Integration of Research, Teaching, and Practice in the Implementation of the Michigan State University Energy Transition Plan

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Abstract

In 2012 Michigan State University (MSU) created a plan (MSU Energy Transition Plan, 2012), which attempts to move the university toward 100 % renewable energy sources and reduced greenhouse gas emissions. This plan has to overcome special challenges due to the fact that MSU's 50,000 student campus self-generates almost 100 % of its electricity and building heat, and that approximately three quarters of its annual energy consumption need to flow into heating the buildings. This paper lays out the roadmap for the Energy Transition Plan and describes the first steps taken towards its goals with the implementation of aggressive energy conservation and recycling programs, changing the fuel source for the university's power plant from coal to natural gas, the construction of a biogas-producing anaerobic digester for cafeteria waste and animal excrements, and the installation of a large (11 MW) solar array. Special attention is given to the integration of the research and teaching missions of the university with the day-to-day operation of the physical plant to ensure reliability of the power supply as well as optimization of the cost structure of the university's energy portfolio.

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1 Introduction

Michigan State University (MSU) is operating its own combined heat and power plant and produces essentially all of its electricity and building heating and cooling. With its ability to function in 'island-mode' MSU can serve as a model for the integration of renewable energy resources into the power production portfolio on the scale of a mid-sized city. We start by giving a historical perspective on how fuel choices and the shifting balance between steam and electricity demands have shaped the current constraints on the existing MSU infrastructure and installed generating equipment. Then we discuss the considerations that led to the 2012 Energy Transition Plan. And finally we detail the implementation of the steps of the Energy Transition Plan and the individual renewable resources that were integrated into our power and heat generating structure, focusing on the opportunities for scholarship and teaching and learning provided.

2 History of Combined Heat and Power at MSU

Michigan State University was founded in 1855 under the name Agricultural College of the State of Michigan, which was changed to Michigan Agricultural College in 1909, to Michigan State College of Agriculture and Applied Science in 1925, and to Michigan State University of Agriculture and Applied Science in 1955. Since 1964 the institution has used its current name, Michigan State University (MSU).

Initially all of the college's buildings were heated with wood fireplaces. A series of building fires resulted from utilizing this technology, and in 1882 the college built a central boiler house to provide heat for its buildings. This heat was delivered in form of steam via a district heating system consisting of underground steam pipes (Forsyth 2016). In 1894 a power plant was completed, which allowed for partial electrification of the campus (Beal 1915). Coal became the major fuel for the campus in 1901, when the Pere Marquette railroad spur was constructed.

A second boiler house was constructed in 1904, along with a network of underground tunnels of six foot six height, which housed the steam pipes and conduits for electricity and telephone wires. This tunnel system initially had a total length of approximately 4100 ft. In 1921 the third campus power plant was constructed, and the old boiler houses were torn down (Koenigsknecht 2011).

After the Second World War a large influx of students and rapid expansion of campus, primarily as a result of the 1945 G.I. Bill helping WWII veterans to receive an education, necessitated the construction of a new power plant in 1948. This fourth plant, located next to the Spartan football stadium, was the main campus source of electrical power until 1965 and used seasonally until 1975.

The fifth and current MSU power plant, the T.B. Simon Power Plant, was put into operation in 1966. At this time the third campus power plant was demolished to make room for the current administration building (Stanford and Dewhurst 2002). The T.B. Simon Power Plant initially had two coal-fired boilers and steam turbine generators, each with a generating capacity of 12.5 MW. In 1974 a third boiler and 15 MW steam turbine generator was added to the T.B. Simon Power Plant, allowing the shutdown of the fourth power plant. In 1974 a fourth boiler unit with fluidized bed and capability of burning multiple fuels was added. Its 21 MW steam generator turbine brought the total electrical peak capacity to 61 MW and made the T.B. Simon Power Plant the largest coal-fired campus power plant in the country. Finally, in 2006 a 24 MW steam turbine driven by a heat-recovery steam generator and a gas combustion turbine with 14.3 MW peak capacity were added, affording the T.B. Simon Power Plant a total peak electrical generating capacity of 99.3 MW. Through careful maintenance all of these 6 power-generating units are still in use today, even after 5 decades of operation of the first units.

The five boilers co-generate electricity and superheated steam by producing steam at a pressure of 875 psi, which is initially used to drive steam turbine generators and then sent through the steam tunnels at a pressure of 90 psi to heat the large majority of campus buildings, now in excess of 17 million square-feet. The steam tunnel network has now grown to a length of more than 13 miles and recently underwent extensive renovations. This electricity and steam co-generation allows the T.B. Simon Power Plant to operate at an average total efficiency of approximately 61 %.

3 Campus Power and Heat Consumption

MSU's rapidly growing student numbers and research productivity has resulted in strongly increasing demands on steam production, but even more so on electricity generation. We examined the annual campus electricity generation over the five decades of the lifetime of the T.B. Simon Power Plant. In fiscal year 1965–66 the electricity production was approximately 120 GWh, and by fiscal year 2012–13 it had increased to approximately 347 GWh, almost tripling over this period of time (solid line in Fig. 1). Since 2012–13 the electricity production has been reduced slightly, in part due to an aggressive energy conservation and efficiency improvement program, as well as due to an increase in off-campus purchases of electricity to take advantage of favorable off-peak rates. During each year between 74 and 81 % of the generated electricity were consumed on campus, with remainder being used to operate the plant and generation equipment.

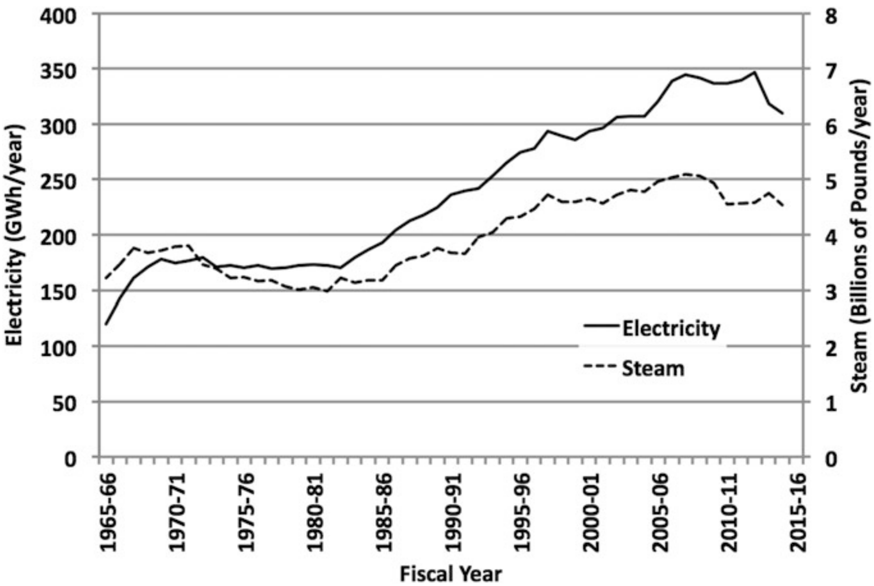

Fig. 1 Time evolution of electricity and steam production at MSU

We can also obtain the total annual steam generation as a function of time (dashed line in Fig. 1). Between 46 and 61 % of this steam has been sent out to campus to heat the buildings, and the remainder was used for electricity production, or, if the electricity demand outpaced the needs for steam, it was simply condensed in cooling towers. Steam demand only increased by less than 50 % during the five decades shown, and the growing imbalance between electricity and steam demands on campus has resulted in a gradual erosion of the overall efficiency of the co-generation process at MSU's T.B. Simon Power Plant.

4 Campus Fuel Mixture

As mentioned above, the main campus fuel at MSU had been coal at least since 1901, when the second MSU power plant was connected to the railroad network. All the way until 2006 coal remained almost the sole fuel powering MSU, even though the first 4 boiler units in the T.B. Simon Power Plant had the capability to burn gas as well. After the installation of the gas combustion turbine in 2006 natural gas became an appreciable part of the fuel mix at MSU.

It is instructive to examine the year-by-year fuel mix during the last decade at MSU (Fig. 2). During this time MSU consumed an average of 6.35 trillion BTU (British Thermal Units) of input energy, with a range between 6.10 and 6.53 TBTU, primarily depending on the severity of the winter weather. One can see that starting

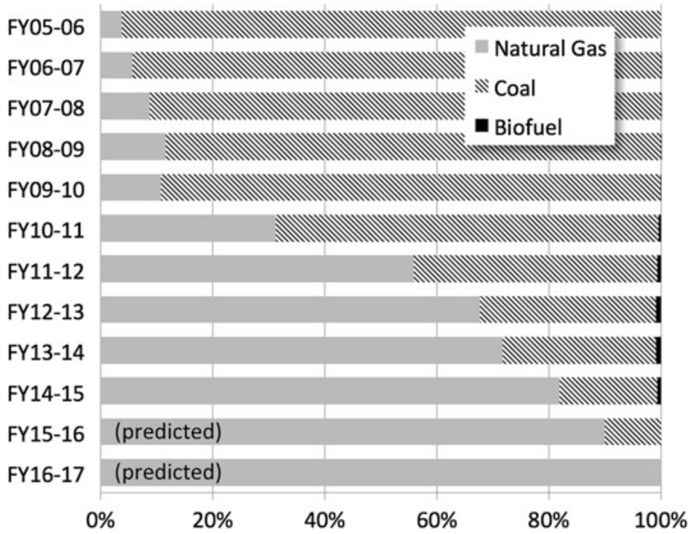

Fig. 2 Year-by-year fuel mixture utilized in the T.B. Simon Power Plant

in FY2011–12 natural gas became the dominant fuel. In April 2015 MSU announced that it would stop burning coal by spring of 2016, after consuming the remainder of the coal pile stored locally. Burning bituminous coal produces approximately 206 lb of carbon dioxide per million BTU, whereas natural gas combustion only emits 117 lb of CO_2 per million BTU (DOE-EIA 2015). Therefore the switch from coal to gas resulted in approximately a 43 % reduction in CO_2 emissions over the 10-year span during which the conversation took place, which is approximately 575 million pounds (= 256,000 metric tons) for MSU. In addition, burning natural gas also reduces greatly the emission of other pollutants, such as dust particulates of diameter less than 2.5 μm (PM2.5), which have been shown to cause 200,000 early deaths per year in the USA (Caiazzo et al. 2013).

In the last decade we also had a small contribution of biofuel to the fuel mix for the T.B. Simon Power Plant. This biofuel fraction reached a maximum of 0.9 % in the fiscal years 2012–13 and 2013–14, but with the complete conversion of the boilers to natural gas the use of biofuels had to be curtailed. Even though this constitutes a slight reduction in renewable energy use at MSU, it is more than compensated for by the overall reduction in harmful emissions.

5 The MSU Energy Transition Plan

In 2009 the university set out to create a long-range plan in order to transition out of a fossil-fuel dominated power and heat production with its rather large greenhouse gas emission footprint contributing to global warming (NRC 2010) into one that relies on renewable energy resources, with the ultimate goal transitioning into 100 % renewable energy use. In 2011 a 25-member steering committee consisting of 6 students, 9 faculty members, and 10 staff members and administrators was formed. This committee reached out to the students involved in the MSU Beyond Coal and Greenpeace movements, as well as to the overall student population and the broader MSU and East Lansing area communities. It authored a report (MSU Energy Transition Plan 2012), which proposed very aggressive targets for reduction of emissions and adoption of renewable energies. The three main goals of the plan are: (1) Improve the physical environment, (2) Invest in sustainable energy research and development, and (3) Become an educational leader in sustainable energy. At the same time the energy transition plan steering committee made sure to keep an eye on costs, environmental impacts, and future growth needs of the university. The MSU Board of Trustees approved this plan in April 2012.

The MSU Energy Transition Plan set future goals for the fraction of campus renewable energy use and for the total greenhouse gas emission reduction (Table 1). The first evaluation point of the plan, FY2015, has been concluded. Since the baseline chosen for the energy transition plan was FY2010, in which some fraction of the emissions reductions due to the fuel switching were already achieved, it has been harder to meet the goals. Relative to FY2010, a reduction of 30.8 % in CO_2 emissions was achieved. (This number has been adjusted to a weather corrected baseline of 6.35 TBTU annual fuel consumption.) The share of renewable energy campus use in FY2015 was at 8.5 %, significantly below the 15 % target. This was in part due to the curtailment of biofuel burning at the T.B. Simon Power Plant.

In the spring of 2017, with the completion of a new substation connecting MSU to the outside grid and allowing the transmission of a much larger power load than previously, it will be possible to purchase electricity and address the balance between steam load and electrical load on the T.B. Simon Power Plant. Further gains in overall efficiency and thus emissions reductions can then be expected, while at the same time saving even more funds from the operations budget, which can be redirected to academic programs. Present simulations of the anticipated optimal purchase patterns indicate annual savings of up to approximately $2.4 million and a net reduction of 20,000 tons of CO_2 emissions, if MSU utilizes the fuel mix of the available grid power. If MSU accepts the "green" surcharge of presently $7/MWh and uses green grid power, then the emission saving will increase to 76,000 tons of CO_2 per year.

Table 1 Goal timetable of the MSU Energy Transition Plan

	% campus renewable energy	% greenhouse gas emission reduction
FY2015	15	30
FY2020	20	45
FY2025	25	55
FY2030	40	65

6 On-Campus Renewable Energy Use and Teaching and Learning Opportunities

Combining practical implementation of renewable energy resources with research and teaching is at the core of the MSU Energy Transition Plan, as is the improvement of energy efficiency and reduction of energy use on campus. The following gives a partial overview of ongoing efforts.

6.1 Biogas

In 2013 MSU designed and constructed a biogas project in collaboration with Anaergia. This anaerobic digester is an improvement over a previous design (Bauer 2013, 2015) and uses farm manure, food processing waste, cafeteria food scraps, and fats, oil, and grease, as well as milk processing waste, as input substances for an anaerobic digester. In 2015 the total feedstock was 22,070 tons. The biogas (60/40 mixture of methane and carbon dioxide, with traces of other gases) is used as combustion fuel for a gas engine and produces a sustained 400 kW of electricity and another 450 kW of heat (MSU-Digester 2014). The digester is used for basic and applied research, as well as for teaching purposes. Ten different MSU classes have used the digester facility as part of their teaching portfolio during the past academic year. Typically these classes use the digester facility anywhere from one-time field trip on-site visits all the way to semester-long real-life laboratory courses. One MSU class, BE475 in the bio-systems engineering program, even combines this teaching tool with a study abroad summer program in Germany and Sweden.

6.2 Spartan Treasure Hunt/Better Buildings Challenge

The greenest energy is the energy not used. In collaboration with General Electric MSU started a program of examining energy use and eliminating energy waste on a building-by-building basis in 2013. The first two building complexes in this program were the Biomedical and Physical Sciences Building and the Engineering building complex. A team of approximately 40 students, faculty, and staff, in approximately equal parts comprised of building occupants and members of the central facilities team met for two days, researched energy use, discussed ways to improve, and wrote up a final list of recommendations. Through application of the Spartan Treasure Hunt facility occupant engagement method, we have evaluated 25 buildings totaling 4,576,992 ft^2 and have identified a total of 669 energy conservation measures (ECMs). To date, two facilities have received funding for ECM implementation at a total cost of $2,166,000 resulting in an annual cost avoidance of $790,000 and over 10 % energy reduction in each facility.

The Better Buildings project of the U.S. Department of Energy is an initiative to optimize energy use and energy savings through building redesign. MSU participates in this project and has completed the upgrade process for the 317,200 square-foot Anthony Hall (34 % energy savings), as well as the 252,000 square-foot Erickson Hall (31 % energy savings).

6.3 Geothermal Energy

Geothermal systems with heat pumps can provide valuable contributions to building heating. In 2012 MSU constructed the 48,000 square-foot Bott Building for Nursing Education and Research and decided to utilize a horizontal geothermal field for building heating. This array of the size of a football field was later augmented with vertical wells and contributed to the Bott Building winning the 2013 Green Judges' Choice Green Education Design Showcase award. The first complete year evaluation of the building energy consumption indicates a contribution of approximately 467 million BTU of geothermal energy to the overall building energy consumption, an approximate share of 20 %. Future senior engineering classes and thesis projects will have the ability to study the performance of this geothermal field and to create improved designs for future projects.

6.4 Data Center Design

Data centers are an ever-increasing consumer of electricity on college campuses. MSU is in the process of designing a new campus datacenter for administrative and academic research computing. This data center will provide flexible and expandable white space at the lowest possible energy consumption for data center cooling. Water-cooling of the servers via rack-rear-door heat exchangers (Bach et al. 2013) is one of the options explored, and a mechanical engineering capstone class, ME416, used the design of a heat exchanger between the closed loop cooling of the data center and the MSU drinking water underground pipelines as its final project. A PUE (= power usage effectiveness = ratio of total power consumed by the data center/power consumed by the servers) of less than 1.1 is the target, whereas current PUE values for existing data centers on campus range from 1.6 to significantly larger than 2. Engineering senior capstone classes have worked on heat exchanger designs for this facility, and future engineering capstone classes will have the opportunity to improve the data center efficiency by refining the pipe design, pump performance, and sensor integration during real-time operation of the data center.

6.5 Solar Array

Starting in 2015 MSU partnered with Customer First Renewables and Innovateus to design, construct, and operate an 11 MW solar array in the form of carports over 5 different large commuter parking lots. This array is currently under construction and when finished will provide approximately 5 % of the annual electricity consumption of the entire MSU campus. Remarkably, due to the availability of the solar power during the highest demand times, this peak shaving will result in this green power becoming cheaper than brown power within 5 years, based on a 2.3 % utility price growth rate predicted by the US DOE-EIA (2015). Over the 25-year life of the solar arrays MSU is expected to reap savings of approximately $10 million in electricity costs.

MSU is a leader in the research on advanced photovoltaic films (Lunt 2012; Suddard-Bangsund et al. 2016), on complex materials with energy applications, and on micro-grid inverters (Qian et al. 2011; Lei et al. 2011). Collaboration with our commercial partners will open new applied research opportunities and serve as real-life teaching laboratories. One senior undergraduate engineering capstone class, ECE480, even designed a computer-controlled early warning system, which can predict large fluctuations in the output of the solar arrays and will enable MSU to compensate through dynamic micro-grid load shifting. A student competition on innovative and creative new solar panel designs was held in the fall semester, and prizes were awarded in December 2015 (Energy Innovation Award 2015).

7 Looking Forward

MSU is a large research university with a 5200-acre campus and one of the largest residence hall systems in the world. Since MSU is producing its own electricity and district heat, the university can serve as a model laboratory for cities of the future. Its own micro-grid can exist in island mode and allows us to study the integration of renewable energy and smart grid technologies. The Energy Transition Plan has set very ambitious and aggressive goals for the near and distant future. Existing renewable energies can be amplified and others (wind, deep geothermal, bio-energy crops, and more) will be explored. The future for renewable energy research, teaching and learning at MSU is shaping up to be exciting.

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Authors Biography

Professor Wolfgang Bauer received his Ph.D. in physics from the University of Giessen, Germany, in 1987. He has been a member of the faculty of Michigan State University since 1988, holding the title of University Distinguished Professor since 2007. He was chair of the Department of Physics and Astronomy from 2001 to 2013 and Founding Director of the Institute for Cyber-Enabled Research from 2009 to 2013. In the last decade his research has concentrated on renewable energy technology, in particular biofuels. He co-owns several companies in this field and has performed consulting work in the renewable energy sector for oil companies and hedge funds. Since 2013 he serves as senior consultant in the office of the Executive Vice President for Administrative Services at Michigan State University.

Dan Bollman holds a Bachelor of Science in Civil Engineering (1984) and Masters in Resource Development (1995), both from Michigan State University. In his current role as Associate Vice President for Strategic Infrastructure Planning & Facilities, Michigan State University (MSU), USA, Dan has leadership and management responsibility for a staff of approximately 1350 employees and is responsible for delivering $174 million in facility services to the campus

community annually. Additionally, he is responsible for in excess of $1 B in capital construction put in place over the past decade. Dan has worked for Michigan State University for 25 years in a variety of facility related capacities. Prior to that he spent 5 years in the U.S. Navy as a lieutenant in the Civil Engineer Corp.

Robert Ellerhorst is the Director of Utilities at the Power and Water Department of Michigan State University (since 1990). Ellerhorst's responsibilities include managing the Power and Water Department to provide reliable and affordable energy and water to MSU faculty, staff, students, and the visiting public. Ellerhorst has a Bachelor of Science (1974) and a Master of Science (1976) in civil/structural engineering; all from MSU. Ellerhorst is a licensed Professional Engineer in the State of Michigan (1979).

Dr. William (Bill) Latta has over 35 years of extensive and broad university administrative experience in a large public university setting. Currently he is the Assistant Vice President for Operations and works in the Office of the Executive Vice President for Administrative Services at Michigan State University. Among the projects he is involved with, facilitating achievement of the university's energy transition plan goals and planning for the future utility power needs of the campus are highly significant. He also provides leadership for a variety of interdisciplinary issues involving the integration of forward planning, physical and business infrastructure, academic and support programs, and their impact on the quality and health of the campus.

Nate Verhanovitz has served Michigan State University since 2005 in various engineering roles. He is presently the performance engineer for the Power and Water department of the Infrastructure Planning and Facilities division of MSU. His primary responsibilities are optimizing thermodynamic processes within the central power plant while maintaining high reliability and quality of electrical and steam utility service.