Green and Alternative Energy Program in Engineering Technology

Dr. Vladimir Gurau P.E., Kent State University, Tuscarawas Campus

Dr. Gurau is an Associate Professor of Engineering Technology at Kent State University. Previously he worked for seven years as a Senior Research Associate in the Chemical Engineering Department at Case Western Reserve University where he served as Principal Investigator on several research programs funded by the State of Ohio's Third Frontier Fuel Cells Program, by the U.S. Department of Energy or in collaboration with General Motors. In this quality he performed research on different fuel cell technologies, including numerical modeling and simulations (Computational Fluid Dynamics and systems optimization), experimental research design, fuel cell component characterization, fuel cell stack design etc. Dr. Gurau has more than two years experience in fuel cell industry with Energy Partners, l.c. (now Teledyne Energy Systems, Inc.) as a research specialist, where he modeled fuel cell phenomena in order to predict and optimize cell performance, including developing of analytical and numerical models (heat and mass transfer in multi-phase, multi-component flows with electro-chemical reactions, flows in porous media, etc). He is the author of several patents related to PEM fuel cells and the author of more than twenty publications in peer review journals or conference presentations in the fuel cells area. Dr. Gurau obtained his Ph.D. degree in 1998 from the Mechanical Engineering Department, University of Miami.

Green and Alternative Energy Program in Engineering Technology

Introduction

A new major in Green and Alternative Energy is offered to students seeking a Bachelor of Science degree in the Engineering Technology Department at Kent State University at Tuscarawas.

The program was conceived to align with the ASME 2030 Vision[1] of enriching students' practice-based experience through design-build-test projects; of exposing students to engineering codes and standards; of providing a more pervasive system perspective; of engaging students in a discovery-based knowledge that promotes greater innovation and creativity; of developing students' professional skills by strengthening teamwork, communication, problem solving, interpersonal and leadership skills and of implementing strategies to attract and retain a more diverse student body.

The program provides students with general and specialized training in renewable energy related fields such as fuel cells, solar and wind energy. New courses in Fuel Cells Technology, Advanced Fuel Cells Technology, Power Technology, and Energy Management Systems have been designed to integrate theory with practical applications. Hands-on experience is emphasized in project and laboratory sessions in which students practice the installation, operation, maintenance and servicing wind and solar systems or learn to operate and characterize fuel cell performance. Along with renewable energy specific courses, students are offered courses in Manufacturing Technology, Automated Manufacturing, Materials and Processes or Engineering Technology Project in which they are exposed among others to manufacturing technologies of fuel cell materials, components, stacks and systems.

Students in this major participate in related research projects such as the design and demonstration of robotic technology for an automated assembly of fuel cell stacks; the design and demonstration of a methanol reformer for production of hydrogen as fuel for fuel cells; fabrication of components for fuel cells using computer numerical control; investigation of manufacturing processes for the production of graphite bipolar plates for fuel cells; or design and fabrication of instrumentation for measuring properties of fuel cell component.

The courses and the research projects that students are involved in enable them to acquire practical skills required in industry and align with the State of Ohio's Third Frontier Fuel Cell Program commitment to accelerate the growth of fuel cell industry in Ohio, to investigate manufacturing processes and technologies, to adapt or modify existing components and systems that can reduce the cost of fuel cell systems, to address technical and commercialization barriers and demonstrate market readiness.

Course description

Fuel Cells Technology

Fuel Cells Technology is a junior level course required for students in the Green and Alternative Energy major and is designed to provide students with a general perspective to fuel cells, with an emphasis in Proton Exchange Membrane Fuel Cells (PEMFCs). Students are introduced to the various types of fuel cells, a historical perspective, terminology, applications, fuel cell operation, basic electrochemical and thermodynamics principles involved in fuel cells, fuel cell components, materials and systems. The course has been designed such that by its completion students:

- learn about the generic fuel cell;
- understand the advantages and disadvantages of fuel cells compared to other energy converters;
- learn the fuels cell components, materials and manufacturing processes;
- learn the various types of fuel cells;
- understand the basic electrochemical and thermodynamics principles involved in fuel cells;
- learn how fuel cells operate and how their performance can be characterized;
- learn basic fuel cell design principles and calculations.

In the fall semester of 2016 the class met two times each week for 1 hour and 15 minutes. The lecture sessions emphasized the principles of fuel cell operation, characterization of fuel cell performance, interpretation of polarization curves and basic electrochemical and thermodynamics principles involved in fuel cells. The class notes, which are supported by PowerPoint slides, were made available to students on Blackboard Learn. There were two laboratory meetings for 1 hour and 15 minutes each, in which students used the Horizon Renewable Energy Educational Kit. In the first meeting students demonstrated the production of hydrogen using an electrolyzer and then used the hydrogen to fuel a PEMFC and demonstrate the conversion of the chemical energy into electricity. In the second laboratory meeting students operated a PEMFC to determine its polarization curve and characterize the fuel cell performance. Students were graded based on three tests, five quizzes, a final comprehensive test, laboratory reports and homework assignments.

Advanced Fuel Cells Technology

Advanced Fuel Cell Technology is an online course with two in class laboratory sessions required for senior students in the Green and Alternative Energy major. The course provides students with a more pervasive fuel cell system perspective and was designed such that by the end of its completion students learn:

- the fuel cell system components;
- to calculate, select, size and integrate fuel cell system components including fuel cell stacks, air compressors, blowers, fans, pumps, electrochemical hydrogen pumps, heat exchangers, components for DC regulation, voltage conversion, inverters, electrical motors and fuel processing systems.
- methods of characterizing and diagnosing fuel cells.

The online lectures, which are supported by PowerPoint slides are video recorded and made available to students using Blackboard Collaborate. As part of their assignments, students are required to create spreadsheets for system components and use them to calculate, size, select and integrate compressors, pumps, electrochemical hydrogen pumps, heat exchangers and reformers into fuel cell systems and determine their net power and overall system efficiency. In the spring semester of 2017, two face-to-face laboratory meetings were added to the coursework for the first time. In the first laboratory meeting students demonstrate the operation of an electrochemical hydrogen pump that can be used to recirculate hydrogen from a fuel cell anode exhaust. In the second laboratory meeting students demonstrate the operation of an electrochemical methanol reformer to produce hydrogen as fuel for a fuel cell. Students are graded based on four tests, a comprehensive final test, laboratory reports and homework assignments.

Power Technology

Power Technology is a junior level course required for students in the Green and Alternative Energy major, designed to provide students with a general perspective of the principles of energy conversion and storage, alternative energy systems and environmental considerations. By the end of its completion students learn about electricity generation technologies including:

- coal-fired power plants
- gas turbines and combined cycle power plants
- combined heat and power
- piston-engine-based power plants
- fuel cells
- hydropower
- tidal and ocean power
- wind and solar power
- biomass power generation
- power from waste
- nuclear power
- environmental considerations and storage technologies

The class meets biweekly for one hour and 15 minutes. In the 2016 fall semester, three laboratory meetings of one hour and 15 minutes were added for the first time. Students used the LabVolt Solar/Wind Energy Training System to get hands-on experience on the installation, operation, maintenance and servicing alternative energy sources. In the first laboratory meeting students become familiar with the solar/wind training systems and components; learn safety practices by performing a lockout/tagout safety procedure; practice proper grounding of critical AC systems and become familiar with and verify the proper operation of circuit protection devices during industrial servicing and maintenance operations. In the second laboratory meeting students become familiar with the planning required to determine an adequate site location for a wind turbine generator; they learn to determine the proper DC wiring to use for a wind-powered system installation; they demonstrate the proper installation and operation of a wind-powered system and develop skills for the proper installation and operation of a stop switch in a wind-powered electrical system. In the third laboratory meeting students learn the proper installation and operation of solar powered systems; they develop skills for the proper installation and operation of a charge controller in a solar-powered electrical system and learn how to check the charge condition of a battery bank. Students are graded based on five tests, a comprehensive final test, laboratory reports and homework assignments.

Energy Management Systems

Energy Management Systems is an online course required for senior students in the Green and Alternative Energy major. The course was designed such that by the end of its completion, students:

- learn the need for energy management and energy accounting;
- learn the functions and components of HVAC systems and learn how to reduce heating, cooling and lighting loads;
- familiarize with control systems for energy management;
- study solar and wind energy sources and learn the benefits from implementing distributed generation and reducing building gas emissions;
- understand how boilers work and learn how to improve boilers load;
- learn building insulation theory;
- understand the steam distribution systems.

Originally, this online course was designed with live online video conference sessions that used Blackboard Collaborate, in which students were recommended to participate. Video recordings of the lectures were made available to the students who were not able to participate to the conference sessions. At students' request, starting with the spring semester of 2017, the lectures supported by PowerPoint slides are video recorded. The original coursework included face-to-face laboratory meetings using the LabVolt Solar/Wind Energy Training System. At students' recommendation, these laboratories are currently being offered instead at the Power Technology course. The laboratory meetings were replaced by new lectures that introduce students to building insulations, boilers and steam distribution systems. Students are graded based on five tests, one comprehensive final test and homework assignments.

Automated Manufacturing

Along with renewable energy specific courses, students are offered courses specific to engineering technology such as Manufacturing Technology, Properties of Materials, Engineering Drawing, CAD Tool Design, Engineering Technology Project, Automated Manufacturing or Materials and Processes 2.

Automated Manufacturing is a junior level course offered to students in Green and Alternative Energy, Mechanical Engineering Technology and Electrical Engineering Technology majors. The course was conceived to enrich students' practice-based experience through hands-on training in programmable automation. By the end of its completion, students learn:

- manufacturing operations, plant layout, manufacturing systems and product definition;
- types of automation in production systems, the reason and the opportunities for automation;
- strategies for automation and process improvement;
- manufacturing models and metrics including production capacity, utilization, availability, manufacturing lead time and work-in-process;
- cost allocation, fixed and variable costs, direct labor, material cost and allocation of overhead costs, cost of equipment usage, machine annual cost and machine hourly rate;
- Computer Numerical Control (CNC) operations and practice to program G-code and operate CNC machines;

- industrial robotics and practice to program and operate industrial robots;
- discrete process control, ladder logic diagrams, programmable logic controllers (PLC) and practice to program PLCs.
- are introduced to microcontrollers and practice to program microcontrollers.

In the fall semester of 2016 the class met biweekly for 1 hour and 15 minutes and consisted of a lecture session and a laboratory session. In the laboratory meetings students practiced hands-on to program and operate computer numerically controlled (CNC) machines, industrial robots and programmable logic controllers (PLCs). At students' request, in the fall semester of 2015 I introduced students for the first time to programming microcontrollers and to using them for discrete and continuous process control. Students thus get to decide for themselves whether programming PLCs through ladder logic diagrams or programming microcontrollers using C++ is more convenient in achieving discrete process control. Students practice engineering communication through a PowerPoint based oral presentation of an automation project. Students are graded based on three tests, homework assignments, laboratory participation and the final project presentation.

Engineering Technology Project

Engineering Technology Project is a course offered to all sophomore engineering technology students and was introduced at the recommendation of the previous ABET accreditation committee. The course was conceived to align with the ASME 2030 Vision of enriching students' practice-based experience through design-build-test projects; of exposing students to engineering codes and standards; of providing a more pervasive system perspective; of engaging students in a discovery-based knowledge that promotes greater innovation and creativity; of developing students' professional skills by strengthening teamwork, communication, problem solving, interpersonal and leadership skills The course includes creative and challenging projects within the engineering discipline such as the green and alternative energy area, robotics and mechatronics. Practical, hands-on experience is emphasized and analytical and design skills acquired in companion courses are integrated. Students work in teams under direct faculty supervision to plan, design, build and test their projects. Engineering communication such as reports, oral and poster presentations are covered. By the end of completing the course students:

- obtain practical, hands-on experience in engineering technology which emphasizes the integration of analytical and design skills acquired in companion courses;
- learn to work in teams;
- learn to plan projects;
- learn to solve design problems and to think creatively;
- get knowledge of engineering communication such as engineering drafting, reports, oral and poster presentations.

Examples of projects that students worked on during the course included the design and fabrication using CNC milling and laser cutting of a nine-cell, 50 cm^2 active area PEMFC stack (Figure 1); a first ever successful demonstration of an automated assembly process of a PEMFC stack using robotic technology; the design, fabrication and testing of instrumentation for measuring physical properties for fuel cell components; the investigation of manufacturing processes for polymer/graphite-based bipolar plates for PEMFCs; the design and build of an unmanned marine remotely operated vehicle, of an unmanned aerial vehicle that will be powered by PEMFC; and the design and build of a universal prototyping machine for CNC milling, 3D printing and laser cutting. Details of some of these projects can be found in Gurau[2-4]. Classwork and homework assignments are graded based on concept, knowledge to use a CAD software such as AutoCad, Inventor, etc. and student's ability to express ideas using ASME Y14.5M-1994 standard rules for engineering drawing. Students take a Student Outcomes Assessment Test (SOAT) as part of the class requirements. Students submit for grading a project plan, written progress reports, an oral presentation supported by PowerPoint slides, a final poster presentation and a project design.

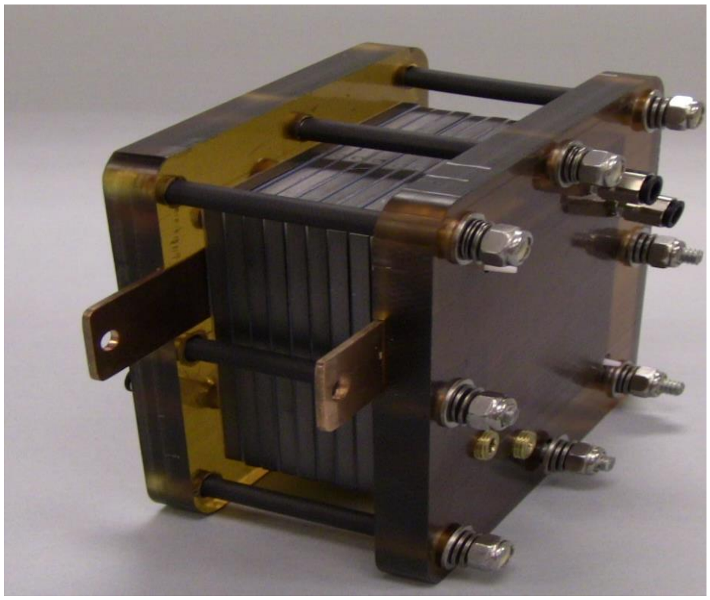

Figure 1
Proton Exchange Membrane Fuel Cell Stack Machined and Built by Students at Kent State University at Tuscarawas

Research

Students in Green and Alternative Energy program are encouraged to participate in related research projects and present their results at Student Research Colloquia and in peer reviewed publications.

An area of research in which students were engaged under the author's supervision was the fabrication of fuel cell components using CNC technology (Figure 2) and the demonstration of a robotic assembly process of fuel cell stacks using an innovative end-effector capable of handling a variety of fuel cell components including bipolar plates, membrane electrode assemblies and gaskets[5,6] (Figure 3). As identified by U.S. Department of Energy, the number one challenge that remains to be resolved on the road to a hydrogen economy is the cost of manufacturing fuel cells. In today's fuel cell industry, fuel cell stacks are assembled manually in a lengthy process involving a repetitive work cycle in which human errors are common. The technology demonstrated successfully at Kent State University at Tuscarawas increases the productivity of the automated assembly of fuel cells and improves the robot's capability to assemble larger stacks. To compare the advantages of the automated assembly process, the fuel cell stack was disassembled and reassembled manually by students (Figure 4).

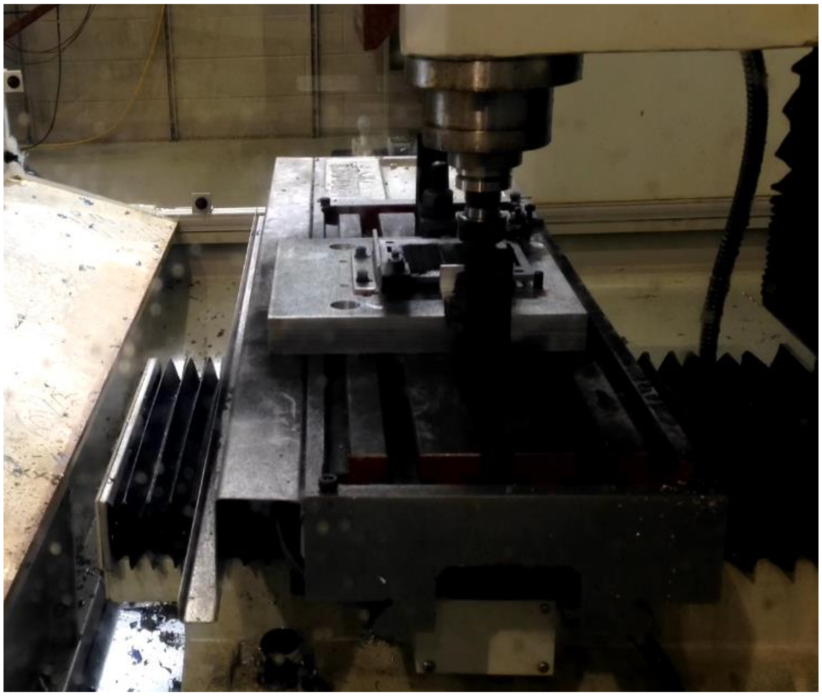

Figure 2
Fabrication of Bipolar Plates for Fuel Cells at Kent State University at Tuscarawas using CNC Milling

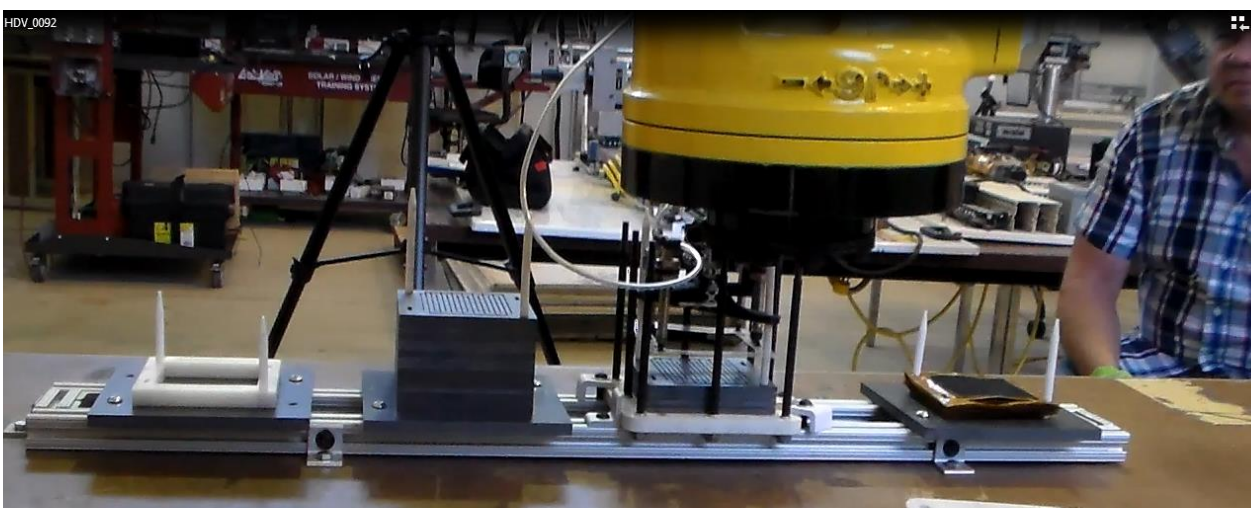

Figure 3
Demonstration of a Robotic Assembly Process of Fuel Cell Stacks Using an Innovative End-Effector

A second area of research in which students participated under the author's supervision was the investigation of a manufacturing process of bipolar plates for fuel cells using compression molding of synthetic graphite used as electrically conductive matrix and phenol formaldehyde thermoset resin used as binder[3]. We have identified the optimum process characteristics including material composition, compression level, curing temperature, the mold design and performed property measurements on the obtained samples. The fabricated samples demonstrated characteristics superior to the requirements of the U.S. Department of Energy. This research resulted in one peer-reviewed paper and a number of conference presentations.

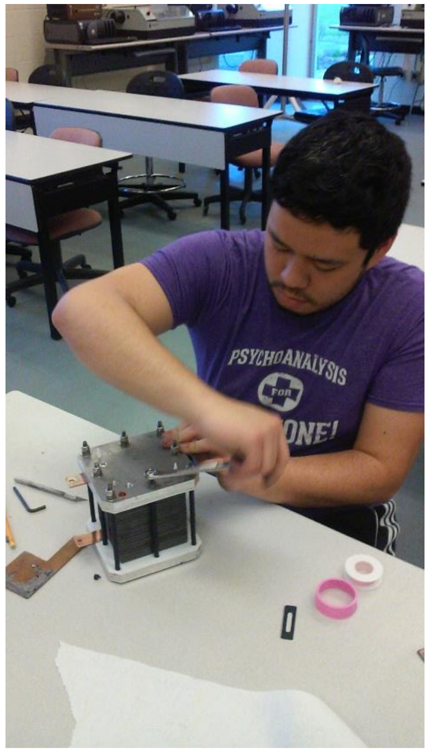

Figure 4

Student Practicing to Assemble Manually a Proton Exchange Membrane Fuel Cell

A third area of research in which students participated under the author's supervision was the design, fabrication and demonstration of a portable methanol reformer for production of hydrogen as fuel for 1 kW Proton Exchange Membrane fuel cell stacks (Figure 5). As identified by the U.S. Department of Energy, one of the most technically challenging barriers to the widespread commercialization of fuel cells is the on-board storage of hydrogen in automotive and portable applications. Although possible to carry it on-board as compressed gas or liquefied, hydrogen has a low storage density and requires high-cost metal hydride canisters. Due to its low energy density, very large volumes of hydrogen canisters would be required. Nevertheless, hydrogen can be carried on-board in the form of a liquid fuel such as methanol, which has a significantly higher energy density and does not require special technology for storage. In the methanol reformer designed and build by us, a solution of methanol in water is fed into the annular space filled with Cu-based catalyst of a tube-in-tube reformer where it reacts at a temperature between 250 and 350^{o}C to produce a mixture of hydrogen and carbon dioxide with small amounts of carbon monoxide. The reactor is heated by the catalytic decomposition of peroxide solution which is fed in the inner tube of the reformer filled with Pt-based catalyst. The methanol and peroxide solutions are kept in flexible reservoirs capable to operate under any gravitational conditions. The solutions are pumped into the reformer through check valves using linear peristaltic pumps driven by stepper motors. The temperature of the reformer is measured by a type J thermocouple. A hydrogen sensor monitors possible hydrogen leaks from the system. The flow rate of the peristaltic pumps and the hydrogen sensor are controlled by an Arduino Mega controller.

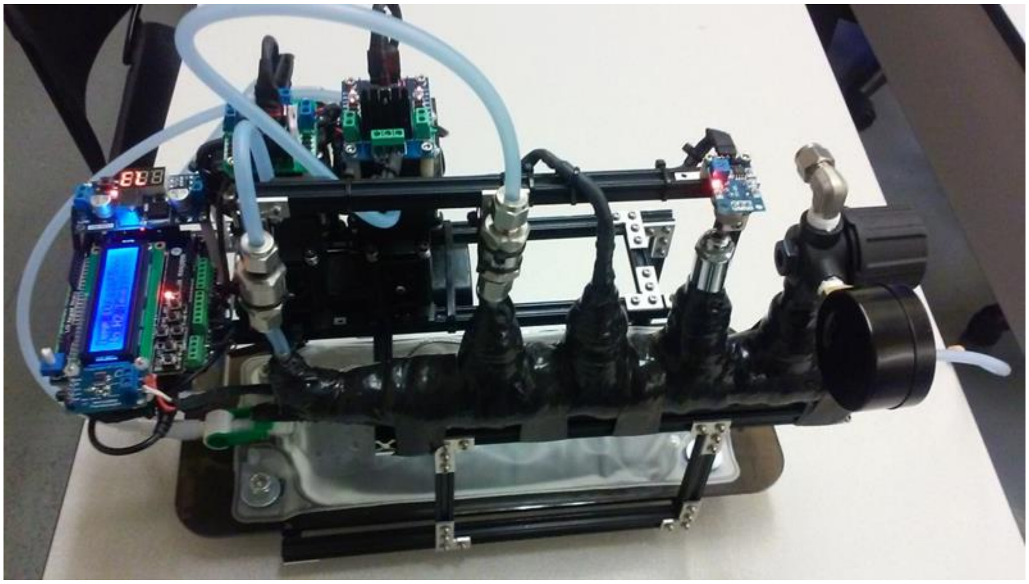

Figure 5
Methanol Reformer Designed and Built at Kent State University at Tuscarawas for On-Board Production of Hydrogen as Fuel for PEM Fuel Cell

Conclusions

A new major in Green and Alternative Energy was introduced at Kent State University at Tuscarawas for students seeking a Bachelor of Science degree in Engineering Technology. The program was implemented to meet the ASME 2030 Vision. New courses in Fuel Cell Technology, Advanced Fuel Cell Technology, Power Technology, Energy Management Systems, Automation Manufacturing, Engineering Technology Project and others, which promote a learn-by-doing student experience were introduced. The courses enrich students' practice-based experience through design-build-test projects; expose students to engineering codes and standards; provide students with a more pervasive system perspective; engage students in a discovery-based knowledge that promotes greater innovation and creativity; develop students' professional skills by strengthening teamwork, communication, problem solving, interpersonal and leadership skills and implement strategies to attract and retain a more diverse student body. Students are encouraged to participate in complex engineering projects and research that align with the State of Ohio's Third Frontier Fuel Cell Program commitment to accelerate the growth of fuel cell industry in Ohio, to investigate manufacturing processes and technologies, to adapt or modify existing components and systems that can reduce the cost of fuel cell systems, to address technical and commercialization barriers and demonstrate market readiness.
The program is intended to be accredited by ABET after the first students graduation.

References:

[1] https://community.asme.org/board_education/w/wiki/7883.asme-vision-2030-project.aspx

[2] V. Gurau: "Demonstration of an Automated Assembly Process for Proton Exchange Membrane Fuel Cells Using Robotic Technology", American Society of Engineering Education, paper ID: #9865, (2014)

[3] V. Gurau: "Investigation of a Manufacturing Process for Intermediate to Mass Production of Polymer Graphite Based Bipolar Plates for Proton Exchange Membrane Fuel Cells", American Society of Engineering Education, paper ID: #9868, (2014)

[4] M. Williams, K. Tignor, L. Sigler, C. Rajagopal and V. Gurau: "Robotic Arm for Automated Assembly of Proton Exchange Membrane Fuel Cell Stacks", The Journal of Fuel Cell Science and Technology, vol. 11 (issue 5), 054501, doi:10.1115/1.4027392 (2014)

[5] V. Gurau and T. Armstrong-Koch: "Further Improvements of an End-Effector for Robotic Assembly of Polymer Electrolyte Membrane Fuel Cells", Energies, Special Issue "Polymer Electrolyte Membrane Fuel Cells 2015" Vol.8, (9), pp. 9452-9463;

[6] V. Gurau: US 2015/0158179 A1: Robotic Fuel Cell Assembly System