Energy Science and Engineering Graduate Education at Tokyo Tech

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Given the importance of energy and electrical power generation worldwide and its impact on the environment, greater numbers of students are choosing to study energy science and engineering as a major. For example, Tokyo Institute of Technology (Tokyo Tech) established an integrated doctoral degree program, Academy for Co-creative Education of Environment and Energy Science (ACEEES), in 2012 with a 7 year grant awarded by the Japan Society for Promotion of Science (JSPS). ACEEES' mission is to educate next generation doctoral students to become global energy scientist and engineers by developing their leadership qualities as well technical knowledge in energy and environmental science through coursework, interdisciplinary projects, research and other activities. The program supports integrated master's and doctoral students' education with quality assurance measures and also provides students a stipend. Although ACEEES is an excellent program and has received JSPS highest program evaluation during a mid-term review, it is a very expensive educational program to operate and does not issue master degrees. To address these issues and as part of the Tokyo Tech educational reorganization that began in April 2016, a new interdisciplinary Energy Science and Engineering master and doctoral graduate major degree program called the "energy course" was created with approximately 140 faculty from 6 departments and approximately 100 students. To graduate from the master or doctoral energy course, students must complete energy theory, discipline-based and career oriented coursework, and prepare a research-based thesis. In this paper, both energy programs will be introduced, discussed and summarized based upon a best practices point of view.

Energy Education

Energy and in particular renewable energy education and degree programs in higher education have been growing over the last two decades with the green economy[1]. For example, the Univ. California Berkeley's Energy and Resources Group has one of the oldest interdisciplinary energy graduate programs which started in 1973[2]. In 2008, Pisupati and Yeboah wrote there were 21 energy engineering programs world-wide and six in Japan[3]. Presently, in the USA there are over 121 degree programs according to the Department of Energy's website[4] and approximately 100 Master programs offered around the world[5]. Furthermore, micro-credentials are also being offered online[6] as well as degree programs at community colleges, baccalaureate and graduate level as the relationship between energy generation, sustainability and global warming awareness has grown in society.

In Japan, interest in studying its energy generation portfolio and energy policy has grown particularly after the Fukushima Nuclear accident in 2011. However, public perception about electrical power generation portfolio or mix and safety are somewhat at odds with statistical evidence regarding potential risk and loss of human life related to producing energy and electrical power[7]. Therefore, there is not only a need for educating energy experts who have a bird's eye view on energy generation and possess fundamental knowledge but also have the ability to communicate that knowledge to the public, a lesson learned from Fukushima[8].

National University Education Reform in Japan

To improve the quality of education in Japan, the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) requested the national universities create a reform action plan in 2012[9] and begin implementation during 2013-2017 under the National University Reform Plan[10]. At Tokyo Tech, the education reform effort took several years and was implemented for the benefit of the students to allow greater freedom in directing their education, opportunities to study-abroad and to promote greater study in the liberal arts. During the 2016 academic year (April – March) the following changes were made

- Academic calendar (April – March) changed from two 15 week semesters to four 8 week quarters
- integrated undergraduate and graduate education programs into new schools
- reduced the number of undergraduate departments by half
- created an institute for liberal arts and require all students to take liberal arts classes
- reorganization of schools and department including integration across 3 campuses
- created interdisciplinary graduate degree programs or majors while maintaining discipline based degree program majors and department structure
- classes were numbered based upon dept. curriculum, major and year in the program (100, 200, 300 1st , 2nd, 3rd year undergraduate courses, 400-500 master courses, 600 doctoral coursework)[11].

This major reorganization allowed an opportunity for launching of new interdisciplinary graduate curriculums in design science and engineering, human centered science and biomedical engineering, artificial intelligence, nuclear engineering, urban design and built environment, and energy science and engineering. For an engineering education program, it is important that the institute graduates meet the needs of industry where they apply and utilize their skills[12]. It should also be noted that engineering education provide various learning experiences for students to construct knowledge and develop skills needed for professional practice[13]. Both of these educational approaches were considered when two different energy engineering programs were created at Tokyo Tech. In this paper, the new Energy Science and Engineering graduate major will be introduced and contrasted to an existing integrated doctoral-master program called Academy for Co-creative Education of Environment and Energy Science (ACESSS) which began about 5 years ago[14]. What has been learned from creating these programs will be presented in order to serve as a guideline for comparison with other institutions.

Academy for Co-creative Education of Environment and Energy Science (ACEEES)

At Tokyo Tech and other peer research institutions, energy science and engineering degree programs are being offered with rising student enrollments due to environmental concerns among the public and growth of the green economy. In addition, growing numbers of students are interested in studying in interdisciplinary degree programs, which give greater exposure and knowledge on topical engineering disciplines and science related fields. For example, Tokyo Tech established a 4-5 year multidisciplinary doctoral degree program, Academy for Co-creative Education of Environment and Energy Science (ACEEES), in 2012 with a 7 year grant awarded by the Japan Society for Promotion of Science (JSPS) Program for Leading Graduate Schools[15].

ACEEES' mission is to educate next generation doctoral students to become global energy scientist and engineers by developing their leadership qualities as well technical expertise in energy and environmental science through coursework, interdisciplinary projects, research and other activities with international industry-government-university oversight (Fig. 1). JSPS created the Leading Graduate Program to support doctoral student education, provide financial support to students, raise doctoral education quality and increase the number of talented doctoral students graduating from Japanese universities. Besides the paper by Okamoto and Matsuzaka[16], there are few publications in the literature in English that explain this type of graduate education program. To date, the leading program grants were awarded to 33 Japanese institutions based upon their proposals and with 40 awarded in the composite type category that focused on broad interdisciplinary topics (Environment, Life Science & Health, Materials…). Three of these programs focus on energy and the environment education at Tokyo Tech, Keio University and Yamanashi University[15]. The ACEEES program supports integrated master's and doctoral students' education with quality assurance measures and also provides students a stipend, which is rare in Japan. (This system is unlike in the USA, where engineering and science graduate students receive stipends for undertaking research as part of their graduate degree education.) Potential ACEEES students are originally admitted into a department and then apply for admission into ACEEES during their first semester enrollment. The ACEEES program requires the students complete coursework, project work, research, participate in workshops, and write a thesis in order to meet graduation requirements as shown in Fig. 1.

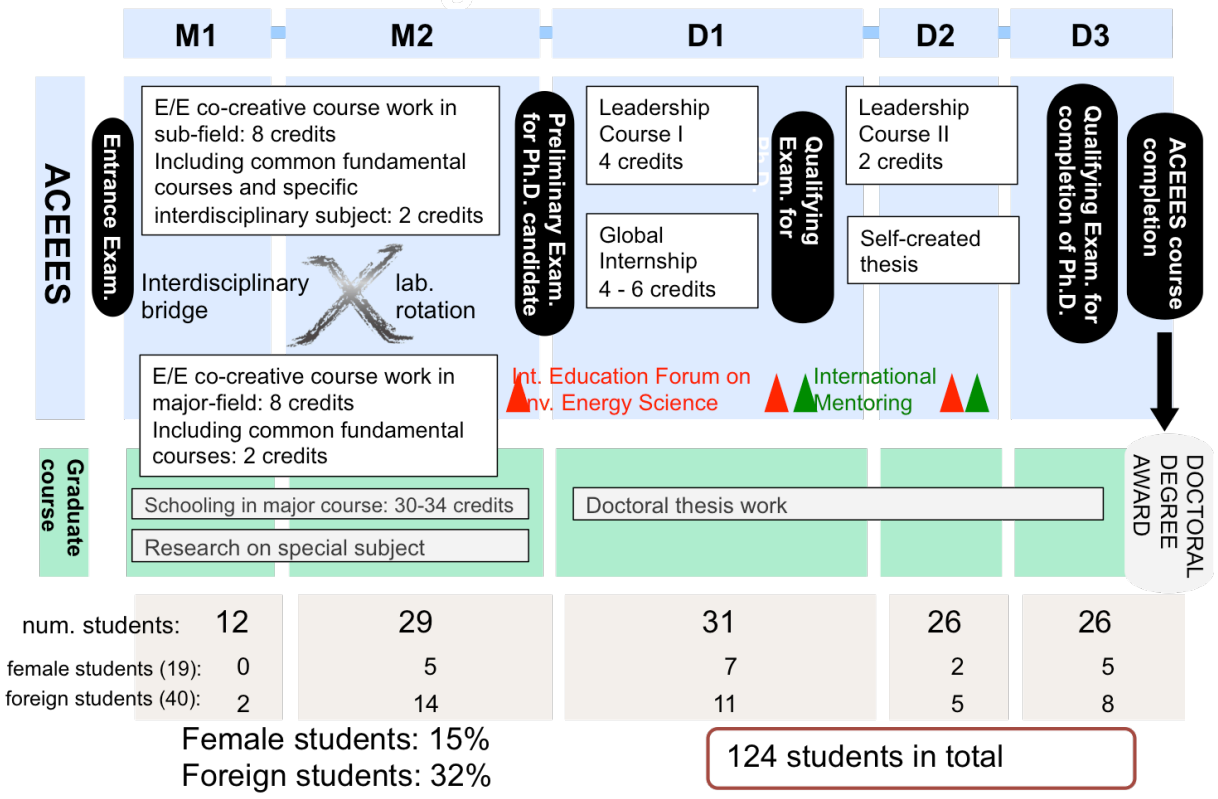

Fig 1. ACEEES integrated master and doctoral degree program.

The light blue regions show the ACEEES specific education and exams required in order to advance thru the program and receive the doctoral degree. ACEEES' students take coursework in their major and also ACEEES coursework as shown in green. They must also complete doctoral thesis research and research on a special project on a topic not related to their major field of research as master students. Approximately 95 % of the students that entered ACEEES have advanced into the doctoral program. The number of doctoral graduates as of April 2017 is 35.

For quality assurance measures, the program has several advisory boards made up of representatives from industry as well as international advisory board members some of whom also teach short intensive courses to the ACEEES students annually. Students periodically meet the advisory board members directly for mentoring. Furthermore, students also participate in business plan competitions and attend lectures from guest speakers. For example, the deputy secretary of the US Department of Energy spoke at a panel discussion in 2016 with a number of students[17].

Furthermore, ACEEES also organizes an annual international five day forum each December, where approximately 200 participants attend to allow students an opportunity to improve their communication and develop leadership skills[18]. As part of the annual student forum, Tokyo Tech students and students from peer institutions make presentations on their energy related research and then undertake group work activity on a general theme related to environment and energy future challenges and orally present their findings to peers and faculty. During the ACEEES forum, the Tokyo Tech students are mentored by overseas faculty advisors to provide research as well career advice. Student presentations are judged and awards are given for best individual and group presentations. Students get to know their peers better and learn about leadership first-hand as well as cross-culture communications by staying in the same hotel room during the workshop.

In addition, ACEEES students must complete a 3-6 month internship as part of the program and presently over 100 students have interned at 99 institutions world-wide. It should be noted the students must pass several exams during the course of the program including a qualifying exam. During the program students access themselves and are also assessed by academic and by corporate staff during an interview on 6 criteria on a 5 point scale (Authenticity, Spirituality, Servitude, Performance, Innovation, and Self-Development). An example of the evaluation results are shown in Fig 2. The students in many cases tend to give themselves higher scores than those of the assessors, which creates an opportunity for assessor to provide feedback related to expectations in the six categories.

Summary of assessment results of doctor 1st year students indicated an average score of 3.8, where as doctoral 3rd years students average score was 4.3 indicating positive development over the course of two years in the doctoral program. Assessments by the overseas mentor show similar trends in communication skills, leadership and assertiveness. Of the 35 doctoral graduates: 66% are working in industry, 10% in government/research institutes, and about 24% are working in academia. Employment after graduation indicates the program has trained them well for the job market and their interdisciplinary degree is accepted by industry.

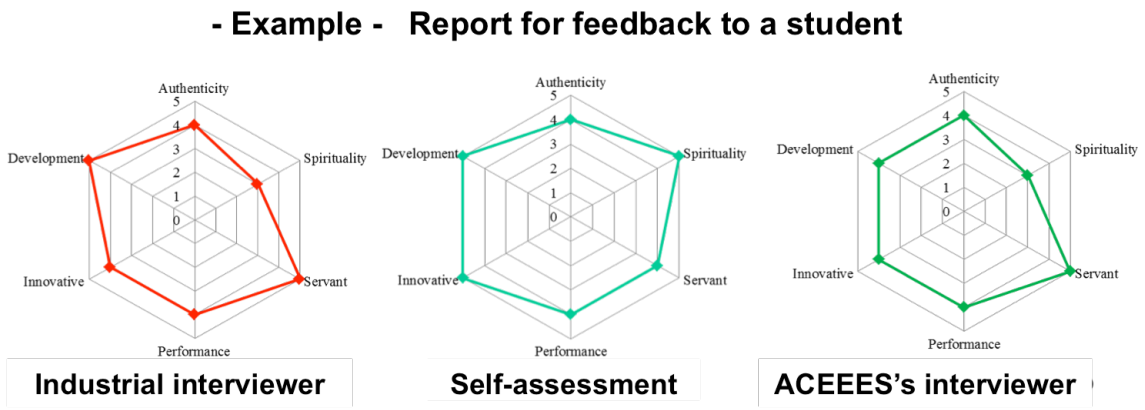

Fig. 2 Doctoral student assessments by self, ACEEES program interviewer and industrial representative

ACEEES has received the highest interim program evaluation by the leading program evaluating committee of JSPS. It is also highly rated by the international advisor board members that participate in the program. It was one of 3 programs out of approximately 40 programs to receive the highest evaluation of S by a JSPS evaluation panel.

It should be noted that approximately 90 % of Tokyo Tech 4 year undergraduate degree students in engineering proceed to completing a 2 year master of engineering (ME) degree at Tokyo Tech resulting in three years research experience over six years prior to graduation. Actually, coursework is concentrated in the first 3 years as undergraduate, where the 4th year students undertake research and write a thesis. Tokyo Tech graduates work primarily in Japanese industry, which prefers students to have a ME that better prepares them to do R&D in the corporate environment. Tokyo Tech graduates are highly sought after by industry and ranked within the top 20 universities world-wide for employability[19]. However, it should be noted that less than 20% of the Tokyo Tech undergraduates proceed to get a doctoral degree. Most students graduate with a ME degree and seek jobs in industry. It should also be noted that the job market for doctoral graduates is much smaller than that of ME graduates in Japan and jobs in academic are very competitive. So although ACEEES doctoral graduates have a high skill set, their opportunities for employment are less than that of ME graduates if they want to work in industry.

The success of the ACEEES indicated there was a need for a graduate energy and environmental course degree curriculum for Japanese as well as international students. However, most Japanese engineering students prefer to graduate with a ME degree which cannot be accommodated within ACEEES.

As part of the curriculum educational reform at Tokyo Tech, the Energy Science and Engineering MS and Doctor degree graduate major called "energy course" began in April 2016 with approximately 140 faculty members, 108 master and 26 doctoral students organized in a virtual department with one administrative staff. The faculty remained anchored within their home department but could choose whether they main affiliation was to the energy course graduate major or to their department. Approximately 1/3 of the faculty have their main affiliation with the energy course and minor affiliation is with the departments. The number of faculty in the

department or course determines how many graduate students can be admitted in the graduate program. The departments hold entrance exams for admission into graduate schools. Once the student is admitted into the graduate school department they can choose between majoring in energy course or a traditional discipline of which there are six different departments (chemistry, applied chemical, mechanical engineering, materials science, electrical engineering and transdisciplinary science and engineering). For example, students majoring in the department of applied chemistry choose to major in the energy course at a much higher percentage than do graduate students majoring in mechanical engineering. Actually mechanical engineering is a very popular degree program at Tokyo Tech and graduating with a degree in energy science and engineering is less appealing for mechanical engineering students. The reason for this is that many Tokyo Tech students seek employment in industry following graduation and the graduate degree will impact where the students end up seeking employment. It remains to be seem if this approach is accepted by industry, since the first cohort of master students will graduate in April 2018. Given the success of 66% of ACEEES graduate finding employment in industry, majoring in engineering science and engineering in a graduate degree program appears to be welcome by Japanese industry.

It should be noted the energy course curriculum for MS/ME and doctoral students is more flexible than that for ACEEES (Table 1). Students can enter as either master or doctor students whereas ACEEES typically admits 1st semester master students. In the Energy Course ME/MS students must complete fundamental courses in energy theory, career development courses, make an interim presentation on their research, undertake thesis research, write a thesis and prepare an oral presentation thesis defense to satisfy graduation requirements. A new class was launched in Jan. 2017, where all the energy course students can enroll in a class for career development and present their research results to faculty and students in a poster session. This allows students and faculty from the 3 campuses in various departments to come together to see the research that is being done outside of their advisor's own research lab. Since the program began in April 2016, and it takes 2 years to complete a MS/ME degree and 3 years to complete a doctor degree, as March 2017, there are currently no graduates. Table 1 summarizes the ACEEES program and energy course graduate major.

The career development courses noted above and in the table are requirements for graduation in order for the students to acquire a series of graduate attributes. The Tokyo Tech innovator and inventor development platform (IIDP) was launched in April 2013 to provide students with transferable skills. It teaches career development courses and coordinates with the departments which of the department courses meet the criteria for the IIDP graduate attributes[20]. The graduate attributes for master students cover career planning, problem solving and communications. Doctoral students graduate attributes go into greater depth. Doctor students choose between two different tracks: academic leader program, which is geared to training students to become future faculty members, and the productive leader program, which is geared to teaching graduates the skills needed to work in industry.

Table 1 Graduate degree program comparison between ACEEES and Energy Science and Engineering course (major)

Program	ACEEES	Energy Course
Year began	2012	2016
Master Degree		
• Entrance exam	required	required
• Coursework (credits)	32-34	30
• Research thesis	required	required
• Program exam	preliminary	thesis research final exam
• Mid-term presentation	none	required
• Sub-course (non-major research report)	required	none
• Financial support	available	none
• Program length	1-1.5 years	2 years
• Degree conferred	none	yes
Doctoral Degree		
• Qualifying/entrance exam	qualifying	entrance
• Coursework (credits)	22	24
• Research thesis	required	required
• Publication required for graduation*	one or more	one or more
• Mid-term presentation	none	require
• Financial support	available	none
• Global Forum workshop participation	recommended	not available
• Overseas mentor	available	none
• Oral thesis defense	required	required
• Internship	required	optional
• Time period	3 years	3 years

Notes. Unique features of ACEEES at the master level is that students need to undertake a research project outside of their major field of research with a different academic advisor.
* the number of peer review published papers required to qualify for graduation depends upon the department.

When the energy course began in 2016, approximately 50 students were expected to join it but in actually over 100 students applied and were admitted. The program popularity was unexpected. It is expected that the number of students will reach 200 in several years depending upon the number of doctoral students and the reception of industry to the master graduates in 2018 and doctoral students in 2019.

Until academic year 2017, both programs run simultaneously. In 2018, the ACEEES program will no longer accept new students but the ACEEES curriculum will continue until the last students admitted graduate in 2022. It appears that for MS/ME graduates the Energy course is the preferred program, whereas for doctoral students, ACEEES appeals to students because of the stipend they receive as well as numerous experience based programs it offers such as internships and annual forum. It remains to be seen if stopping the ACEEES stipend will cause problems for the remaining students with limited financial resources to complete their doctoral degree.

From the faculty point of view creating both graduate programs resulted from faculty with different disciplines and in different departments working together. Based upon the experience of creating ACEEES initially, it allowed the energy course to be setup rather quickly since many of the core faculty members in the energy course are in leadership positions in ACEEES. In addition, it should also be noted that one of the student groupwork activities carried out in the ACEEES annual global forum, where students are asked to address energy challenges and propose a solution, has been used as doctoral student groupwork activity that takes place annually in the UK-Japan Engineering Education League workshop[21]. So the impact of ACEEES has been broader than just educating students, it has also indirectly become a test bed to develop new program activities.

Engineering education which is designed to educate professionals that practice engineering is based upon studying coursework, project based learning, laboratory based education and off-campus experience based learning such as internships or study-abroad. It has been stated by Litzinger et al[13], that *engineering education should encompass a set of learning experiences that allow students to construct deep conceptual knowledge, to develop the ability to apply key technical and professional skills fluently, and to engage in a number of authentic engineering projects*. Furthermore, engineers also need to be able to work in teams and across disciplines[22]. Both of these degree programs presented in this paper follow these best practices in engineering education but ACEEES does it to a greater degree in providing more learning experiences since it employs staff that implement programs and make student placements in internships. It remains to be seen to what extent the knowledge of graduates differ and how industry reacts to and assesses the energy course graduates, which is a topic for future work.

Concluding remarks

The institute reorganization provided an opportunity to create a new interdisciplinary energy science and engineering graduate major for master and doctoral students. The ACEEES program was used as a blue-print for the new energy course program which greatly facilitated its creation and also has served as a test bed for project-based learning. ACEEES provides more learner based experiences which is important to engineering students such as overseas internship and the global forum workshop due its large operating budget and supporting staff members. Of the two programs, energy course appears more sustainable given declining financial support for education in Japan.

In 2019, the Energy course curriculum will increase coursework taught in English so there will be an expected increase in international students applying for admission. As the energy course completes it first year in March 2017, it appears to be well accepted by the students and applications for admission exceed the initial quota. We are looking forward to assessing the graduating master student learning outcomes in 2018 and doctoral students in 2019 to improve the energy course program for future students and compare it to the ACEEES graduates

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