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Unlocking Manufacturing Sustainability: Energy Efficiency Opportunities through the US Department of Energy's Better Plants Program Energy Treasure Hunts (2023–2024)

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Abstract: The US manufacturing sector faces critical challenges: improving sustainability, reducing energy consumption, and reducing greenhouse gas emissions. Energy Treasure Hunt (ETH) training, a service provided by the US Department of Energy's Better Plants program, offers a compelling solution. Although ETHs have traditionally focused on energy and cost savings, data indicate that ETHs can be used to identify opportunities to reduce emissions and water use and to support a sustainable and circular operation. These 3-day on-site events engage employees in a collaborative search for operational and maintenance efficiency improvement opportunities. The success of ETHs lies in a comprehensive methodology. Each phase in an ETH uses various tools and resources to empower employees to identify practical solutions. This study presents data from 13 ETHs conducted between 2023 and 2024 across diverse manufacturing subsectors in the United States and demonstrates that the events can help create a pragmatic decarbonization pathway. Through the events, a total of 234 energy and emissions reduction opportunities were identified, and the potential impact is significant. Implementing the recommendations could translate to annual savings of 497,299 MMBtu of energy, 64,374 kgal of water, and 4.85 million tCO_2e of emissions. The fiscal savings from the proposed recommendations translate into nearly $5 million annually. This study identifies the opportunities by energy system type and by the specific actions recommended, while also analyzing the identified opportunities, presenting the most established sustainability recommendations. Case studies from participating partners are presented to further demonstrate that ETHs provide a practical and impactful approach to reducing energy consumption, emissions, and operating costs and promote a more sustainable future for the industrial sector.

Keywords: energy efficiency; sustainability; energy treasure hunt; industrial decarbonization; kaizen; emissions reduction

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1. Introduction

The US Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy's Manufacturing Energy Consumption Survey 2018 data indicate that the industrial sector accounts for roughly 35% of all energy consumption in the United States. Of this industrial energy use, 78% is derived from fossil fuels (petroleum, natural gas, and coal), 13% is from generated electricity, and roughly 9% is from renewable energy [1]. These statistics have compelled large energy users within the industrial sector to establish goals, focusing on sustainability, and to consider socioeconomic impact as a key factor in their business decisions.

Across the manufacturing sector, sustainability has become a leading consideration in the boardroom. The US Environmental Protection Agency (EPA) defines sustainable manufacturing as "the creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources. Sustainable manufacturing also enhances employee, community, and product safety" [2]. This definition can encompass water, waste, circularity, air pollution, energy, safety, community, and more. The broad use of the term has led organizations to develop dedicated sustainability teams, conservation programs, and goals for an array of subject areas. In recent years, decarbonization efforts have become one of the most prevalent sustainability goals amongst major manufacturers. The passing of the Inflation Reduction Act in 2022 marked the largest investment in combating climate change in the United States, and all eyes are now on decarbonizing the manufacturing sector [3].

Global greenhouse gas (GHG) emissions have continued to rise over the past few years, reaching around 59 $GtCO_2e$ in 2019, but the growth is slowing [4]. Multiple nations, subnational governments, and companies have announced net-zero CO_2 emission targets, as per the United Nations' Net Zero Stocktake 2023 report [5]. The United States has a goal to achieve net neutrality by 2050, which will be challenging given that the United States contributed 11% of the total global GHG emissions in 2021 [6,7]. In 2022, industrial emissions contributed to approximately 30% of total US GHG emissions [8]. Industrial emissions need to be drastically reduced to limit global temperature increases to within 1.5 °C of preindustrial levels.

As part of the industrial decarbonization effort in the United States, in 2022, the DOE published the Industrial Decarbonization Roadmap, which outlines four key technological pillars to decarbonize the different industrial sectors—energy efficiency; electrification; low-carbon fuels, feedstocks, and energy sources; and carbon capture, utilization, and storage [9,10]. Energy efficiency is the foundational pillar of decarbonization [9]. This key pillar can include material and resource efficiency, given the definition in the Industrial Decarbonization Roadmap. Worrell and Boyd conducted a bottom-up analysis of decarbonizing the US manufacturing sector by 2050 and found that an 86% reduction in emissions is possible by implementing multiple decarbonization measures [11]. The study found that efficiency measures contributed 56% of the decarbonization of the manufacturing sector, with 34% from energy efficiency and 22% from material efficiency measures.

Efficiency measures for industrial decarbonization can have multiple benefits beyond cost savings and GHG emission reductions. These include energy and resource security, air pollution reduction, other environmental benefits, productivity improvements, better resource management, waste minimization, and economic spillovers, as summarized by Kim et al. [12]. Kim et al. also identified economic barriers as the most significant obstacle to energy efficiency implementation while also discussing organizational and institutional barriers (such as a lack of experience in technology and a lack of information about energy efficiency and energy-saving technology), behavioral barriers (such as inertia), and technological barriers (such as a lack of data collection and analysis infrastructure and a lack of integration and applicability).

DOE has voluntary partnership programs for manufacturers to assist with their organizations' sustainability goals: the Better Plants (BP) and Better Climate Challenge (BCC) programs [13,14]. The manufacturers that join either or both programs (referred to as partners from here on) sign up for energy efficiency and/or decarbonization goals with optional water and waste goals. Partners receive technical assistance support, tools, resources, and national recognition. As part of the technical assistance, partners can receive In-Plant Trainings (INPLTs). INPLTs are 2- to 4-day events led by experts in manufacturing processes who train plant staff in a specified system or procedure, such as compressed air or Energy Treasure Hunts (ETHs). INPLTs combine classroom instruction and a hands-on evaluation of manufacturing facilities to identify, prioritize, implement, and replicate energy-saving solutions using various DOE tools. The BP program has two solicitations for INPLTs annually, wherein partners apply to host an event on a specified system at one of their facilities. Through this process, partners can apply to receive training and to have ETHs facilitated at their sites [15].

ETHs are 2- to 3-day on-site events at manufacturing plants that engage employees in identifying operational and maintenance efficiency (mostly energy efficiency) improvement measures [16]. ETHs are an adaptation of the Japanese kaizen methodology [17]. Although the kaizen methodology was developed in 1986, today, this methodology remains relevant and is still used to improve manufacturing energy efficiency. As demonstrated in the study by Androniceanu et al., kaizen can be a powerful tool for identifying and implementing energy-saving measures, even in the face of economic and behavioral barriers [18]. ETHs, by their cyclical nature and emphasis on employee ownership, can help address these barriers and foster a culture of continuous improvement within organizations. Another recent study by Venkatesan and Kundu demonstrates the effectiveness of kaizen events in helping small and medium enterprises (SMEs) in India to achieve significant energy savings and reduce their carbon footprint. By leveraging the principles of lean manufacturing kaizen events, SMEs can identify and implement targeted improvements that contribute to both operational efficiency and environmental sustainability. These findings highlight the potential of kaizen events and ETHs as valuable tools for manufacturers seeking to address energy efficiency and decarbonization challenges [19].

Recognizing the value of continuous improvement in achieving energy reductions and building culture in the industrial sector, early ETHs were designed for this purpose. Toyota pioneered ETHs in the late 1990s, noting that their energy reduction program could be more impactful if employees were more engaged. The US Environmental Protection Agency (EPA) included ETHs as an integral part of its ENERGY STAR® Industrial Partnership [20]. Since then, numerous manufacturing organizations have adopted ETHs as a fundamental tool in energy reduction efforts, then embedding these activities within their overall sustainability strategies.

Not only is building a culture of continuous improvement wise from the perspective of lean manufacturing, but also for international standards such as ISO50001: Energy Management. The standard explicitly states in Section 10.2 that, “the organization shall continually improve the suitability, adequacy and effectiveness of the EnMS. The organization shall demonstrate continuous energy performance improvement” [21]. In a 2019 report, which outlines the process that the DOE’s National Renewable Energy Laboratory (NREL) undertook to obtain ISO50001 certification, they highlight the importance of continual improvement as a core aspect of a robust energy management system. It is stated that the certification can pave the way for “more rigorous assessments to identify additional energy and cost efficiencies”, and ETHs can help satisfy the requirement for continuous improvement, while providing a structured format for an energy assessment [22]. Using ETHs as a method for deploying a culture of continuous improvement was also exemplified by a case study on Intertape Polymer Group Inc. (IPG), a company that has achieved significant success with the program, finding that employee engagement is a critical factor. IPG’s Philip Kauneckas, a Certified Energy Manager, underscores the importance of surpassing traditional audits and engaging employees in asking “why” about current practices. This fosters a culture of questioning and problem-solving, leading to ongoing optimization [23].

The study presented in this paper explores how ETHs can be leveraged beyond the traditional cost and energy savings to achieve broader decarbonization and sustainability goals. By pinpointing opportunities to reduce water use, material consumption, and GHG emissions, ETHs can significantly contribute to a more sustainable manufacturing landscape. The US Energy Information Administration’s 2018 Manufacturing Energy Consumption Survey (MECS) shows that nearly 50% of manufacturing facilities surveyed participated in some type of energy-management activity, such as energy audits or assessments [24]. However, there is a lack of granular data or studies on how the ETHs contribute to energy efficiency and the sustainability goals of organizations.

Furthermore, DOE Better Plants partners have recognized the effectiveness of ETHs in reducing energy and water use as well as GHG emissions and are expanding their focus to supply chains. General Motors created a self-paced treasure hunt program to expand supplier participation in ETHs by a factor greater than 10 compared to previous levels [25]. Similarly, Johnson Controls established a supplier program to provide assistance in conducting ETHs, noting that many of the improvements identified ranges from 5 to 10 percent savings and were implemented immediately [26]. These initiatives broaden the impacts of ETHs beyond scope 1 and 2 reductions and target broader decarbonization within scope 3 supply chains.

The positive environmental impact of ETHs extends beyond simple energy savings. ETHs can reveal opportunities to implement circular economy principles, like water reuse or material repurposing. This continuous-improvement cycle, fueled by data and analysis, empowers manufacturers not only to achieve immediate gains but also to identify long-term strategies for a more sustainable future. By extending the scope of ETHs beyond just energy to encompass a broader sustainability focus, ETHs can help accelerate the manufacturing sector's transition toward a sustainable future.

2. Methods

2.1. What Does an Energy Treasure Hunt Entail?

ETHs, or energy kaizens, are continuous-improvement events focused on energy-conservation opportunities and project identification. For the BP program, an ETH is a 3-day event that focuses on operational and maintenance energy efficiency improvements [27]. Typically, an ETH focuses on low-cost/no-cost efforts with low capital and quick payback periods; it should not be compared to the results of a full detailed energy audit. Partners are encouraged to think of an ETH as a continuous cycle conducted by those closest to the process [28]. Sites are encouraged to have ETHs multiple times per year to foster an energy-awareness culture in their facilities. Through the BP INPLT process, a facilitator (BP representative) helps walk the host facility and organization through the three phases of the event: preparation, event, and follow-up (Figure 1). These trainings promote the replication and knowledge transfer of the process such that they serve as "train the trainer" events. Participants learn the process of conducting an ETH, execute the process with BP staff for support, and then leave prepared to conduct their own ETHs at their home facilities post-event [27].

Figure 1. Energy Treasure Hunt phases [27].

2.1.1. Phase One: Preparation

Before hosting the event, the facilitator (BP representative) has several planning conversations with the core host-site team coordinating the logistics and data collection for the event. These meetings allow the facilitator to develop an understanding of the plant's energy costs, end uses, and processes using the pretraining data collection form [27]. Data availability from the plant is established, including the types, ratings, and capacities of major equipment used (such as large motors) in the plant; these indicates where the largest opportunities to improve might be found and, thus, help determine which diagnostic equipment to apply during the event to collect critical performance data. Targeted data collection is crucial for the quality and success of an ETH.

The facilitator hosts a pre-event webinar to set event expectations for participants and provide facility operational details. To prepare for the event, the host partner invites participants from several facilities to join the event to receive the training. Ideally, participants return to their home facilities and deploy the event framework independently. Other topics covered in the webinar include reviewing common opportunities that can be expected, data to be collected, and tools to be used during the event (both software tools and diagnostic equipment).

2.1.2. Phase Two: Event

The event takes place at the plant over the course of 2–4 days to observe the idle facility, observe the operating facility, and complete the report-out to site leadership. The event begins with a welcome, safety review, and overview of the agenda. The facilitator reviews common opportunities and the tools available for the event. Participants are split into teams (to spread functions, expertise, or areas across working groups), each with a leader who is tasked with keeping a detailed log of the possible recommendations. The plant host provides the group with an initial site tour. Participants then divide into their predetermined teams and begin looking for opportunities.

An ETH ideally involves three teams of five participants, each reporting to the facilitator. Teams should focus on specific areas, and team leaders should be chosen beforehand. While team members can be nominated in advance, they can also be selected during the event's kickoff. The host site is responsible for confirming participants and team leaders, assigning focus areas, training individuals, providing data, obtaining management approval, and arranging logistics. They also prepare the closing presentation with guidance from the facilitator. The facilitator prepares opportunity sheets, conducts training, presents opening remarks, assists teams, and contributes to the closing presentation. Team leaders must coordinate access to plant resources, identify energy-saving opportunities, evaluate project viability, facilitate data collection, and summarize findings. They should also present their findings to management. Team members should have leadership skills, technical expertise, analytical abilities, and some knowledge of plant operations. Teams should include participants from various departments, such as maintenance, production, engineering, and subject matter experts. Fresh perspectives from individuals outside their daily roles can be valuable. External participants, like consultants or representatives from other facilities, can also contribute unique insights. By carefully considering these factors and assembling well-rounded teams, organizations can maximize the effectiveness of their Energy Treasure Hunts and achieve significant energy savings.

If the event can start on an idle day, like a day during a nonoperational weekend, the group can observe the idle plant to identify opportunities. Starting on an idle day is not always possible if the host facility operates continuously, but, for many sites that do not, it can be valuable to the ETH process. Observations that can be made during an idle state include lights on with no occupancy, fans turned on when not needed for exhaust, compressed-air lines leaking, and so forth. Generally, equipment should be turned off when production is not running, so observing the idle state may help find equipment unnecessarily left on. The process shown in Figure 2 is repeated multiple times as needed during the remaining event days, enabling the continuous evaluation and identification of opportunities while the plant is in normal operation.

Figure 2. Energy Treasure Hunt event process [28].

To empower participants in their search for improvement opportunities, the DOE treasure hunt toolkit offers a suite of resources. Checklists provide a system breakdown, detailing components for assessment and typical parameters to identify opportunities. Data collection sheets outline the minimum measurements needed to quantify savings from common opportunities and include tips for data collection. System-specific cheat sheets provide some rules of thumb to enhance system understanding, facilitate back-of-the-envelope savings estimates, and enable quick feasibility checks for potential solutions. Finally, the toolkit includes opportunity-sheet templates to document identified savings opportunities effectively. This standardized format ensures that information is preserved between project identification and implementation, streamlining the knowledge-transfer process. To help ensure the culture of continuous improvement is spread throughout the organization after the one-time event, these resources are made available online for public access. These documents can be found on the Better Buildings Solution Center website or outlined in additional detail in the report US Department of Energy Better Plants Program Energy Treasure Hunt Exchange Toolkit [27]. Throughout the process, various diagnostic tools are used. Typically, a pre-curated Energy Treasure Hunt kit provided through the BP Diagnostic Equipment Program is shipped to the host site [29]. The standard kit includes the equipment shown in Figure 3 and allows participants to gain experience in properly using equipment to take measurements to evaluate possible energy savings.

Diagnostic Equipment Pictured	
(1) Acoustic imager	(4) Pressure transducer
(2) HOBO data logger	(5) Anemometers
(3) Current Transducers	(6) IR camera
Other Equipment in kit which are not pictured	
Clamp meter	Laser distance meter
Light meter	Ultrasonic Leak Detector
Digital thermometer	Thermocouple
IR thermometer	Plug load logger

Figure 3. Energy Treasure Hunt kit.

One of the most valuable tools for an ETH that has been developed by the DOE is the MEASUR tool suite (v1.5.2), an open-source, free software available for direct download on a PC or online at measur.ornl.gov. It is a collection of 6 assessment modules, over 70 quick calculators, 1 Treasure Hunt module, 2 equipment inventory options, and 1 data exploration module. The calculators were designed for quick on-the-spot calculations. The assessment modules are much more robust, exploring common energy-consuming system operational parameters. The Treasure Hunt module is a blend of the quick calculators and assessment modules [30]. The Treasure Hunt module was designed to complement the ETH diagnostic tools previously mentioned. The module uses a systematic approach to analyze, organize, and present possible recommendations during the event. During the ETH event, the facilitator trains participants on quantifying energy and cost savings using the MEASUR software. Once the event ends, the software can be used to prepare the closeout presentation to management [31]. Before the end of the on-site event, the event hosts invite facility leadership to a report-out presentation. This activity provides the opportunity for the ETH team to obtain leadership buy-in for planned activities post-event. It allows leadership to understand the results and provides visibility to the participants. Before the development of this tool, facilitators were burdened with using a multitude of Excel workbooks acting as separate energy-saving calculators. This tool allows for a streamlined approach and reduces the barrier for ETH process implementation. Additional information about the treasure hunt module can be found in the user manual within MEASUR.

The most important tool for an ETH is considered by some to be the facilitator. A good facilitator is a leader, has a technical thought process and excellent communication skills, and knows how to talk to people from a variety of positions, from technicians to C-suite representatives. The facilitator needs to field questions from participants about how to use diagnostic equipment, which variables to measure to calculate energy savings, how to execute calculations, and more. A facilitator must be knowledgeable and able to teach participants the ETH process. It is also key that the facilitator can adapt to dynamic environments. Often, events do not go as planned and must change, and the facilitator must be ready to pivot activities and scheduling to accommodate facility conditions or activities, scope change, the interests of the participants, or other unforeseen circumstances.

2.1.3. Phase Three: Follow-Up

Following the ETH, a prioritization and implementation phase commences. This stage involves evaluating the identified energy-saving opportunities and outlining the next steps for actualizing the savings. Available within the MEASUR tool, the Project Implementation Tracker serves as a valuable tool during this process by facilitating the prioritization of activities to occur post-event by allowing participants to compare and rank opportunities. Additionally, it helps monitor project progress by tracking the implementation schedule and project results [27]. The host site and organizations are ultimately responsible for continuous project follow-up and continuing the ETH process over time. Through the BP program, Technical Account Managers (TAMs) are assigned to each partner, serving as the connection between the BP program and the partner. TAMs are made available to partner organizations and can assist with continued training and coordination virtually. With their recent training, participants are equipped to host and facilitate their own ETHs. Additionally, the Diagnostic Equipment Loan Program, MEASUR analysis tool, and other facilitation and implementation guidance documents are available year-round.

2.2. Analysis Methods for Reviewing DOE's Better Plants Energy Treasure Hunt Events

ETHs have been included as a BP INPLT offering since 2016 [13]. However, INPLT activities were suspended because of the COVID-19 pandemic from 2020 to 2022 and resumed in 2023. Since their resumption, the program has facilitated 17 ETHs. This pause created a unique opportunity for a systematic and standardized comparison of ETH results. Before the pause, there were many facilitators using differing recordkeeping methods. However, since the pause, all ETHs offered by the BP program have been conducted using the MEASUR tool suite. The MEASUR tool suite allows for a formal approach for calculations and a uniform format for all ETHs.

Using the implementation-tracking function in MEASUR, the recommendations from each of the 17 ETHs were exported to a Microsoft Excel file and combined into one dataset. For this analysis, additional fields were added to the MEASUR-generated results sheet, including company identification number, North American Industry Classification System (NAICS) code, the year of the ETH, and the month of the ETH. Assessment recommendation codes (ARCs) were added to each opportunity to anonymize the specific opportunity recognized by participants during an ETH. ARCs are five-digit codes that were created and are used by DOE's Industrial Assessment Centers (IAC) program. An ARC was given for each recommendation to sort by savings type, equipment type, and so forth. This classification allowed for standardized opportunity identification.

Additionally, to anonymize the results of the analysis by facility, the original utility costs, total consumption, and emission factors were removed. For energy costs, the weighted averages were calculated based on the utility rates and total consumption of each facility, resulting in an average electricity rate of \$0.061/kWh and a natural gas rate of \$4.89/MMBtu. For simplicity, water cost was not separated by incoming or sewer costs; instead, water unit costs were assumed at a conservative \$4/kgal based on discussion with experts. Emissions-savings calculations were completed using the average US GHG emissions factors, representing 100-year global warming potential based on the Intergovernmental Panel on Climate Change Fifth Assessment Report global warming potential values for CO_2, CH_4, N_2O, and other greenhouse gases [32], from the EPA and eGRID (Emissions & Generation Resource Integrated Database) 2023 version [33]. The analysis then considered a variety of statistics that could be beneficial to the scientific community, such as systems with the most recommendations, systems with the most cost savings, and so forth.

3. Results

For this analysis, 17 ETH events between 2023 and 2024 were evaluated in detail. The manufacturing subsectors represented in this analysis, based on provided NAICS codes, included electrical equipment, appliance, and component manufacturing; transportation equipment manufacturing; plastics and rubber products manufacturing; textile product mills; furniture and related product manufacturing; fabricated metal product manufacturing; nonmetallic mineral product manufacturing; machinery manufacturing; primary metal manufacturing; food manufacturing; and chemical manufacturing.

During the 17 events, 371 opportunities were identified: 339 energy recommendations and 32 water recommendations. On average, each event produced 21 opportunities and a total energy savings of approximately 19%. It should be noted that the identification and quantification of projects was performed by each ETH event team during the 3-day event at a given facility. A summary of event-level information is shown in Table 1.

Table 1. BP program-level summary of ETHs (2023–2024).

Term	Results
Total number of events	17
Total number of opportunities identified	371
Total identified water savings (kgal)	24.42 million
Total identified energy savings (MMBtu)	2.46 million
Total identified emissions savings (tCO_2e)	146.45 million
Total identified cost savings	$16.2 million

Overall, the 17 ETHs identified almost 2.5 QBTU (million MMBtu) of possible energy savings and 24.2 million kgal of water savings. These amount to 116 million tCO_2e of scope 1 emissions and 30.5 million tCO_2e of scope 2 emissions, a total of 146 million tCO_2e emissions that could be avoided by implementing the recommendations discovered. In total, about $16.2 million in savings was identified, 30.7% of which was from electricity, 65.9% from natural gas, and 3.4% from water savings. This shows that ETHs can be expanded beyond energy efficiency to broader sustainability goals, such as reducing water use and emissions. Table 2 further summarizes the identified savings by utility type.

Table 2. Savings summary by utility type.

Utility Type	Count (%)	Utility Savings	Utility Units	Total Energy Savings MMBtu	Total Emissions Savings tCO_2e	Total Cost Savings USD
Electricity	261 (70%)	81,333,922	kWh	277,511	30,500,221	4,978,309 (31%)
Natural gas	78 (21%)	2,183,229	MMBtu	2,183,229	115,951,292	10,671,601 (66%)
Water	32 (9%)	24,422,309	kgal		-	555,827 (3%)
Grand total	**371**			**2,460,740**	**146,451,513**	**16,205,737**

The recommendations were categorized by energy systems (as prepopulated in MEASUR): motor, pump, fan, compressed air, lights, process heating, steam, process cooling, steam, HVAC, and other. For this analysis, water and renewables categories were added.

The other category became a catch-all for opportunities that did not fit into a specific system previously listed. The other opportunities were further organized into subsystems: computers/office plug loads, miscellaneous plug loads, vacuum systems, and vending.

Table 3 shows an overall summary of the event findings by system type, the number of recommendations by system, average and total energy savings (MMBtu), average and total emissions savings (tCO_2e), and average and total cost savings (USD). Compressed-air systems had the most potential opportunities, with 77 recorded recommendations, or 21% of all identified recommendations. The second-most identified opportunities were for process heating systems, which had 57 recommendations, or 15% of all opportunities identified. HVAC, steam, fans, and lights all had similar opportunity counts in the low 30s and high 20 s, each roughly 10% of the total number of identified opportunities. The categories with the fewest recommendations were process cooling, renewables, and the subcategories under other. It is notable that the US Energy Information Administration's 2018 MECS identified that the most-used retrofits to improve energy efficiency were facility lighting, HVAC, compressed-air systems, direct machine drives, and process heating [24]. These findings contain the same top recommendations as the ETH events with compressed air, process heating, HVAC, machine drives, and lighting.

Table 3. Systems summary of ETH-identified opportunities.

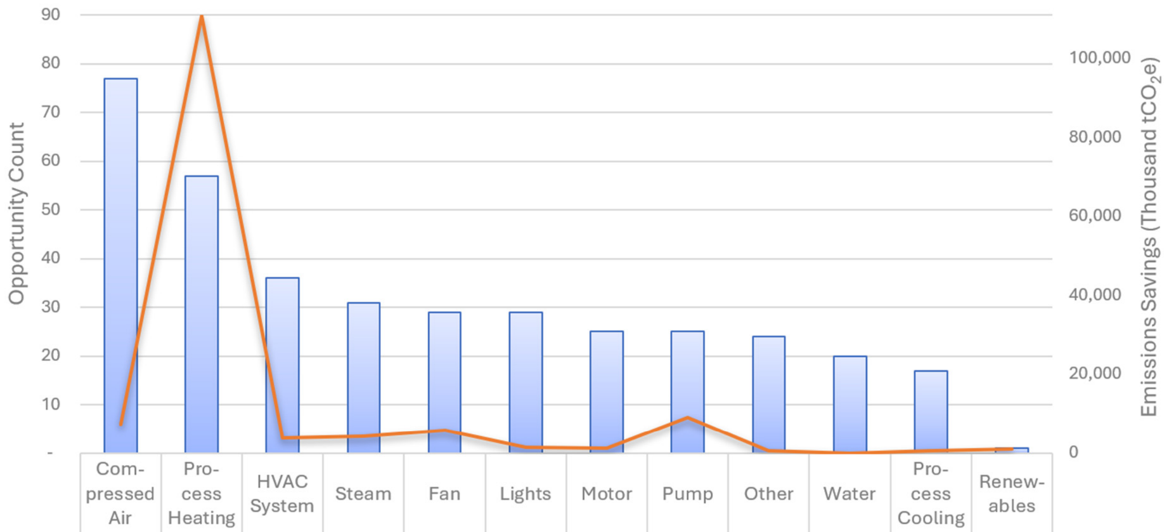
Energy System	Count (%)	Average Energy Savings	Total Energy Savings	Average Emissions Savings	Total Emissions Savings	Average Cost Savings	Total Cost Savings
		MMBtu		tCO_2e		USD	
Compressed Air	77 (21%)	889	68,484	95,207	7,330,967	15,371	1,183,536
Process Heating	57 (15%)	37,235	2,085,134	1,945,714	110,905,680	179,474	10,229,991
HVAC System	36 (10%)	1167	38,506	104,913	3,776,883	17,652	635,468
Steam	31 (8%)	3308	82,709	141,699	4,392,675	13,614	422,021
Fan	29 (8%)	1969	57,104	203,072	5,889,084	32,257	935,467
Lights	29 (8%)	466	3,520	51,240	1,485,970	8364	242,543
Motor	25 (7%)	467	11,685	51,369	1,284,223	8385	209,613
Pump	25 (7%)	3625	83,384	366,576	9,164,409	67,568	1,689,194
Water	20 * (5%)	51	51	279	5585	14,032	280,630
Process Cooling	17 (5%)	381	6094	39,401	669,823	7347	124,898
Renewables	1 (0.3%)	8392	8392	922,374	922,374	150,552	150,552
Other	24 (6%)	237	5676	25,993	623,840	4243	101,824
Misc. plug loads	10 (3%)	47	282	5166	30,993	843	5059
Computers/office Plug loads	6 (3%)	470	4703	51,686	516,864	8436	84,364
Vacuum systems	4 (1%)	162	647	17,787	71,146	2903	11,613
Vending	4 (1%)	11	44	1209	4837	197	789
Grand total	**371**		**2,460,740**		**146,451,513**		**16,205,737**

* Eight water recommendations and one energy recommendation were made for this system.

Notably, when total emission reductions were considered, adding renewables reduced emissions the most, followed by process-heating opportunities. Typical ETHs do not include renewables, such as rooftop solar, as normal opportunities because of the high capital cost. However, as decarbonization and sustainability have gained prominence in decision-making, recent ETHs have added specific opportunities for installing solar panels based on the host plants' requirements. Through the ETHs, the land/roof areas for installing solar energy systems and potential credits/incentives were identified, which can help industrial plants plan for such projects. The use of software programs, such as the National Renewable Energy Laboratory's PVWatts, allowed for a quick and easy analysis of solar panel capacity and area requirements [34]. The DSIRE (Database of State Incentives for Renewables & Efficiency) website enabled the identification of incentives at the national, state, local, and utility levels that could reduce the capital and operation costs of solar energy systems [35].

Several of the events yielded significant potential water conservation and cost-saving opportunities. Water is not a primary focus of ETHs; however, when identified, water saving opportunities are included in the event findings. Like savings for other utilities, water utility savings result from multiple systems. Notably, the water system category in Table 3 represents recommendations that were categorized strictly as water *system* savings; the associated energy savings in the table resulted from recommendations for a piece of electrical equipment. This was a result of non-motor energy used in a water treatment process. The total water *utility* savings in Table 2 capture savings from multiple systems, including water, HVAC, and pumps. Of the 20 water conservation opportunities recorded, 19 were in the water system, saving 69,930 kgal of water; 3 were in the HVAC system, saving 12,324 kgal of water; 2 were in the pumping systems, saving 48,340 kgal of water; and 5 were in the steam system, saving 4435 kgal of water. These findings suggest that ETHs extend beyond energy savings and contribute to a more sustainable water management strategy within the manufacturing sector.

Figure 4 shows a graphical representation of the systems, the numbers of recommendations, and the total potential emissions savings identified during the ETHs.



	Com-pressed Air	Pro-cess Heating	HVAC System	Steam	Fan	Lights	Motor	Pump	Other	Water	Pro-cess Cooling	Renew-ables
Opportunity Count	77	57	36	31	29	29	25	25	24	20	17	1
Total Emissions Savings	7331	110,906	3777	4393	5889	1486	1284	9164	624	6	670	922

Figure 4. Emissions savings and opportunity counts by energy system (full table in Appendix A).

Figure 4 also shows the total count of opportunities by system, with the bar graph using the primary *y*-axis for the total count. The orange line graph that overlaps the bar chart utilizes the secondary *y*-axis, indicating the total potential emissions savings (thousand tCO_2e) identified during the ETH. The chart is organized by decreasing opportunity count: from compressed air, which had the most recommendations, to renewables, which had the fewest. Though compressed air had the most opportunities, process heating, not compressed air, had the greatest potential savings (111 million tCO_2e and $10.2 million). The least savings were identified in the other systems ($101,824).

For further analysis, each recommendation was sorted using DOE's Industrial Assessment Centers ARC database. The top-five recommended opportunities, regardless of system, are shown in Table 4 and Figure 5.

Table 4. Top-five most-recommended ETH opportunities by ARC (full table in Appendix B).

ARC	ARC Description	Count (%)	Total Energy Savings MMBtu	Total Emissions Savings tCO_2e	Total Cost Savings USD
2.6218	Turn off equipment when not in use	78 (21%)	209,850	16,769,482	2,318,153
2.4236	Eliminate leaks in inert gas and compressed air lines/valves	44 (12%)	16,044	1,763,314	287,812
2.4146	Use adjustable frequency drive or multiple speed motors on existing system	25 (7%)	66,987	7,362,328	1,201,694
2.7142	Utilize higher efficiency lamps and/or ballasts	24 (6%)	12,702	1,396,064	227,868
2.1131	Repair faulty insulation in furnaces, boilers, etc.	15 (4%)	85,241	4,534,097	420,360

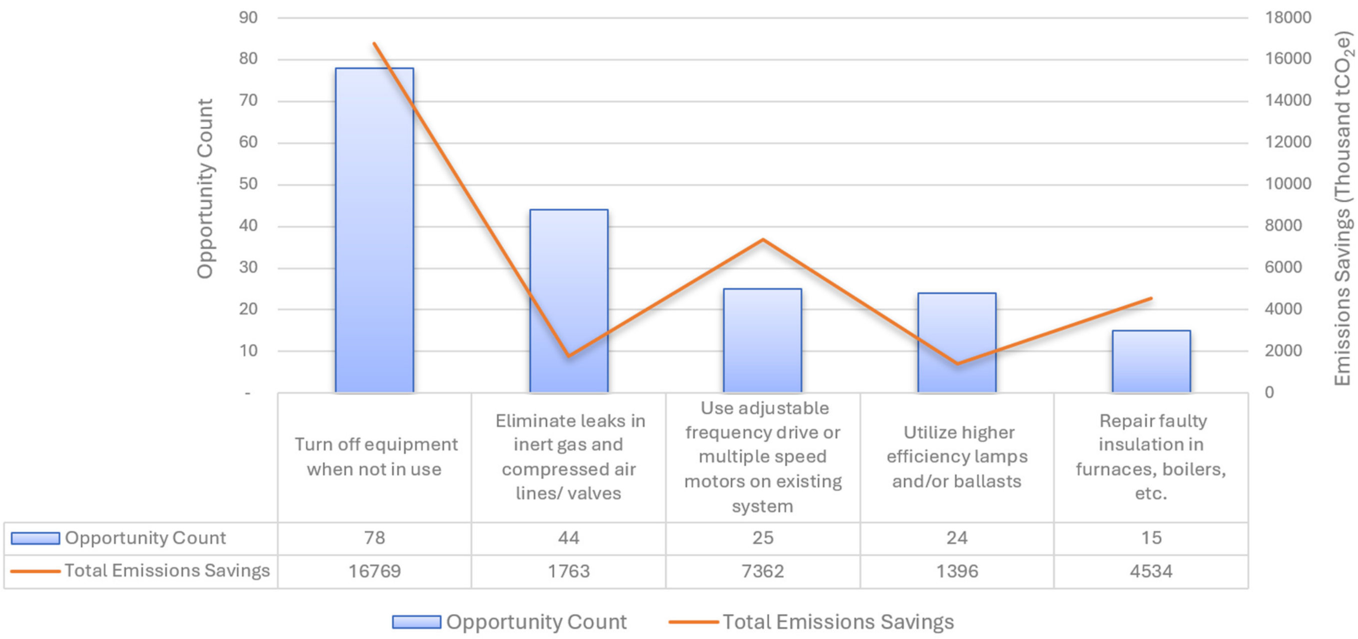


Figure 5. Top-five most-recommended opportunities by ARC.

Figure 5 shows the total opportunity count by ARC, with the bar graph using the primary *y*-axis for the total count. The orange line graph that overlaps the bar chart utilizes the secondary *y*-axis, indicating the total potential emissions savings (thousand tCO_2e) identified during the ETHs by ARC. Figure 5 accounts for 135 opportunities, more than half of the opportunities identified. As expected from an ETH, the most common opportunity identified was turning off equipment when not in use, representing 21% of recommendations, 8.5% of potential energy savings, and 11% of emissions reductions. Turning off equipment is a typical example used when explaining low-cost/no-cost opportunities during these events, and the data gathered further supports that assertion. The second-most common recommendation was eliminating gas/compressed air leaks, followed by using adjustable or variable frequency drives, using higher-efficiency lights, and, finally, repairing faulty insulation in process-heating equipment.

The program, through these 17 ETHs, identified several opportunities that promote the practice of circularity within participating facilities. These include reusing HVAC condensate water, a very pure form of water typically drained, for other purposes. Additionally, switching to LED lighting not only significantly improves efficiency but also reduces the need for the disposal of hazardous materials like fluorescent bulbs and ballasts. In a different circumstance, liquid storage tanks destined for disposal were repurposed to enhance the efficiency of the compressed air system. Furthermore, the program identified opportunities to reuse wood chips for playground mulch and repurpose waste foam padding by using it for upholstery with a more sustainable adhesive selection. These examples demonstrate how ETHs can not only promote efficiency, decarbonization, and water-use reduction, but also contribute to a more circular industrial economy.

4. Future Work

Future work in this area could focus on increasing the data quantity and reducing the limitations of this study. The data could be expanded with additional events—increasing the number of data points and thus improving the population sample to allow for more specific conclusions by industrial subsector. Additional data to be added and reviewed could include implementation costs, simple payback calculations, and follow-up with implementation rates. These values tend to be difficult to quantify during an event and need to be obtained in the months after the event. It is recommended that a process be put into place for the post-event feedback to be collected from the facility 1 year after the event, which will allow the time needed for projects to be completed or plans for completion that align with the organizations' investment planning timelines. This could include a follow-up implementation survey to gather useful statistics to further the study, such as implementation rate, actual capital cost, actual measured energy savings, etc.

Additional improvement could also be achieved through facilitator-standardization training and by immediately correcting classifications recommended by participants. The studied events had different facilitators. This study assumed that the facilitators used the same opportunity-classification practices (e.g., water recommendations were not classified as pump recommendations). The fundamental structure of ETHs challenges this assumption because employee participants are implementing the process, and participants may not correctly identify system classifications during the training. This vulnerability allows for human error to affect the statistics. The facilitator would need to ensure data consistency by applying the correct classifications during the event or relabeling the opportunities after the event.

5. Conclusions

The data presented in this study support the assertion that ETHs are a reliable strategy to assist manufacturers in project identification, thus supporting their energy efficiency, sustainability, and decarbonization goals. The goal of an ETH is to find the low-hanging fruit of energy efficiency opportunities in a facility, and this study's results show that sites can reduce their energy use by nearly 20% by following the ETH practices prescribed by the DOE BP program. Of all the identified opportunities, 21% were from turning off equipment, a prime example of a low-cost/no-cost recommendation. Furthermore, the identification of opportunities for both scope 1 and scope 2 emission reductions highlights the potential for ETHs to contribute to broader industrial decarbonization goals. Some participating organizations have even extended their ETH programs with their suppliers, allowing for a reduction in their scope 3 emissions. The 371 identified opportunities included pathways for reducing both scope 1 and scope 2 emissions, and roughly 21% of the opportunities identified have the potential to reduce scope 1 emissions by 116 million tCO_2e across the considered events.

There are several factors to consider in the program enhancement and expansion as the BP ETH team continues to analyze and improve the process. In the BP/BCC programs, the TAM is a resource that could allow for reinforcing the continuous-improvement aspect of ETHs, with follow-up after ETHs and providing the expertise needed to execute the suggested projects, new strategies, or organization changes. This includes incorporating an energy management system structure inspired by ISO 50001, with a focus on identifying and addressing the most significant energy users (SEUs) within facilities. Additionally, the team is investigating the integration of decarbonization assessments, the standardization of the cost of carbon in analyses, and the development of water-focused treasure hunts. These advancements hold promise for further amplifying the program's impact on sustainability in the manufacturing sector.

Manufacturers that host regular ETH events and apply the findings will inevitably create a continuous-improvement cycle for identifying, quantifying, and implementing efficiency measures. Additionally, leveraging ETHs as a workforce-development tool will equip employees with the skills to conduct future events independently, enabling participants from other facilities to gain the facilitation skills needed to conduct their own ETHs, thus continuing to support the participating organizations' overall sustainability goals.

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Appendix A

Table A1. Summary of ETH-identified opportunities by system (used for Figure 4).

Energy System	Count	Total Energy Savings MMBtu	Total Emissions Savings tCO_2e	Total Cost Savings USD
Compressed Air	77	68,484	7,330,967	1,183,536
Process Heating	57	2,085,134	110,905,680	10,229,991
HVAC System	36	38,506	3,776,883	635,468
Steam	31	82,709	4,392,675	422,021
Fan	29	57,104	5,889,084	935,467
Lights	29	13,520	1,485,970	242,543
Motor	25	11,685	1,284,223	209,613
Pump	25	83,384	9,164,409	1,689,194
Other	24	5676	623,840	101,824
Water	20	51	5585	280,630
Process Cooling	17	6094	669,823	124,898
Renewables	1	8392	922,374	150,552

Appendix B

Table A2. Summary of ETH identified opportunities by ARC (used for Figure 5).

ARC	ARC Description	Count	Total Energy Savings MMBtu	Total Emissions Savings tCO_2e	Total Cost Savings USD
2.6218	Turn off equipment when not in use	78	209,850	16,769,482	2,318,153
2.4236	Eliminate leaks in inert gas and compressed air lines/valves	44	16,044	1,763,314	287,812
2.4146	Use adjustable frequency drive or multiple speed motors on existing system	25	66,987	7,362,328	1,201,694
2.7142	Utilize higher efficiency lamps and/or ballasts	24	12,702	1,396,064	227,868
2.1131	Repair faulty insulation in furnaces, boilers, etc	15	85,241	4,534,097	420,360
2.2135	Repair and eliminate steam leaks	15	34,813	1,848,918	186,886
2.2511	Insulate bare equipment	14	21,525	1,193,204	116,704
2.7224	Reduce space conditioning during non-working hours	11	3871	374,131	57,652
2.4231	Reduce the pressure of compressed air to the minimum required	7	1564	171,882	28,055
2.7313	Recycle air for heating, ventilation and air conditioning	7	28,952	2,731,563	415,870
2.2414	Use waste heat from hot flue gases to preheat	6	84,653	4,495,921	413,783
2.4239	Eliminate or reduce compressed air usage	6	403	44,276	7227
2.7447	Install vinyl strip/high speed/air curtain doors	6	3793	249,678	29,626
3.4154	Eliminate leaks in water lines and valves	6	-	-	6664
2.1113	Reduce combustion air flow to optimum	5	77,563	4,119,371	379,127
2.1116	Improve combustion control capability	5	1,584,916	84,174,889	7,747,053
3.4116	Meter recycled water (to reduce sewer charges)	5	-	-	242,656
3.4151	Minimize water usage	5	-	-	70,976
2.1121	Use insulation in furnaces to facilitate heating/cooling	4	43,419	2,359,303	224,485
2.1133	Adjust burners for efficient operation	4	10,859	592,722	56,757
2.2694	Use highest temperature for chilling or cold storage	4	442	48,537	7922
2.2113	Repair or replace steam traps	3	17,078	907,013	83,477
2.2127	Flash condensate to produce lower pressure steam	3	3052	162,092	15,938
2.2531	Re-size charging openings or add movable cover or door	3	2357	125,180	11,521

Table A2. *Cont.*

ARC	ARC Description	Count	Total Energy Savings MMBtu	Total Emissions Savings tCO_2e	Total Cost Savings USD
2.4322	Use or replace with energy efficient substitutes	3	635	69,779	11,389
2.6211	Conserve energy by efficient use of vending machines	3	32	3521	575
2.6231	Utilize controls to operate equipment only when needed	3	437	48,050	7843
2.7135	Install occupancy sensors	3	658	72,332	11,806
2.7231	Use radiant heater for spot heating	3	1974	137,228	17,094
3.4146	Change method of deionized water production	3	78	8541	1394
3.4156	Use flow control valves on equipment to optimize water use	3	-	-	43,288
2.1233	Analyze flue gas for proper air/fuel ratio	2	42,194	2,240,923	206,244
2.2211	Use optimum temperature	2	4995	265,284	87,488
2.2422	Use waste heat from hot flue gases to generate steam	2	7651	406,345	37,542
2.2514	Cover open tanks 2.2515 use optimum thickness insulation	2	5148	283,554	27,492
2.2614	Use cooling tower or economizer to replace chiller cooling	2	1685	185,208	30,230
2.4111	Utilize energy-efficient belts and other improved mechanisms	2	2189	240,541	39,262
2.4222	Install adequate dryers on air lines to eliminate blowdown	2	7373	810,301	132,259
2.4323	Use optimum size and capacity equipment	2	414	45,450	7418
2.7124	Make a practice of turning off lights when not needed	2	160	17,574	2868
2.8117	Install sub-metering equipment	2	108	11,916	1945
3.4114	Replace city water with recycled water via cooling tower	2	-	-	11,232
3.7222	Minimize overflows by installing level controls	2	-	-	97,951
2.1134	Eliminate leaks in combustible gas lines	1	6354	337,461	31,058
2.1135	Repair furnaces and oven doors so that they seal efficiently	1	6	319	29
2.2437	Recover waste heat from equipment	1	3449	183,176	16,859
2.2622	Replace existing chiller with high efficiency model	1	2771	304,560	49,711
2.2625	Chill water to the highest temperature possible	1	185	20,339	3320
2.2691	Shut off cooling if cold outside air will cool process	1	2565	281,898	46,012

Table A2. *Cont.*

ARC	ARC Description	Count	Total Energy Savings MMBtu	Total Emissions Savings tCO_2e	Total Cost Savings USD
2.4133	Use most efficient type of electric motors	1	6	626	102
2.4224	Upgrade controls on compressors	1	359	39,420	6434
2.4226	Use/purchase optimum sized compressor	1	20,427	2,245,050	366,442
2.4237	Substitute compressed air cooling with water or air cooling	1	12	1293	211
2.5123	Reduce fluid flow rates	1	500	54,947	8969
2.6127	Maintain air filters by cleaning or replacement	1	145	15,884	2593
2.6212	Turn off equipment during breaks, reduce operating time	1	615	67,544	11,025
2.6232	Install set-back timers	1	13	1418	231
2.6241	Reduce temperature of process equipment when on standby	1	8	885	144
2.6242	Minimize operation of equipment maintained in standby condition	1	602	66,145	10,796
2.7229	Air condition only space necessary	1	6	649	106
2.7312	Minimize use of outside make-up air for ventilation except when used for economizer cycle	1	2159	237,300	38,733
2.7492	Use proper thickness of insulation on building envelope	1	1855	98,519	9067
2.9114	Use solar heat to make electricity	1	8392	922,374	150,552
3.4152	Carefully control water level in mass finishing equipment	1	24,500	1,301,195	119,756

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