Manufacturing Letters 47 (2026) 20–24

Contents lists available at ScienceDirect

Manufacturing Letters

journal homepage: www.elsevier.com/locate/mfglet

Letters

Key insights from US Department of Energy Better Plants workforce development bootcamps (2022–2025) ☆

Wei Guo *, Kalie Miera, James Nguyen, Alexandra Botts, Paulomi Nandy, Thomas Wenning, Jennifer Travis

Oak Ridge National Laboratory, 2360 Cherahala Blvd., Knoxville, TN 37932, USA

ARTICLE INFO

Article history:
Received 7 May 2025
Received in revised form 25 November 2025
Accepted 2 December 2025
Available online 6 December 2025

Keywords:
Manufacturing
Energy efficiency
Workforce development
Technical training

ABSTRACT

This study examines the effectiveness of the US Department of Energy's Better Plants Program Bootcamps, which are designed to enhance participants' technical skills in improving energy efficiency and optimizing operations in manufacturing facilities. Through the analysis of survey data collected from 529 participants across 9 bootcamps, the research investigates the motivations, benefits, and demographic trends of attendees. The findings reveal that skill acquisition and improvement are primary drivers for participation, with key benefits including hands-on training on diagnostic equipment and software tools, networking opportunities, and access to technical resources. The analysis shows strong participation from sectors characterized by high energy consumption and employment, such as chemical and transportation equipment manufacturing. Over 50% of participants have job titles that include "EHS" or "Energy" showing their key roles in leading energy efficiency and energy management efforts in manufacturing. Furthermore, the analysis highlights the distribution of participants across managerial, engineering, and technical roles, revealing a higher representation of managers and engineers. This observation suggests a need for targeted outreach to engage technicians, equipment operators, maintenance staff, and floor workers to ensure comprehensive workforce development. The post-bootcamp survey showed that the participants highly valued the opportunities for peer learning and idea exchange, and the benefits they gained from them. This research contributes to the advancement of manufacturing education by demonstrating the efficacy of specialized training in addressing critical industry challenges and fostering a more competent and empowered workforce.

1. Introduction

To improve energy resilience and security, the US Department of Energy (DOE) launched the Better Plants Program in 2011 to enhance energy efficiency at manufacturing sites while preparing the next-generation manufacturing workforce [1]. By December 2024, more than 310 organizations with over 3,700 facilities had joined Better Plants, including manufacturing and water and wastewater treatment companies [2]. By joining the program, partners pledge to pursue ambitious, long-term efficiency goals, typically 25 % energy savings in 10 years. Better Plants supports partners with technical assistance, including many workforce development opportunities, to address significant barriers and challenges to improving energy efficiency [1].

Better Plants offers three primary workforce development programs: In-Plant Trainings, Virtual Trainings, and Bootcamps [3–6]. Since its launch in August 2022, Better Plants has conducted nine bootcamps (six focused on energy efficiency and three focused on emission reduction) at Oak Ridge National Laboratory. In-Plant Trainings and Virtual Trainings each focus on a single energy topic, offering depth but limited scope. In-Plant Trainings provide plant-specific, hands-on experience but are less scalable, and Virtual Trainings are widely accessible but less hands-on experience. Bootcamps combine breadth, hands-on learning, and standardized content, helping reinforce and expand the skills gained from both In-Plant and Virtual Trainings. This paper analyzes data gathered from polls and surveys at the bootcamps. It also analyzed the industries, occupations, and professional backgrounds of all 529 bootcamp participants.

2. Overview of the bootcamps

The inaugural bootcamp focused on energy efficiency [7] took place in August 2022, followed by five more held in January and

☆ This article is part of a special issue entitled: 'Manufacturing Education' published in Manufacturing Letters.

* Corresponding author.
E-mail address: guow@ornl.gov (W. Guo).

https://doi.org/10.1016/j.mfglet.2025.12.001

October 2023, May and October 2024, and February 2025. The bootcamp runs for 4.5 days and focuses on training participants on how to identify and implement projects that could reduce energy costs and improve energy resilience for their facilities. Topics include energy management and energy efficiency for all major energy systems in manufacturing facilities (e.g., process heating, process cooling, compressed air systems, and other motor-driven systems) [8].

The bootcamps provide immersive, hands-on learning experiences using bench-top demonstration models of pumping, fan, lighting, compressed air, and process heating systems. These models are designed to help participants identify the most common energy saving opportunities, such as reducing compressed air leaks, lowering compressed air pressure setpoints, and minimizing heat loss from oven walls, while also gaining practical experience with diagnostic tools like ultrasonic flow meters and leak detectors. Through guided instruction with DOE-developed tools such as MEASUR [9], VERIFI, and the Plant Water Profiler [10], attendees learn to calculate energy, water, and related cost savings across various system improvements.

The bootcamp focused on emission reduction [11] was launched in August 2023, with two more in February and September 2024. The curriculum covers emission accounting, onsite energy integration, alternative fuel adoption, electrification strategies, and corporate goal achievement roadmap development. Through hands-on training with DOE's specialized software tools, attendees develop technical proficiency in baselining, benchmarking, and assessment methodologies essential for establishing meaningful sustainability targets.

Both types of bootcamps also provide access to Oak Ridge National Laboratory's advanced manufacturing facilities, where participants experience next-gen manufacturing technologies in real-world settings. For a comprehensive overview of both types of bootcamps' structure and curriculum design, please refer to the detailed agendas on their homepages [8,11]. The presentation slides, exercise questions, and other handout materials were compiled into a workbook and distributed to participants. A PDF version of the workbook was also shared with participants after the bootcamps and is available to others upon request.

Compared with other in-person training workshops, the bootcamps incorporate several distinctive practices: 1). Hands-on instruction with energy systems, diagnostic equipment, and software; for example, sharing practical tips on using infrared thermometers correctly for low-emissivity surfaces and installing ultrasonic flow meters for various piping arrangements; 2). Interactive learning through Kahoot! quizzes at the end of each session to reinforce key concepts; 3). Structured networking activities such as Project Bingo (where participants visit Better Project and Better Practice Award–winning posters to complete a Bingo sheet during the Monday afternoon Energy Management Gallery Walk session) and People Bingo (which features questions about both personal interests and energy-related professional experiences). These activities, along with dedicated time for peer learning and discussion, are designed to strengthen personal connections and encourage collaboration among participants. Post-Bootcamp survey results further highlight the value of these networking opportunities and the importance of peer-to-peer knowledge exchange.

3. Participant data analysis

The bootcamps have collectively trained 529 individuals, with 369 and 160 attending the bootcamps focused on energy efficiency and emission reduction, respectively (Table 1). The first two energy efficiency focused bootcamps exceeded the predetermined capacity for participants (65). The total participants number of the bootcamp focused on energy efficiency dropped to approximately 55 in October 2023 but increased to 68 for the May 2024 session and then stabilized at around 50 for the October 2024 and January 2025 sessions. Similarly, the other type of bootcamp had the most participants for the first two sessions but then dropped to 36, a decrease of 42 %. For both types of bootcamps alike, the percentage of non-partner participants increased steadily from 9 % to 50 %. This higher percentage of non-partners indicates growing interest from non-partner organizations, potentially reflecting broader awareness or outreach efforts for the bootcamps.

Fig. 1 shows job title categories of participants for both types of bootcamps. The bootcamps focused on energy efficiency attracted a diverse professional audience, with Environmental and Sustainability categories leading participation at 74 and 66 attendees, respectively, demonstrating these as leadership roles in energy initiatives across manufacturing organizations. The Energy category followed with 41 participants, whereas Safety (35), Facility (32), and Health (32) also showed substantial representation, reflecting the increasingly integrated approach to sustainability within manufacturing operations. This distribution highlights how health and safety teams have evolved beyond traditional compliance roles to become critical in energy and sustainability initiatives. Please note that participants whose job titles include more than one of these terms are included in each of those categories.

The bootcamps focused on emission reduction revealed a distinct professional composition, with the Sustainability category having the highest attendance at approximately 53 participants, representing over 36 % more participation than the second-ranked Environmental category. The Energy category maintained its third-place ranking, although representation was notably lower compared with that of the bootcamps focused on energy efficiency,

Table 1
Partner and non-partner bootcamp participants breakdown.

Bootcamp	Date	Number of participants at each session	Number of participants from partner organizations	Number of participants from non-partner organizations
Focused on Energy Efficiency	August 2022	68	62	6
	January 2023	70	65	5
	October 2023	57	51	6
	May 2024	68	52	16
	October 2024	54	27	27
	February 2025	52	30	22
	Total	**369**	**287**	**82**
Focused on Emission Reduction	August 2023	62	58	4
	February 2024	62	44	18
	September 2024	36	20	16
	Total	**160**	**122**	**38**
Total		**529**	**409**	**120**

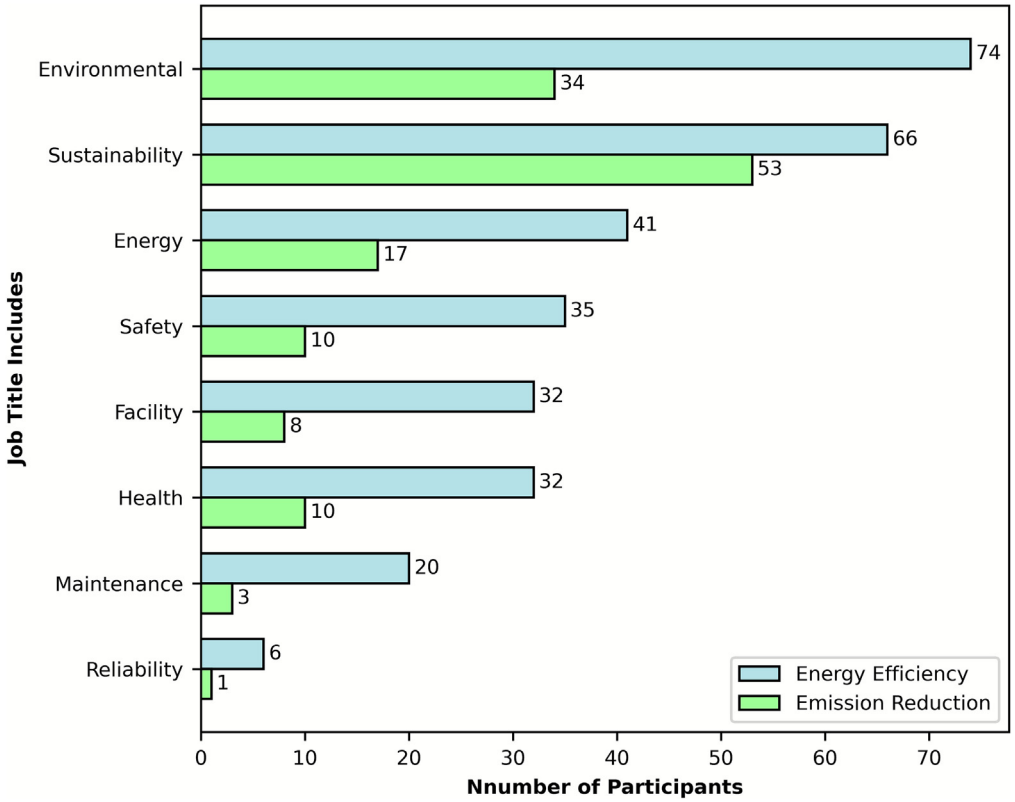

Fig. 1. Number of participants in each job title category attending the bootcamps.

highlighting the evolving organizational landscape around emission reduction initiatives. This pronounced participation from sustainability professionals reflects their expanding role as the primary architects of corporate emission reduction strategies.

Fig. 2 shows the distribution of participants across three job position categories: Manager/Leader (has significant managerial responsibilities), Engineer/Analyst (focuses on the technical side of projects), and Technician (needs technical guidance from the Engineer/Analyst). For both types of bootcamps, Manager/Leader constitutes the largest group, 42 % and 50 % of all participants for the bootcamps, respectively. The Engineer/Analyst category follows, with about 11 % and 36 % less than the Manager/Leader category for the two types of bootcamps, respectively.

The Technician category shows notably lower participation rates, which reveals important insights about current workforce development approaches for manufacturing. The low participation of technicians could be due to time and availability constraints, limited Better Plants' outreach to front line staff, and the perception that the technical level of the bootcamp content is more relevant to engineers and managers. This imbalance might suggest that workforce development currently strengthens planning and technical capacity but may leave gaps in shop-floor execution. Future programs could target technicians through tailored content, flexible scheduling, and team-based participation to ensure knowledge is effectively implemented across all levels.

Fig. 3 displays the frequency of participation or representation across the top 10 sectors, identified by three-digit North American Industry Classification System codes. Chemical (325) and Transportation Equipment (336) industries had the highest participation in both bootcamps. Food (311) and Nonmetallic Mineral Product (327) held the third spots for the bootcamps, respectively. All these industries have energy-intensive processes related to process heating, steam, compressed air, and motor drive systems that can be complex and hard to optimize.

Consistently high participation from these manufacturing sectors demonstrates the value they derive from this training that addresses their energy and emission reduction challenges. As emission reduction becomes increasingly central to industrial competitiveness, these bootcamps provide critical knowledge and skills that help manufacturing facilities navigate the complex transition to low emission operations while maintaining productivity and profitability.

4. Post-bootcamp survey results

At the end of each bootcamp session, a survey was conducted to evaluate various aspects of the program [12,13]. Of the 282 answers collected (48 % of respondents), with 193 participants from the bootcamps focused on energy efficiency and 89 from the ones focused on emission reduction, the two most common reasons for attending were to Acquire New Skills and Update Skills. This highlights that skill acquisition and improvement were the primary motivations for participation in both bootcamps, even with the availability of Professional Development Hours certificates. The survey response rate of 48 % was lower than expected, potentially due to the lack of tangible incentives, participant survey fatigue, or perceptions that the survey results would have minimal impact.

The survey question, "Which sessions do you think are the most informative? (Please try to limit your answers to 3 choices)," asked participants to identify the most valuable sessions from the list of all presentation topics. For the bootcamps focused on energy efficiency, the top selections were Compressed Air, Energy Basics and Understanding Your Utility Bills, and Process Heating. For the bootcamps focused on emission reduction, the most popular

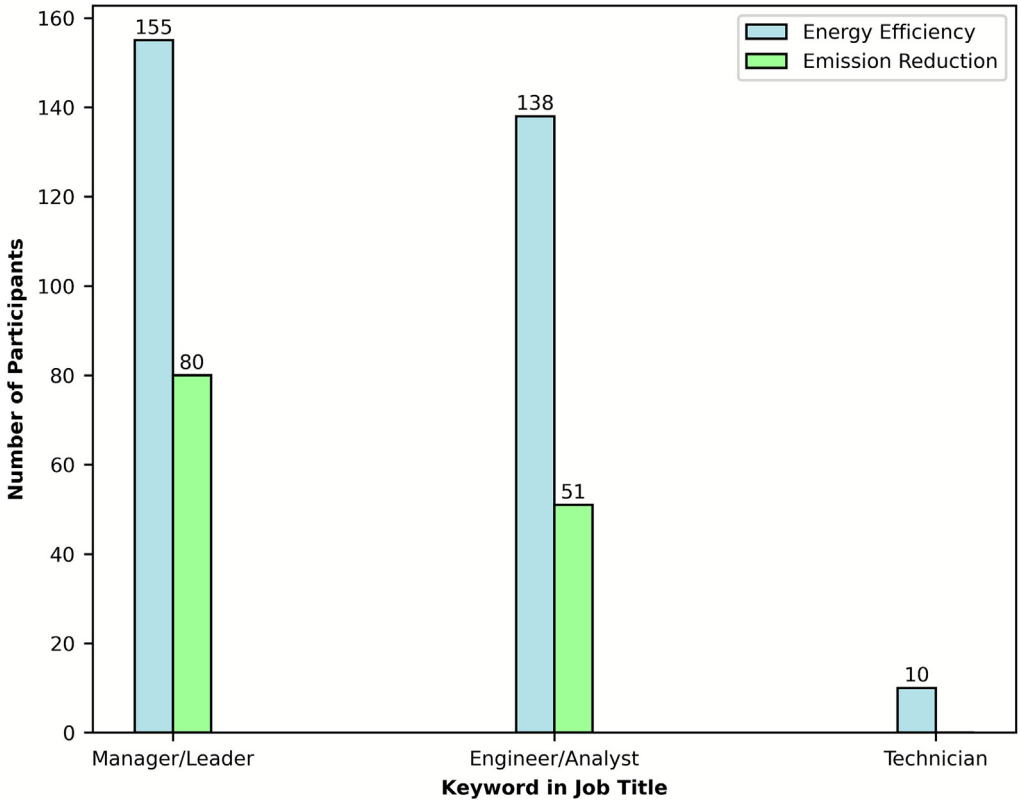

Fig. 2. Distribution of bootcamp participants based on managerial and technical responsibilities.

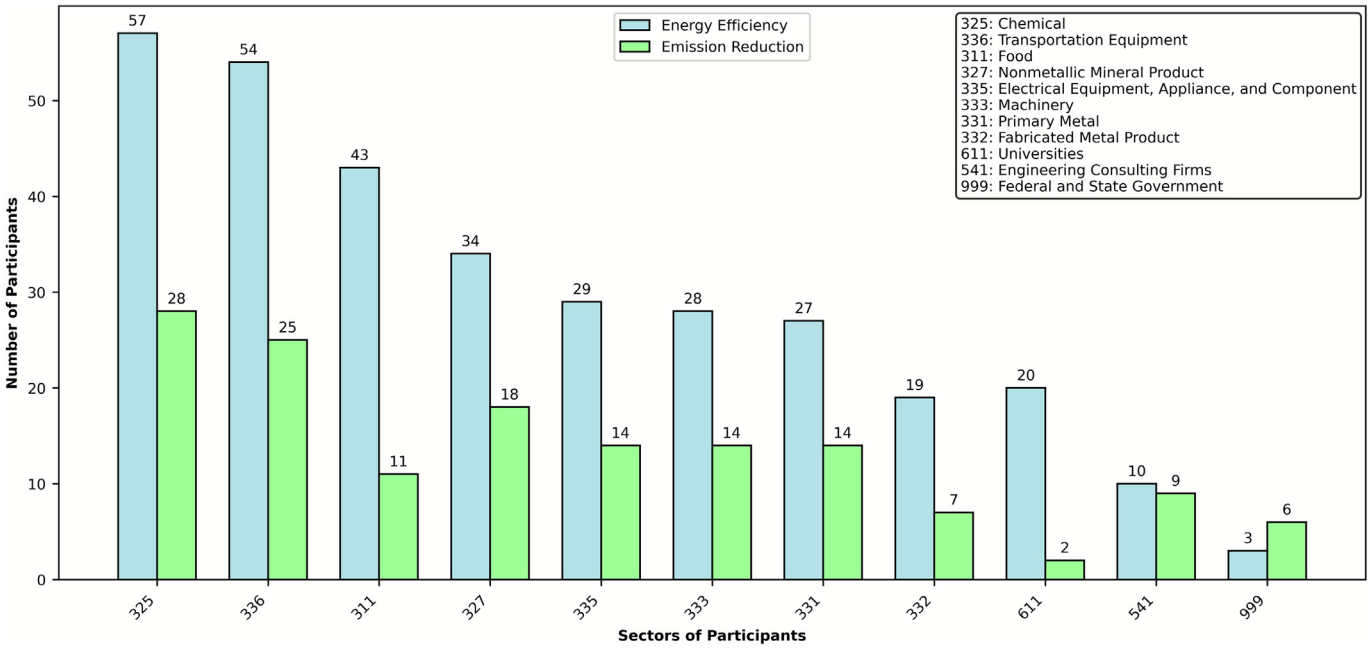

Fig. 3. Distribution of bootcamp participants based on North American Industry Classification System codes.

choices were Energy Efficiency, Industrial Electrification, and Renewable Energy Contracting. The survey results suggest that, for the bootcamps focused energy efficiency, participants prioritize practical knowledge and systems with high energy savings potential such as process heating and compressed air, while, for the bootcamps focused on emission reduction, attendees focus more on popular strategies like electrification and renewable energy contracting to reduce emissions. Future programs could emphasize these high-interest topics and offer more resources to help participants apply the knowledge in their workplaces.

The open box survey question, "What benefits did you receive by attending the Bootcamp?" was used to assess the value of the bootcamps to participants. The key benefits highlighted by participants are summarized as follows:

- High-quality training presentation materials and Better Project and Better Practice awards posters facilitating replication and adoption across organizations and industry sectors.
- Hands-on training on diagnostic equipment to perform measurement and software tools such as MEASUR and VERIFI to quantify savings.
- Networking opportunities that connected attendees with peer professionals, DOE representatives, and Better Plants technical account managers who are experts in energy efficiency field.
- Confidence and inspiration gained from seeing others pursue similar or more ambitious energy saving and emission reduction goals.
- Dedicated time for discussions, knowledge exchange, and brainstorming.

What surprised the Bootcamp organizers was how highly participants valued the opportunities for peer learning and idea exchange, and the benefits they gained from them.

For the bootcamps focused on energy efficiency, 90 % of participants "Strongly Agreed" or "Agreed" that the bootcamp was a valuable experience, and 72 % said they would recommend it to their coworkers. For the bootcamps focused on emission reduction, 90 % of participants also "Strongly Agreed" or "Agreed" on its value, and 90 % indicated they would recommend it to colleagues. To evaluate the long-term impact of the bootcamps, 6-month post bootcamp surveys was conducted, and the survey results will be studied and shared publicly.

5. Conclusions

This study demonstrates the effectiveness of Better Plants Bootcamps in enhancing workforce capabilities for manufacturers. The primary drivers for participation were skill acquisition and improvement, with attendees benefiting significantly from hands-on training on diagnostic equipment and software tools, networking opportunities, and access to technical resources.

Participants with job titles that include "Environmental," "Sustainability," and "Energy" lead the categories, accounting for over 50 % of total participants and highlighting their pivotal role in driving energy and emission reduction initiatives for manufacturing. The bootcamps attracted a very high proportion of managers and engineers, indicating a potential need for targeted outreach to technicians, equipment operators, maintenance staff, and floor workers. The consistently high participation from energy-intensive sectors (e.g., chemical) and high-employment sectors (e.g., transportation equipment) sectors reflects industry recognition of the Bootcamps as a practical avenue to address pressing operational and sustainability challenges. The growing share of attendees from non-partner organizations further suggests expanding industry demand and trust in this training model.

Participants ranked Compressed Air, Energy Basics and Understanding Your Utility Bills, and Process Heating as the top three most valuable sessions for the bootcamps focused on energy efficiency, whereas the sessions on Energy Efficiency, Industrial Electrification, and Renewable Energy led for the other type of bootcamp. These preferences reflect the significant potential of these energy systems and topics to drive improvements in energy efficiency and operational optimization.

Beyond individual skill development, by increasing dedicated discussion time, the bootcamps bring together professionals from diverse companies, roles, and sectors, to share challenges, exchange best practices, and co-develop solutions. The survey results highlighted the strong value of structured cross-industry peer learning, networking, and gaining inspiration from peer companies or counterparts in similar roles.

CRediT authorship contribution statement

Wei Guo: Writing – original draft, Visualization, Data curation, Conceptualization. **Kalie Miera:** Writing – review & editing, Conceptualization. **James Nguyen:** Writing – original draft, Visualization. **Alexandra Botts:** Writing – review & editing, Conceptualization. **Paulomi Nandy:** Writing – review & editing, Conceptualization. **Thomas Wenning:** Funding acquisition, Data curation, Conceptualization. **Jennifer Travis:** Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

The authors appreciated the support from US DOE Better Plants program and participating manufacturing companies.

References

[1] US Department of Energy (DOE). Better Buildings, Better Plants Program and Challenge 2025. https://betterbuildingssolutioncenter.energy.gov/better-plants.
[2] US Department of Energy (DOE). Better Buildings Progress Report 2024 n.d.
[3] Guo W, Wenning T, Nimbalkar SU, Travis J, Levine E. US DOE in-plant trainings to develop expertise and replicate success. 2019 ACEEE summer study. Portland, OR, USA: ACEEE; 2019. p. 2019.
[4] Guo W, Wenning T, Nimbalkar SU, Travis J, O'Neill J, Lung B. US Department of Energy Better Plants Program's Approach to Manufacturing Workforce Development. 2023 ACEEE Summer Study, Detroit, MI, USA: ACEEE; 2023.
[5] Guo W, Wenning TJ, Travis JM, Armstrong KO, Nimbalkar SU, Levine E. Delivering effective virtual energy-focused trainings: successful strategies and lessons learned from the virtual cohort in-plant training pilot. International Journal of Energy Management 2021;3.
[6] Botts A, Miera K, Wenning T, Guo W, Travis J. Workforce development opportunities through the US department of energy's better plants program 2025. International Journal of Energy Management 2025;7.
[7] US DOE. Better Plants Bootcamp Focused on Energy Efficiency 2025. https://energybootcamp.ornl.gov.
[8] US DOE. Better Plants Bootcamp Focused on Energy Efficiency Agenda 2025. https://energybootcamp.ornl.gov/wp-content/uploads/securepdfs/2024/12/Better-Plants-Energy-Bootcamp-Agenda-Feb-2025_12-03-2024.pdf.
[9] Accawi G, Root RM, Blondheim N, Howard D, Hernandez R, Armstrong K, et al. MEASUR-manufacturing energy assessment software for utility reduction. Oak Ridge TN (United States): Oak Ridge National Laboratory (ORNL); 2022.
[10] Malhotra M, Thirumaran K, Garcia Gonzalez S, Armstrong KO, Nimbalkar SU. Plant water profiler: a water balance and true cost of water calculator for manufacturing plants. Oak Ridge TN (United States): Oak Ridge National Laboratory (ORNL); 2021.
[11] US DOE. Better Plants Bootcamp Focused on Emission Reduction n.d. https://decarbbootcamp.ornl.gov.
[12] US DOE. Bootcamps Focused on Energy Efficiency Survey Questions n.d. https://www.surveymonkey.com/r/J6FZ933.
[13] US DOE. Bootcamp Focused on Emission Reduction Survey Questions n.d. https://www.surveymonkey.com/r/KD5HCZV.