Proceedings of the ASME 2022 Turbo Expo
Turbomachinery Technical Conference and Exposition
GT2022
June 13-17, 2022, Rotterdam, The Netherlands

GT2022-83102

ENERGY AND THE UNIVERSITY: THE ROLE OF GAS TURBINES AT US UNIVERSITIES AND STRATEGIES FOR ENHANCING ENERGY LITERACY

Erica Winegardner, Emma Lemay, Stephen Lynch, Karen A. Thole, Jacqueline O'Connor
Pennsylvania State University, University Park, PA USA

ABSTRACT

Ambitious international decarbonization goals and growing demand for energy are two powerful mandates that set the agenda for the gas turbine industry for the next several decades. To meet these goals and needs, educators must focus on the development of not only technical skills, but also energy literacy. Energy literacy has three components – the cognitive (awareness of energy concepts and technologies), the affective (awareness of the interaction between energy and greater societal issues), and the behavioral (agency to make energy-related decisions) – that can be significantly enhanced by not just curricular interventions, but also non-curricular activities. This paper begins by describing the energy landscape at Tier 1 Research (R1) Universities in the United States. Over 50% of R1 universities in the US use gas turbines to help meet their campus power and heating needs, and almost 60% of these universities have public facing information about campus energy production and usage, indicating an opportunity for enhancing energy literacy amongst the student body through better energy communication. Using these peer institutions as a backdrop, we focus on efforts by the Center for Gas Turbine Research, Education, and Outreach at the Pennsylvania State University as a case study to learn how to enhance energy literacy in engineers through both curricular and non-curricular interventions. The non-curricular intervention includes an energy dashboard, displayed in the student collaboration space for the Department of Mechanical Engineering, that shows real-time statistics on power and steam production, as well as gas turbine engine data from an advanced instrumentation package in one of the power stations on campus. The curricular intervention includes use of data from this dashboard in an introductory thermodynamics course, including the use of engine data in Brayton cycle analysis. In describing these efforts, we highlight the critical role that gas turbine technology and the gas turbine industry can play in enhancing the technical education and energy literacy of the future workforce.

Keywords: energy literacy, gas turbine, combined heat and power

NOMENCLATURE

CHP	Combined heat and power
DoE	Department of Energy
HRSG	Heat recovery steam generator
Kpph	Thousand pounds per hour
ME	Mechanical engineering
MW	Megawatt
OPP	Office of the Physical Plant
R1	Tier 1 Research University
STARS	Sustainability, Tracking, Assessment, and Rating System

INTRODUCTION

Ambitious decarbonization goals around the world have brought energy and the environment to the forefront. The Glasgow Climate Change Conference in November 2021 highlighted the need for rapid decarbonization, setting international goals around methane reduction, coal usage reduction, and a halt to deforestation [1]. Given the need for deep decarbonization not just in energy, but in all sectors of industry [2], issues surrounding energy and climate will touch all engineering disciplines for the next generation of engineers.

As the U.S. National Academy of Sciences has provided in a recent report, "the gas turbine industry will continue to play a critically important role in the generation of electric power, industrial applications, and aircraft propulsion…for decades to come, both domestically and globally" [3]. Likewise, a separate National Academies study on Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions [4] highlighted advances in gas turbine engineering as critical to reducing overall carbon emissions from global transportation and advancing overall goals of decarbonizing the footprint of our current economy and transportation systems. Advancing gas turbine technologies to decarbonize aviation is even more critical now. Improved turbine efficiency requires not only new technology advances but also engineers equipped with new tools such as machine learning, additive manufacturing, high-fidelity computational methods and, of utmost importance, energy literacy, to truly understand the interplay between technologies.

One of the significant challenges in achieving these decarbonization goals is the development of a next-generation, energy-literate workforce. A panel discussion held at Turbo Expo 2020 highlighted several of these needs [5], including the need for system-level thinking; comfort with digital systems and new data methods; appreciation of business, regulatory, and economic drivers; and the interpersonal skills to work on large diverse teams; in addition to a deep understanding of engineering fundamentals. To this end, educators across the world need to consider new and innovative ways to keep pace with this rapidly changing engineering landscape and produce a workforce ready to address future challenges.

The current study focuses on issues of *energy literacy.* The most commonly referenced definition comes from DeWaters and Powers [6], which encompasses three main components: the cognitive, the affective, and the behavioral. The cognitive covers the basic knowledge of energy, how it can be generated and used, and the impacts of energy on the environment and society. The affective covers the attitudes that develop from this knowledge and how sensitive and aware individuals are to current energy issues. Lastly, the behavioral covers how an individual's knowledge and attitudes affect their actions and decisions. The United States Department of Energy (DoE) has created a concept inventory to define energy literacy that encompasses similar elements as DeWaters and Powers, but also includes being able to apply knowledge about energy to solve problems such as the decarbonization of society or development new technology for energy storage [7].

Additionally, the DoE outlines seven "essential principles," each encompassing six to eight "fundamental concepts," to provide guidance on the teaching of energy literacy across a broad spectrum of audiences. The first three principles summarize the natural laws of energy, energy flow, and biological processes dependence on energy. The last four are more complex and are as follows: "various sources of energy can be used to power human activities, and often this energy must be transformed from source to destination"; "energy decisions are influenced by economic, political, environmental, and social factors"; "the amount of energy used by human society depends on many factors"; and "the quality of life of individuals and societies is affected by energy choices." These last four principles focus on human-energy interactions and play a large role in technological and design decision making for engineers and are therefore important considerations when developing an energy literacy curriculum for engineers.

The majority of studies on energy literacy have focused on middle and high school students or the general public, with only a few studies done at the university level [8–13]. Most studies agree: the general population is not energy literate. A study of 1231 junior high students across multiple regions in Taiwan reported students averaged a grade of 53.2% when tested on knowledge of energy concepts, like units and how electricity flows [12]. A household study in Germany found that, in general, individuals lack knowledge about energy usage in the home. However, they were able to expand their knowledge and improve their behaviors through an interactive house monitoring system [11]. A survey at the University of Plymouth found that students had a lack of knowledge on energy literacy that may have affected their behavioral choices [9].

One method to address the lack of energy literacy among students is through energy-specific education. However, education expectations and challenges vary greatly between engineers and non-engineers. Engineers are expected to have more technical knowledge and problem-solving skills. In their careers, these students will be directly using energy-related concepts that they've learned in the classroom. As such, one of the goals of this study is to develop energy literacy educational interventions specifically for engineers, rather than the general university population. One of the challenges in improving energy literacy in engineering students is that an instrument for measuring energy literacy in engineers does not exist. The most commonly used instrument for measuring energy literacy comes from DeWaters and Powers [14], which targets middle and high school students and has not been updated since 2013. This instrument has been successfully used across the world to assess energy literacy in children [10,13,15], but it lacks several features that would be necessary for measuring energy literacy in engineering students who need to use energy knowledge for a career, not just everyday life. Our initial work lays the foundation necessary for eventually developing an instrument targeted at engineers.

To address this need for a more energy literate engineering workforce, a team in the Center for Gas Turbine Research, Education, and Outreach at the Pennsylvania State University have initiated efforts to enhance energy literacy through both curricular and non-curricular methods. This paper introduces these efforts as a case study for how to increase energy literacy in engineers, as well as the unique role that gas turbine technology can play in facilitating energy literacy education for engineering students. To achieve the goal of increasing energy literacy, we use energy data in both curricular and non-curricular interventions for engineering students.

The use of campus energy data in classroom activities is likely happening at many universities, but very little is published on the subject and so best practices are not available in the open literature. For example, an internet search can identify multiple syllabi at different universities that include projects based around campus energy data. However, none of these interventions are being rigorously studied to report how the data was incorporated and the impact of the intervention. For example, Wade et al. [16] described an effort to incorporate information about campus heating and cooling systems into thermodynamics courses, but the outcomes were not rigorously measured. Some progress has been made in measuring curricular interventions in the sustainability literature, particularly by Steinemann [17]. However, the study is based around effectiveness of teaching sustainability issues like sustainable buildings, recycling, composting, and transportation, rather than a focus on energy. Further, the study targeted a general university audience, rather than a technical audience like engineering students.

In this work, we start to rectify the lack of open data and best practice information on the use of campus energy data in engineering programs. This initial paper outlines the plan for the use of campus power and steam generation data in the mechanical engineering curriculum as a case study for how these data may be implemented in other engineering settings. To first provide a background, we review the methods of power generation at the 131 Tier 1 Research Universities in the United States, more than 50% of which have gas turbines providing part of their campus energy and heating needs. We discuss the ways in which these universities are communicating with their students and the public about energy, particularly campus energy production and usage. Next, we focus on the energy production and literacy activities at the Pennsylvania State University, a representative public Tier 1 Research University in University Park, Pennsylvania. We discuss the curricular and non-curricular activities around enhancing energy literacy and outline a pathway by which the gas turbine research and industrial communities can reach the next generation of engineers.

ENERGY LANDSCAPE AT US R1 UNIVERSITIES

Of the almost 4,000 universities and colleges in the United States, 131 of them are designated as "Tier 1 Research Universities," which indicates these schools, in addition to their baccalaureate programs, confer the largest number of doctoral degrees and have the highest levels of research expenditures. These universities represent the most research-active institutions and also educate over 3.8 million students every year. Most of these universities are relatively large, ranging from approximately 12,000 students at the Massachusetts Institute of Technology on the low end of enrollment, to 98,783 students at the Pennsylvania State University across 24 campuses at the high end of enrollment. Given the size of the physical plant required to support a large number of students, many of these universities generate their own electricity and heating on campus.

Universities have a considerable role in producing CO_2 emissions in the United States, accounting for nearly 2% of the national CO_2 emissions [18]. Universities across the country are actively working to reduce their carbon impact. Many universities have changed their source of fuel, improved campus energy infrastructure, and increased efficiency of buildings and operational systems to reduce their campus carbon footprint. To give a sample view of how universities across the US are tackling carbon emissions, we tracked energy information about Tier 1 Research Universities (R1). These universities were chosen because they are typically rather large, requiring dedicated sources of energy for electricity and heating, and have the research and educational influence to drive the decarbonization movement for universities. However, the largest impact these universities can have on decarbonization is not by improving campus technology, but rather by producing informed students with the tools to decrease carbon emissions.

To compare energy usage and energy literacy at R1 universities, we collected information from each university about their electricity generation: whether campus operated a gas turbine for power and/or heating needs, whether campus had an on-site combined heat and power (CHP) system, and whether it used renewable energy to power campus. Additionally, we tracked whether the university had publicly available information on how the campus was using energy, referred to as "energy dashboards." This information was gathered by searching the internet for news articles, open-source websites, and energy reports that answered these questions. Many R1 universities have sustainability websites that promote their decarbonization efforts. These websites highlight renewable energy usage and improvements to campus that reduce carbon dioxide emissions, such as implementing a CHP plant.

Additionally, a number of the universities self-report their energy usage with the Sustainability, Tracking, Assessment, and Rating System (STARS), a program of the Association for the Advancement of Sustainability in Higher Education [19]. This program gives ratings to universities' efforts based on all aspects of sustainability. It contains information on where universities acquire their energy, what renewable energy they invest in, and if they have a CHP plant to provide electricity and steam to campus. Using these reports, and other sources listed above, some trends in both energy usage and energy literacy could be found among R1 universities. It should be noted that this information was gathered based off what was publicly available, mostly reported by the university or journals affiliated with the university. As such, if a university has not made information on its energy usage publicly available, it may have been categorized incorrectly. As seen in Table 1, a little over 50% of universities have a gas turbine installed and roughly the same number have CHP plants. Around 82% of R1 universities produce or purchase electricity generated using renewable sources. Many of these universities use solar arrays and wind turbines to produce renewable energy. Almost 60% of R1 universities have an energy dashboard publicly available.

Table 1. Number and percentage of R1 universities that use gas turbines, CHP plants, renewable energy, and energy dashboards, and the number of students.

	Quantity	Percentage	Students
Gas turbine power plants	69	53.1%	2,244,583
Combined heat and power	71	54.2%	2,215,559
Renewable energy	108	82.3%	3,172,060
Energy dashboard	77	59.4%	2,372,780

Several universities not only monitor their energy usage, but also make public dashboards of this energy information accessible to students. By providing these resources to students already interested in energy, as well as increasing the awareness of students not already involved, universities can increase their impact on student energy literacy. Some universities have already developed public dashboards. However, many of the dashboards are not easy to navigate, are not maintained, or cannot be accessed by the general public due to security concerns. In addition, there is very little literature about how the dashboards are developed or their efficacy.

One superlative example is an energy dashboard at the University of California at Davis, which has optimized their dashboard's impact by making an energy dashboard that is visually appealing while providing useful data [20]. The dashboard opens on an interactive map that shows the buildings on campus as varying sizes of dots based on the energy use intensity of each building. The buildings are categorized as laboratories, offices, housing, classrooms, and community spaces. The map can also display the annual energy use of each building, as well as data for total campus energy, central heating and cooling plant output, energy saving projects, and energy and water challenges. Additionally, they provide a tool to download specific data. This tool allows customization of the data set, including which buildings to capture, the metric being measured, and the timeframe of data collection. This tool is an example of how universities can give their students access to energy data.

This initial survey of just research-intensive universities shows the great interest of students and educators around energy and sustainability. In particular, gas turbines play a significant role in the energy landscape at US universities. At Penn State, we are using our gas turbine combined heat and power system as the basis for the development of an energy dashboard, as well as curricular enhancements for mechanical engineers with the goal of improving energy literacy.

ENERGY CASE STUDY: PENN STATE

The Pennsylvania State University is a Tier 1 Research University in Pennsylvania with 24 campuses located across the state, with over 97,000 students and 33,000 employees. The focus of the current work takes place at its University Park campus in central Pennsylvania, which in Fall 2021 had 40,600 undergraduate and 6,330 graduate students enrolled, as well as 3,223 faculty and 3,169 staff. As a land-grant institution, its mission is not only focused on research and education, but also transfer of research to the population of the Commonwealth of Pennsylvania through educational offerings, outreach programs, and extension services. In this study, we use Penn State's University Park campus and its mechanical engineering program as a case study for how energy data can be incorporated into engineering curricula to enhance engineering student energy literacy.

Power Production and Utilization

Penn State's University Park campus is 13 square miles with 312 buildings, including classrooms, research buildings, dormitories, and agricultural facilities. In 2021, the campus consumed an average of 28 MW of electrical power and produced approximately 8 MW of electrical power on the premises, as shown in Figure 1. In addition, the campus also produced all of the steam needed to heat and cool campus buildings, with a yearly average of 142 kpph of steam.

Penn State's on-site power and steam generation includes two CHP plants and a solar farm. The East Campus Power Plant has a Solar Turbines Taurus 70 combustion turbine with a nameplate capacity of 7 MW. The West Campus Power Plant has three steam turbines with a 6.8 MW capacity and a recently installed Solar Turbines Taurus 60 combustion turbine with a 5.6 MW capacity. The solar farm has 2 MW capacity. The remainder of campus electricity demand is imported from the grid.

University Park's heating needs are met by a system of boilers and a heat recovery steam generator (HRSG) at the East Campus Steam Plant. In the East Campus CHP facility, the exhaust from the gas turbine passes through a duct burner and into the HRSG, which results in a steam capacity of 117 kpph. The total steam production across campus, including the use of boilers, can be seen in Figure 2.

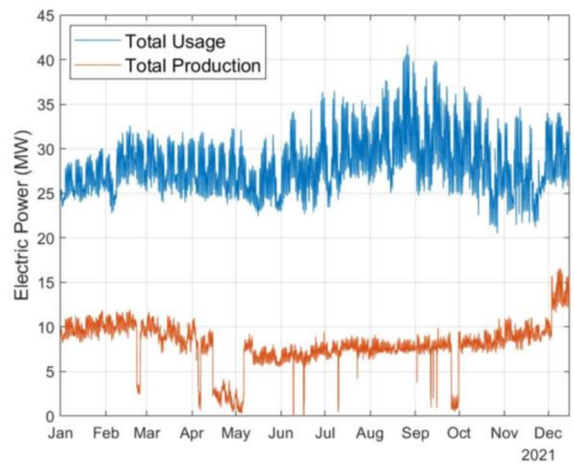

Figure 1. Penn State's University Park campus electricity production and usage in 2021.

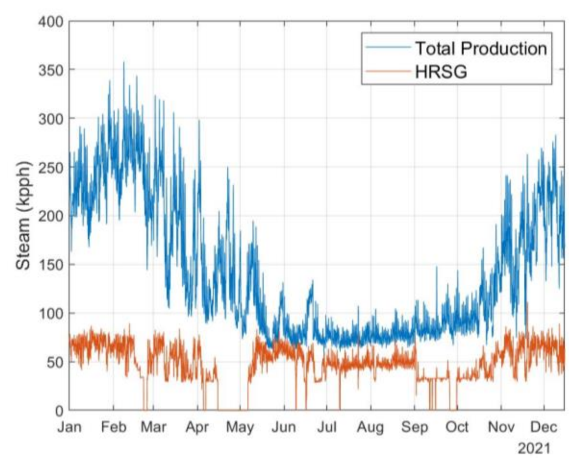

Figure 2. University Park steam production in 2021.

The recently installed Taurus 60 [21] will increase both the electric power and steam generation on campus significantly. Figure 1 depicts a power generation increase in December 2021, which resulted from the Taurus 60 first firing and electricity production. The electricity generation jumps from just under 10 MW up to 15 MW. In addition, the steam production will also increase. The addition of a second HRSG will increase the capacity by 92 kpph, for a total of 209 kpph from both HRSGs. Steam turbines will be employed at the West Campus Steam plant in a combined cycle co-generation configuration to generate additional electricity. Furthermore, an advanced instrumentation package was purchased with the new Taurus 60 turbine, which will provide more data on the state of the machine and will also be used for educational purposes, described next. Students will have access to pressure data from the inlet, combustion system and exhaust; temperature data from the compressor exit, turbine exit, and HRSG entrance; as well as the CHP and electrical efficiencies of the machine.

The Energy University

The Commonwealth of Pennsylvania has a strong focus on energy. Pennsylvania is the second largest producer of natural gas in the United States, second in electricity generation from nuclear power, and third in coal production. Recently, Pennsylvania's governor has set a goal of cutting emissions statewide by 80% by 2050 based on 2005 levels. Penn State has already cut campus greenhouse gas emissions by about a third since 2005. Given the history of the Commonwealth as well as the University's goal to educate a prepared workforce, there is a strong push by Penn State to become an Energy University.

In addition to the push towards being an Energy University, Penn State has already been recognized as a top five university in the nation in scholarly output in five key energy categories as indicated through Penn State publications [22]. These include: energy policy, economics and law; fossil fuels to maximize efficiency including extraction, conversion, combustion, transportation, carbon capture and sequestration; renewable energy including photovoltaics, wind, hydro, biofuels and conversion of waste to energy as well as nuclear energy; systems/technology including grid technology, vehicle and building efficiency, energy storage and management; and environmental impact including the energy-water-food nexus, carbon footprint, climate change and land use. These areas continue to be important Penn State's research and educational programs.

Energy and Gas Turbine Curriculum

Currently, Penn State has a large number of energy-relevant majors and degrees. Focusing on mechanical engineering, where this new energy literacy curriculum is being developed, we offer a range of courses focusing on energy, and several on gas turbine technologies. Table 2 shows a list of these courses and whether they are offered at the undergraduate (UG) or graduate (G) level; this list does not include the list of core required courses, including thermodynamics, heat transfer, computational tools, etc., which are described in Ref. [23]. Many of these courses are offered at other universities, making many of the energy literacy interventions that will be tested on this curriculum transferrable to other institutions.

Table 2. List of example gas turbine relevant courses offered in Mechanical Engineering at Penn State.

Course	UG/G
ME400: Thermodynamics of Propulsion and Power Systems	UG
ME404: Gas Turbines	UG
ME422: Principles of Turbomachinery	UG
ME430: Introduction to Combustion	UG
ME433: Fundamentals of Air Pollution	UG
ME455: Automatic Control Systems	UG
ME461: Finite Elements in Engineering	UG
ME512: Conduction	G
ME513: Convection	G
ME514: Radiation	G
ME521/ME522: Fluid Mechanics I and II	G
ME523: Numerical Solutions Applied to Heat Transfer and Fluid Mechanics Problems	G
ME530: Fundamentals of Combustion	G
ME597: Gas Turbine Design	G

ENHANCING ENERGY LITERACY AT PENN STATE

Given the significant interest in energy and sustainability at Penn State, as well as the breadth of both required and elective courses at the undergraduate and graduate level that have a significant energy focus, researchers at the Penn State Center for Gas Turbine Research, Education, and Outreach are working to incorporate campus energy data into the student experience through both non-curricular and curricular interventions. Previous studies have shown that energy literacy enhancement is particularly effective if students have a personal connection to the energy systems about which they are learning; projects and activities surrounding campus energy and sustainability are a particularly effective way of engaging students with energy topics and enhancing energy literacy [9,24,25]. In this work, we are incorporating campus energy data into student experiences in two ways. First, we have developed an energy dashboard that will be displayed in the ME Knowledge Commons, a laboratory and collaboration space for mechanical engineering students at Penn State; students have a required lab course that meets in this facility and students have access to a tool library and other resources to work on projects in this space. Second, we are incorporating campus energy data into a required core course – ME300: Engineering Thermodynamics – with a pilot offering in Spring 2021.

Energy dashboards

The University Park energy dashboard is displayed in the mechanical engineering building in a space where ME students gather regularly. There are two main parts of the display. The first display is a video that provides students relevant background information about campus power and steam resources, as well as the basics of gas turbine and CHP operation. This video is highly visually appealing, featuring sweeping drone footage of campus and dynamic maps showing students the location of energy and steam resources on campus. This video not only provides an overview of campus energy resources, but also draws in viewers.

The second display is a summary of the live data streams from campus. The data streams are displayed in four parts: power, steam, the Taurus 60 turbine data, and high-level efficiency data. The data is collected by the Penn State Office of the Physical Plant (OPP) for monitoring the campus power, steam, and emissions, and is collected through a software made by Icetec Energy Services [26]. The software offers downloadable hourly data that will be used in student analysis as well as live data streams, some of which will be displayed on our energy dashboard.

The design for the data stream summaries were developed iteratively over the course of the Fall 2021 semester with input from the authors, engineers at Penn State's OPP, and Icetec. The first summary display on electricity generation is shown in Figure 3. It displays live campus electricity production from three sources – the East and West campus CHP plants and the solar farm – as well as electricity imported from the grid. These data are displayed as instantaneous numbers (in units of MW) that update each second, as well as a graph displaying trends from the previous week.

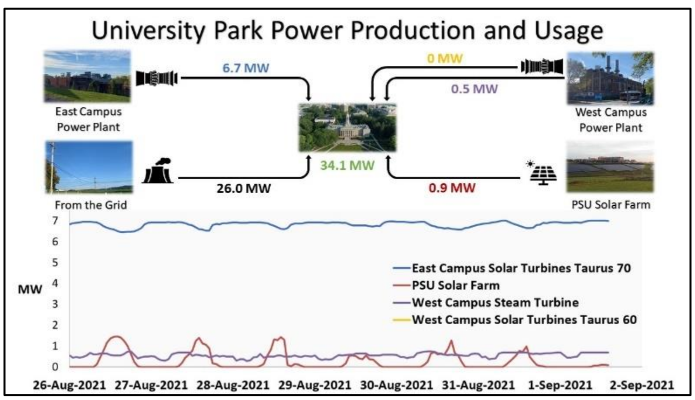

Figure 3. University Park electricity generation display

The second display, in Figure 4, provides the steam generation data from three sources: the campus boiler system and the East and West campus HRSGs. Similar to the power display, this dashboard features steam production values that update on a per-second basis, as well as a moving line chart that shows trends for the past week. The third display in Figure 5 shows instantaneous measurements from the advanced instrumentation package installed in the new Taurus 60 in the West Campus Steam Plant. Inlet pressure, combustor change in pressure, exhaust pressure, barometric pressure, relative humidity, inlet temperature, turbine exist temperature, HRSG entrance temperature, as well as CHP and electric efficiency are all displayed as live data streams.

The last summary screen shows the CHP and electrical efficiencies for both steam plants, as well as the power usage plotted in comparison to CO_2 emission equivalent production display, as shown in Figure 6. These four data screens alternate automatically on the second monitor, displaying each of the data sets for roughly 10 seconds at a time while the informational video loops continuously on the first monitor. The goal of these displays is to make students aware of campus energy production in a dynamic and visually appealing way.

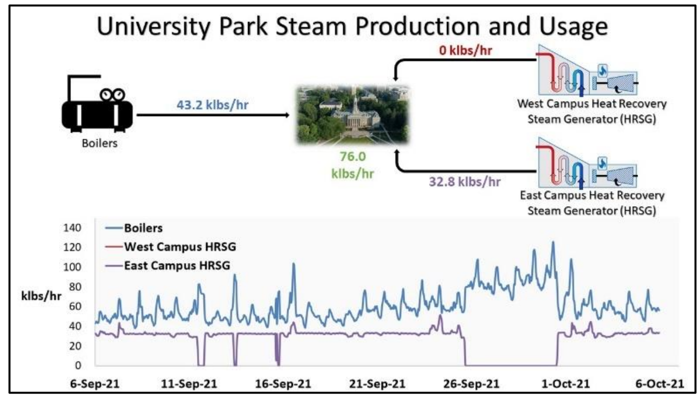

Figure 4. University Park steam production display

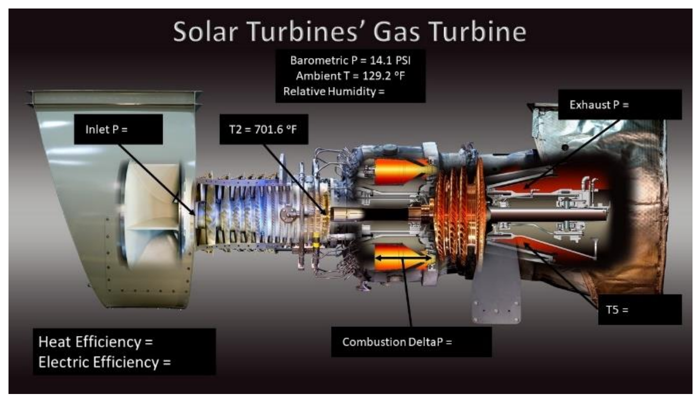

Figure 5. University Park Taurus 60 data display

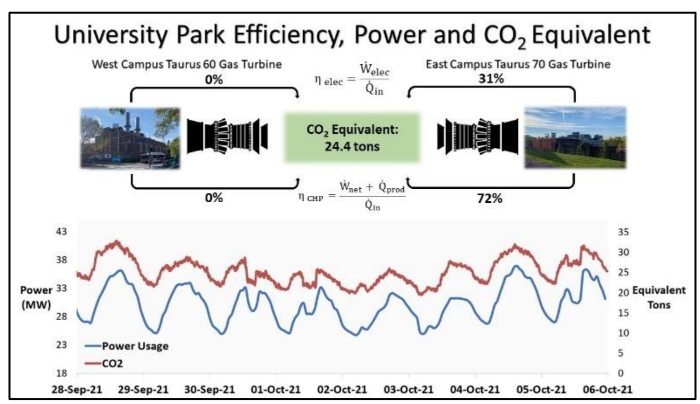

Figure 6. University Park electrical efficiency, CHP efficiency, and CO_2 equivalent generation versus power

Curriculum enhancements

Data collected from the energy dashboard described in the previous section is also available in tabular format for use in courses. A data file with at least 88 different data streams is uploaded each month from the campus monitoring software to a shared folder on a department SharePoint site. The data is available to any faculty member who would like to use it in class.

The initial deployment of this data is in a second-year required course: ME300 – Engineering Thermodynamics. The section of course with the data-based curriculum enhancements is taught by Dr. Jacqueline O'Connor with Erica Winegardner as the graduate teaching assistant. The course has 85 students and is offered in a resident, synchronous format. The course is comprised of eight modules, outlined in Table 3.

Table 3. Course overview for ME300 – Engineering Thermodynamics

Module	# Classes	Topics
1: Introduction to Thermodynamics	2	Definitions; basic conservation principles; control volumes
2: Properties, States, and Processes	7	Definitions of properties, states, processes, cycles; dimensions; equilibrium
3: Properties of Gases	3	Ideal gas equations of state; non-ideal gas equations of state
4: Phase Changes	4	Vapor dome; properties of liquids and solids
5: Energy Conservation and the First Law	4	Heat and work interactions; the First Law for closed systems; basic cycle analysis
6: Steady Flow Energy Equation	6	Conservation of mass; steady flow energy equation; steady flow devices (nozzles, diffusers, compressors, turbines, heat exchanges)
7: The Second Law	8	Statements of the Second Law; efficiency; entropy; reversibility; Gibbs equations of state; isentropic relations; isentropic efficiencies
8: Cycle Analysis	12	Performance metrics; Rankine cycle; vapor compression cycle; Brayton cycle; Otto cycle; Diesel cycle; Stirling cycle

Energy literacy themes are incorporated into the course in three ways: in-class examples, homework problems that use the campus energy data, and a final project using the campus energy data. A pre-knowledge survey is used in the first week of class to determine a baseline level of energy literacy. The survey questions are derived from three sources. First, we use some of the questions from the energy literacy instrument developed by DeWaters and Powers [8], choosing questions that relate to larger themes in energy rather than home electricity use. Second, we construct questions about energy sources, uses, and impacts based on the concept inventory outlined by the US DoE [7]. Finally, we ask questions specific to Penn State University Park campus energy usage, which could be answered if students had seen the energy dashboard described in the previous section. The same survey is assigned at the end of the semester to understand gains in energy literacy throughout the semester. Institutional review board approval has been obtained to run this study and use data from these surveys as well as student assignments for analysis of energy literacy development; students have to consent to participate in the study in order to have their responses to the survey or any of their assignments used for further analysis and publication.

The first way in which energy concepts are presented throughout the semester is through the use of in-class examples. Whenever a new topic is introduced in the course, a motivating example is provided to give students context for the theoretical knowledge they are about to learn. For example, before a discussion on the proper way to draw a control volume, we discuss jet engines and how thrust is produced. We then use the jet engine as a platform by which to show how control volumes are drawn and used for analysis. Another motivating example is a combined-cycle gas turbine power plant when we discuss cycle efficiencies. We can motivate the understanding of efficiency by looking at the efficiency of two thermodynamic cycles separately, then put together in a combined cycle configuration to increase efficiency of a thermal power plant.

These motivating examples provide students with useful context for understanding theoretical concepts. We use more in-depth real-world energy examples in worked problems as well. For example, compressed-air energy storage is used in a worked problem pertaining to the calorific equation of state for ideal gases. In this problem, students see how excess energy from the electrical grid can be used to compress air, increasing its internal energy, and then how that stored internal energy could be used at a later time to produce electricity when required.

The second way energy literacy themes are incorporated into the course is through the use of campus energy data in homework problems. We use campus energy data in four homework assignments throughout the semester to help familiarize students with the data and to allow them a pathway towards understanding energy use on their own campus. For example, the advanced instrumentation package on the Taurus 60 engine at the West Campus Steam Plant provides information about both pressure and temperature at several points throughout the engine and HRSG. In the fourth homework assignment, students use these data to calculate other properties of the air, including density and specific volume, as well as changes in internal energy and enthalpy from one station to the next, using ideal gas equations of state. These types of problems help students build data handling and analytical skills, which they may not have needed in previous courses, as well as a deeper understanding of fundamental principles through their application to real-world situations.

The third way energy literacy themes are incorporated into the course is with a final project, in place of a final exam. The final project centers around a Brayton cycle analysis and the operation of the Taurus 60 in the West Campus Steam Plant. Students research information about the Taurus 60, finding key metrics like compressor pressure ratio, heat rate, net power, and mass flow rate. These values are used as inputs to both ideal and non-ideal cycle analyses. Using data from the engine, students compare their cycle analyses in terms of net power output and thermodynamic properties at several stations with the actual engine data. Students also calculate CO_2 production and talk about the role of these power plants on campus, as well as their impacts on the environment.

After the course is completed, data from students who agreed to participate in the study will be collected. Their responses to the pre- and post-class knowledge surveys will be compared with their performance on homework problems, quiz questions, and exam questions regarding energy. We will use textual analysis of their discussions in the final project to identify evidence of improved energy literacy. These findings will be synthesized into guidance for integrating energy literacy topics and campus energy data into this course and others, including both core courses and electives. Results will be presented to the faculty in Mechanical Engineering and other energy-relevant departments, and access to the energy dashboard and data streams will be made available for use across campus.

In particular, data from campus energy sources, including the advanced instrumentation package on the gas turbine, are already slated for incorporation to several courses after this initial offering in ME300. First, it will be used in both the undergraduate (ME404) and graduate (ME597) gas turbine courses to inform more advanced cycle analysis and component analysis than could be done in ME300. Additionally, the data streams will be incorporated into the new ME laboratory course in a unit on big data analysis to help students build skills with data analytics. As we can obtain several years of data in one file, this data stream would be an interesting case study for understanding patterns in campus operations using data analytics methods.

CONCLUSION

Enhancing energy literacy in tomorrow's engineering workforce is a critical priority. In this work, we are using campus energy data through public energy dashboard displays as well as curricular enhancements to develop energy literacy in mechanical engineering students at Penn State. Using evidence-based techniques for curricular enhancement, we hope to make students more aware of the energy use around them and provide them with skills to translate to their careers, where the energy transition will undoubtedly impact their career trajectories.

The gas turbine community has a particularly vital role to play in the development of energy literacy, given the prevalence of gas turbine facilities on college campuses to meet heat and power needs. *The power generation source closest to over 2.2 million students at just a small segment of university campuses in the United States is a gas turbine.* The presence of gas turbine technologies in educational settings provides exciting opportunities for industry partners to reach a wide variety of students. As described in this work, gas turbine technologies can be used as teaching tools in engineering courses, helping to better prepare a workforce with enhanced knowledge of these technologies and a range of energy issues.

Further, outreach to non-engineering students who play an important role in the energy transition is needed for our society. We expect the case study we present in this paper for mechanical engineering at Penn State to expand into other disciplines across our institutions. We offer this paper as an educational example and a critical call to action for other institutions to collaborate with us to ensure we have a future workforce prepared to meet the decarbonization goals.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support of the Leonhard Center for the Enhancement of Teaching and Learning at the Penn State College of Engineering for development of the energy dashboard and initial curricular interventions. Additional financial support for educational and outreach activities comes from the following Penn State units: the Center for Gas Turbine Research, Education, and Outreach, the Department of Mechanical Engineering, the Office of the Physical Plant, and the Institutes for Energy and the Environment. We very much appreciate the assistance of Michael Prinkey at Penn State's Office of Physical Plant, as well as John Webster, Vanja Bucic, and Craig Stewart at Icetec, for the development of the energy dashboard. Finally, we gratefully acknowledge the support from Solar Turbines and Center of Excellence program monitor Dave Voss.

REFERENCES

[1] COP26, 2021, *The Glasgow Climate Pact*, Glasgow, Scotland.
[2] IEA, 2021, *World Energy Outlook 2021*.
[3] National Academies of Sciences Engineering, and Medicine, 2020, *Advanced Technologies for Gas Turbines*, The National Academies Press, Washington, DC.
[4] National Academies of Sciences Engineering, and Medicine, 2016, *Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions*, The National Academies Press, Washington, DC.
[5] 2021, *Engineering in 2030 – How Must Our Educational Programs Change to Better Equip the Needed Workforce*, ASME Turbo Expo Plenary Panel.
[6] DeWaters, J., and Powers, S., 2008, "Energy Literacy among Middle and High School Youth," *Proceedings - Frontiers in Education Conference, FIE*, IEEE.
[7] 2017, *Energy Literacy - Essential Principles and*

Fundamental Concepts for Energy Education, U.S. Department of Energy.

[8] DeWaters, J. E., and Powers, S. E., 2011, "Energy Literacy of Secondary Students in New York State (USA): A Measure of Knowledge, Affect, and Behavior," Energy Policy, **39**(3), pp. 1699–1710.

[9] Cotton, D. R. E., Miller, W., Winter, J., Bailey, I., and Sterling, S., 2015, "Developing Students' Energy Literacy in Higher Education," Int. J. Sustain. High. Educ., **16**(4), pp. 456–473.

[10] Nelson, M., Hoople, G. D., Mejia, J. A., Chen, D., and Lord, S. M., 2020, "What Is Energy? Examining Engineering Students' Conceptions of Energy," *ASEE Annual Conference and Exposition, Conference Proceedings*.

[11] Schwartz, T., Denef, S., Stevens, G., Ramirez, L., and Wulf, V., 2013, "Cultivating Energy Literacy-Results from a Longitudinal Living Lab Study of a Home Energy Management System," *Conference on Human Factors in Computing Systems - Proceedings*, pp. 1193–1202.

[12] Yeh, S.-C., Huang, J.-Y., and Yu, H.-C., 2017, "Analysis of Energy Literacy and Misconceptions of Junior High Students in Taiwan," Sustainability, **9**(3), p. 423.

[13] Akitsu, Y., Ishihara, K. N., Okumura, H., and Yamasue, E., 2017, "Investigating Energy Literacy and Its Structural Model for Lower Secondary Students in Japan.," Int. J. Environ. Sci. Educ., **12**(5), pp. 1067–1095.

[14] DeWaters, J., Qaqish, B., Graham, M., and Powers, S., 2013, "Designing an Energy Literacy Questionnaire for Middle and High School Youth," J. Environ. Educ., **44**(1), pp. 56–78.

[15] Fah, L. Y., Hoon, C. K., Munting, E. T., and Chong, C. A., 2012, "Secondary School Students' Energy Literacy: Effect of Gender and School Location," OIDA Int. J. Sustain. Dev., **3**(7), pp. 75–86.

[16] Wade, J. L., Wadsack, K. E., Ruddell, B. L., and Nelson, B. A., 2019, "Using Campus Energy System Data to Save Energy and Provide Students with Real-World Learning Experiences," *2019 ASEE Annual Conference & Exposition*.

[17] Steinemann, A., 2003, "Implementing Sustainable Development through Problem-Based Learning: Pedagogy and Practice," J. Prof. Issues Eng. Educ. Pract., **129**(4), pp. 216–224.

[18] Sinha, P., Schew, W. A., Sawant, A., Kolwaite, K. J., and Strode, S. A., 2010, "Greenhouse Gas Emissions from U.S. Institutions of Higher Education," J. Air Waste Manage. Assoc., **60**(5), pp. 568–573.

[19] AASHE, "Sustainable Campus Partners - The Association for the Advancement of Sustainability in Higher Education" [Online]. Available: https://www.aashe.org/scp/.

[20] UC-Davis, "CEED - Campus Energy Education Dashboard" [Online]. Available: https://ceed.ucdavis.edu/.

[21] 2021, "Taurus 60," Sol. Turbines [Online]. Available: https://www.solarturbines.com/en_US/products/power-generation-packages/taurus-60.html.

[22] NSF, 2022, "Higher Education Research and Development Survey" [Online]. Available: https://www.nsf.gov/statistics/srvyherd/.

[23] "Penn State Mechanical Engineering Core Courses" [Online]. Available: https://www.me.psu.edu/students/undergraduate/curriculum-mecore.aspx. [Accessed: 16-Dec-2021].

[24] Demeo, A. E., Feldman, D. P., and Peterson, M. L., 2013, "A Human Ecological Approach to Energy Literacy through Hands-on Projects: An Essential Component of Effectively Addressing Climate Change," J. Sustain. Educ., **4**, pp. 1–16.

[25] Menon, S., and Suresh, M., 2020, "Synergizing Education, Research, Campus Operations, and Community Engagements towards Sustainability in Higher Education: A Literature Review," Int. J. Sustain. High. Educ., **21**(5), pp. 1015–1051.

[26] 2021, "Icetec Energy Services" [Online]. Available: https://icetec.com/.