edu

The consultants visited the university and the laboratory on November 2 and 16, respectively, to review the ESE program. Their written evaluations are attached to this proposal. They expressed great support for the program that has been developed and also offered key recommendations that will be implemented, as discussed below, with recommendations italicized.

- *The ESE doctoral program should be oriented towards addressing "Grand Challenges" in energy, those key systems problems which have the potential, if solved, to have major positive influence towards resolving the nation's major issues of dependence upon foreign sources of energy, climate change, and environmental sustainability.* This emphasis on *grand challenges* is being implemented, in part by the choice of the six areas of initial energy emphasis for the ESE degree program.

- *The faculty for the CIRE/ESE program should be recruited with this "Grand Challenges" framework in mind.* The recruitment process is described above. The initial CIRE faculty of 38 is distributed across these various areas of energy research as shown in the table below.

Research area	**Number of faculty**
Nuclear energy	5
Bioenergy and biofuels	6
Renewable energy	3
Energy conversion and storage	6
Distributed energy and grid management	6
Environmental and climate sciences related to energy	4
Cross cutting over several energy areas	8

- *Qualification procedures for doctoral student recruitment into the ESE doctoral program should be focused upon selection of the best and brightest candidates.* An extensive recruiting program has been initiated in the fall of 2010, led by the Human Resources unit of Oak Ridge National Laboratory. Teams of recruiters and research experts visited 30 top universities throughout the fall, to attend job/grad school fairs and talk to students about the ESE doctoral program being organized at the University of Tennessee in partnership with ORNL. Literature was distributed and students encouraged to apply for the ESE program. Thousands of students received the literature and expressed interest in this new program. The application deadline is in middle January.

  The full intent is to choose the best and the brightest for this new interdisciplinary program. The university does not have the capability to engage in active national recruitment of graduate students on its own, so the partnership with ORNL presents a remarkable opportunity to recruit top students in an aggressive manner.

  The list of the 30 universities visited by these recruiting teams is shown below. Five others were slated to be visited also, but the job/grad school fairs for these occurred on the same days as some of the 30. These will be visited in future years.

1	California Institute of Technology
2	Carnegie Mellon University
3	Duke University
4	Florida State University
5	Georgia Institute of Technology
6	Harvard University
7	Massachusetts Institute of Technology
8	North Carolina State University
9	Purdue University
10	Rensselaer Polytechnic Institute
11	Stanford University
12	University of California– Berkeley
13	University of Chicago
14	University of Illinois – Urbana Champagne
15	University of Michigan – Ann Arbor
16	University of Tennessee – Knoxville
17	University of Texas – Austin
18	University of Virginia – Charlottesville
19	Vanderbilt University
20	Virginia Tech University
21	Texas A&M University
22	Clemson University
23	University of South Carolina – Columbia
24	Michigan State University
25	Arizona State University
26	University of Florida - Gainesville
27	Indiana University
28	University of Colorado – Boulder
29	Auburn University
30	Washington State University

- *The new ESE courses 511 and 512, "Introduction to Energy Science I and II" should be developed emphasizing critical thinking focused upon the major and very complex energy issues confronting society, and the technological directions that will be required to address these issues.* These two courses will be expanded versions of an energy technology course currently being taught by Professor Riedinger at the undergraduate level, one for the Haslam Scholars at the second year level and the other for senior-level physics and engineering majors. Both courses emphasize the underlying technology in each of the energy solutions for the future, set in the context of cost, resources available, impact on the climate, public acceptability, etc. The graduate courses, ESE 511 and 512, will be expanded versions of these undergrad courses, with a partial emphasis on quantitative analysis of the various energy options.

- *The originators of the ESE doctoral program recognize the critically important role of innovation and technology transition to the economy of new knowledge and intellectual property resulting from research dissertations, and have incorporated opportunities for doctoral students to obtain insight into entrepreneurship and business start-up by development of business plans and participation in business plan competitions.* Entrepreneurship will be an important and crucial element for some of the ESE students, and a necessary partial emphasis for all. This will be incorporated in several ways. The College of Business Administration has a center devoted to entrepreneurship, and linkages with

faculty in this center will be built. The College of Engineering currently presents a course in entrepreneurship relative to engineering technologies and business opportunities, and students will be directed to this course if such a direction is desired by a particular student.

- *Add a timeline to the ESE proposal to make it clear how and when CIRE will get students engaged with a research advisor, involved in research, through major exams, etc., in the manner intended.* This timeline is presented on page 12 of this proposal, and describes the expected progress of students through the various hurdles.

- *The CIRE Director should establish a strategic planning process with CIRE faculty to consider new energy-related research areas. For example, carbon capture and sequestration beyond terrestrial management, coal to liquid fuel processing, and high-efficiency clean combustion are not currently well represented by the current 10 areas, but they might become targeted grand challenges for the program in the future.* The current six areas of energy-related research have been chosen in part by an analysis of the current strengths of the two institutions. However, these need to evolve and be amended, and a strategic planning committee of the faculty will be appointed to engage in this discussion. The two institutions will make some new staff hires in future years, and it is possible that these hires could reflect new directions established by the current CIRE faculty in consort with departments and divisions.

- *"Reduce Energy Consumption" is one of the grand challenges listed under the "Distributed energy and grid management" area of research. CIRE should consider making energy efficiency a more visible part of its ESE curriculum and research program, drawing on a broader range of UTK capabilities in subjects such as green buildings and industrial systems engineering.* Energy efficiency is part of several of the initial six areas of energy-related research in CIRE, but it could well emerge as a major area of its own. This will be studied in detail by the Strategic Planning committee to be established from the CIRE faculty.

- *UTK may need to develop more new courses than the few already targeted for the core curriculum; based on their titles, few of the existing courses appear to have 'energy' as their principal focus. New courses on topics such as solar photovoltaic systems and combustion science might be valuable.* One of the first activities of the initial CIRE faculty will be to study carefully the list of courses compiled by the UTK/ORNL Task Force, as it worked for eight months in 2010 to design the ESE program. Many courses exist, as listed in this proposal. However, some new courses will need to be created, and these additions will be initiated by the CIRE faculty, working closely with the appropriate department.

- *Think about how to bring a 'distance learning' component to the program, such that specialized energy courses could be shared between UT and other universities that develop similar cooperation with ORNL.* The University of Tennessee has worked closely with the seven Core Universities of UT-Battelle ever since the formation of this organization in 1999 and the award of the contract to manage ORNL, starting in 2000. It is a very good direction to engage in discussions about sharing of courses and capabilities between UT and the core

universities, if these other universities engage with ORNL in their own energy program of some type. ORNL leadership has begun discussions of a partnership with some or all of the core universities, modeled on the UT-ORNL ESE program. Discussions of one of these universities with UTK have already occurred about the nature of the program and ways to share courses and capabilities. Other such discussions will be organized.

- *Energy policy and law courses should be added to the curriculum. For example, the UT College of Law could provide valuable curriculum options to cover energy regulatory issues.* The CIRE faculty will begin to discuss not only the courses needed for each of the six energy specialty areas, but also those required for the Knowledge Breadth Curriculum. Adding existing courses in the College of Law will be strongly considered.

- *Since many grand challenges in energy fields require the capability of high-performance computing, the ESE doctoral program might consider offering the existing computational sciences certificate for appropriate students*. Computational science is a very important part of several (most) of the initial energy-related research areas. Offering the ESE students the option to take the courses needed to earn the computational sciences certificate will be done.

- *Some research areas and grand challenges covered by the ESE doctoral program will have a natural close affinity to entrepreneurial and management sciences. As a result, the program may want to develop the entrepreneurship track more in certain research areas than in others*. Some of the research performed by ESE faculty and students will be more fundamental in nature, while others will have a heavy emphasis on applications. The latter especially will be well suited to entrepreneurial emphases. In fact, one of the initial CIRE faculty from ORNL started his own company based on laboratory intellectual property, left the lab for a few years to develop the product and the company, and then returned to ORNL after selling the company. This type of entrepreneurial expertise will be very important for some of the CIRE areas of research

Q. Financial estimate form

The anticipated expenditures related to the ESE program are shown in the Financial Estimate Form below. Renovation of space and purchase of furniture will be needed for CIRE offices at UTK (in Greve Hall) and at ORNL (in the Joint Institute for Computational Sciences). A small administrative staff will be required. Most of the CIRE faculty will be paid by their home unit at UT or at ORNL. However, it will be necessary to occasionally pay faculty to develop and teach a specialized energy course, which explains the *Faculty* line in the budget form.

The costs of the new ESE program will be covered by three sources of income. ORNL or UTK research groups will pay for the full cost of the graduate student once the student joins that group for dissertation research - stipend, tuition, and insurance. Secondly, UTK will provide a Research Incentive Fund proportional to the volume of grants and contracts that come to the university by virtue of CIRE-related activity, e.g., ORNL support of ESE graduate students (in the interdisciplinary or the conventional PhD program). Thirdly, the Tennessee Legislature has appropriated $6.2M of one-time funds for support of CIRE.

In the table given below, the revenue from ORNL (in support of graduate students working in groups at ORNL) is listed as 'federal grants.' The revenue from 'institutional reallocations' comes from central administration at the university in the form of the Research Incentive Fund (RIF) as a percentage of earned indirect costs on grants or contracts attributed to the center. The tuition and fees are paid to the university by ORNL or a university research grant once a student chooses a research group. The $6.2M allocation from the State of Tennessee is needed especially in the early years of the program, since the first two classes of graduate students will have to be paid a stipend and their tuition covered *before* they choose a research group. However, one can see from the table that after five years the $6.2M State allocation can still be intact, assuming the university uses part of the tuition income for support of this program. The tuition and fees income automatically goes to the university and not to CIRE. It is the decision of the Chancellor about whether a portion of the tuition income will be applied to the operation of CIRE. The $6.2M one-time state allocation to CIRE is preserved and maintained only if the full body of earned tuition is forwarded to CIRE.

It is anticipated and assumed that grants and contracts will provide additional support to CIRE in coming years. The purpose of this new center is not only to develop and operate a new PhD program (ESE) but also to bring together researchers and faculty to compete for interdisciplinary grant and center funding opportunities. One such initiative has already begun, in the form of an emerging bioenergy proposal for a National Science Foundation IGERT grant (Integrative Graduate Education and Research Traineeships). This is the BEST program being developed by faculty in various areas of bioenergy - the BioEnergy Science and Technology Graduate Fellowship Program. The existence of an interdisciplinary ESE PhD is perfect for building the BEST program around it. The university now has two active IGERT programs (five-year grants) and BEST should have an excellent opportunity to compete for NSF graduate student resources.

Other opportunities for new funded programs will arise regularly. NSF engineering research centers are very important and very prestigious grants to compete for and capture, and UTK has not yet had success in this arena. The existence of CIRE should facilitate such proposals by teams of CIRE faculty.

THEC Financial Estimate Form
Univerity of Tennessee Knoxville
Energy Science and Engineering PhD

	Year 1	Year 2	Year 3	Year 4	Year 5	
I. Expenditures						
A. One-time Expenditures						
New/Renovated Space	$200,000					
Equipment	$8,000	$4,000	$2,000			
Library						
Consultants	$5,000					
Travel						
Other						
Sub-Total One-time	$213,000	$4,000	$2,000			
B. Recurring Expenditures						
Personnel						
Administration						
Salary	$140,000	$144,200	$148,500	$153,000	$157,600	
Benefits	$40,600	$41,800	$43,100	$44,400	$45,700	
Sub-Total Administration	$180,600	$186,000	$191,600	$197,400	$203,300	
Faculty						
Salary	$10,000	$10,000	$10,000	$10,000	$10,000	
Benefits						
Sub-Total Faculty	$10,000	$10,000	$10,000	$10,000	$10,000	
Support Staff						
Salary	$70,000	$72,100	$100,000	$103,000	$106,100	
Benefits	$20,300	$20,900	$29,000	$29,900	$30,800	
Sub-Total Support Staff	$90,300	$93,000	$129,000	$132,900	$136,900	
Graduate Assistants						
Salary	$560,000	$1,298,000	$2,079,000	$2,907,000	$3,782,000	
Benefits	$23,000	$54,000	$87,000	$122,000	$158,000	
Tuition and Fees	$223,000	$517,000	$829,000	$1,159,000	$1,507,000	
Sub-Total Graduate Assistants	$806,000	$1,869,000	$2,995,000	$4,188,000	$5,447,000	
Operating						
Travel	$50,000	$51,500	$53,000	$54,600	$56,200	
Printing	$5,000	$5,200	$5,400	$5,600	$5,800	
Equipment	$2,000	$2,000	$2,000	$2,000	$2,000	
Other	$12,000	$12,000	$12,000	$12,000	$12,000	
Sub-Total Operating	$69,000	$70,700	$72,400	$74,200	$76,000	
Total Recurring	$1,155,900	$2,228,700	$3,398,000	$4,602,500	$5,873,200	
						5 year sum
TOTAL EXPENDITURES	$1,368,900	$2,232,700	$3,400,000	$4,602,500	$5,873,200	$17,477,300
II. Revenue						
Tuition and Fees	$223,000	$517,000	$829,000	$1,159,000	$1,507,000	
Institutional Reallocations	$67,000	$184,000	$376,000	$595,000	$826,000	
Federal Grants	$355,000	$980,000	$2,000,000	$3,162,000	$4,392,000	
Private Grants or Gifts						
Other	$6,200,000					5 year sum
TOTAL REVENUES	$6,845,000	$1,681,000	$3,205,000	$4,916,000	$6,725,000	$23,372,000