BITES and TEST Web tools to Enhance Undergraduate Thermodynamics Course

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Abstract

In the Thermodynamics course offered by the author at University of Maryland Eastern Shore for engineering undergraduates, two web-based tools -(i)BITES (Buildings Industry Transportation and Electricity Generation Scenarios) developed at National Renewable Energy Laboratories (NREL) and (ii) TEST (The Expert System for Thermodynamics) developed at San Diego State University are introduced to the students and integrated with the course project and classroom instruction.

The BITES tool provides a framework to discuss thermodynamic cycles related to power, refrigeration, Otto, and Diesel cycles to energy production and utilization in commercial and residential buildings, as well as the transportation and industrial sector at large, and their relevance to carbon emission, ozone depletion, and climate change. The TEST tool is introduced to facilitate student comprehension of thermodynamic analyses of these cycles and the constituent processes. While students continue to struggle with solving problems related to thermodynamic cycles, practicing with the TEST software alleviates some of the difficulty with the progress of the course.

The ABET outcomes related to ethical and professional responsibilities and the impact of engineering solutions in global, economic, environmental, and societal contexts are strongly aligned to the course content. Relevance of Kigali and Paris accords, and the preceding Kyoto and Montreal protocols are also highlighted in the context of the course.

The paper will provide an overview of the course and the project work incorporating the web tools. Relevant student surveys and course assessments for the last two offerings of the course by the author will also be included.

1.0 Introduction

A traditional first course for engineering students in thermodynamics typically covers the material selected from the first 8-10 chapters of popular textbooks in the subject [1-3]. The author of this paper has continued to use the text by Moran et al.[1] over most of the last decade for the thermodynamics course that he offers. Like other textbooks for engineering thermodynamics, it covers the basic thermodynamic analyses related to first and second laws of thermodynamics for selected open and closed systems undergoing thermodynamic cycles and constituent processes relevant to engineering applications. Although this textbook, like other similar textbooks, peripherally incorporates some of the contemporary issues related to energy production and utilization, it falls short with regard to providing a framework to inform students about the present-day challenges, design solutions, and policy considerations that are associated with the field of thermodynamics. In addition, the software tool integrated with the text is not intuitive or user-friendly and does little in terms of improving student comprehension and problem-solving skills. In recent offerings of the course the author has integrated the BITES [4] and TEST [5] web-based tools to address these issues to have a stronger alignment with relevant ABET outcomes and the overall goal of continuous improvement of the engineering curricula. The BITES tool provides a vehicle to improve student awareness related to sustainability issues and addresses a key ABET outcome outlined by engineering accreditation commission (EAC) [6] stated as *"the ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts".* The "TEST" software improves student comprehension and problem-solving skills in thermodynamics in alignment with the ABET outcome stated as "*an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics".* Other educators have also reported challenges with student comprehension and problem-solving skills in the first course in thermodynamics in the engineering curricula and intervention strategies using a variety of web-based software tools [7-9] to improve student performance.

2.0 BITES (Buildings Industry Transportation Electricity Generation Scenarios)

The author first used the BITES web tool to introduce school teachers and college professors during a K-16 outreach effort conducted under the auspices of NBBEP (National Bioenergy and Bio-products Education Program) and BEAT(Bioenergy Academy for Teachers) [10]. The author interfaced with Department of Energy (DOE) personnel involved with the development of the tool and obtained and fine-tuned a hands-on easy to navigate basic tutorial for the outreach effort [11]. The K-12 teachers and college professors alike received the tool and the tutorial positively, and some have successfully integrated BITES with appropriate lessons in their classrooms which in turn has motivated the author to include BITES in the thermodynamics course that he offers to the engineering undergraduates at UMES.

The first course in thermodynamics in the engineering curriculum tends to be difficult for students. Unfortunately, a lot of students are unaware of how generation and utilization of energy in buildings, industry, and transportation sectors that are discussed in the context of the thermodynamics course are intimately related to global warming and ozone depletion issues integral to the overarching sustainability considerations for the future. BITES tool and the tutorial have provided a framework to introduce these issues to the students in the thermodynamics course and paved the way for discussing the Kyoto protocol and Paris agreement intended to reduce global warming; and Montreal protocol and Kigali agreement to address ozone depletion and climate change issues [12]. The BITES tutorial mentioned above was incorporated as a team project assignment in the course [11]. The teams were also required to comment on how efficiency and carbon emission considerations of electricity generation plants and internal combustion engines, as well as improved coefficient of performance (COP) of refrigerators and heat pumps introduced in the BITES tool, were related to power, Otto, and Diesel cycles, as well as refrigeration/heat pump cycles discussed in the course. Furthermore, as part of the project work, the students were also required to remark on considerations addressed in Montreal protocol and Kigali agreement that are driving the use of alternative refrigerants in heating, refrigeration, and air-conditioning systems. Realization of the relevance to contemporary issues of our time and the complexity of policy decisions in the broader framework that takes into account not only the environmental concerns but also the social and economic considerations appeared to generate more interest in the course lectures among some students in the class who could see beyond their grade concerns.

BITES tool allows users to create 'what if' scenarios to explore and compare outcomes related to baseline reference cases of the carbon footprint by adjusting energy inputs to buildings, industry, transportation, and electricity generation sectors in the United States. Although the tutorial walks the user through using the tool in the "Basic" mode, motivated users can easily transition to utilizing the tool in the "Advanced" mode once they get there feet wet with the 'Basic' mode.

Interested readers and educators are encouraged to visit the website (bites.nrel.gov) and use the web tool for a personal experience with the software, nevertheless, a brief example of the tool usage is provided below for ready reference.

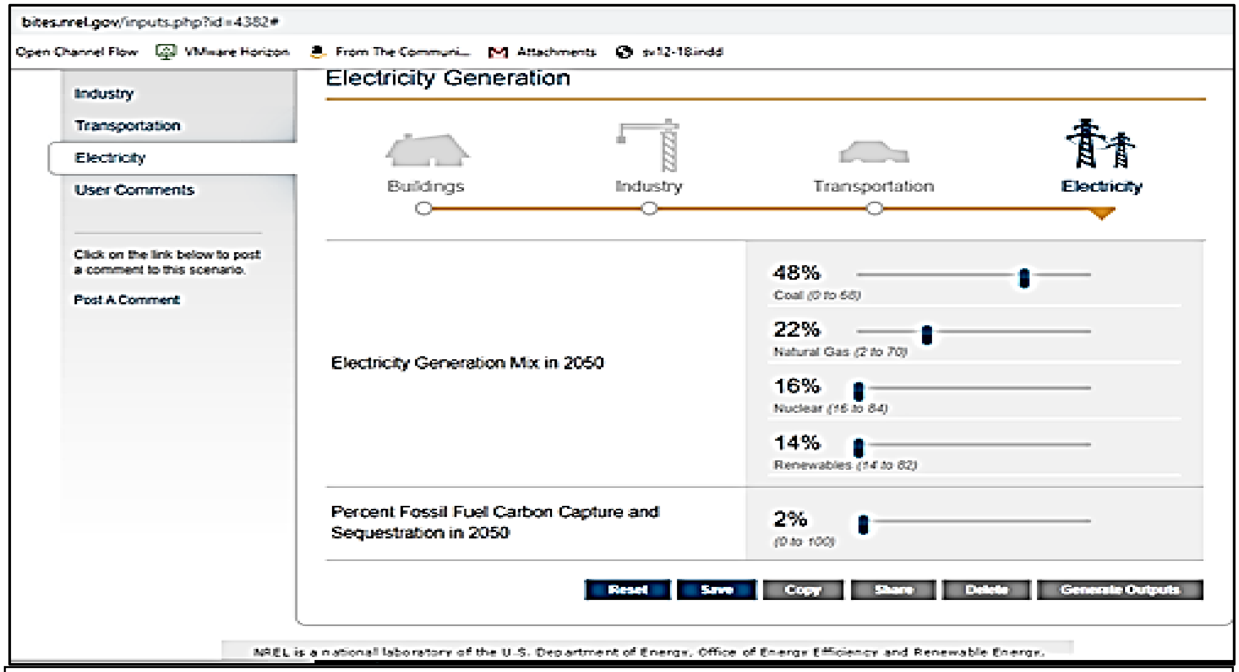

Figure 1a: Base case scenario 2010-11

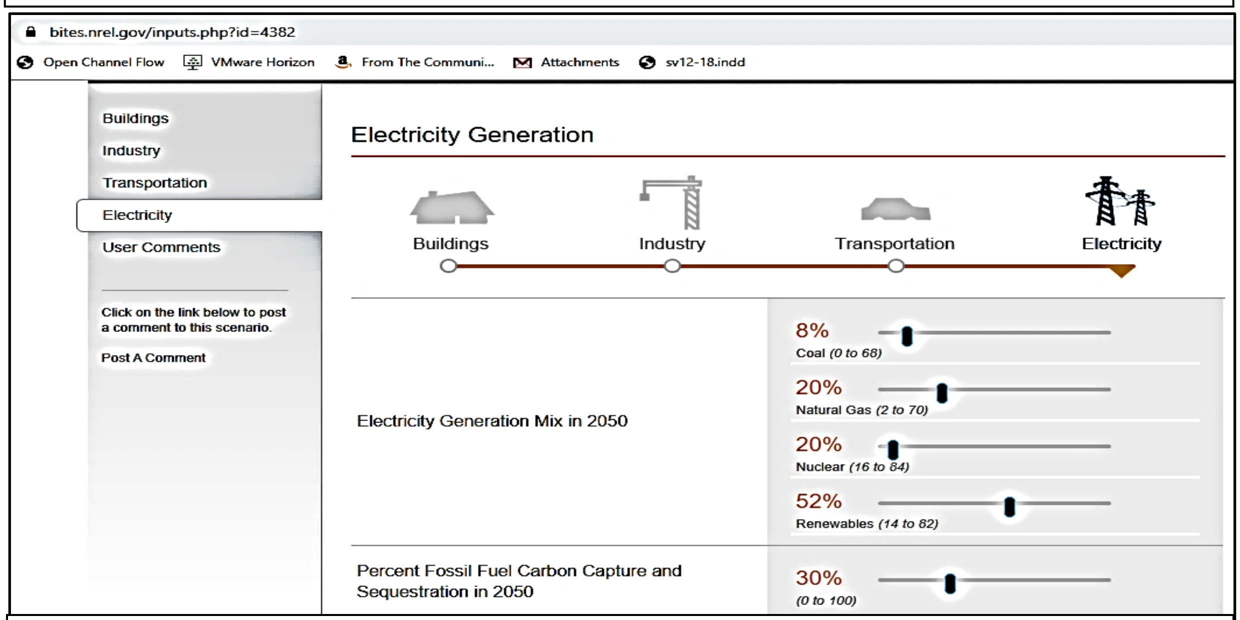

Figure 1b: Slider adjustments for best case

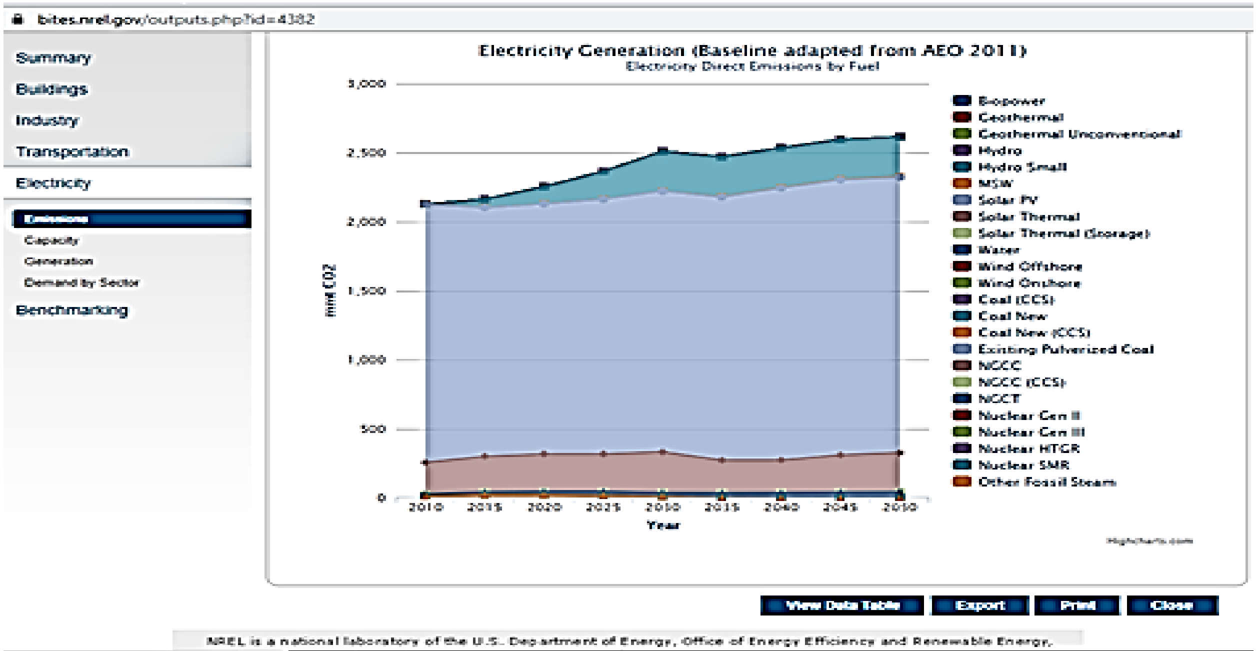

Figure 1c: Carbon emissions for base case (1a)

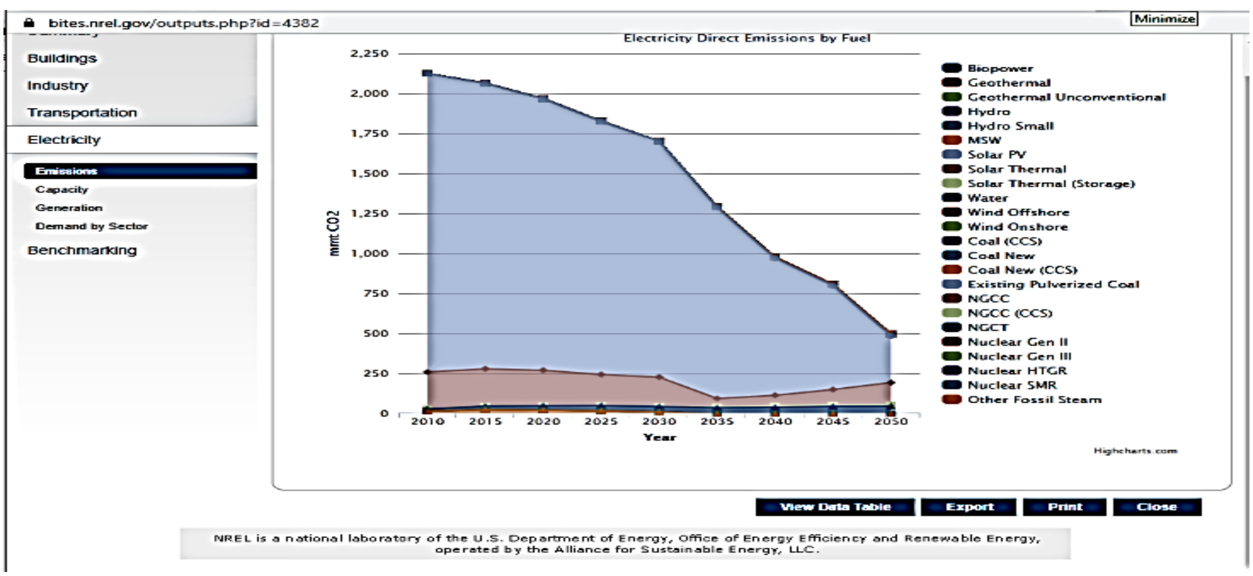

Figure 1d: Carbon emissions for best case (1b)

To use the tool to create new scenarios a user will need to visit the BITES website and register. The home page includes a short video overview of the tool and the basics of how to use it. Figure 1a is a screenshot of the scenario for the base case that closely parallels the electricity generation outlay in the United States in the 2010-11 timeframe that is largely based on fossil fuels. Figure 1b is a user created scenario with sliders moved in the desired directions in “basic mode” of the tool so that fossil fuels have been largely replaced with the renewables. Figures 1c and 1d are the screenshots from the outputs of the web tool that shows the difference in carbon emissions with the two scenarios. It should be noted that carbon emissions keep rising if we continue with the outlay with the base case until 2050 without making any changes. Figure 1e shows the framework for slider adjustments in the advanced mode that provides a knowledgeable user with more avenues (sliders) for adjusting the electricity generation outlay in the United States. In this example, the tool was used only for the electricity generation scenarios. It can be used in a similar fashion for the buildings, industry, and transportation categories individually. Scenarios can also be played out with simultaneous adjustments in all four categories together. It should be noted however, each adjustment of sliders in the real world is driven by social, economic, and environmental considerations that are also significantly influenced by governmental policies. People, planet, profit and policies – popularly unified as the 4P's will drive how the future evolves [13].

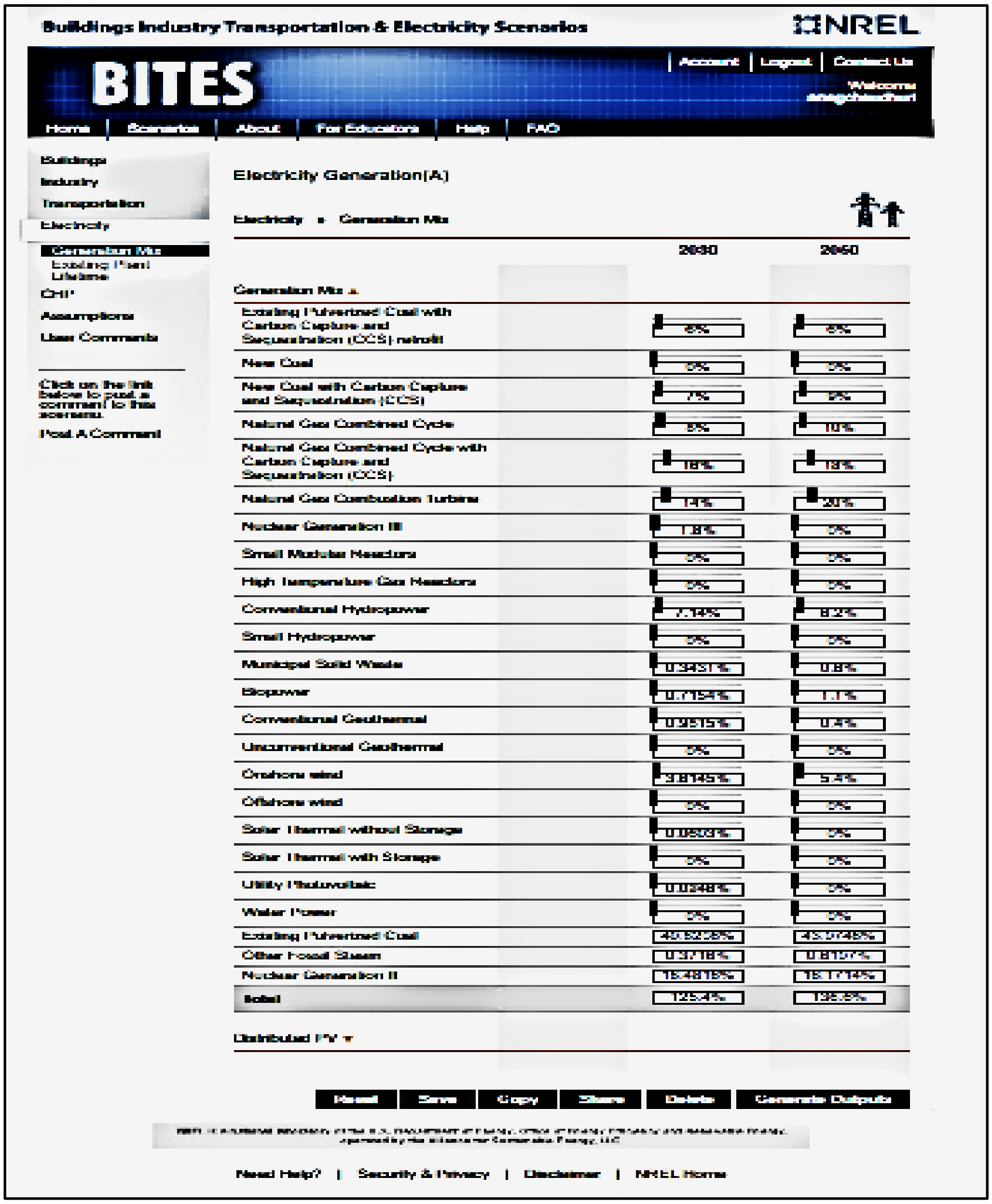

Figure 1e: Slider adjustments for "Advanced" mode

3.0 TEST (The Expert System for Thermodynamics)

The subject of thermodynamics has deep scientific, engineering, and philosophical significance. From an engineering point of view it also provides the foundational knowledge to analyze a variety of designed systems that includes heating and air-conditioning systems for commercial and residential buildings, various internal combustion engines used in transportation systems, as well as, electric power generation systems. Students have to conceptualize laws of thermodynamics, basic ideas related to open and closed systems, become proficient in using thermodynamic tables to determine properties of steam, ideal gases, and common refrigerants as they change states while undergoing processes that are integral to thermodynamic cycles, mass and energy balance equations, and the notion of entropy and its implications on efficiency and coefficient of performance(COP) of ideal and practically realizable power generation, refrigeration, and other engineering systems.

Developing a comprehensive understanding of concepts, along with navigating the property tables for steam, ideal gases, and refrigerants within and outside the vapor dome, and dealing with the different unit systems and conversions presents significant difficulties for the engineering students in the first thermodynamics course in the curriculum. Teaching the subject effectively also has challenges especially related to problem-solving exercises within the limitations of a typical 50-minute lecture session while engaging the students in the process, especially with problems involving analyses of complete thermodynamic cycles. Web tools such as "TEST: The Expert System for Thermodynamics" are excellent platforms to alleviate some of these problems from both learning and teaching point of view. An overview of the web tool and its capabilities are outlined in reference [14]. The intent in this paper is to present how the TEST tool has been used in the thermodynamics course at UMES and its perceived impact from a pedagogical point of view. It is important to point out here, for a first 3 credit course in thermodynamics for engineering undergraduates only some of the expansive content of the tool was utilized.

The TEST web tool was introduced to the students in the 3rd week of the semester after the students were introduced to the evaluation of thermodynamic property tables. Since the convenience of using web tool can get in the way of developing the fundamental cognitive skills associated with manually looking up properties while simultaneously determining the state (compressed, mixture, or superheated) and quality of the thermodynamic fluid, it is advisable to hold back on introducing the tool till such time the students have developed a basic understanding of manually navigating the property tables. A few screenshots from the web tool are shown in Figures 2a, 2b, and 2c for illustration. Figure 2a provides an overview of the webpage to access the property tables for thermodynamic fluids and Figure 2b shows a tabular layout for conveniently accessing the analysis tools for states, systems, processes, and cycles. Once the students became familiar with using the property tables available at the back of their text they found it convenient to use the TESTapps to verify the results. In the System-State Testapps as shown in Figure 2c if any two properties for the chosen thermodynamic fluid are provided, the state is completely determined and the software fills out the other cells consistent with the definition of simple compressible systems.

In the past, time limitations got in the way of solving an entire problem involving a complete thermodynamic cycle such as a Rankine cycle or a Vapor Compression cycle within a 50 minute

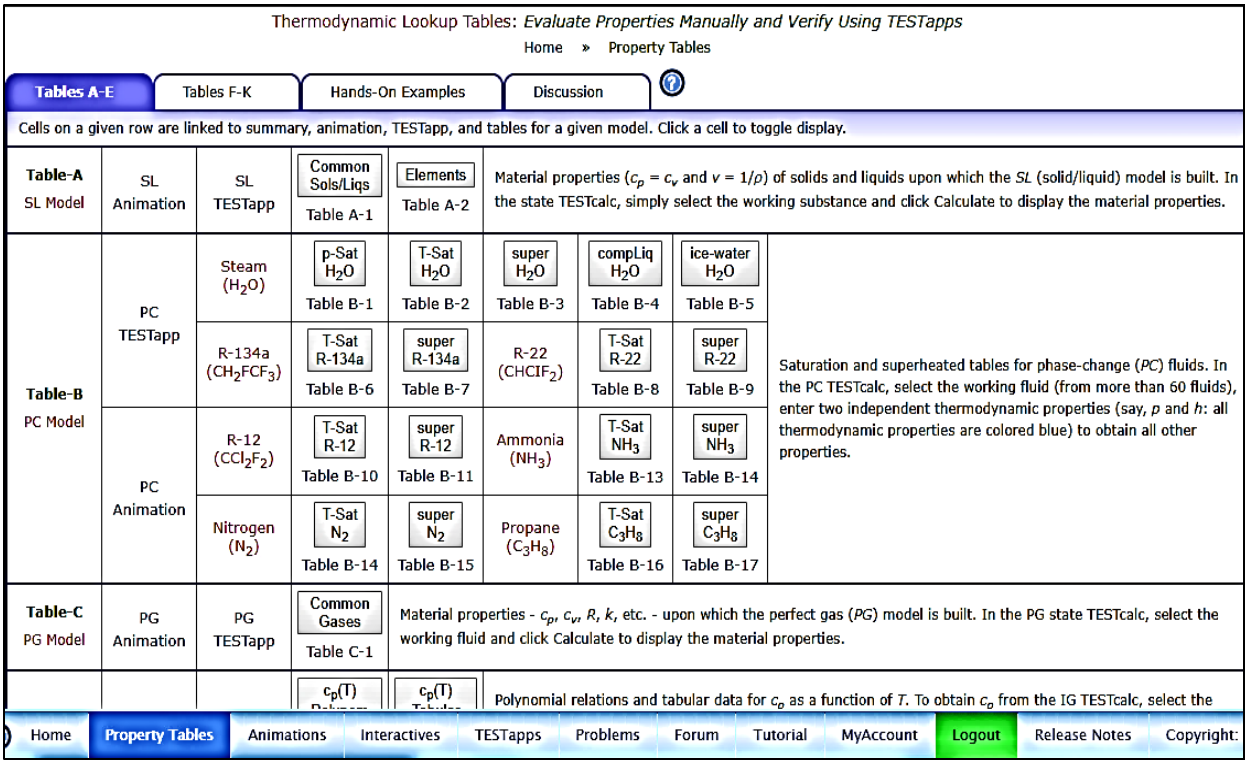

Figure 2a: Property tables in TEST web tool

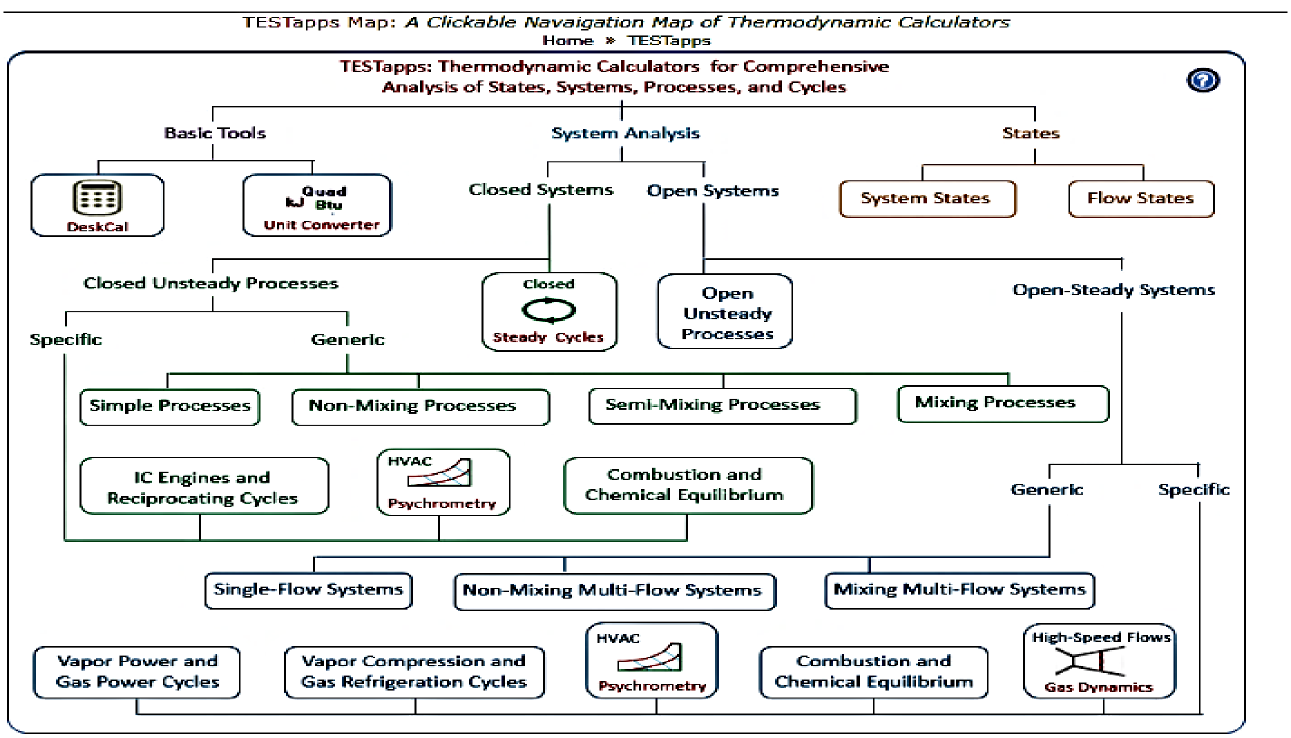

Figure 2b: TESTapps clickable access layout

class period. The rapid processing ability of the web tool was extremely useful in alleviating the time limitation issues and allowed the students to be engaged with the entire process of determining all the states at the input and output of the boiler (evaporator), turbine (expansion valve), condenser, and pump (compressor); work, heat transfers, and entropy generation of processes in each of the devices; and efficiency/ COP (coefficient of performance) calculations within a single class period. The author has learned through discussion with the students that solving entire cycle problems in class helped with their comprehension and allowed them to understand how each of the earlier chapters contributed to the development of the overall concept.

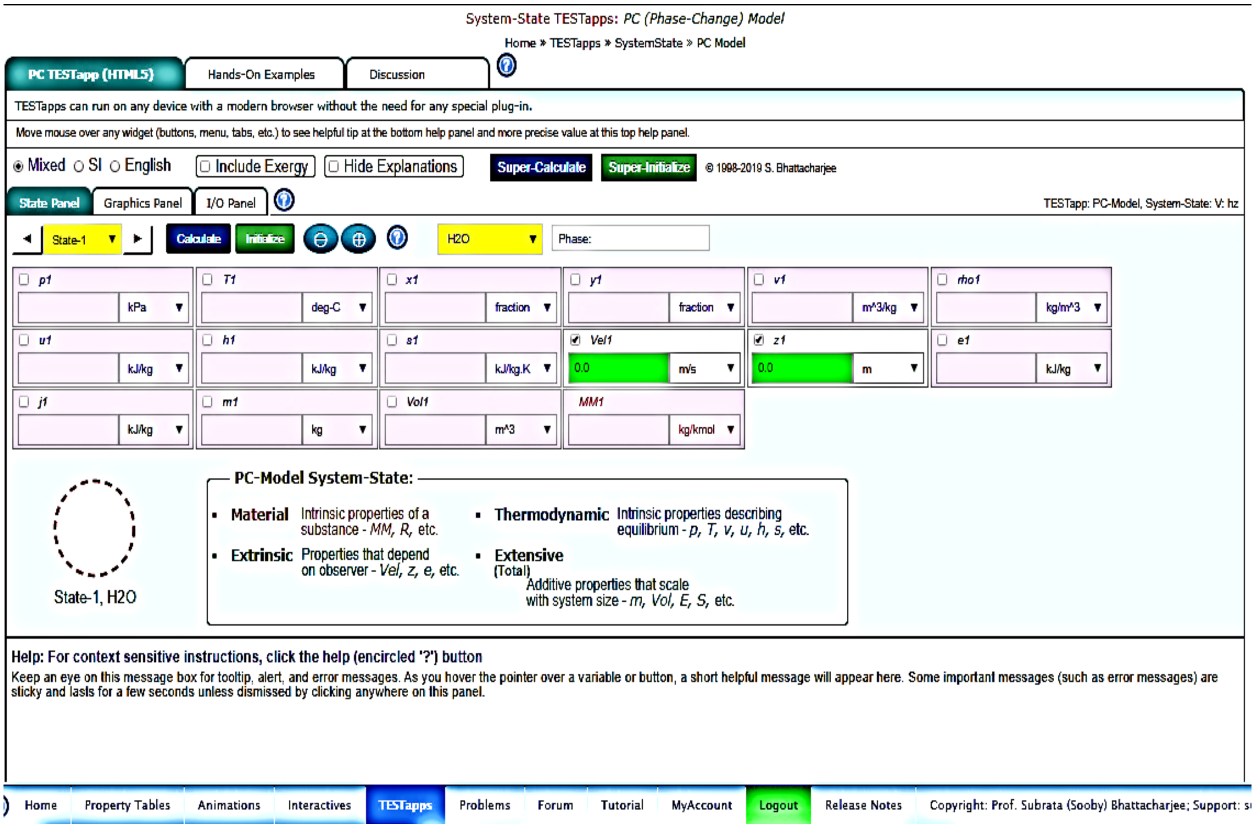

Figure 2c: System State (specifying two properties will completely define state)

For the interested reader an example of the sequence of use of the web tool to solve an entire Rankine Cycle problem that was assigned as part of the class project to the students is provided here for ready reference. The students were provided a demonstration of a Rankine Cycle apparatus available in the UMES Thermal Science and Fluid Mechanics laboratory prior to the assignment. A typical power cycle problem as given below was assigned as a project for the students to solve by hand and verify using the TEST web tool. Time limitations do not allow such problems to be included with regular exams and tests in the classroom.

4.0 Example Problem Solved Using TEST

A steam power plant is to operate between the boiler and condenser pressures of 10 kPa and 2MPa with a maximum temperature of 400° C as shown in the figure below? If saturated water exits the condenser at the condenser pressure, what is the maximum efficiency possible from the power cycle?

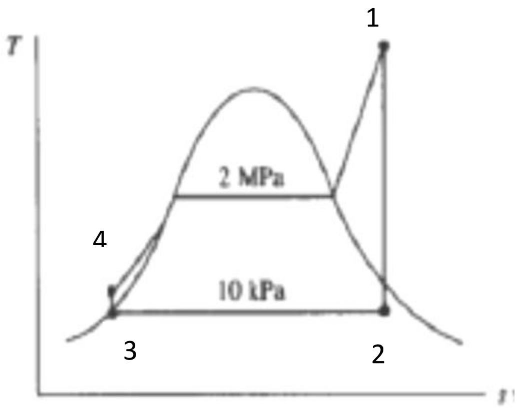

Figure 3a: T-S diagram for Rankine Cycle

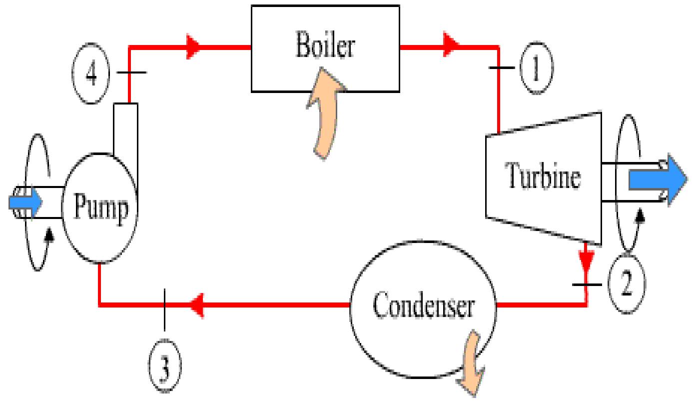

Figure 3b: Devices in Rankine Power Cycle

The temperature entropy (T-S) diagram and the states at the inlet and outlet of the devices are shown in Figures 3a and 3b. For maximum efficiency it can be surmised the power plant will operate under a Rankine cycle with an isentropic turbine and pump. Ignoring the kinetic and

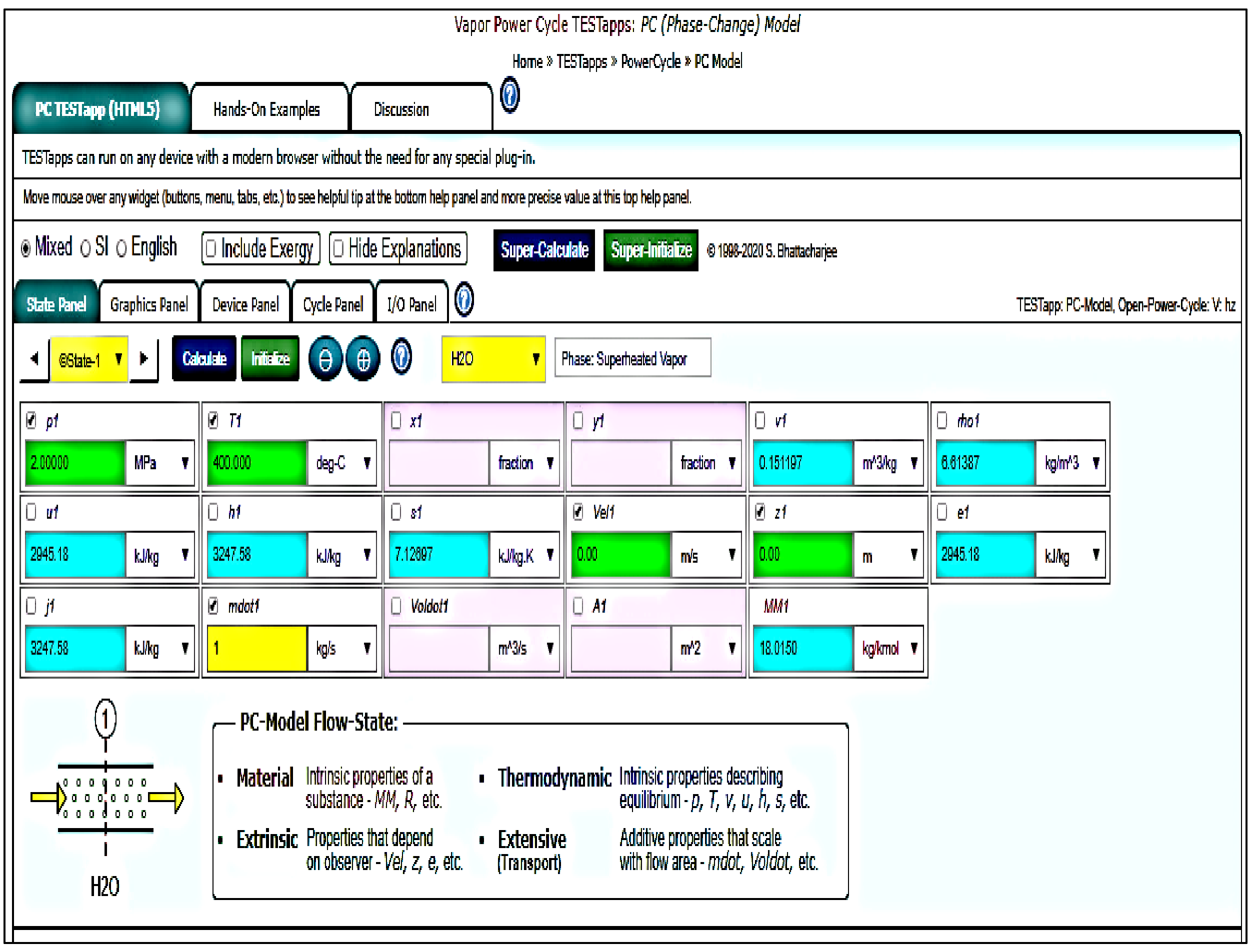

Figure 4a: State Panel (Given P = 2MPa and T=400ºC determines all other properties)

potential energy effects, the efficiency can be determined using Equation (1) with the enthalpies at all the states:

$$n = \frac{(h1 - h2) - (h4 - h3)}{(h1 - h4)} \quad (1)$$

where, the numerator corresponds to the difference of turbine work *(h1-h2*) and pump work *(h4-h3)* and the denominator provides the net heat transfer in the boiler *(h1-h4).*

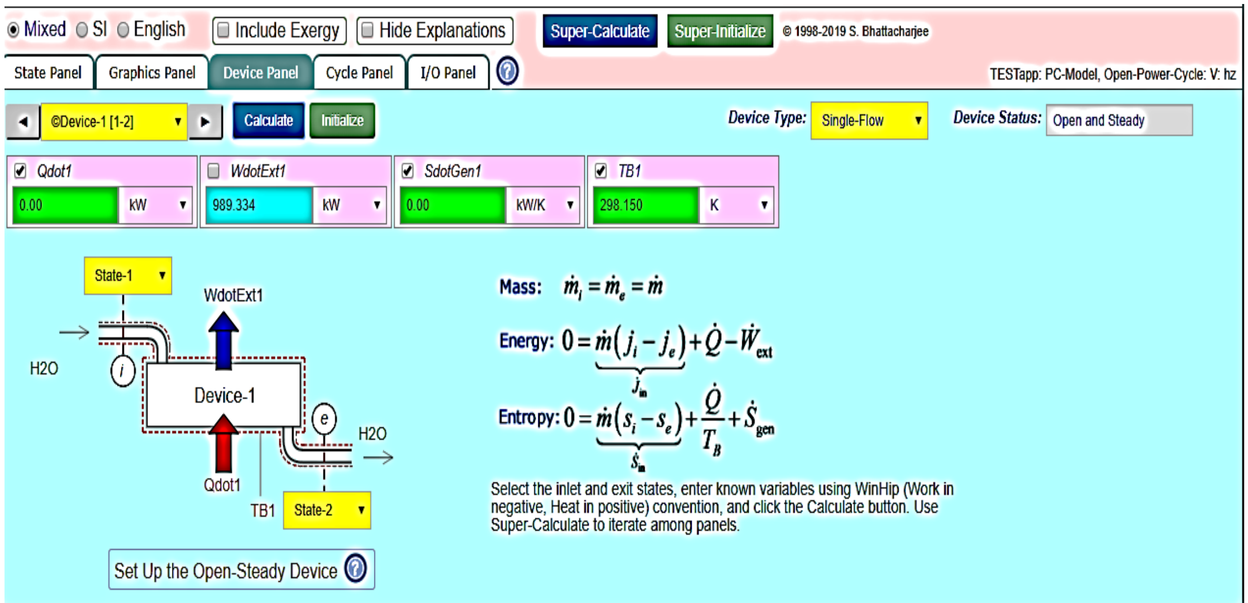

Figure 4b: Device-1[State 1- State2] Turbine

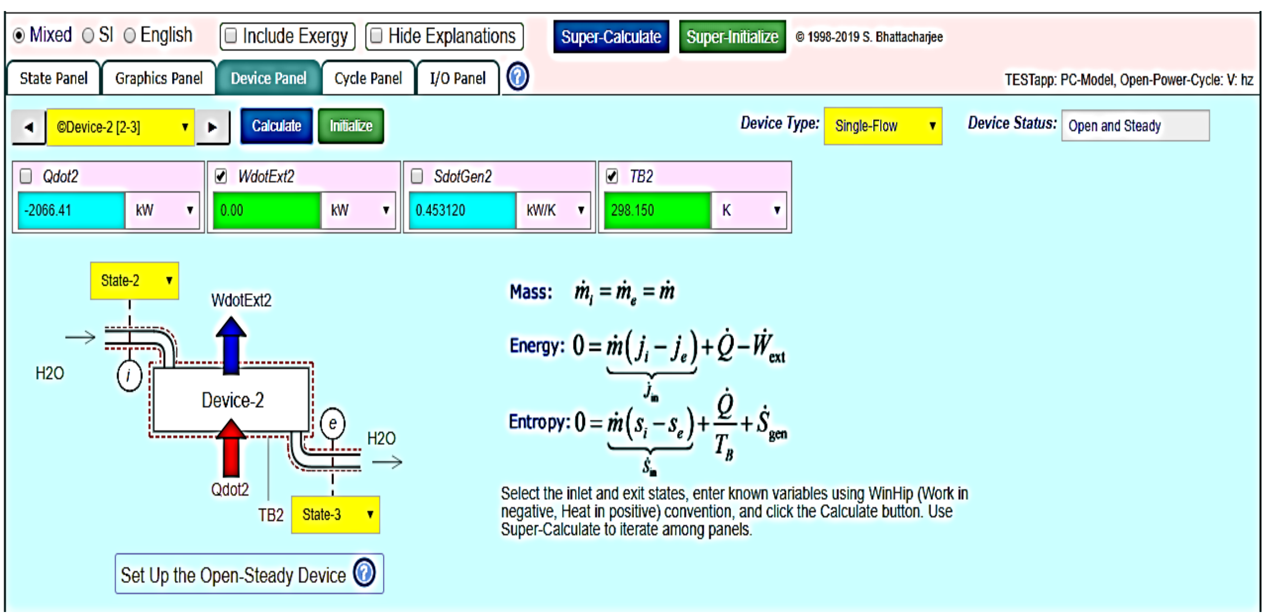

Figure 4c: Device 2[State 2- State 3] Condenser

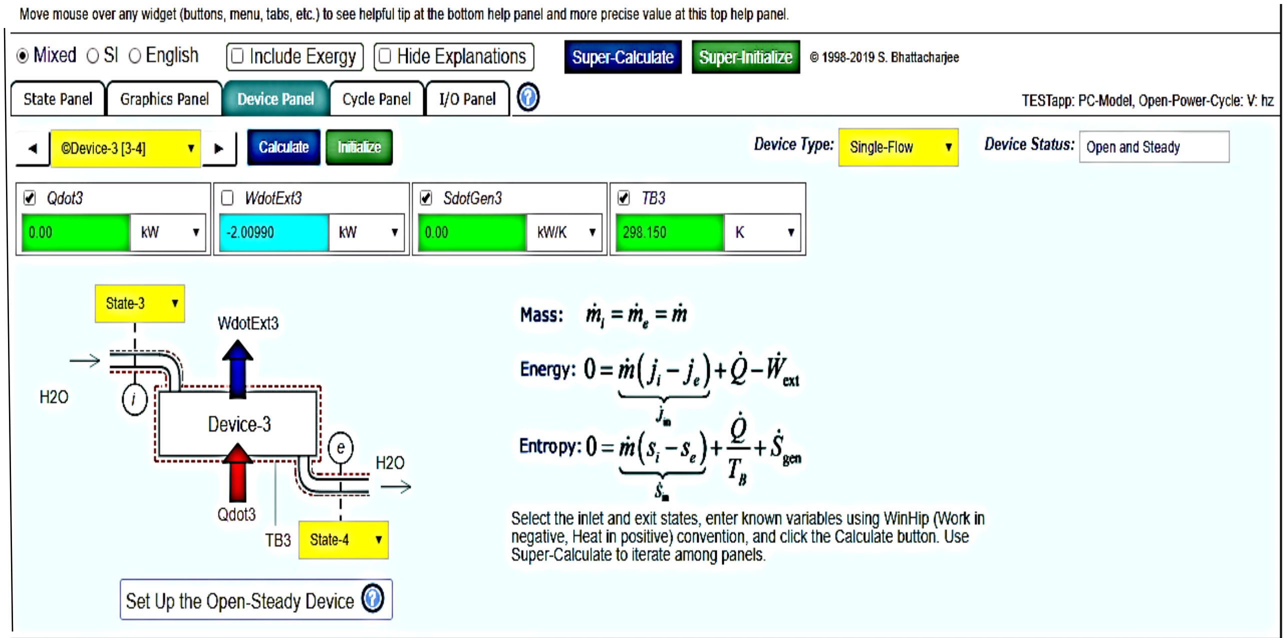

Figure 4d: Device 3[State 3- State 4] Pump

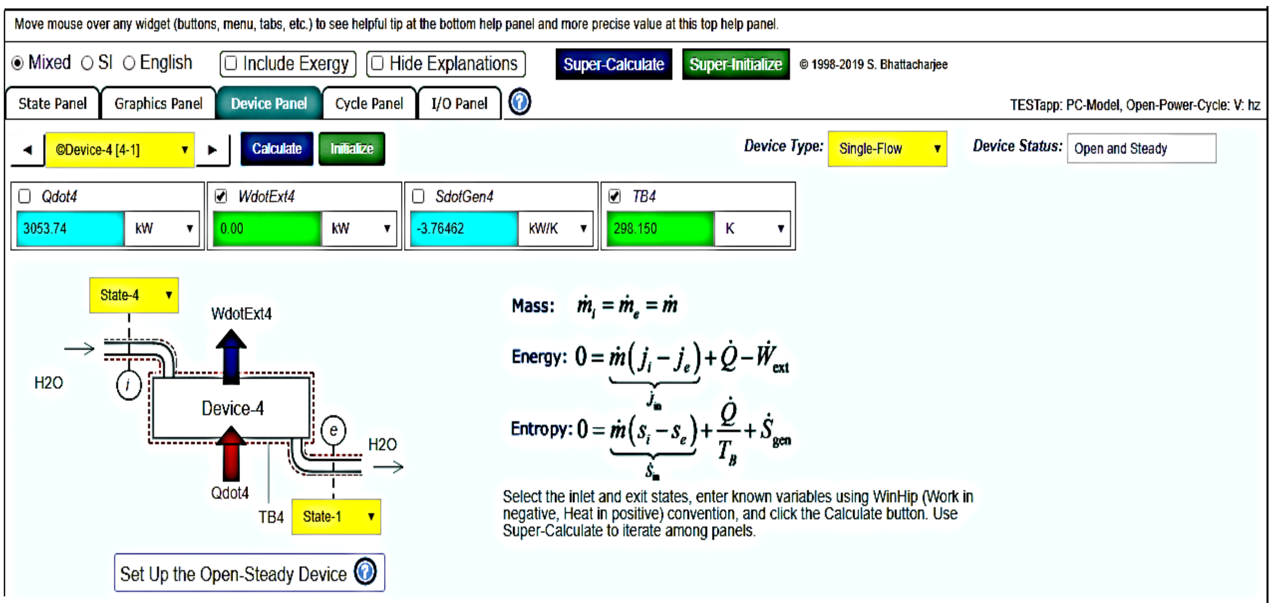

Figure 4e: Device 4 [State 4- State 1] Boiler

A user can navigate to the TESTapp for vapor power cycle using the navigation map shown in Figure 2b, to access the state panel, device panel, and cycle panel in sequence. Given two properties in state 1 (pressure = 2MPa; Temp = 400^{o}C), the state is completely specified and using the state panel in the web tool all other properties including enthalpy and entropy at the state can be determined as shown in Figure 4a. Using the ideal Rankine cycle assumption, since entropy in state 1 and state 2 are equal, the pressure at state 2 (10 kPa) and the entropy at state 2 can be entered in the state panel to obtain all other properties corresponding to state 2 including enthalpy value that is used in the efficiency calculation. It may be noted when using the steam table one has to first solve for quality of the steam at state 2 from the entropy and pressure values and then determine the enthalpy at state 2 using the quality and the enthalpy of saturated liquid and saturated vapor at that pressure. The web tool simplifies the process using the rapid processing ability of the computer. Continuing with the process at state 3 specifying a quality of 0 (saturated liquid) and pressure of 10 kPa completely determines the state, finally, the state 4 can be completely determined using boiler pressure (2MPa) and entropy at state 3 (isentropic pump: implies entropy at state 3 = entropy at state 4). Once all the states are completely determined, the device panel in the web tool can be invoked to determine the work done, heat transfer, and entropy generation for each of the processes taking place in the turbine, condenser, pump, and boiler. For the turbine state 1 is the input and state 2 is the output (Figure 4b); for the condenser state 2 is the input and state 3 is the output (Figure 4c); for the pump state 3 is the input and state 4 is output (Figure 4d) and for the boiler state 4 is the input and state 1 is the output (Figure 4e) completing the cycle. It should

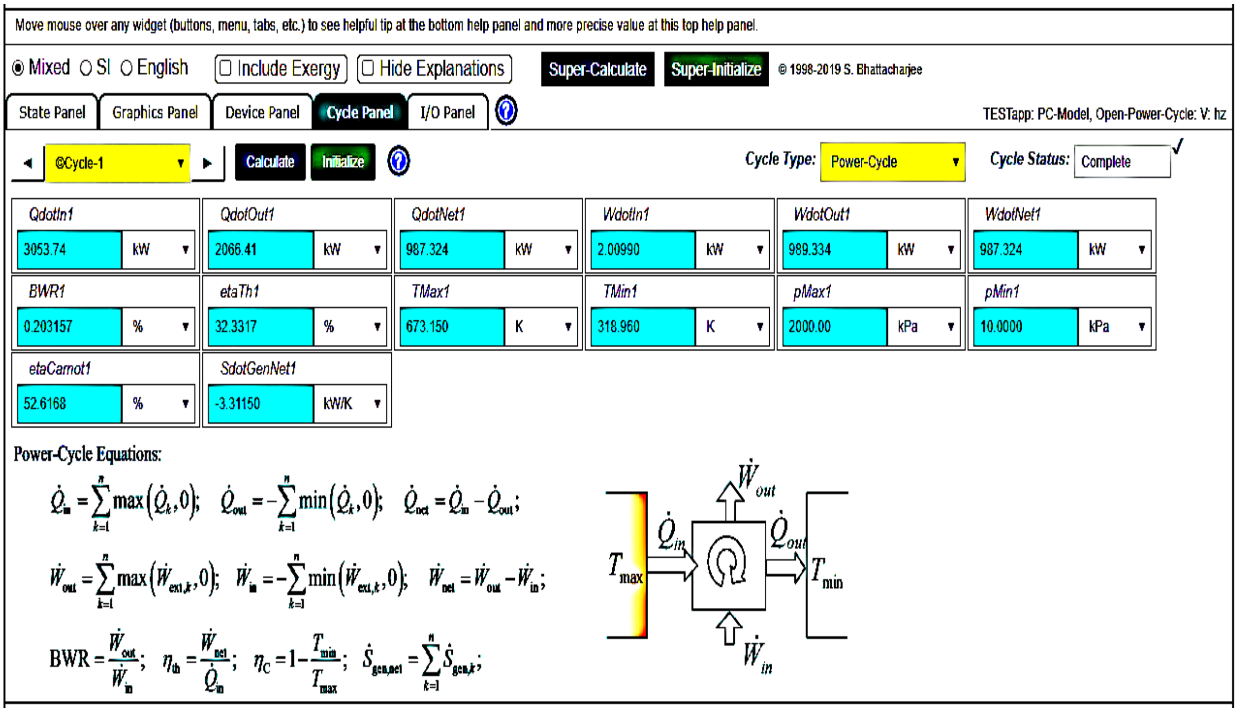

Figure 4f: Cycle Panel (Efficiency, BWR, work, heat transfer and other relevant cycle data)

be noted to process the device outputs appropriately the user has to use right judgment and input work done to be zero for the heat transfer processes in the boiler and condenser, and heat transfer and entropy generation to be zero for the isentropic processes assumed for the turbine and pump to obtain the desired outputs.

Once all the device outputs have been processed, the user can invoke the cycle panel and calculate the efficiency (32.33%), back work ratio, and other work and heat transfer related quantities for the cycle (Figure 4f).

The web tool can be used efficiently for working through more complicated problems that include isentropic efficiencies of devices, reheat, and regeneration, as long as all the relevant states are completely defined. Also, as it may be inferred from the navigation map (Figure 2b), the user can analyze vapor compression (refrigeration and heat pump), gas turbine, and other internal combustion engine related cycles (Otto, Diesel, etc) by selecting proper options in the web tool.

5.0 Assessment

As mentioned earlier, the web tools have been introduced recently to enhance the first course in thermodynamics offered to the engineering undergraduates at UMES. The BITES tool and the written assignment related to Paris, Kyoto, Kigali, and Montreal agreements/protocol were incorporated with the intent of reinforcing the relevance of energy production, energy utilization, sustainability, and environmental issues to the fundamentals of thermodynamics. Besides broadening the student outlook, the intent was to generate interest and insight that will help them to develop clarity and judgment with regard to energy solutions that we engineer and the socio-economic policies we pursue. The TEST web tool was more closely tied with the course material and was included to improve student comprehension and problem-solving skills. In the 2018 and 2019 fall semesters, each student who took the course was requested to fill out a survey to get their feedback. Tables 1a and 1b document the data on student feedback for the BITES and TEST tools respectively. It can be easily gleaned from Table 1a, most students agreed that the BITES web tool was easy to navigate and it improved their understanding of energy and environmental issues. The graded project assignment was on "Basic Mode" intended to whet the appetite and to draw them to explore additional avenues of knowledge. Contrary to expectations, however, not all students were interested in exploring the "Advanced Mode" of the BITES tool as the survey indicates. The survey (Table 1a) confirms that most students felt that the carbon footprint issue was significant and that the energy and environmental issues will play a critical role in their lifetime.

Student feedback (Table 1b) indicates most students felt the TEST web tool helped with their learning and their efforts to comprehend a challenging course. In fact, almost 100% of the students surveyed in both 2018 and 2019 confirmed that the TEST web tool helped them with understanding the fundamentals of thermodynamics related to power systems. As Table 1b indicates that in fall 2018 quite a few of the students found the TEST web tool hard to navigate, however, in 2019 fewer students indicated this difficulty. This is partly because more time was spent in class to solve

Survey of BITES Tool and assigned Exercise

	Strongly agree	Agree	Neutral	Disagree
The class project with BITES improved your understanding of energy and environmental issues.	Fall 18 : 71.4% Fall 19: 28.6%	Fall 18: 28.6% Fall 19: 42.8%	Fall 18: 0% Fall 19: 28.6%	Fall 18: 0% Fall 19: 0%
BITES tool/website was easy to navigate.	Fall 18: 57.2% Fall 19: 57.2%	Fall 18: 42.8% Fall 19: 28.6%	Fall 18 : 0% Fall 19: 7.1%	Fall 18: 0% Fall 19: 7.1%
The carbon footprint issue is overrated.	Fall 18: 28.6% Fall 19: 0%	Fall 18: 0% Fall 19: 0%	Fall 18:28.6% Fall 19:21.4%	Fall 18:42.8% Fall 19:78.6%
You will continue to explore the tool after the course to get a better understanding of "Advanced Level".	Fall 18: 28.6% Fall 19: 21.4%	Fall 18: 42.8% Fall 19: 28.6%	Fall 18: 28.6% Fall 19: 42.8%	Fall 18: 0% Fall 19:7.2%
In your lifetime energy and environmental issues will be very important.	Fall 18 : 100% Fall 19: 57.2%	Fall 18: 0% Fall 19: 21.4%	Fall 18: 0% Fall 19: 21.4%	Fall 18: 0% Fall 19: 0%
Exposure to BITES have increased your interest in renewable energy.	Fall 18: 71.4% Fall 19: 50%	Fall 18: 28.6% Fall 19: 35.7%	Fall 18: 0% Fall 19: 14.3%	Fall 18: 0% Fall 19: 0%

Table 1a: Student survey data for BITES Web Tool

problems using the software in 2019 fall, but more so since a larger percentage of the students indicate they used the web tool to solve 10 or more problems at home in 2019. The survey indicates all the students readily agreed that the TEST tool should continue to be used with the thermodynamics class in the future offerings of the course.

Survey of TEST Tool and assigned Exercise

	Strongly agree	Agree	Neutral	Disagree
The TEST software helped me with learning how to determine properties of thermodynamic fluids and gases	Fall 18:71.4% Fall 19: 54.5%	Fall 18: 28.6% Fall 19 : 27.3%	Fall 18: 0% Fall 19:18.2%	Fall 18: 0% Fall 19: 0%
The TEST software helped me with learning fundamentals of thermodynamic power cycles.	Fall 18:28,6% Fall 19: 27.3%	Fall 18:71.4% Fall 19:63.6%	Fall 18: 0% Fall 19: 9.1%	Fall 18: 0% Fall 19: 0%
The TEST software website is easy to navigate.	Fall 18: 42.8% Fall 19: 45.4%	Fall 18: 0% Fall 19:36.4%	Fall 18:14.4% Fall 19:18.2%	Fall 18: 42.8% Fall 19: 0%
You will continue to explore the tool after the course to get a better understanding	Fall 18:28.6% Fall 19:36.4%	Fall 18: 57.2% Fall 19: 36.4%	Fall 18:14.2% Fall 19:18.2%	Fall 18: 0% Fall 19: 9.0%
You used the software to solve more than 10 problems related to the thermodynamic class	Fall 18: 42.8% Fall 19: 81.8%	Fall 18: 28.6% Fall 19: 9.1%	Fall 18:28.6% Fall 19: 9.1%	Fall 18: 0% Fall 19: 0%
The TEST software should be used for future offerings of the course.	Fall 18:57.2% Fall 19: 45.4%	Fall 18:42.8% Fall 19:36.4%	Fall 18: 0% Fall 19:18.2%	Fall 18: 0% Fall 19: 0%
I found the thermodynamics course to be hard	Fall 18: 14.2% Fall 19:36.4%	Fall 18:28.6% Fall 19: 45.4%	Fall 18:28.6% Fall 19:18.2%	Fall 18:28.6% Fall 19: 0%
Thermodynamics is an important course for engineering students	Fall 18: 57.2% Fall 19: 91%	Fall 18: 42.8% Fall 19: 9%	Fall 18: 0% Fall 19: 0%	Fall 18: 0% Fall 19:0%

Table 1b: Student survey data for TEST Web Tool

6.0 Conclusion

In the opinion of the author, both web tools served their intended purpose. The tools not only helped with student comprehension and problem-solving skills but also served to broaden student perspective and insight. The written assignment in the project with regard to Paris, Kyoto, Kigali and Montreal Protocol/Accord, generated a lot of conversation in the classroom concerning fossil fuels, carbon emissions, renewable energy, ozone depletion, and future refrigerants. Also, it was interesting to read the student write-ups that featured Greta Thunberg, President Trump, US withdrawal from Paris accord, controversies about climate change and solutions, economic considerations, and US energy policy, as well as several other current and relevant topics. Furthermore, several outcomes listed in the ABET engineering accreditation criteria (EAC) were directly impacted by the course and the project requirement, in particular, the first four of the seven outcomes listed in the newly modified ABET EAC outcomes[6]. For ready reference they are reproduced below:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics (TEST)
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors (BITES and TEST)
3. an ability to communicate effectively with a range of audiences (Project and Written Assignment)
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts (BITES)

7.0 Acknowledgment

The author would like to acknowledge the efforts of the students in the 2018 and 2019 fall semester offerings of the Thermodynamics course (ENME/ENAE 345). The author is also grateful for the support of the developers of the BITES tool by the National Renewable Energy Laboratories (NREL) of the Department of Energy (DOE). The author would also like to thank Dr. S. Bhattacharya of San Diego State University for making the TEST web tool easily available for the user community in academia and elsewhere.

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