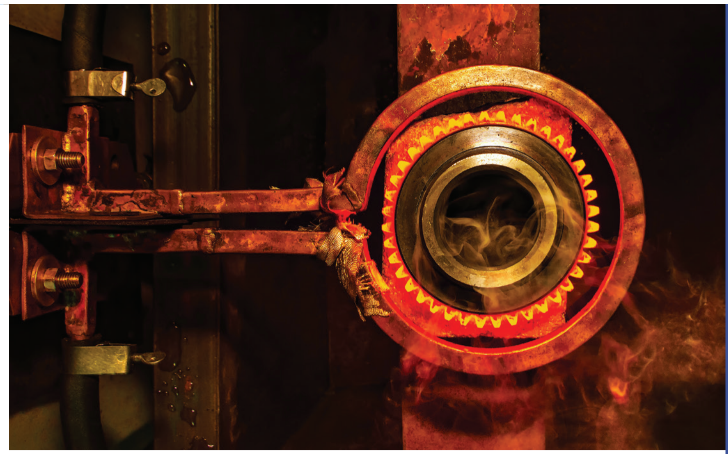

Industrial Electrification Assessment Framework

AUTHORS AND ACKNOWLEDGMENTS

The Industrial Electrification Assessment Framework was developed by the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) as part of the Better Buildings, Better Plants program, with input from the Better Climate Challenge Electrification Working Group. This framework was developed by staff at Oak Ridge National Laboratory (ORNL) and Electric Power Research Institute (EPRI) in collaboration with DOE

Authors

Kiran Thirumaran—Oak Ridge National Laboratory (ORNL), Lead Author
Kalie Miera—ORNL
Blake Billings—ORNL
Paulomi Nandy—ORNL
Thomas Wenning—ORNL
Baskar Vairamohan—Electric Power Research Institute (EPRI)
Scott Bishop—EPRI
Brandon Johnson—EPRI
Stephen Perry—EPRI

Better Climate Challenge Industrial Lead

John O'Neill, U.S. Department of Energy

Working Group Participating Organizations

Chemours
Colgate-Palmolive Company
HNI Corporation
Honeywell
Ingersoll Rand Corporation
Johnson Controls Inc.
Lear Corporation
Lundberg Family Farms
Saint-Gobain
Schneider Electric
Siemens
Steelcase
Stellantis
Stryker
Trane Technologies
Volvo Group North America
Whirlpool
Xerox Corporation

Reviewers

Keith Jamison – U.S. Department of Energy
Vijay Vittal - Arizona State University
Dee Spolarics - Volvo Group North America
Nahian Ismail Chowdhury - Volvo Group North America
Robert Lung - Lindahl Reed, Inc
Arvind Thekdi – E3M Inc.
Prasad Kandula—ORNL
Sachin Nimbalkar—ORNL

Industrial Electrification Assessment Framework

ACRONYMS AND ABBREVIATIONS

AC = alternating current

CO_2 = carbon dioxide

CO_2e = carbon dioxide equivalent

DC = direct current

DOE = U.S. Department of Energy

DSIRE = Database of State Incentives for Renewables and Efficiency

eGRID = Emissions & Generation Resource Integrated Database

EPA = Environmental Protection Agency

FAT = factory acceptance test

HP/IHP = heat pump/industrial heat pump

HVAC – Heating, Ventilation and Air Conditioning

IEA – International Energy Agency

IR = infrared

kV = kilovolt

kVA = kilovolt-amperes

MCC = motor control center

MEASUR – Manufacturing Energy Assessment Software for Utility Reduction (a free DOE software tool)

MMBtu/h = million British thermal units per hour

MT = metric ton

MW = microwave heating or megawatt

NREL = National Renewable Energy Laboratory

O&M = operations and maintenance

PF = power factor

RTU = Rooftop unit

SLD = single-line diagram

V = volt

VERIFI = Visualizing Energy Reporting Information and Financial Implications (a free DOE software tool)

VRF = variable refrigerant flow

ABOUT THIS FRAMEWORK

Purpose

Electrification refers to the process of transitioning from fuel-powered systems to electric-powered systems, or electrotechnologies. This document first provides an overview of industrial electrification, including possible advantages and common applications. Next, it provides a comprehensive, step-by-step framework for assessing the potential for electrification at an individual industrial facility. The steps in this framework include inventorying current fuel-powered systems, evaluating a manufacturing facility's electrification readiness, and identifying, evaluating, and prioritizing strategies and technologies. This document also contains information about project implementation, and the appendices provide tools and resources to support organizations pursuing electrification.

Audience for this Framework

This document is tailored to provide guidance to industrial organizations exploring electrification as a component of their energy strategy. This guidance will be most useful to those within an organization tasked with developing and executing energy management plans or operational strategies (e.g., corporate energy managers). This guidance is also helpful to partners with a mix of facilities such as manufacturing, warehouses, and office space. This framework outlines a process for developing a realistic, actionable electrification plan at the facility level.

Key Objectives of Industrial Electrification

Organizations may pursue electrification for a variety of reasons. Depending on the context, electrification can offer more precise control and simpler automation, improved product quality, and/or significant long-term cost savings due to reduced fuel expenses, lower maintenance costs, and increased productivity. It can also be a strategy for improving energy performance and, in certain cases, reducing emissions.

Because electrification projects are typically capital-intensive, it is essential to comprehensively consider all effects in a holistic manner before discounting electrification as too costly. Even if an organization is primarily interested in the safety benefits of electrification, quantifying other benefits like quality improvements can help improve the business case to pursue such projects. Considering all these factors holistically provides a more accurate understanding of the true value and potential benefits of electrification, rather than focusing solely on upfront expenses.

A manufacturer's electrification strategy may also vary depending on their key objectives and how much they value various impacts.

How to Use This Framework

This framework is designed to provide an end-to-end process to evaluate a manufacturing facility's electrification readiness, identify different strategies to deploy, assess the feasibility of various technologies and strategies, and identify tools and resources required to implement the technology. It is designed to enable users to focus on individual sections to obtain specific information they need and does not need to be read cover-to-cover.

This framework can also be used alongside its companion document, the *Industrial Electrification Technologies Booklet*, which provides greater detail on specific electrotechnologies and their advantages, disadvantages, and common applications. The Booklet should be used as an additional reference while working through step 2a of this framework, *Identifying Strategies for Electrification*.

Both documents focus primarily on three categories of electrification: process heating, heating, ventilation, and air conditioning (HVAC), and onsite transportation (e.g., forklifts and utility vehicles). These are three of the largest energy uses in the industrial sector with significant electrification potential, and they are also some of the most ubiquitous, regardless of the type of facility. Other notable industrial electrification opportunities exist, such as transitioning thermal separations to membrane separations, but they are not as widely applicable and are not a specific focus of this document.

EXECUTIVE SUMMARY

Overview of Industrial Electrification

Electrification is a key strategy for improving energy efficiency in the industrial sector. Process heating, HVAC, and onsite transportation (e.g., forklifts and utility vehicles) are three of the most common energy uses in the industrial sector and offer substantial potential for electrification.

Relationship Between Electrification and the Grid

Electrified systems require a consistent and sufficient energy grid, with considerations for geographic variations in grid capacity, electricity prices, and emissions intensity, as well as future grid developments and renewable energy integration. Lack of sufficient infrastructure to deliver necessary power is a significant barrier to industrial electrification. And even when infrastructure is sufficient, electricity prices greatly impact the feasibility of electrification opportunities. As for emissions impacts, they depend on the regional grid mix, but in many U.S. regions (though not all), electrification can deliver immediate emissions reductions because electric systems are typically more efficient than fuel-based alternatives.

Advantages of Electrification for Industrial Applications

There are several advantages common to most electric heating technologies. Electric heating allows for precise control of heat generation, making it ideal for applications requiring critical temperature control. Electric heating is more responsive than fuel-based heating, facilitating advanced automation and integration with production lines, which can enhance product quality and consistency.

Electrification also creates a safer and more comfortable working environment by eliminating open flames, smoke, waste, heat, noxious emissions, and loud noise. Specific electrotechnologies can provide additional unique advantages for certain applications. These advantages are covered to some extent in this document, and in greater detail in the companion document, the *Industrial Electrification Technologies Booklet*.

To navigate these opportunities and challenges effectively, the *Industrial Electrification Assessment Framework* provides a structured approach to evaluate electrification potential and make informed decisions.

Industrial Electrification Assessment Framework

In order to understand whether electrification is a viable pathway to achieve organizational goals, facility-level assessments are required to account for variations in infrastructure, electric grid composition, energy sources, and system conditions at different sites. The Industrial Electrification Assessment Framework includes three essential steps for how to conduct such an assessment: inventorying, screening, and evaluation. Completing these three steps results in a site-level electrification plan that manufacturers can use for project implementation.

Step 1: Establish Inventory and Energy Use

In Step 1, organizations establish an inventory of fuel-powered equipment, which involves identifying fuel-fired systems, gathering key system information, determining fuel use and emissions, and developing an electrification suitability rating.

Identifying Fuel-Fired Systems

Organizations should identify all fuel-fired systems through a comprehensive site audit, blueprint review, maintenance records, and personnel engagement. This information creates an inventory to track essential parameters including design, operating conditions, equipment age, and additional system characteristics for electrification decision-making.

Gather Key System Information

The inventory of current fuel-fired systems should be built out further by gathering key system information, including design attributes, current operating conditions, and equipment age. Additional system parameters such as make, model, equipment location, proximity to existing high-power lines, and facility space, further inform project feasibility.

Determine Fuel Use and Emissions

Estimating energy use and emissions for each fuel-fired system is crucial for project prioritization, using tools including direct measurement, engineering estimation, and utility bill analysis, using EPA emission factors to calculate emissions from fuel use.

Develop Electrification Suitability Rating

Electrification suitability ratings help prioritize fuel-fired systems for a more detailed analysis by using subjective or quantitative scoring methods based on relevant parameters. This serves as a starting point to evaluate a process based on readily available information. After this step, an organization will have a comprehensive list of all fuel-powered equipment on-site and the information needed to begin identifying suitable electrification opportunities.

Step 2a: Identifying Strategies for Electrification

In Step 2a, organizations identify possible electrotechnology replacements for each fuel-powered system on-site. Decision-making tools, including color-coded matrices and flowcharts, allow users to methodically identify the most suitable technology for their application. The tools provide a preliminary screening, but process-specific, facility-specific, and product-specific parameters must be evaluated in detail prior to final selection. A detailed analysis of alternative technologies is provided in the *Industrial Electrification Technologies Booklet*.

Electrotechnologies for Process Heating

Common electric process heating methods include resistance heating, induction heating, electric arc heating, infrared for surface heating and drying, and microwave and radio frequency heating. Not every technology will be well-suited for every application, but there may be several options for any given process heating need. Thermal energy storage allows renewable electricity to be stored as heat.

Electrotechnologies for HVAC

HVAC systems are crucial for regulating manufacturing environments, and recent advancements make HVAC systems easier to electrify than many process heating systems. Variable refrigerant flow systems, electric boilers, and heat pumps are suitable for various environments, with geothermal heat pumps being more region-specific.

Electrotechnologies for Forklifts and Utility Vehicles

Selecting forklift power options depends on operational needs, load capacity, environment, and cost, with considerations for charging/refueling infrastructure, battery types – and their respective costs and suitability for continuous operations – supported by consultations and technological advancements.

Step 2b: Assessing Facility's Electric Infrastructure Readiness

Electrification readiness refers to how prepared a facility is to transition its energy sources and processes from nonelectric sources to electricity. Defining a facility's electrification readiness includes estimating the increased load from electrification, assessing the existing electric infrastructure, and identifying advanced electricity management techniques.

Estimate Increased Electric Load from Electrification

When switching to electric systems, users can estimate the new electric load by comparing the efficiency of current systems to the expected efficiency of the new systems. This helps determine the capacity required to support new electrical loads. Tools like the DOE's MEASUR platform can help assess system efficiency, fuel usage, heat losses, and potential energy savings.

Assess Existing Electric Infrastructure

Users can evaluate the current electrical infrastructure's capacity to handle additional load by assessing transformers, switchgear, distribution panels, and wiring systems, using the *Electrification Readiness Checklist* and single-line diagrams to identify potential upgrades or replacements needed for efficient and safe electrification.

Identify Advanced Electricity Management Techniques

After evaluating the facility's electrical infrastructure and completing an initial load analysis, electricity management techniques such as load management, energy efficiency improvements, power factor correction, remote monitoring, voltage regulation, and renewable energy integration can optimize current operations, maximizing how much electrification is possible without needing to make expensive upgrades to electric infrastructure.

Step 3: Evaluating and Prioritizing Projects

Step 3 includes evaluating electrification projects and prioritizing which to pursue based on holistic benefits, technical feasibility, energy availability and reliability, and financing.

Evaluating Impact

Assessing the holistic benefits of electrification projects can offer financial justification and assist in prioritization. Beyond cost and energy, facilities should consider possible additional advantages of electrification, such as enhanced productivity, reduced maintenance and scrap, improved product quality, enhanced safety, and reduced emissions.

Evaluating a Project's Technical Feasibility

When assessing the feasibility of switching to electrotechnologies, organizations must evaluate existing process requirements, perform technology feasibility screening, check product quality requirements, and conduct pilot testing to ensure seamless integration without disrupting production or compromising safety and quality.

Evaluating Energy Availability and Reliability

To ensure energy availability and reliability for electrification projects, it may be necessary to evaluate and upgrade electrical infrastructure, revise energy procurement strategies, and develop contingency plans. It is crucial to collaborate with utilities on capacity planning, grid upgrades, resiliency plans, and integrating advanced electricity management techniques.

Identifying Financing Opportunities

Effective project evaluation for electrification involves leveraging diverse financing strategies and identifying incentives to optimize financial and operational outcomes.

Drafting a Facility-Level Electrification Plan

Using insights from the technology evaluation and infrastructure assessment, users can create an electrification plan that aligns with facility capabilities and prioritizes projects based on multiple factors. Projects can be prioritized for short-, mid-, and long-term implementation.

Project Implementation

After an electrification plan has been developed, organizations can begin to implement it. Proper planning to secure funds for projects, ensure regulatory compliance, coordinate safe installation, and develop workforce training before implementing an electrification project can help create a seamless transition.

Securing Project Funds

Securing funds for project execution involves obtaining internal and external funding, presenting a business case, applying for loans, and leveraging government grants, tax credits, and utility rebates. All necessary funding should be secured before procurement and installation.

Regulatory Compliance and Permitting

Ensuring compliance with local codes, regulations, and safety standards, obtaining necessary permits and approvals early, and engaging with regulatory authorities can prevent delays and legal issues in project implementation.

Installation and Testing

It is essential to coordinate with contractors for safe installation, conduct Factory Acceptance Tests, and ensure thorough testing and commissioning of new electrical infrastructure, while planning for custom built electrotechnologies and necessary workforce training.

Documentation

Organizations should document all changes to electrical infrastructure and processes, update standard operating procedures and maintenance procedures, ensure workforce training and safety compliance, and integrate enhanced data handling capabilities into existing systems.

Workforce Training

Collaboration with electrotechnology vendors to develop training programs for the workforce, specify training requirements in solicitation documents, and ensure training for efficient and safe operation and maintenance of new technologies can ensure a seamless transition.

Monitoring and Maintenance

Implementing a monitoring system for early issue detection and establishing a regular maintenance schedule integrated with vendor plans will ensure optimal performance and longevity of the electrical infrastructure.

Continually Review and Update Electrification Plan

Organizations should revise the electrification plan after each major project or significant facility change and adjust it as new technologies and techniques are identified, ensuring the strategy remains timely, effective, and responsive.

Electrification offers industrial facilities a strategic opportunity to enhance operational efficiency and achieve goals related to productivity, quality, safety, cost, and emissions, guided by a systematic framework for assessment and implementation. By refining electrification strategies in response to technological advancements and regulatory changes, facilities can overcome challenges, unlock new efficiencies, gain a competitive advantage, and fully realize the benefits of electrification.

OVERVIEW OF INDUSTRIAL ELECTRIFICATION

The industrial sector uses approximately one-third of the energy consumed in the United States. Electrification is a key strategy for improving energy efficiency in many economic sectors, including industry. The International Energy Agency (IEA) has highlighted the significant potential of electrification in industrial processes in several publications.[1]

Electrification is the transition from fuel-powered equipment or processes to electrically powered alternatives. Most of the fuel consumed in manufacturing facilities is for process heating (such as furnaces and ovens), space heating and cooling (including steam boilers and rooftop units), and on-site transportation (such as forklifts and utility vehicles). Notably, while over 50% of the energy consumption in the manufacturing industry is from process heating, less than 5% of this energy is electrified. Figure 1 illustrates the energy consumption for process heating, broken down by energy source across major manufacturing sectors. Except for the iron and steel sector, which has increasingly shifted to electric arc furnaces, the electric contribution to process heating is minimal. These data show substantial potential for electrification within the manufacturing sector.[2]

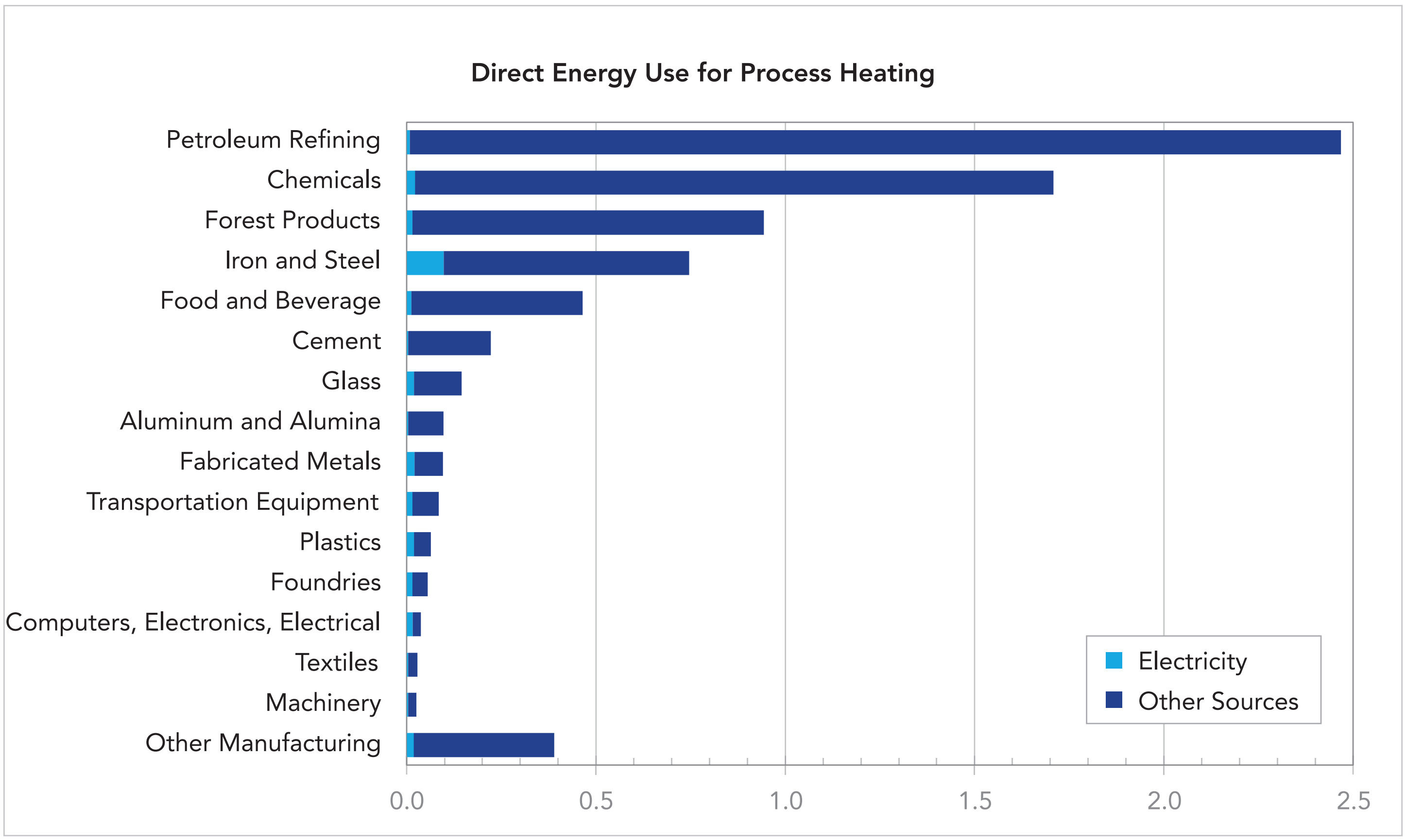

Figure 1. Energy used by process heating equipment by energy source, showing the potential for electrification in different sectors in 2018.

[1] International Energy Agency, Industrial Electrification, https://iea-industry.org/publications/topic-sheet-industrial-electrification/

[2] U.S. Energy Information Administration, Manufacturing Energy Consumption Survey, 2018 (Washington, DC: U.S. Energy Information Administration, 2018).

Conducting a facility-level electrification assessment helps to identify and evaluate opportunities systematically. A facility level approach evaluates the energy use, equipment, and processes within an individual facility/plant boundary to identify electrification opportunities.

Electrification and the Grid

Just as fuel-powered system reliability requires consistent fuel sources, electrified systems need a sufficient and consistent power grid. Electrification of industrial-scale energy loads require an understanding of the grid's capacity– which varies geographically. Some grid regions may have limitations such as insufficient transmission capacity, which can impact electrification efforts. Electricity prices vary geographically, impacting the business case for the same type of project across different regions. Additionally, if pursuing electrification to lower emissions, it is important to consider the emissions intensity of electricity, which also varies regionally. In many U.S. regions, electrification provides immediate emissions reductions because of the increased efficiency of electric systems over fuel–based alternatives, regardless of the current grid mix. These impacts are even stronger when electric systems are powered by renewable energy.

When investing in electrification infrastructure, such as the purchase of a new furnace, it is essential to consider not just the present condition of the grid but also its expected development. For example, utilities may have plans to expand transmission capacity that could impact timing for electrification. Similarly, companies pursuing emissions reductions should study projections of how the grid's emissions intensity may change over time and consider emissions over the entire life of that system, beyond the moment of installation. Most grid regions have integrated alternative energy sources in recent history, (Figure 2)[3] and most projections indicate they will continue to do so, (Figure 3)[4] meaning the emissions impact of electrification is likely to continue increasing.

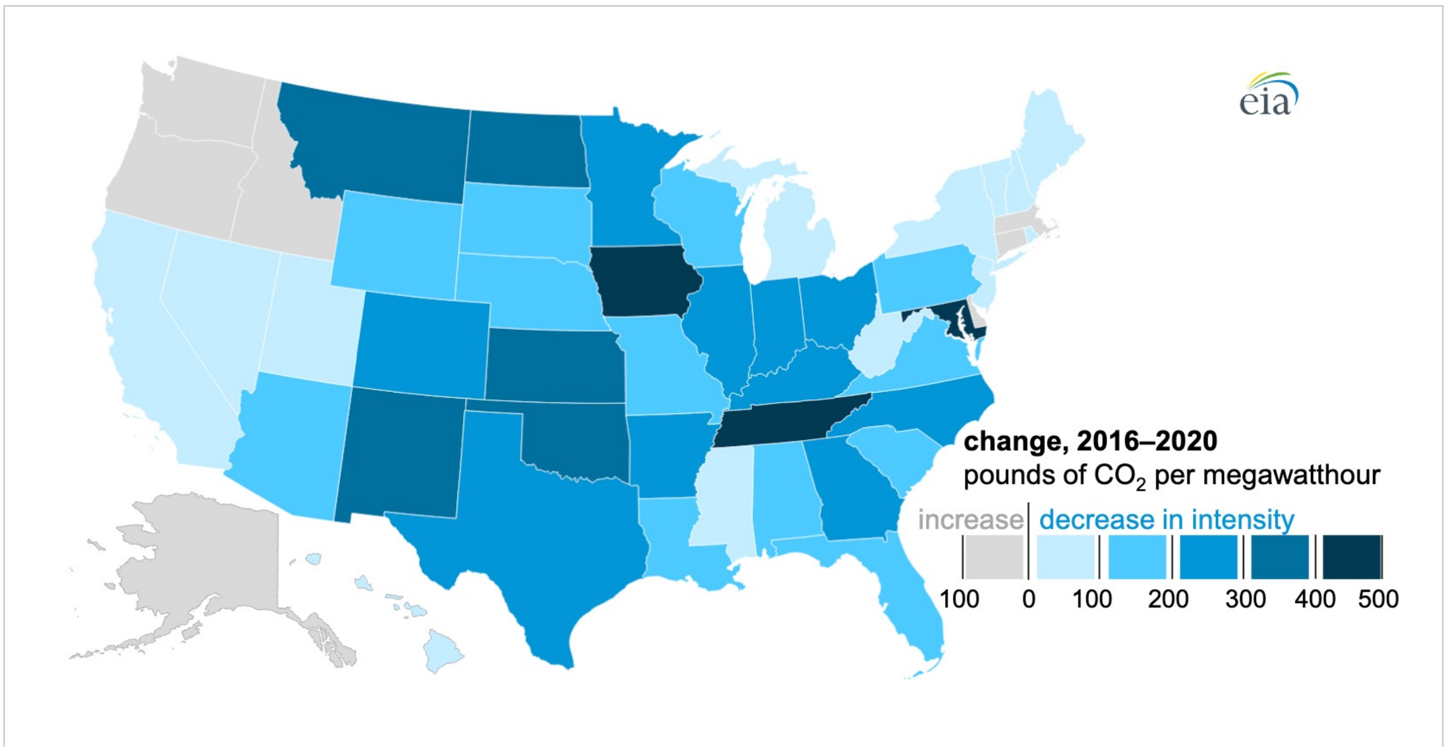

Figure 2. Historic change in grid's emissions intensity

[3] U.S. Energy Information Administration, Power Plant Operations Report (U.S. Energy Information Administration).

[4] U.S. Energy Information Administration, Annual Energy Outlook 2023—U.S. Electricity Generation from Selected Fuels (Washington, DC: U.S. Energy Information Administration, 2023).

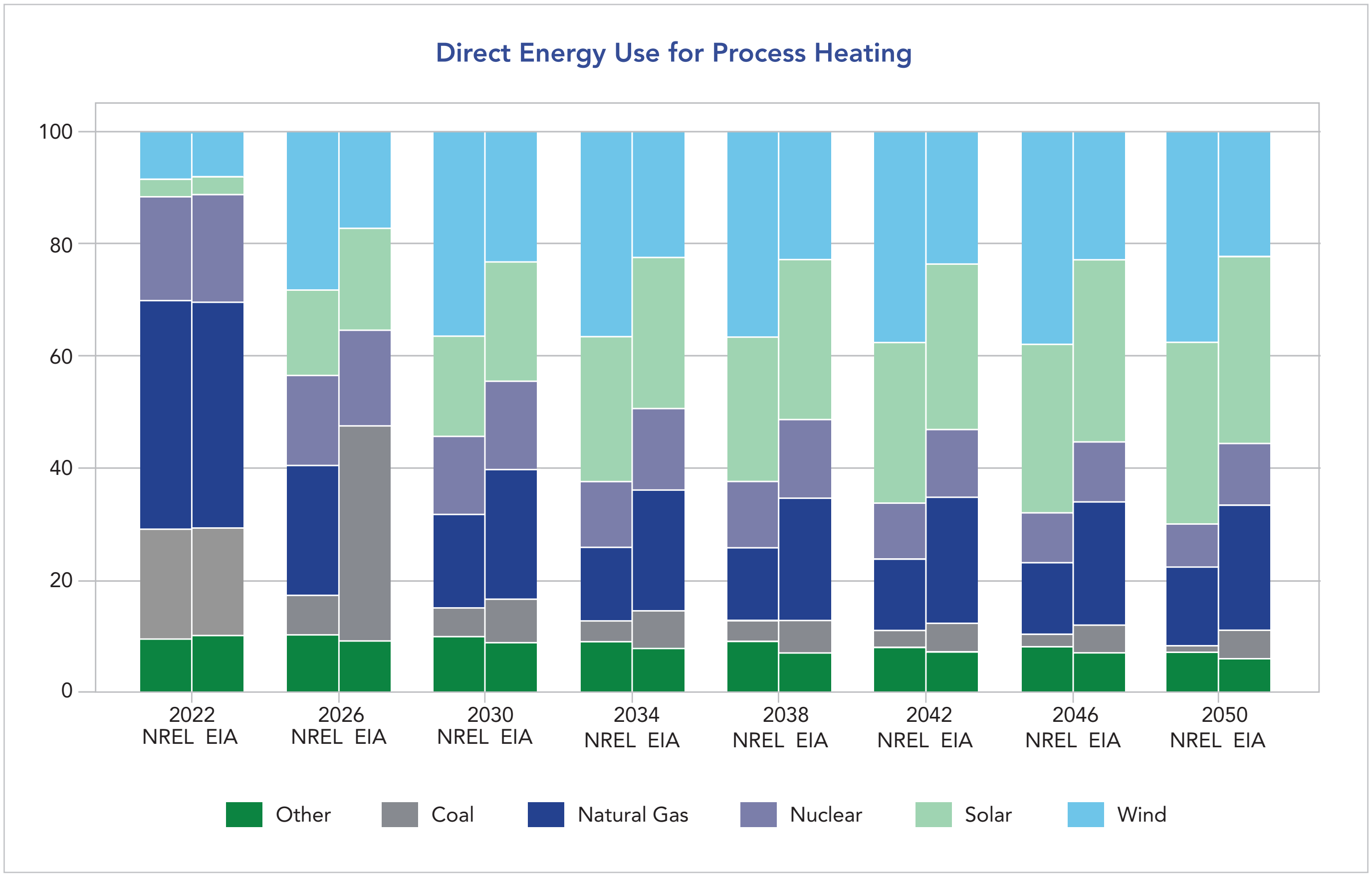

Figure 3. Projected change in fuel mix for electricity generation in the United States from the National Renewable Energy Laboratory and U.S. Energy Information Administration.

Advantages of Electrification

The use of electricity for heating has inherent advantages, which are common for most electrotechnologies.

- **Easier process control and monitoring:** Electricity allows for precise control of heat generation, making it suitable for applications in which temperature control is critical.
- **Ease of automation:** Electric heating, being more responsive, lends itself to implementing advanced control strategies and integrating with the broader production line.
- **Product quality:** Precise and responsive control combined with a higher degree of automation can lead to improved product quality and consistency. These results are process- and product-dependent and should be carefully assessed and implemented.
- **Reduced emissions:** Electrification has the potential to reduce emissions compared with traditional fuel–based heating methods, depending on the source of the electricity.
- **A more comfortable, safe working environment:** Heating via electrification is safe and efficient with no open flame to endanger the operator. An electric system further improves working conditions for technicians by eliminating smoke, waste heat, noxious emissions, and loud noise.

In addition to these common benefits, specific electrotechnologies have characteristics favorable to certain applications and have technology-specific benefits. Several of the unique advantages of specific electrotechnologies are listed in Table 1. The companion document to this framework, the *Industrial Electrification Technologies Booklet*, provides more details on the advantages, disadvantages, and common applications of these technologies.

Table 1. Summary of Major Electrotechnologies

Technology	Advantages	Common Application
Resistance	Highly efficient and suitable for all materials and heating processes	Liquid heating such as lubricating oils, heavy or light oils, and waxes
Electric Infrared	Compact footprint and has fast heating rates, improving productivity	Drying of material or curing of paint
Induction	Can provide targeted, precise heating to a specific location depending on coil design	Remelting and heat treatment of metals
Microwave	Provides uniform volumetric heating and can selectively heat specific materials	Drying application in food and chemicals sector
Heat Pumps	Highly efficient with the ability to upgrade heat rather than generate it, offering significant energy savings	Space heating, water heating, and low-temperature processes
Electric Boiler	Compatible with a wide range of industrial heating applications	Steam generation and water heating

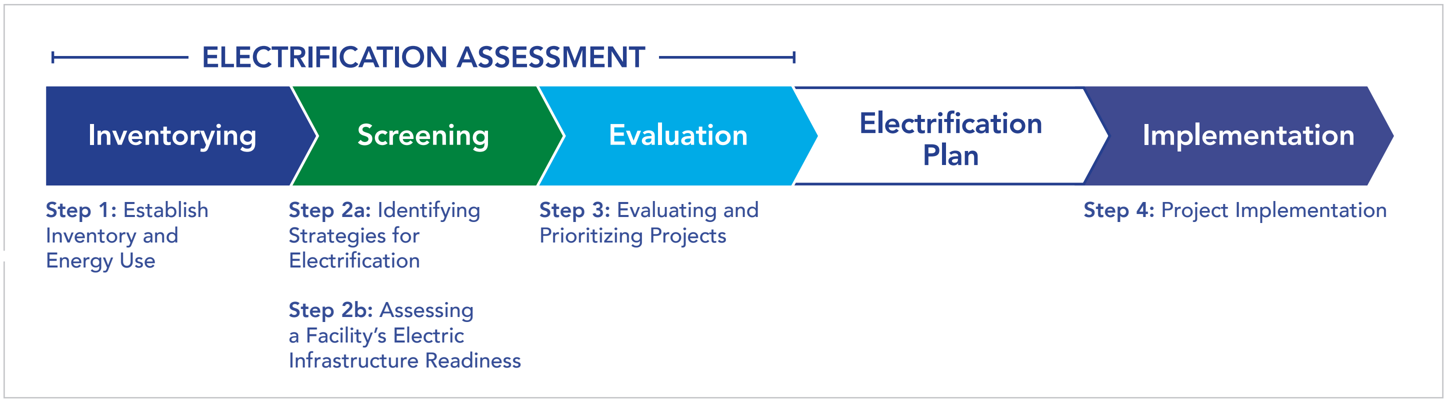

Figure 4. Electrification Assessment Framework

INDUSTRIAL ELECTRIFICATION ASSESSMENT FRAMEWORK

Assessing an organization's electrification readiness requires facility-level assessments because of critical differences between different facilities within an organization's portfolio. Different locations can have distinct electrical infrastructure, electric grid composition, and availability of renewable energy sources. Prices for electricity and for fuels being replaced by electrified systems also vary regionally. Different locations often have existing systems that could be electrified, and similar types of systems across facilities might have different age and performance characteristics impacting decision-making on system electrification. Logical changes at one plant may be expensive or impractical at another.

Figure 4 outlines a framework for conducting a facility-level electrification assessment. The first step inventories the site's fuel-fired systems; understanding the existing equipment, its operation, and what it does for the plant is essential for a successful assessment. The next step, technology screening, helps to identify suitable electrification technologies and understand the facility's existing electric infrastructure. These screening steps can be performed simultaneously or successively depending on the site's needs and available information. Finally, a comprehensive evaluation of the identified technologies is necessary to assess their overall impacts and feasibility. Completion of these three steps results in a site-level electrification plan. Manufacturers can then strategically implement electrification projects with confidence.

Electrification requires external engagement, including collaborating with vendors and equipment manufacturers to explore available technologies and working with local utilities to understand the effects of electrification on a facility's electric load. Involving these external entities throughout the process is essential to leverage their expertise effectively and address specific challenges as they arise.

STEP 1. ESTABLISH INVENTORY AND ENERGY USE

The initial step in conducting a facility-level electrification assessment is creating a precise inventory of fuel-fired systems. This inventory lays the groundwork for identifying suitable thermal processes for electrification and prioritization based on factors such as cost or emission reduction.

Upon completing this step, the user will have a comprehensive list of all fuel–powered equipment on-site and the relevant information to begin identifying suitable electrification opportunities. Figure 5 provides an overview of the steps involved in establishing an inventory.

Identify Fuel-Fired System

To identify all fuel-fired systems in an industrial facility, conduct a site audit to inspect areas where such equipment is likely to be used, including boilers and heating systems. One way to identify all equipment, particularly smaller equipment, is to systematically walk through the entire plant, starting from the main supply pipe and tracing all fuel-delivery pipes to the end-use equipment. Additionally, review the facility's blueprints or schematic diagrams for fuel-fired equipment. Maintenance records are a valuable resource, providing details on equipment, such as furnaces and boilers, that require regular servicing. Consulting with on-site personnel can offer insights into the operation of the equipment, ensuring no equipment is overlooked.

Figure 5. Steps to establishing an electrification inventory.

Gather Key System Information

A useful inventory requires parameters that will aid in electrification decision-making. The following list details essential parameters in a comprehensive inventory, along with key considerations for each.

- **Design parameters** provide insight into the original built condition of the equipment. The key design parameter to include is the total heat input capacity of the equipment. Other useful design parameters include the maximum achievable temperature, physical footprint, and production capacity.
- The **operating parameters** of the thermal heating system specify the system's current operations, which may differ from its design parameters. Parameters such as operating temperature, burner firing rate, efficiency, operating hours, and average product flow help determine the equipment's current operating condition. The load factor, the average load divided by the peak load, is another common parameter to understand the equipment's operating condition. A method to calculate the load factor is provided in Appendix B.
- **Age of equipment** is critical in planning for major capital improvements such as electrification. Understanding the expected useful life of the equipment helps in timing replacements and upgrades. Replacing large equipment at end-of-life is more cost-effective than retiring still-functional equipment early. Identifying the age of the equipment streamlines identification of which systems need immediate attention, and which should wait for future upgrades.
- **Additional system parameters** and characteristics should be included as part of the inventory. These parameters may include the make, model, and location of the equipment. Knowing the proximity to existing high-power lines and the space available at the facility help gauge the difficulties with project implementation.

Determine Fuel Use and Emissions

Estimating the energy use and emissions for each fuel-fired system is crucial for prioritizing projects. Various tools and methods can help accurately establish energy use and emissions. Although direct measurement through permanent submetering or instantaneous spot measurements provides the most precise energy use data, system-level engineering estimation and a top-down utility bill analysis can make a sufficiently accurate first-order estimation. Appendix E presents steps to perform a simple utility bill analysis to provide insights into the facility's thermal system energy use profile.

System emissions can be calculated from the fuel use using specific emission factors for each fuel type. Default emission factors for fuels are made available by the U.S. Environmental Protection Agency.[5] More detailed guidance on calculating system emissions is described in DOE's *Better Climate Challenge Greenhouse Gas Emissions Reporting Guidance Document.*[6]

Develop Electrification Suitability Rating

Rating each fuel-fired system's suitability for electrification helps determine which systems to prioritize for more detailed analysis. This score can be assigned using subjective scales or quantitative methods based on the different parameters affecting electrification. Two methods to establish an electrification suitability rating are provided in Figure 6 and Table 2 as examples. Please note that this scoring is a starting point in evaluating a process and should be kept simple. It should use readily available information without requiring significant time.

---

[5] U.S. Environmental Protection Agency Center for Corporate Climate Leadership, "GHG Emission Factors Hub," U.S. Environmental Protection Agency, last updated February 22, 2024, https://www.epa.gov/climateleadership/ghg-emission-factors-hub.

[6] U.S. Department of Energy, Better Climate Change Greenhouse Gas Emissions Reporting Guidance Document (Washington, DC: U.S. Department of Energy, 2024). https://www.osti.gov/biblio/2428034

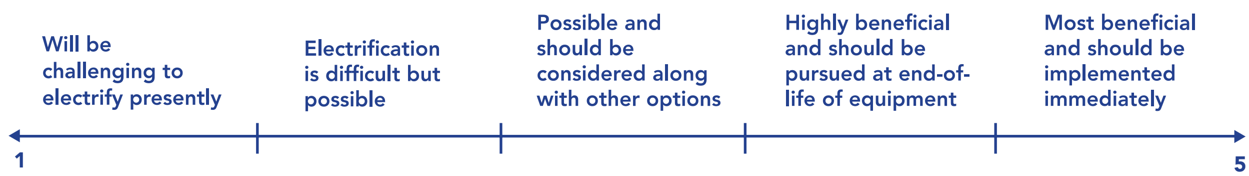

Figure 6. Establishing electrification suitability scores—examples.

The example in Figure 6 illustrates a simple, subjective scoring system for fuel-powered systems. The rating can be established by the facility's subject matter expert or through collective discussion with engineers and operators. Relevant expertise and insights from vendors, contractors, utility representatives, and external consultants can be used as necessary to determine appropriate ratings.

A quantitative scoring method can integrate various criteria assessing a system's suitability for electrification. Multiple criteria can be selected based on the specific needs of the process, with each system rated on a scale of 1 (least suitable) to 10 (most suitable). A weighted average for each system can then be used to calculate the total suitability score. The following list contains criteria to consider in determining the suitability of electrifying existing systems. This list is not comprehensive nor universal, the criteria selected should reflect the plant's priorities.

- **Production flexibility needs:** Electric heating systems offer rapid heating, enabling quick temperature adjustments. This flexibility is essential for managing frequent changes in furnace temperature, production demands, and product variations. If the existing process is a bottleneck requiring higher throughput or more flexible operation, it would score high on this metric.
- **Need for accurate temperature control:** Electric heating systems provide temperature control using sensors and automated devices resulting in a precise spatial temperature profile. Adjustments are straightforward, involving the activation or deactivation of heating elements to maintain desired temperatures. If the process required strict temperature controls for product quality, it would score higher for this consideration.
- **High current scrap loss:** Electric heating uniformly heats materials, reducing scrap losses. If scrap loss in the process is high and could be reduced through electrification, a higher rating should be assigned.
- **Safety and noise concerns:** Electric heating systems are quieter and emit minimal harmful radiation. The cooler operating environment of electric furnaces provides a safer and more comfortable workspace for operators. Current safety and noise concerns with the existing system can help determine the rating in this category.
- **Additional criteria:** It is important to consider other factors influencing the decision to electrify specific systems. These include maintenance and operational needs that impact system upkeep and reliability. Convenience factors, such as the integration of electric forklift charging, and level of redundancy available to ensure a smooth transition, can also be considered.

Table 2. Example of Suitability Scores Table

	Potential Emission Reduction	Need for accurate temperature control	Productivity Needs	Scrap Loss Reduction	Suitability Rating
Weighting factor	1.0	1.5	2.0	2.5	
Furnace 1	8	7	6	9	7.6
Furnace 2	6	9	7	6	6.9
Steam Boiler	7	9	3	1	4.1

STEP 2A. IDENTIFYING STRATEGIES FOR ELECTRIFICATION

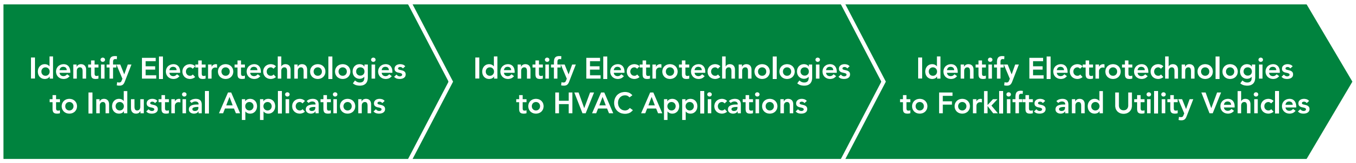

Figure 7. Identifying strategies for electrification.

In Step 2a of the Industrial Electrification Assessment Framework, manufacturers identify the most relevant technology categories for replacement of the fuel-powered systems identified in Step 1. These projects are further evaluated in Step 3.

Fuels consumed in manufacturing facilities are primarily dedicated to process heating applications (such as melting, drying, and heat treatment), HVAC (including space heating and conditioning), and on-site transportation (such as forklifts and utility vehicles). This section discusses suitable electrotechnologies for each application, with an emphasis on process heating, which is unique to the manufacturing sector and accounts for over 50% of the energy used in the sector.

Organizations should identify alternative electrotechnologies for each fuel-powered system at the site. Facilities can begin with systems deemed most suitable based on the suitability ratings determined during the "Establish Inventory" step.

Electrotechnologies for Process Heating

Electric heating systems employ technologies to transform incoming electrical energy at the line voltage into thermal energy, effectively heating materials. Common electric process heating options include:

- Resistance heating: Uses electric currents to generate heat, making it suitable for a wide range of applications.
- Induction heating: Provides precise and rapid heating through electromagnetic induction, which is ideal for metal processing.
- Electric arc heating: Generates intense heat using electric arcs and is commonly used in steelmaking.
- Electric infrared processing: Uses infrared radiation suitable for surface heating and drying.
- Microwave and radio frequency heating: Penetrate materials to provide uniform heating, which is beneficial for food processing and drying.
- Thermal energy storage: Offer a way to store renewable electricity as heat and achieve high temperatures suitable for various process heating applications.

Understanding these technologies' fundamental principles and assessing their advantages and limitations are essential to make informed decisions. A more detailed analysis of these technologies is provided in the Industrial Electrification Technologies Booklet.

Matching Electrotechnologies to Process Heating Applications

To explore applications of electrotechnology for fuel-fired heating systems, it is essential to analyze the specific process requirements and identify which existing and emerging electrotechnologies can competitively meet these needs.

The color-coded matrix in Figure 8 allows users to quickly identify commonly used electric heating solutions for specific industrial processes. It pairs heating applications with suitable electrotechnologies based on applicable temperature ranges and typical uses observed in the field. The color coding—blue for temperatures below 800°F, yellow for 800°F to 1,200°F, and red for above 1,200°F—helps users understand which temperature ranges generally best serve each technology. While a more detailed analysis considering the nuances associated with the operations at the site is necessary later, this preliminary screening can be made from a general understanding of the process.

Thermal Process Steps	Iron and Steel	Petroleum Refining	Chemical Industry	Glass	Aluminum	Forest Products	Food Processing	Cement	Textiles	Ceramics
Calcining	RH/IH	RH/IH	RH		RH	RH		RH		
Curing and forming			IR/RH/HP	RH		IR/RH	IR/RH		IR/RH	IR/HP
Drying		RH/HP	IR/MW/ HP		IR/RH/HP	IR/MW/ RH/HP	IR/MW/ RH/HP		IR/MW/ HP	RH/IR/HP
Fluid heating	EB/MW/ RH/HP	IH/HP	MW/HP			EB/MW/ RH/HP	EB/MW/ RH/HP		EB/MW/ RH/HP	
Heat treatment (metal and nonmetal)	IH/RH		RH	RH	IH	RH				RH
Metal and nonmetal reheating	EAF/IH		RH/IH		IH					
Metal and nonmetal melting	EAF/IH			RH	IH					RH
Reactive thermal processing	EAF/IH	RH/MW	RH/MW							
Smelting, agglomeration etc.	EAF/IH		RH					RH		
Steam generation	EB	EB	EB		EB	EB	EB	EB	EB	

Figure 8. Key industrial process heating applications, temperature ranges, and preliminary matching of process heating applications with electrotechnologies. RH: resistance heating, IH: induction heating, EAF: electric arc heating, EIR: electric infrared processing, MW: microwave heating, RF: radio frequency heating, EB: electric boiler, HP: industrial heat pump. Color indicates the upper-bound temperature range for a given application:

<800°F   800°F–1,200°F   >1,200°F

While Figure 8 provides high-level matching of technologies to their applicable temperature ranges and common industrial applications, the flowchart presented in Figure 9 outlines the considerations for initial screening based on specific characteristics. Each node in the flowchart presents two options, guiding the user step by step through the material properties or specific process needs. It starts with broader categories, such as curing, drying, and baking, then delves into specialized applications. This structured decision-making tool is another way for users to methodically identify the most appropriate electrotechnology for their application.

The flowchart considers several initial key process considerations, but is not all-encompassing. Process-specific, facility-specific, and product-specific parameters beyond the scope of the flowchart influence the technology selection process and must be evaluated in detail. Similarly, this flowchart focuses on technical feasibility; it omits economic and other factors. More detailed modeling and analysis is discussed in "Step 3. Evaluating and Prioritizing Projects".

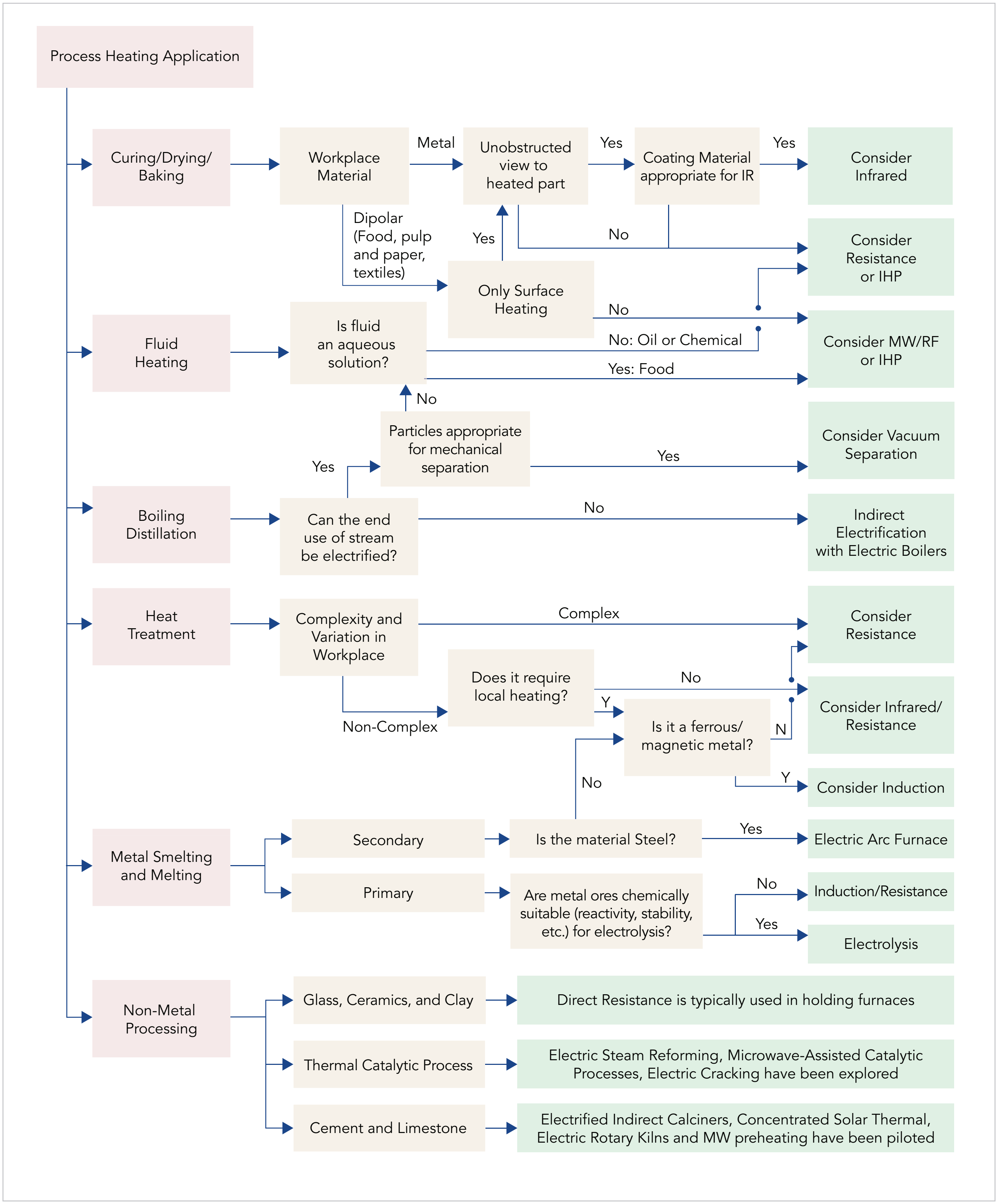

Figure 9. Electrification technology screening flowchart.

Electrotechnologies for HVAC

Industrial HVAC systems ensure comfort in office spaces and efficiency in manufacturing areas. In office environments, HVAC systems maintain consistent temperatures and enhance indoor air quality by filtering pollutants and controlling humidity. These systems support a comfortable and productive workspace for employees. In manufacturing environments, HVAC systems regulate temperatures to protect sensitive equipment and materials, provide adequate ventilation to remove fumes and dust, and manage humidity to prevent equipment corrosion and maintain product quality. Specialized HVAC solutions cater to unique manufacturing processes, such as clean rooms in semiconductor manufacturing, which require precise environmental controls.

These systems can be electrified using advanced technologies to replace conventional fuel-fired systems, presenting a significant opportunity for reducing emissions and improving energy efficiency. Common electric HVAC options include electric heat pumps, electric boilers, variable refrigerant flow (VRF) systems, electric resistance heating, and geothermal heat pumps. An overview of these technologies and their common applications are provided in the Industrial Electrification Technologies Booklet.

Matching Electrotechnologies to HVAC Applications

When selecting the ideal HVAC technology for industrial applications, it is crucial to consider the factors that address both the comfort of office environments and the specific needs of manufacturing areas. The decision table in Table 3 compares commonly used electric HVAC systems against key selection criterions. Users can systematically compare the suitability of each technology based on the priorities of individual sites.

Table 3. HVAC Decision Table.

Criteria	Air/Water Source Heat Pumps	Electric Boilers	VRF Systems	Electric Resistance Heating	Geothermal Heat Pumps
Energy Efficiency	High	Medium	High	Low	Very High
Initial Cost	Medium	Low	High	Low	High
Operating Cost	Low	High	Low	High	Very Low
Maintenance	Medium	Low	Medium	Low	Medium
Regional Applicability	Dependent	Independent	Independent	Independent	Dependent
Scalability	High	High	Medium	Medium	Medium
Integration with Existing Systems	High	High	Medium	High	Medium
Temperature Regulation	High	Medium	High	Low	High
Indoor Air Quality (for Office)	High	Medium	High	Low	High
Environmental Control (for Manufacturing)	High	Medium	High	Low	High

Very high-performance characteristic

Favorable or high-performance characteristic

Medium or moderate performance characteristic

Low or less favorable performance characteristic

To use this table effectively, first understand the specific needs and key criteria of the site. Energy efficiency, costs, scalability, maintenance, temperature regulation, and indoor air quality are self-explanatory criteria. The others are explained in more detail below.

Integration with existing systems refers to the ease of incorporating new HVAC technology into the facility's infrastructure. For example, if your organization's office building has modern ductwork and a building management system, VRF systems are highly suitable. VRF systems seamlessly integrate with existing components, lowering installation costs and downtime. In manufacturing environments, specialized needs are common. For instance, foundries with bag house systems for dust removal benefit most from electric boilers, which work with existing ventilation systems to maintain air quality. Similarly, semiconductor clean rooms requiring precise environmental control might find heat pumps ideal because their stable and consistent performance meets stringent conditions.

Regional applicability indicates regional impacts on the effectiveness of an HVAC technology, such as climate and geological conditions. For instance, geothermal heat pumps are highly efficient but depend on suitable ground conditions, which vary regionally. Conversely, electric boilers generally provide reliable heating solutions across climates, making them a versatile option.

Environmental controls refer to the system's ability to regulate environmental factors such as temperature, humidity, and air quality. This can be critical in manufacturing environments needing specific conditions to ensure product and process quality and safety.

Electrotechnologies in HVAC systems have seen significant advancements in recent years and are seen as the easier to electrify than process heating systems, especially in milder climates. Many principles found in the electrification of commercial HVAC systems are similar or identical to industrial HVAC systems.

Electrotechnologies for Forklifts and Utility Vehicles

Various options exist to electrify industrial forklifts through replacement of conventional internal combustion engines. Common electric options include lead-acid batteries, lithium-ion batteries, and hydrogen fuel cells. These replace traditional natural gas- or propane-fueled internal combustion engines, generating electricity for vehicle power. Each system presents unique considerations, enabling facilities to make informed choices based on specific operational needs and environmental goals.

Transitioning to electric forklifts requires adequate charging infrastructure for operational efficiency. Battery-powered forklifts need charging stations with sufficient capacity to support the fleet's energy demands. This may involve upgrading electrical systems, ensuring proper ventilation for lead-acid battery charging, and providing designated charging areas to minimize downtime. For hydrogen fuel cell forklifts, facilities must establish safe and efficient hydrogen refueling stations, which can require specialized equipment.

Matching Electrotechnologies to Forklifts and Utility Vehicles

Choosing between lithium-ion batteries, lead-acid batteries, fuel cell electric forklifts, or a hybrid forklift (combining electric and internal combustion engines) depends on your specific needs and operational environment. Each has different advantages, the optimal choice depends on operational requirements, such as load capacity, operating environment, cost considerations, and environmental goals. Table 4 helps users identify the most suitable technology for their specific priorities.

[7] U.S. Department of Energy Better Buildings, *Decarbonizing HVAC and Water Heating in Commercial Buildings*, DOE/EE-2525 (Washington, DC: U.S. Department of Energy, November 2021).

Table 4. Forklifts and Utility Vehicles Decision Table

Criteria	Lead-Acid Battery	Lithium-Ion Battery	Fuel Cell
Initial Cost	Low	High	High
Operating Cost	Moderate	Low	Moderate-High
Maintenance	High	Low	Low
Run Time	Moderate	High	Very High
Refueling/Recharging	Slow	Fast	Very Fast
Emissions	None	None	None
Indoor Air Quality	Excellent	Excellent	Excellent
Suitability for Multishift	Poor	Good	Excellent

Very high-performance characteristic

Favorable or high-performance characteristic

Medium or moderate performance characteristic

Low or less favorable performance characteristic

To use this table effectively, first understand the needs of the facility and applicable key criteria. Initial cost, maintenance, run time, refueling/recharging speed, emissions, and indoor air quality are self-explanatory. The other criteria are explained in more detail below.

Operating cost refers to the ongoing expenses associated with running the forklifts, including energy consumption, maintenance, and potential repairs. Lead-acid batteries have moderate operating costs, but they can increase when considering needed additional ventilation infrastructure to manage hydrogen gas released during charging. Alternatively, lithium-ion batteries have low operating costs because of their higher efficiency and longer lifespan. Fuel cells range from moderate to high operating costs depending on fuel prices and usage, and hybrids generally have high operating costs due to the complexity and maintenance of dual systems.

Suitability for multishift operations is important for facilities with continuous operations. Lead-acid batteries are poorly suited for multishift use because of long charging times and high maintenance. Lithium-ion batteries are good for multishift use because of their quick charging and efficiency. Fuel cells offer fast refueling and long run times, making them ideal for multishift environments. Hybrids also perform well in multishift operations, balancing run time and refueling flexibility.

In general, fuel cell forklifts are ideal for high demand, multishift operations because of their fast refueling and longer run times. Lead-acid batteries may suffice for cost-sensitive, moderate-use scenarios. Lithium-ion forklifts are optimal for operations valuing fast charging, long runtime, and environmental impact. Hybrid forklifts serve well for those seeking operational flexibility without committing to electric models, offering a blend of traditional fuel and electric power.

Flowcharts and decision tables in this document serve as good starting points to filter through the viability of technologies. Discussions with vendor representatives, consultants, and utility personnel can also help identify the appropriate technology and fill in knowledge gaps. Upon the initial identification of the technology, however, it is critical to understand if any complications will arise from electrification. Steps for further evaluating electrotechnologies and implementing electric systems are detailed in the following section.

Additionally, with electrotechnologies constantly improving and the scope of their industrial applications growing, stay informed about technological

[8] Electrified Processes for Industry without Carbon (EPIXC), DOE's 7th Clean Energy Manufacturing Innovation Institute https://epixc.org/

advancements to capitalize on emerging technologies and new applications that are developed. Organizations can join a research consortium or sign up for relevant publications from groups working in this area. The DOE's Clean Energy Manufacturing Innovation Institute[8] is one such consortium of public and private stakeholders tackling barriers to industrial electrification. Established in 2023, the institute conducts research, development, and demonstrations focused on developing and scaling electrified processes that reduce emissions, improve flexibility, and enhance the energy efficiency of industrial process heating systems.

STEP 2B. ASSESSING A FACILITY'S ELECTRIC INFRASTRUCTURE READINESS

An industrial facility's electrification readiness refers to how prepared the facility is to transition its energy sources and processes from nonelectric sources to electricity. Electrification readiness can be quantitatively and qualitatively established by determining its ability to support new electric loads. Assessing readiness requires evaluating individual components (e.g., upgrading transformers, switchgear, and distribution panels) of the network to determine its capacity to accommodate increased electrification demands and new electric loads.

Figure 10 defines a facility's electrification readiness in three steps. These steps are expanded in the following sections.

Figure 10. Defining a facility's electrification readiness.

Estimate Increased Electric Load from Electrification

When a facility electrifies, fuel is swapped out for electricity. To plan these projects effectively, facility personnel need to estimate additional electricity needs. This estimation is calculated by comparing current energy use with expected efficiency of the new electric system. This analysis clarifies the extent of new electric loads and the capacity required to support them.

Fuel-fired systems lose energy, a significant portion of which is through combustion exhaust. Tools like the DOE's MEASUR platform (introduced in Appendix A) help facilities understand their systems' efficiency. For example, the Steam System and the Process Heating Assessment modules within MEASUR estimate boiler and furnace combustion efficiency. These tools assist with detailed calculations, such as determining fuel usage, identifying heat losses, and estimating potential energy savings. Alternatively, personnel can make an informed estimate based on their system's characteristics.

The efficiency of the electric system will depend on the technology chosen and installation. Electric systems are advantageous, as they offer precise temperature control and do not have energy losses associated with the combustion exhaust. In the screening stage, when personnel are unsure of the applicable electric system, 70–80% efficiency can be assumed in determining electric load increases. Additional guidance on this determination and an example are provided in Appendix B.

Assess Existing Electric Infrastructure

Examine the current electrical infrastructure to identify its additional load capacity and determine the maximum amount it can support. This step includes evaluating the capacity and condition of transformers, switchgear, distribution panels, and wiring systems. Figure 11 depicts a typical electrical distribution system, detailing the flow of electricity from generation to consumption at an industrial facility. Details on the specific components and their functions are provided in Appendix F.

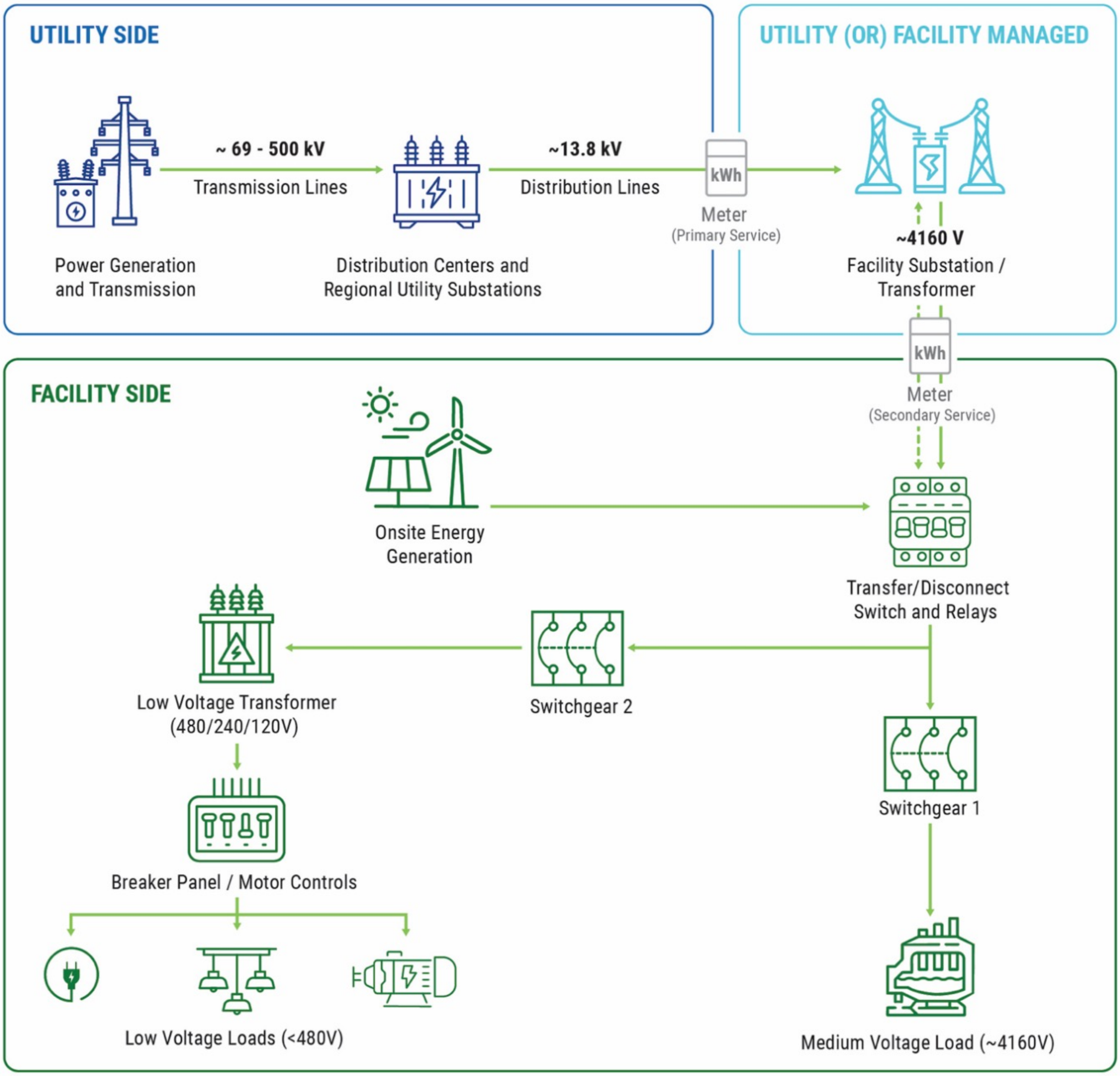

Figure 11. Components of a facility's electric infrastructure.

Assessing infrastructure readiness involves identifying potential bottlenecks or areas requiring upgrades or replacements to handle the increased load efficiently and safely. The Electrification Readiness Checklist in Appendix C provides a structured approach to evaluating electrification readiness. This checklist consists of a series of questions assessing each component's capacity within the electrical system. It includes guidance notes for navigating the checklist and gathering necessary information, most of which can be sourced from the facility's single-line electrical diagram.

A single- or one-line diagram is an essential document that represents a facility's electrical distribution infrastructure. It provides a simplified illustration of the electrical load flow from the utility service point to end-use branches, highlighting major components and their connections. This diagram is pivotal for understanding how electricity is distributed, identifying critical nodes, and pinpointing areas where upgrades may be necessary to support new electrification initiatives. A detailed guide to reviewing a facility's single-line diagram is included in Appendix D.

<table>
<tr><th colspan="3">Assessing Facility's Electric Supply Capacity</th></tr>
<tr><td colspan="3">Assessing Utility Hosting Capacity</td></tr>
<tr><td>What is the total capacity available from the utility substation to the facility?</td><td>a. MW</td><td rowspan="5">Hosting capacity is the maximum amount of new demand or consumption that can be added to the grid without causing disruption. Utility-owned substations can serve one or multiple facilities, and their available hosting capacity depends on the regional demand, spare capacity available, and planned expansions. Limitations to a utility's hosting capacity can be a limitation to the facility and need to be evaluated for electrification.

How to collect data can be determined by communicating directly with the utility representatives. Load factors and equipment profiles might be required for accurate assessment.</td></tr>
<tr><td>What is the supply voltage to the facility from the grid?</td><td>V</td></tr>
<tr><td>What is the facility's peak electric demand?</td><td>b. MW</td></tr>
<tr><td>When does the facility's peak electric demand occur?</td><td></td></tr>
<tr><td>What is the facility's average electrical demand?</td><td>MW</td></tr>
<tr><td colspan="3">Assessing On-site Generation Capacity</td></tr>
<tr><td>What is the facility's existing on-site electricity generation capacity?</td><td>MW</td><td rowspan="6">On-site renewable electricity generation (e.g., solar, wind) greatly supports electrification activity at the site by providing additional capacity.

The U.S. Department of Energy provides technical assistance and resources to help industries determine their on-site generation opportunity. Check Onsite Energy Program for more information.

How to collect data The operations of the on-site generation assets are typically tracked internally or by a third-party operator. Available capacity needs to be determined based on the system's least productive period.

Notably, energy storage can be configured to operate in various schemes, and it should be considered as additional capacity only if it is available to operate during the peak load period. Energy storage systems primarily used for backup purposes should not be included in this analysis.</td></tr>
<tr><td>What is the on-site generating capacity during the facility's peak load period?</td><td>c. MW</td></tr>
<tr><td>What is the energy storage capacity available to support the peak load period?</td><td>d. MW</td></tr>
<tr><td>Does the facility plan to install new or additional on-site renewables?</td><td>Yes/No</td></tr>
<tr><td>If yes, what is the potential additional capacity available from renewable sources during the peak load period?</td><td>e. MW</td></tr>
<tr><td>A. Total Additional Capacity Available:
[(a) – (b) + (c) + (d) + (e)]</td><td>MW</td></tr>
</table>

Figure 12. Key consideration during each step of evaluating and implementing an electrification project.

Identify Advanced Electricity Management Techniques

After evaluating the electrical infrastructure and completing an initial load analysis, the facility can evaluate integrating electricity management techniques. These techniques are essential for optimizing current operations and for scaling the system to handle future demands efficiently. In other words, if existing infrastructure is insufficient for the additional load required for electrification, these changes can maximize electrification readiness by reducing existing loads or providing additional load capacity. The following strategies can enhance the efficiency and reliability of the facility's electrical system:

- **Load management and demand response:** Load shedding or load shifting strategies distribute the existing electrical load more efficiently. This could involve staggering the operation of heavy equipment to reduce electricity demand during peak demand periods. Smart load management systems can help distribute loads based on demand patterns and energy costs. This capability optimizes energy usage and minimizes peak demand charges. Demand response programs offered by electric utilities provide incentives for reducing electricity consumption during peak demand periods, helping manage costs and supporting grid stability.
- **Energy efficiency:** Improving efficiency across industrial systems provides an opportunity to reduce overall energy demand, freeing up capacity for broader electrification initiatives. By upgrading to more efficient machinery within a system-level approach, optimizing process controls, and implementing energy management practices, industrial plants can significantly cut their energy use. These efficiencies reduce operational costs and lessen the burden on electrical grids. With lower demand from existing systems, additional capacity becomes available for electrification. More information on energy efficiency opportunities for individual systems can be found on the Better Buildings Solution Center.[9]
- **Power factor correction:** Power factor correction involves adjusting the ratio of real power (power used for productive work) to apparent power (power supplied by the utility). A facility with a low power factor is less efficient. By installing power factor correction capacitors, a facility can improve its power factor, allowing it to handle a higher total load with the same amount of power. This maximizes the use of existing electrical infrastructure and often reduces charges on utility bills. More information on power factor and billing by the utility can be found in *Better Plants' Understanding Your Utility Bills – Electricity* document.[10]
- **Remote monitoring and management:** Remote monitoring capabilities integrated into the control system enable real-time monitoring of electrical parameters and performance metrics. This promotes proactive maintenance and troubleshooting, minimizing downtime and maximizing productivity.
- **Voltage regulation:** Implementing voltage regulation measures (e.g., voltage regulators, capacitor banks) ensures consistent voltage levels within acceptable limits, especially during periods of high demand or when integrating renewable energy sources into the grid. By maintaining stable voltage, these measures help prevent equipment inefficiencies and potential downtime, allowing support of additional loads without upgrades to existing infrastructure.
- **Integration with renewable energy sources:** Renewable energy sources such as solar or wind power can integrate into the facility's electrical system and can be used to power additional load from electrified systems. Upgrading control systems to accommodate these sources allows for more efficient use of renewable energy and reduces reliance on the grid. As plants consider electrification and integration of onsite renewable energy sources, an important factor is whether operating with DC (direct current) instead of the conventional AC (alternating current) could offer additional benefits. Most applications currently use AC power, typically using inverters in renewable systems to convert DC to AC for compatibility. However, a facility that self-generates its power could potentially optimize for DC—if the equipment is compatible—resulting in efficiencies by avoiding conversion losses.

[9] U.S. Department of Energy Better Buildings, "Decarbonization: Prioritizing Energy Efficiency," Better Buildings Solution Center, https://betterbuildingssolutioncenter.energy.gov/better-plants

[10] Christopher Price, Alexandra Botts, Senthil Sundaramoorthy, Subodh Chaudhari, and Thomas Wenning, *Understanding Your Utility Bills: Electricity*, ORNL/SPR-2021/1839 (Oak Ridge, Tennessee: U.S. Department of Energy, 2021). DOI: https://doi.org/10.2172/1833978.

STEP 3. EVALUATING AND PRIORITIZING PROJECTS

After identifying the most promising electrotechnology and assessing the facility's electrification readiness, the next step is to evaluate the electrification projects and determine which to move forward with, and when. Technology feasibility, integration with existing systems, energy availability, cost-effectiveness, and potential environmental impacts must be carefully considered for a smooth transition to electrification and maximum benefits.

emissions). These off-site emissions can be established by estimating new energy consumption for electric systems and adjusting for expected losses with process integration and proportion of energy sourced from renewable resources. Tools such as the Electrification Impact Calculator aid in modeling and comparing pre- and post-electrification emissions; more details on this tool are provided in Appendix A.

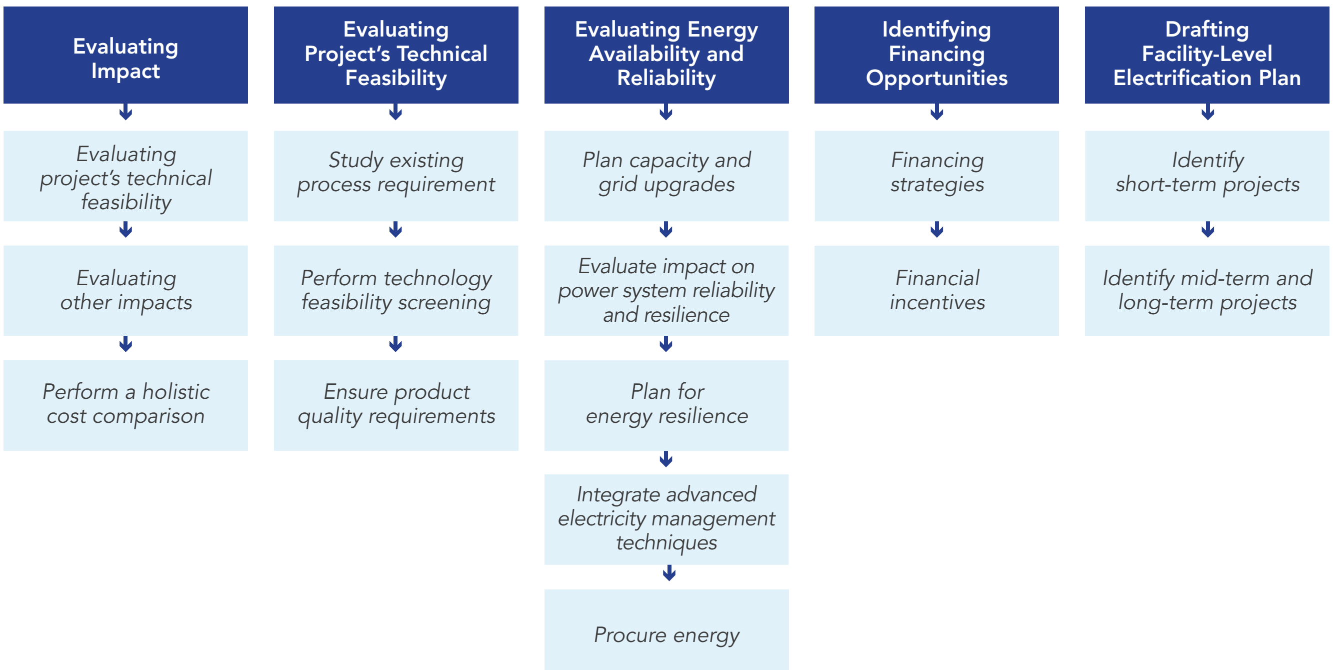

Figure 13. Key consideration during each step of evaluating and implementing an electrification project.

Evaluating Impact

Evaluating the holistic benefits of electrification projects can help justify the projects financially and aid in prioritization. In addition to cost, energy, and emissions impacts, facilities should consider other benefits associated with electrification to determine the full value of a project.

Quantifying Energy and Emissions Impact

To calculate emissions impacts of electrification in industrial facilities, first establish a baseline of current emissions using existing fuel consumption data and appropriate emission factors. This information should be available from the facility's inventory if "Step 1: Establish Inventory and Energy Use" was completed. With electrification, on-site fuel emissions (Scope 1 emissions) are replaced by off-site electricity generation (Scope 2

Electrification can also reduce process emissions, particularly in applications where processes inherently release vapors or gases, such as drying organic materials or food processing. Electrotechnologies provide more precise control, which can minimize the release of these emissions by maintaining optimal temperature levels and reducing over-processing.

As the electric grid transitions to renewable sources, emissions associated with facility electricity consumption will decrease over time. Forecasting analysis can estimate future emission reductions based on projected greening of the grid. Agencies like the U.S. Environmental Protection Agency (EPA) and the National Renewable Energy Laboratory (NREL) track and publish data on grid emissions and the increasing share of renewable energy in the grid mix. By considering emissions over the projected lifetime of new electrification projects, facilities can confidently determine their long-term emissions impacts.

Evaluate Other Impacts

Impacts of electrification activities on factors other than energy and emissions reduction are significant, including impacts to productivity, maintenance, product quality, and safety. These are discussed more in Table 5.

If the necessary data to evaluate these impacts is unavailable, the facility can conduct an audit and implement protocols to gather the information. This may involve inspecting equipment, updating standard operating procedures, consulting with facility personnel, and using onsite measurements to estimate key metrics associated with productivity, maintenance, and safety. This approach establishes an accurate baseline, allowing for a comprehensive assessment of electrification opportunities and impacts.

It is important to note that although the table outlines the common non-energy benefits associated with electrification, additional impacts unique to each facility and its operations may exist that are beyond the scope of the table. Moreover, electrification can also affect the larger community, including workforce opportunities and economic development. These broader effects should be considered as deemed appropriate by the organization, depending on their priorities.

Table 5. Potential Non-energy Benefits to Explore

Potential Benefit	Impact	How to Quantify
Productivity	Electrotechnologies offer accelerated and rapid heating capabilities providing higher productivity compared to fuel-fired systems.	▸ Track production line output pre-electrification. ▸ Infer productivity improvements from pilot test and case studies.
Maintenance	Electric equipment generally requires less maintenance than fuel-fired systems.	▸ Analyze historical maintenance records for fuel-fired equipment. ▸ Use industry averages for electric equipment maintenance costs.
Materials/Waste	Precise and uniform heating that electrotechnologies provide typically translates to a reduction in scrap.	▸ Monitor waste disposal records for materials related to fuel-firing (prior to electrification). ▸ Quantify post–waste reduction from vendor tests and changes to process.
Quality	Consistent heating allows manufacturers to replicate successful production runs consistently, leading to a higher level of product quality control.	▸ Identify and monitor key quality performance indicators pre-electrification. ▸ Consider additional data collection in test runs with electric systems in a lab setting to establish product quality.
Safety	While the risk of exposure to harmful emissions, noise, and vibrations associated with combustion equipment is reduced, it is possible electrification could come with electrocution and flammability concerns that need to be addressed.	▸ Analyze worker injury/illness data related to combustion equipment operation. ▸ Conduct employee surveys to assess perceived safety impacts.

Perform a Holistic Cost Comparison

A holistic cost analysis comparing traditional fuel-fired systems with electrotechnology will facilitate decision-making. The analysis should incorporate all the benefits discussed previously, including a cost of carbon appropriate for the facility[11]. Although the cost impact associated with most benefits can be quantified (e.g., reductions in maintenance, waste), others (such as safety and workforce opportunities) might need to be tracked qualitatively or using non-economic parameters.

The Electrotechnology vs. Fuel Fired Thermal Processing Cost Comparison Model Tool[12], developed by DOE, assists organizations in considering these diverse impacts and evaluating projects in a systematic and streamlined manner. This Microsoft Excel-based tool provides a comprehensive framework by accounting for variables such as energy use, maintenance cost, auxiliary equipment, other utilities, materials, labor, and water use. Figure 14 shows a representative analysis output from the tool. In the comparative analysis between a gas furnace and an induction furnace, the induction furnace evidently incurs significantly higher energy costs compared with the baseline system. However, when additional cost components, such as labor and product loss, are considered, it becomes apparent that the overall cost of ownership for an induction system is more favorable.

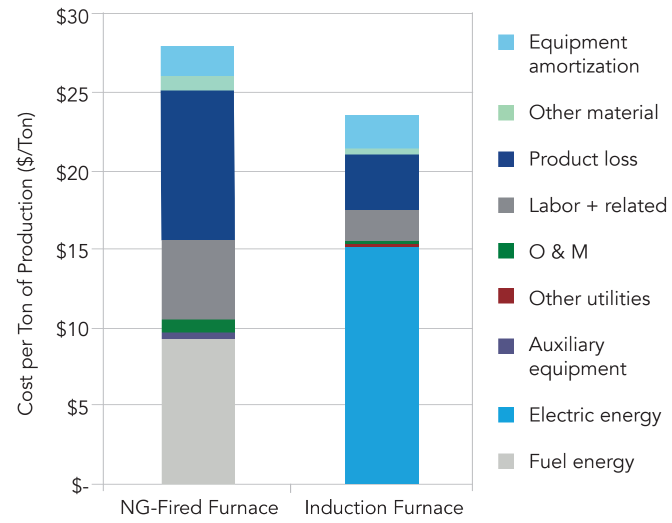

Figure 14. Holistic cost comparison results from case study on natural gas–fired furnace vs. induction furnace in a forging plant.

Evaluating a Project's Technical Feasibility

When considering a switch to electrified solutions in process or space heating, it is critical to understand if any complications will arise from changing to a different energy source. Understanding the fundamentals of the manufacturing process is key to ensuring that an overall shift to an electrified process does not interrupt production, alter product quality, overtly disrupt personnel comfort, create safety issues, or cause complications with other equipment.

Study Existing Process Requirement

Understanding existing process conditions and requirements is essential to evaluating feasibility. This requires evaluation of the heating process beyond the initial parameters captured in "Step 1: Establishing Inventory and Energy Use." This deeper evaluation includes determining process requirements such as the amount of heat, the volume of product processed, required downstream temperatures, humidity levels, the need for specialty gases, and cooling requirements. Additionally, integration with upstream and downstream processes should be assessed, as well as floor space availability for system installation. Ensuring that the new system can meet all observed process requirements needs to be determined

Perform Technology Feasibility Screening

Engineering models can serve as an initial screening to determine if a technology can adequately meet the heating requirements of a process. The level of detail and methods used to establish feasibility will vary for each technology–application pair and will depend on factors such as the complexity of the system design, heat transfer characteristics, and data availability. The Better

[11] The cost of carbon refers to the economic impact or financial value associated with greenhouse gas emissions, typically measured as the price per metric ton of CO_2 equivalent (CO_2e) emitted. More information on this topic is published by Better Climate Challenge working group on "Financial Analysis for Industrial Decarbonization" https://betterbuildingssolutioncenter.energy.gov/climate-challenge/working-groups12 U.S. DOE. The Electrotechnology vs. Fuel Fired Thermal Processing Cost Comparison Model Tool. https://energyefficiency.ornl.gov/tools-training/

[12] U.S. DOE. The Electrotechnology vs. Fuel Fired Thermal Processing Cost Comparison Model Tool. https://energyefficiency.ornl.gov/tools-training/

Climate Challenge program has developed tools to assist organizations in this effort. At the time of publishing this document, initial screening tools for heat pumps (industrial and HVAC applications) and electric forklifts are available. More details on the available calculators are provided in Appendix A.

The feasibility screening ensures that the chosen technology can be appropriately sized and can deliver the expected performance under specific operating conditions. Organizations are advised to use in-house engineering expertise for this task. Alternatively, a technology vendor or engineering consultancy firm can be hired to evaluate the project.

Ensure Product Quality Requirements

Consult with suppliers, engineers, operators, and quality departments to ensure that switching to electrified equipment will not compromise product quality. For instance, when converting a painting process from gas-fired dryers to radiative dryers, it may be necessary to check with the paint supplier to ensure that the paint maintains the same characteristics when dried using radiative electric heaters. If challenges arise from the switch, it could present an opportunity to collaborate with a supplier or consider different technologies. Insights from facility personnel who manage the production process can also help identify potential problems that might be exacerbated by electrification.

Product testing via pilot run allows a facility to experience the technology firsthand and confirm its suitability for the facility's application. This testing can involve piloting a smaller version of the technology or partnering with a vendor to assess performance in a controlled environment that closely mimics the actual production needs. By conducting thorough testing, the facility can mitigate risks and gain confidence in the technology's ability to integrate seamlessly with the facility's existing processes.

Evaluating Energy Availability and Reliability

Energy availability and reliability become increasingly critical with the installation of electrotechnology for essential production processes. Depending on the size of the electrification project, it may be necessary not only to upgrade the existing electrical infrastructure but also to revise energy procurement strategies and backup systems.

As part of "Step 2b: Assessing a Facility's Electric Infrastructure Readiness," a facility would have initially screened its infrastructure to gauge readiness for electrification. Once an actual electrification project is identified and evaluated, the facility will have more precise information regarding these added electrical loads and the variability that each project will introduce. It is crucial for the facility to revisit the initial electric infrastructure screening and perform a more detailed evaluation to ensure that the facility's infrastructure is fully capable of supporting the new demands without compromising safety or efficiency.

Planning and executing the following topics in collaboration with the utility is crucial for addressing the energy needs effectively.

Capacity planning and grid upgrades: Changes or upgrades to utility-side infrastructure may be required to support facility electrification, which could include adding new substations or transformers. Collaborate with the utility to assess whether the existing grid infrastructure can support the facility's electrification needs. Communication should be initiated with the electric utility as early as possible. Discussing electrification plans, energy requirements, and long-term goals early in the process ensures alignment, understanding, and the availability of necessary capacity at the facility.

It is important to consider designing these upgrades with future growth in mind, ensuring that the infrastructure can handle potential increases in facility output and energy consumption. This forward-thinking approach allows for scalability and minimizes the need for further significant modifications as the facility expands or further electrifies. Utilities often provide incentives and can offer valuable insights into preparing the facility's internal electric distribution systems, as well.

Assess the availability of space to host new equipment and infrastructure, such as upgraded switchgear or substations that may be necessary to support electrification. Ensuring that there is adequate space for these expansions is a critical factor in planning for grid upgrades and electrification projects.

Evaluate Impact on Power System Reliability and Resilience: Electrification projects, especially those involving large, variable loads like electric arc furnaces, can significantly impact the power grid. Further, the highly cyclic nature of these loads, with large power requirements in short bursts followed by low demand, may affect power system reliability and operation. This variability needs to be carefully analyzed in partnership with your utility to ensure that the power grid can accommodate these fluctuations without compromising stability or efficiency.

Facilities should consider taking a more detailed approach to evaluating its electric infrastructure based on the specific requirements of each new electrification project, including peak load demands, energy consumption patterns, and the potential need for enhanced capacity or improved resilience in their electrical systems.

Plan for energy resilience: Develop contingency plans and risk mitigation strategies to address potential disruptions to electricity supply, equipment failures, or other operational challenges associated with electrification. Evaluate the need for backup power systems, redundancy measures, and emergency response protocols to ensure continuity of operations. Consider onsite power generation, such as combined heat and power systems, which could provide backup power as needed for short periods.

If the facility's resilience plan includes the use of renewable energy sources (e.g., solar, wind) and/or battery storage solutions, coordinate with the electric utility to effectively integrate these sources into the grid.

Integrate advanced electricity management techniques: Electricity management techniques such as demand response, peak load reduction, and smart load balancing can help enhance electrification. Opportunities associated with these techniques should be evaluated and incorporated into the electrification plan if they have not already been considered during the initial assessment step. These programs can provide incentives for reducing electricity consumption during peak demand periods, helping to manage costs and support grid stability. More information on these strategies is provided in "Step 2: Assessing a Facility's Electric Infrastructure Readiness."

Energy procurement: Become familiar with the electric utility's tariff structure and rates. Some utilities offer incentives or special rates for industrial customers pursuing electrification or adopting renewable energy technologies. Procuring energy at an appropriate cost without affecting the grid requires coordination with local energy suppliers and distributors. Understanding rate structure bands can help determine the cost of the additional load.

Identifying Financing Opportunities

Understanding the different ways to finance a project, as well as identifying potential incentives that can enhance its economic viability, is an essential part of project evaluation. This overview discusses the key financing strategies and incentives that can help facilities implement electrification projects effectively, ensuring optimal financial and operational outcomes.

Financing Strategies for Electrification Projects

Electrification projects can leverage various financing strategies catering to different organizational preferences and project scopes. Energy-as-a-service (EaaS), performance contracting, and conventional loans and leases provide flexibility in managing financial outlays. Using EaaS, facilities pay for energy improvements through savings or fixed fees without upfront capital, suitable for companies seeking to minimize initial investments. Performance contracting offers a pay-for-performance approach, where payments are based on the energy savings achieved. Traditional loans and leases offer straightforward financing but require upfront costs and fixed repayments. The Better Buildings Financial Navigator helps facilities navigate these financing options and guide facilities in securing the funding that best suits their needs, ensuring facilities take full advantage of available incentives and optimize project prioritization.[13]

Incentives for Electrification Projects

Electrification projects could also qualify for unique sources of funding, including federal and state government grants, tax credits, and utility rebates. Incentives and grants for specific types of projects can significantly influence which projects are prioritized. The Funding and Incentives Resource Hub, available on the Better Buildings Solution Center, can assist facilities in navigating and discovering the many rebates, funding opportunities, and other incentives

[13] U.S. Department of Energy Better Buildings, "Financing Navigator," Better Buildings Solution Center, https://betterbuildingssolutioncenter.energy.gov/financing-navigator.

available to manufacturers.[14] The Database of State Incentives for Renewables and Efficiency (DSIRE) is another resource to explore state-level incentives and credits.[15]

Additionally, utilities across the country offer rebates and incentives, including time-of-use rates, rebates, grants, loans, and support services. Time-of-use rates encourage consumers to use electricity during off-peak hours, reducing strain on the grid, and rebates and grants help offset the costs of equipment. It is important to discuss available rebates with a facility's utility representative and apply for these rebates before commissioning the project to demonstrate the effect of the funds. As the landscape of energy policy and utility initiatives evolves, staying informed is crucial for maximizing the benefits of electrification.

Drafting a Facility-Level Electrification Plan

With the insights gained from the evaluation of the technologies and the facility's infrastructure assessment, personnel can draft an electrification plan that prioritizes projects based on their impact and alignment with facility capabilities. Projects can be prioritized into short-term, mid-term, or long-term categories based on various factors, including project cost, emissions impact, and equipment end-of-life. These factors may vary based on organizational priorities. Time-sensitive external rebates and incentives can also influence the prioritization of certain electrification projects over others. Furthermore, assessing the increase in electrical demand from electrifying specific equipment against the site's existing electrical capacity provides crucial insights into the facility's limitations, which can influence the scheduling of electrification initiatives.

Identify Short-Term Projects

Identify opportunities that can be implemented in the near term without substantial electric infrastructure upgrades, utilizing existing capacity. Projects suitable for short-term implementation often include forklift replacements, electrifying portions of the HVAC system, and small-scale pilot projects for process heating applications. While short-term electrification projects managed within existing capacity are not always feasible, particularly in energy-intensive industries, projects laying the groundwork for future electrification efforts can still be considered for the short term. Energy efficiency measures reduce overall energy consumption without significant upgrades to the electrical system and should be included in electrification planning discussions. Some advanced energy management techniques described in the "Evaluating Energy Availability and Reliability" section of this document ("Integrate advanced electricity management techniques") should also be in the short-term project road map.

Identify Mid-Term and Long-Term Projects

Plan for future projects that require more significant infrastructure changes or capacity expansions. These projects are typically more complex and may require strategic planning and phased implementation. Projects involving the integration of energy management techniques, such as load management, will have synergy with other electrification efforts and need to be properly evaluated. In addition to the impact, the age of the equipment and its life expectancy can also play a significant role in determining the project timeline.

The next steps for this evaluation should be documented as part of the electrification planning effort. An electrification plan can serve as a blueprint that guides the implementation of electrification projects, considering both immediate possibilities and future expansions. An example of an electrification readiness report is provided in Figure 15, and a template is available in Appendix C.

[14] U.S. Department of Energy Better Buildings, "Funding and Incentives Resource Hub," Better Buildings Solution Center, https://betterbuildingssolutioncenter.energy.gov/funding-incentives-hub.

[15] NC Clean Energy Technology Center, "Database of State Incentives for Renewables and Efficiency," DSIRE, https://www.dsireusa.org/.

Electrification Plan – Example

Electrification Plan

Company Name: Company ABC

Facility Address: ABC Street, Oak Ridge, Tennessee

Contact: Mark Smith

Electrification Projects

	Equipment End of Life	Implementation Cost	Emission Reduction	Electric Demand Increase	Notes
Induction	2030	$400,000	80 MT/year	200 kW	
Resistance heat treatment oven	2027	$275,000	64 MT/year	160 kW	
Electrify Steam Boilers	2035	$350,000	85 MT/year	250 kW	
Electric RTU	2026	$120,000	24 MT/year	60 kW	
Electric Forklifts	2025	$200,000	20 MT/year	50 kW	Total 10 units
Electrify Utility Vehicles	2027	$140,000	15 MT/year	15 kW	Total 5 units

Electric Capacity Available

Capacity Available at the Site This is based on the capacity available at the switchgears. *(From result C1 in the Electrification Readiness Worksheet)*	100 kW
Potential Capacity with Facility-Level Upgrades This is based on the capacity available at the switchgears. *(From result B1 and B2 in the Electrification Readiness Worksheet)*	1000 kW
Potential Capacity with Utility Upgrades This is based on the capacity available at the switchgears. *(From result A1 in the Electrification Readiness Worksheet)*	2000 kW

Electrification Plan		
Short Term Projects	**Mid Term Projects**	**Long Term Projects**
Electric Forklifts	▶ Electrify Utility Vehicles ▶ Resistance Heat Treatment Oven	▶ Induction Furnace ▶ Implement Onsite Solar ▶ Explore load management with microgrids.

Project Activity Tracking				
Activity/Task	**Task Lead**	**Start Date**	**Duration**	**Status**
Upgrade Forklifts and Utility Vehicles: Fleet Analysis	Alice Brown	2024-08-15	1 month	Initiated
Upgrade Forklifts and Utility Vehicles: Vendor Selection	Alice Brown	2024-09-15	1 month	Planning
Electrify Forklifts: Procurement and Installation	John Doe	2025-02-01	3 months	Not Started
Electrify Utility Vehicles: Procurement and Installation	John Doe	2025-09-01	3 months	Not Started
Install Electric RTU: Site Assessment	Jane Smith	2025-09-01	1 month	Not Started
Install Electric RTU: Electrical Upgrades	Jane Smith	2025-11-01	2 months	Not Started
Resistance Oven Installation: Energy Audit	Tom Wilson	2026-01-01	1 month	Not Started
Resistance Oven Installation: Procurement & Delivery	Tom Wilson	2026-05-01	3 months	Not Started
Induction Furnace: Feasibility Study	Emily White	2027-01-01	3 months	Not Started
Onsite solar and microgrid: Feasibility Study	Emily White	2027-04-01	6 months	Not Started

Figure 15. Example electrification plan.

PROJECT IMPLEMENTATION

Proper steps considered during the implementation phase of the electrification project will help create a smooth transition. The major steps and associated considerations to project implementation are summarized in this section.

Securing Project Funds

Securing the necessary funds is essential for moving a project from the planning phase to actual execution. This step involves obtaining both internal and external funding sources. For internal funding, check with the finance department to understand the specific process, which may include presenting a detailed business case for the project. External loans can be pursued by submitting well-prepared applications to financial institutions. Once the required capital is in place, project stakeholders can focus on procurement and installation.

As discussed in "Step 3: Evaluating and Prioritizing Projects," electrification projects may also qualify for federal and state government grants, tax credits, and utility rebates. Each of these opportunities typically has a unique application process, and facilities must be aware of application timelines. Some grants, particularly utility rebates and government grants, may require the project be qualified before equipment procurement. Although equipment vendors can assist in arranging the necessary documents and applications, facility personnel must ensure all applicable funding is being secured.

Regulatory Compliance and Permitting

Ensure that any planned upgrades, expansions, or installations comply with local building codes, electrical regulations, safety standards, and process compliance. Obtain necessary permits and approvals from regulatory authorities before implementation. This includes not only electrical infrastructure but also the technology. For significant equipment upgrades, research additional permit requirements. To prevent potential legal issues and delays, it is critical to start this process early. Engage with appropriate agencies and personnel well in advance to understand specific requirements and timelines. Establishing early communication with regulatory authorities, building inspectors, and utility representatives helps identify potential challenges, streamline the permitting process, and avoid bottlenecks impacting project timelines.

Installation and Testing

Once the plans are finalized and permits obtained, proceed with the implementation of the upgrades or expansions. Coordinate with contractors or in-house maintenance teams to carry out the installation safely and efficiently. Aligning this step with the industry-standard approach of conducting a Factory Acceptance Test (FAT) helps cover various aspects such as safety, reliability, performance, and efficiency. By integrating the testing with the company's existing standard operating procedures (SOP) for factory acceptance testing, the facility can integrate electrification seamlessly with the facility's existing processes. After installation, conduct thorough testing and commissioning to ensure that the new electrical infrastructure operates as intended and meets performance requirements.

As identified during the evaluation phases, upgrading electric infrastructure may involve adding new sub-stations, upgrading existing transformer capacities, adding new distribution panels, installing additional wiring, or upgrading switchgear to handle higher loads. To prevent potential blackouts or brownouts at the facility, it is critical that any required upgrades to the infrastructure (both utility-side and facility-side) are completed and thoroughly tested before the implementation of the electric heating system itself.

Many electrotechnologies are custom-built and require additional planning with the original equipment manufacturers. Additional steps and processes may be required to ensure successful implementation and installation of these new systems. Lab-scale testing can be completed to ensure repeatable product quality with new systems. For custom-built equipment, equipment specifications may need to be altered to meet the space availability in the existing area. New electrotechnology equipment will need to be coordinated with the process parameters (e.g., flow rates, temperature) of the system and account for the upstream and downstream processes involved. Additionally, partners should consider the capability of vendors to provide comprehensive workforce training on the operation and maintenance of equipment as part of the installation agreements.

Documentation

Document all changes made to the electrical infrastructure and processes, including updated schematics, equipment manuals, testing, and maintenance procedures. Electrifying equipment will inherently alter operation and maintenance procedures, necessitating a well-trained workforce to ensure proper functioning. Updates should be made to the standard operating procedure documentation, maintenance procedures, process controls, and other considerations included in the facility's management of change processes. A crucial aspect to consider is the review of workforce safety regulations and the implementation of appropriate maintenance procedures, training, and lockout/tagout programs because handling 600 V and above equipment introduces a new set of safety considerations. Additionally, changes to the systems may enhance data handling and analysis capabilities, which may need to be integrated into existing systems.

Workforce Training

Collaborating with electrotechnology vendors can significantly benefit post-implementation success. These vendors often possess extensive knowledge of their equipment and can help develop training programs for the facility's workforce. Since not all vendors may offer this type of training, it is advisable for companies to explicitly specify their training requirements in solicitation documents to ensure vendors are prepared to meet these needs. This approach helps set clear expectations and ensures that proper training is included as part of the vendor's service offering. This collaborative approach ensures that the facility's team is properly trained on the operation and maintenance of the new technologies, maximizing efficiency and minimizing downtime.

Consider incorporating additional training modules or sessions that align with organizational practices for new technology deployment, such as certification training. Provide training to relevant personnel on operating and maintaining the new equipment to ensure safe and efficient long-term operation. This effort helps preserve key information about the changes and can be invaluable for onboarding new employees during transitions.

Monitoring and Maintenance

Implement a system for ongoing monitoring of electrical system performance for early detection of any issues or abnormalities. Establish a regular maintenance schedule to inspect and maintain the electrical infrastructure, preventing downtime and prolonging the equipment's lifespan. This maintenance schedule could be integrated with the vendor's scheduled maintenance plans for any newly installed equipment.

Continually Review and Update Electrification Plan

Upon the implementation of each major project (or when significant changes occur within the facility, such as expansions, upgrades, or shifts in operational priorities), the electrification plan should be revised to reflect these changes and their impacts on subsequent steps. Additionally, as new electrotechnologies and energy management techniques are identified and evaluated, the electrification plan may require adjustments. This dynamic process is essential for adapting to new technologies and ensuring that the electrification strategy remains effective and responsive in a rapidly evolving landscape. Regular updates and course corrections are crucial for maintaining an effective and adaptive electrification plan that aligns with the latest advancements and operational requirements.

CONCLUSION

Electrification presents a strategic opportunity for industrial facilities to significantly enhance operational efficiency while achieving other organizational goals, like productivity, quality, safety, cost, and emissions goals. This framework is a road map to guide facilities through the process of assessing and implementing electrification at the facility level.

Through the systematic assessment of electric infrastructure readiness, evaluation of feasible electrification strategies and technologies, and careful planning of project implementation, organizations can ensure that their move toward electrification is both strategic and beneficial. Emphasis on the holistic benefits of electrification—not just the environmental impact but also improvements in productivity, safety, and operational costs—underscores its potential as a transformative force within the industrial sector.

As the grid continues to evolve and incorporate more renewable energy sources, the benefits of electrification will expand further, making it even more important for manufacturers to have an electrification strategy in place. Facilities are encouraged to continually revisit and refine their electrification strategies in response to technological advancements and changes in regulatory landscapes to fully capitalize on the opportunities presented by electrification.

The challenges of transitioning to electrified systems are nontrivial, but the strategic approach outlined in this framework equips facilities with the necessary tools and knowledge to navigate these complexities while harnessing the significant benefits of electrification. By adopting a methodical and informed approach to electrification, facilities can unlock new efficiencies, gain a competitive advantage, and achieve their organizational priorities.

APPENDIX A: DOE CALCULATORS FOR ELECTRIFICATION

The U.S. Department of Energy has developed free software tools to assist facilities in monitoring their energy data.

MEASUR Tool Suite: The MEASUR Tool Suite, developed by the U.S. Department of Energy, is a comprehensive resource for industrial plants to enhance energy efficiency and reduce utility costs. This platform contains seven software tools and approximately 80 calculators to assess all major industrial systems and provide detailed analyses of energy consumption across systems within a facility, including compressed air, pumps, fans, steam, and process heating. Users input energy use data, system specifications, and operational parameters, enabling the tool to identify energy-saving opportunities and simulate the impact of potential improvements. MEASUR tools can generate detailed reports summarizing energy usage, potential savings, and efficiency opportunities, making them an invaluable asset for facilities committed to optimizing industrial systems and achieving significant energy cost savings. The MEASUR Tools Suite can be accessed at https://measur.ornl.gov/landing-screen.

Electrification Impact Calculator: The Electrification Impact Calculator is designed to help industrial facilities evaluate the environmental and economic impacts of transitioning from traditional energy systems to electrified solutions, including the integration of renewable energy. By inputting data on current energy systems, proposed electrification technologies, and financial parameters, the tool calculates potential reductions in emissions and assesses the economic benefits of such transitions. It incorporates Emissions and Generation Resource Integrated Database (eGRID) factors to reflect regional or national grid characteristics, ensuring accurate environmental assessments. The Electrification Impact Calculator can be accessed at https://electrification.ornl.gov/

Forklift Calculator: Forklifts, or lift trucks, are crucial in logistical operations such as distribution warehouses and shipping depots. Traditionally powered by fuels such as propane, electric and hydrogen-powered forklifts offer numerous economic and environmental advantages. This tool provides life cycle cost and emissions estimates for electric, propane, diesel, gasoline, and hydrogen-powered forklifts.

Heat Pump for HVAC Tool: HVAC equipment is vital for providing year-round conditioned air, enhancing the work environment in manufacturing facilities. This tool compares energy use and emissions of HVAC equipment options, including electric, natural gas, and propane, as well as air-source heat pumps, geothermal heat pumps, and traditional furnaces.

Industrial Heat Pump Tool: Designed to support the evaluation of heat pump technology in industrial applications, this tool is a practical resource for assessing the feasibility and benefits of heat pumps, which are known for their efficiency and environmental advantages. A pinch analysis can be used in tandem with this calculator to identify key process applications with potential for heat pump

The tools mentioned are available on the Software Tools page on the Better Buildings Solution Center: https://betterbuildingssolutioncenter.energy.gov/better-plants/software-tools.

APPENDIX B: ELECTRIFICATION INVENTORY—TEMPLATE

Equipment Name/ID	Install Date (year)	Rated Capacity (MMBTU/h)	Typical Annual Operating Hours (h)	Operating Temperature (°F)	Load Factor	Fuel Used	Estimated Yearly Energy Use (gas or other fuel, MMBTU)	Baseline System Efficiency (%)	Proposed Electric System Efficiency (%)	Expected Increased Demand with Electrification (kW)	Electrification Suitability Rating
Process Heating Systems											
Total Process Heating System											
HVAC Systems											
Total HVAC System											
Warehouse Utility Vehicles											
Total Forklift System											

Electrification Inventory— Instructions

This section offers detailed formulas and additional guidance to accurately fill out the inventory template.

Process Heating and HVAC Systems

- $Load\ Factor\ =\ \frac{Average\ Operating\ Capacity\ ((MMBTU/hr))}{Rated\ Capacity\ (MMBTU/hr)}$
- $Estimated\ Annual\ Energy\ Use\ =\ Rated\ Capacity\ \times\ Load\ Factor\ \times\ Typical\ Annual\ Operating\ Hours$
- $Increased\ Demand\ with\ Electrification\ = \frac{Rated\ Capacity\ of\ Baseline\ Equipment \times Baseline\ Systems\ Efficiency}{Expected\ Electric\ System\ Efficiency}$
- System Efficiency can be calculated from the energy inputs or the losses in the system based on the data available:
    - System Efficiency = Useful Energy Output/Total Energy Output
    - System Efficiency = $(Total\ Energy\ Input\ -\ Sum\ of\ All\ Losses)/Total\ Energy\ Output$

Note:

- It is recommended that the overall system efficiency (not equipment efficiency) is used to compare the baseline and electrified scenarios to account for associated energy reduction opportunities.
- Common losses in the baseline fuel-fired system are combustion or stack losses, cooling losses, losses at walls and fixtures, leakages, and atmospheric losses. Software tools such as the U.S. Department of Energy's MEASUR platform make accurate estimations of overall system efficiency by taking all losses into consideration. In the absence of a detailed energy model, estimation can rely on system knowledge. Combustion analysis performed by burner operators or vendors estimates the done-by-vendors combustion or stack losses, typically the biggest losses associated in a well-insulated system, and can provide indication of system efficiency.
- Electric System Efficiency is determined by the electrotechnology used and configuration of the system. Electrotechnologies have responsive controls, provide precise heating of components, and have no losses associated with combustion. If the appropriate alternative electric system has not yet been identified, a conservative percent (70–80%) efficiency can be assumed and used as a placeholder.
- An Electrification Priority Rating can assist in devising an electrification plan for the facility. This rating is established by evaluating the potential effects of electrification on system performance, product quality, productivity, emissions, costs, and safety. Additionally, factors such as the availability of technology and its seamless integration with current production processes can be considered if known. These ratings are subject to revision and updating as the facility progresses in its electrification journey. They can be qualitative, such as low, medium, high, or assigned a numerical value ranging from 1 (low) to 5 (high).

Warehouse Utility Vehicles

- $Energy\ Use\ =\ Battery\ Capacity\ \times\ Depth\ of\ Discharge\ \times\ Charges\ per\ Year\ \times\ Combined\ Efficiency$
- $Combined\ Efficiency\ =\ Charger\ Efficiency\ Rating\ \times\ Charge\ Return\ Factor$

Where,

- Depth of Discharge is the estimated percentage of the battery used before it is recharged, and
- The Charger Efficiency Rating and Charge Return Factor depend on the type of chargers. Some common charger types include ferroresonant (78% average efficiency rating and 115% return factor), silicon-controlled rectified (80% average efficiency rating and 118% return factor), and high-frequency (93% average efficiency rating and 115% return factor).

Electrification Inventory— Example

Equipment Name/ID	Install Date (year)	Rated Capacity (MMBTU/h)	Typical Annual Operating Hours (h)	Operating Temperature (°F)	Load Factor	Fuel Used	Estimated Yearly Energy Use (gas or other fuel, MMBTU)	Baseline System Efficiency (%)	Proposed Electric System Efficiency (%)	Expected Increased Demand with Electrification (kW)	Electrification Suitability Rating
Process Heating Systems											
Furnace 1	2021	1.2	8,760	1700	42.00%	Natural Gas	4,415	50%	75%	235	Mid
Heat Treat Furnace 2	2010	3.5	1,664	1200	44.04%	Natural Gas	2,565	60%	75%	820	Mid
Gas Genera-tor	2011	1.6	1,664	1900	44.10%	Propane	1,174	80%	95%	395	Low
Drying Ovens	2010	1.5	3520	400	76.00%	Natural Gas	4,013	80%	95%	370	High
Total Process Heating System (A)							**12,167**		**12,167**	**1,820**	

APPENDIX C: ELECTRIFICATION READINESS WORKSHEET

Assessing Facility’s Electric Supply Capacity		
Assessing Utility Hosting Capacity		
What is the total capacity available from the utility substation to the facility?	a. MW	**Hosting capacity** is the maximum amount of new demand or consumption that can be added to the grid without causing disruption. Utility-owned substations can serve one or multiple facilities, and their available hosting capacity depends on the regional demand, spare capacity available, and planned expansions. Limitations to a utility’s hosting capacity can be a limitation to the facility and need to be evaluated for electrification. **How to collect data** can be determined by communicating directly with the utility representatives. Load factors and equipment profiles might be required for accurate assessment.
What is the supply voltage to the facility from the grid?	V	
What is the facility’s peak electric demand?	b. MW	
When does the facility’s peak electric demand occur?		
What is the facility’s average electrical demand?	MW	
Assessing On-site Generation Capacity		
What is the facility’s existing on-site electricity generation capacity?	MW	**On-site renewable electricity generation** (e.g., solar, wind) greatly supports electrification activity at the site by providing additional capacity. The U.S. Department of Energy provides technical assistance and resources to help industries determine their on-site generation opportunity. Check Onsite Energy Program for more information. **How to collect data** The operations of the on-site generation assets are typically tracked internally or by a third-party operator. Available capacity needs to be determined based on the system’s least productive period. Notably, energy storage can be configured to operate in various schemes, and it should be considered as additional capacity only if it is available to operate during the peak load period. Energy storage systems primarily used for backup purposes should not be included in this analysis.
What is the on-site generating capacity during the facility’s peak load period?	c. MW	
What is the energy storage capacity available to support the peak load period?	d. MW	
Does the facility plan to install new or additional on-site renewables?	Yes/No	
If yes, what is the potential additional capacity available from renewable sources during the peak load period?	e. MW	
A. Total Additional Capacity Available: [(a) – (b) + (c) + (d) + (e)]	MW	

Assessing Facility's Transformer Capacity

Transformer ID	
What is the type of service from the utility?[1]	Primary/ Secondary
Is the transformer nearing the end of its lifespan?[2]	Yes/No
What is the primary and secondary voltage at the transformer?	V
What is the total capacity of the facility transformer?	a. kW
What is the present peak load on the transformer?	b. kW
B1. Total Additional Capacity Available at the Facility Substation: [(a) – (b)]	kW
Transformer ID	
What is the type of service from the utility?[1]	Primary/ Secondary
Is the transformer nearing the end of its lifespan?[2]	Yes/No
What is the primary and secondary voltage at the transformer?	V
What is the total capacity of the facility transformer?	a. kW
What is the present peak load on the transformer?	b. kW
B1. Total Additional Capacity Available at the Facility Substation: [(a) – (b)]	kW

Facility Transformers: Industrial facilities typically have one or more dedicated transformers that step down the voltages from 12.47 kV to 4,160 V (medium) or 480 V (low). The number of feeder circuits available, its maximum capacity, and present load will determine the hosting constraints at these facility transformers.

[1] Primary and Secondary Service: Depending on the contractual agreement with the utility, these transformers can be owned and maintained either by the utility or the facility. The type of service is also typically dictated based on this ownership of these assets. Depending on the size of the electrification opportunity at the site, understanding existing utility agreements and potentially renegotiating them becomes critical.

[2] Transformer Lifespan: The age of the transformer can help determine if is close to its end of life and if a replacement or upgrade is warranted. The typical lifespan of a transformer can vary depending on factors such as its type, usage conditions, and maintenance. General-purpose dry-type transformers typically last more than 25 years, and oil-filled transformers have a typical lifespan of around 20–30 years.

How to collect data: The transformers and other electrical components on the facility's electric distribution side can be evaluated by reviewing the facility's one-line electrical diagram and as part of a scheduled arc flash study.

Notably, the rated capacity can be represented in kilovolt-amperes (apparent power) in some cases as opposed to kilowatts (real power). Kilowatts can be calculated from kilovolt-amperes using the formula: kVA = kW × power factor. Power factor can be assumed to be 0.7–0.8 if not known.

Assessing Facility's Electric Loads and Electric Distribution		
How many major switchgears (SWGs) are at there at the facility?		SWGs act as the first node in the electric distribution system from the facility transformer. Each SWG needs to be assessed separately.
How many Motor Control Centers (MCC) or other load distribution centers that connect directly to the facility transformer are at the facility?		Although MCC and switchboards are typically downstream of SWGs and are the distribution point for other loads, in some cases, they can be connected and draw power directly from the main facility transformers.
Switchgear/Motor Center/Switchboards ID: ____		
What is the operating voltage?	V	Each circuit in use needs to be assessed separately to determine its available capacity to host additional electric equipment . The template on the following page can be used to determine this from the individual loads on each circuit. The required information for rated capacity can be determined from the electrical drawing. When up-to-date electrical diagrams are not available, an inspection might be required.
How many electric circuits are part of the unit?		
How many of the electric circuits are in use?		
How many of the electric circuits are in use?	a1. kW a2. kW	

Summary of Switchgear/Motor Center/Switchboards				
Circuit ID: __	Circuit ID: __	Circuit ID: __	Circuit ID: __	Circuit ID: __
Rated Capacity: Capacity in Use: Available Capacity, b1:	Rated Capacity: Capacity in Use: Available Capacity, b2:	Rated Capacity: Capacity in Use: Available Capacity, b3:	Rated Capacity: Capacity in Use: Available Capacity, b4:	Rated Capacity: Capacity in Use: Available Capacity, b5:
C1. Total Additional Capacity Available at the Switchgear: [a1 + a2 + … + b1 + b2+ ….]			kW	

Assessing Individual Electrical Circuits		
Does the circuit have additional breaker panels that further split into multiple sub-circuits before the serviced load?	Yes/No	If yes, each used in the sub-panels circuit needs to be assessed separately.
Does the circuit have additional stepdown transformers near the end load?	Yes/No	The required information can be determined from the electrical drawing.
What is the maximum power capacity at the circuit?	a. kW	Determined based on the minimum of the limiting power among the transformers, circuit breakers, and any other component

Electric End Users Served by Circuit _____				
Unit ID: __ Voltage: Rated Amp: Type: Motors/Heating Load	Unit ID: __ Voltage: Rated Amp: Type: Motors/Heating Load	Unit ID: __ Voltage: Rated Amp: Type: Motors/Heating Load	Unit ID: __ Voltage: Rated Amp: Type: Motors/Heating Load	Unit ID: __ Voltage: Rated Amp: Type: Motors/Heating Load
			Total load on the circuit[1]:	b. kW
			Additional Capacity Available at the Circuit[2] [(a.) – (b.)]	kW
		Total load on the circuit[1]:	b. kW	

Note:

[1.] The total load on the circuit is calculated as the sum of all the loads active in the circuit. It is common to define the individual electric loads in terms of the current (amps) drawn by them. For a typical three-phase alternating current (AC) load, the power drawn can be calculated from its amps drawn using the formula [P (kW) = √3 × PF × amps × Voltage]/1,000. Power factor (PF) can be assumed to be 0.7–0.8 if not known.

[2.] A safety factor of 80% is typical when designing these systems. Any capacity above 80% should not be construed to be additional available capacity.

Electrification Plan Template

Basic Information	
Company Name:	
Facility Address:	
Contact:	

Electrification Projects

	Equipment End of Life	Implementation Cost	Emission Reduction	Electric Demand Increase	Notes
Project 1					
Project 2					
Project 3					
Project 4					
Project 5					

Electric Capacity Available

Capacity Available at the Site This is based on the capacity available at the switchgears. *(From result C1 in the Electrification Readiness Worksheet)*	
Potential Capacity with Facility-Level Upgrades This is based on the capacity limitation at the facility transformers. *(From result B1 and B2 in the Electrification Readiness Worksheet)*	
Potential Capacity with Utility Upgrades This is based on the capacity limitation at the utility. *(From result A1 in the Electrification Readiness Worksheet)*	

Project Prioritization		
Short Term Projects	Mid Term Projects	Long Term Projects
• • • • • •	• • • • • •	• • • • • •

Project Activity Tracking				
Activity/Task	Task Lead	Start Date	Duration	Status

The following considerations can help build an effective electrification plan.

- Projects are prioritized into short-term, mid-term, or long-term categories based on various factors, including project cost, emissions impact, and equipment end-of-life.
- Comparing the increase in electric demand from electrifying specific equipment with the site's available electric capacity provides insight and aids in project prioritization. Near-term projects can be implemented with the additional capacity available at the site, but midterm and long-term projects have capacity demand higher than what is available at the facility transformers or utility substation.
- Time-dependent external incentives can also influence the prioritization of certain electrification projects over others.
- Reevaluate the plan when significant changes occur within the facility, such as expansion, upgrades, or shifts in operational priorities.

APPENDIX D: REVIEWING SINGLE-LINE WIRING DIAGRAM—GUIDE

A single-line diagram (SLD), also referred to as a one-line diagram, is a simplified symbolic representation of an electrical power system for a facility. It provides a high-level view of the electrical system's components and interconnections.

Step 1: Understand the Symbols Used in a Single-Line Diagram

The standardized schematic symbols in an SLD are defined by IEEE Standard 315, ANSI Y32.9, and CSA Z99. These standards play an important role in ensuring consistency across SLDs. Although graphical symbols may vary slightly from diagram to diagram, the symbols are mostly consistent. Typically, a legend of symbols is located somewhere on the SLD. A sample of more common symbols is provided in Figure D-1.

Step 2: Identify the Different Labeling of Components Represented in the Diagram.

In addition to understanding the symbols in an SLD, it is important to read the descriptive labeling included near the symbols that identify specific components by equipment number, electrical power ratings of equipment, conductor sizes, or other important electrical characteristics. Figure D-2 is an example of the type of labeling that can be found on an SLD.

Note that in a three-phase alternating current (AC) system, the SLD represents all three phases of the system. Horizontal lines represent different buses showing areas where power is distributed to other system components such as transformers, switches, breakers, and various loads at specified voltages.

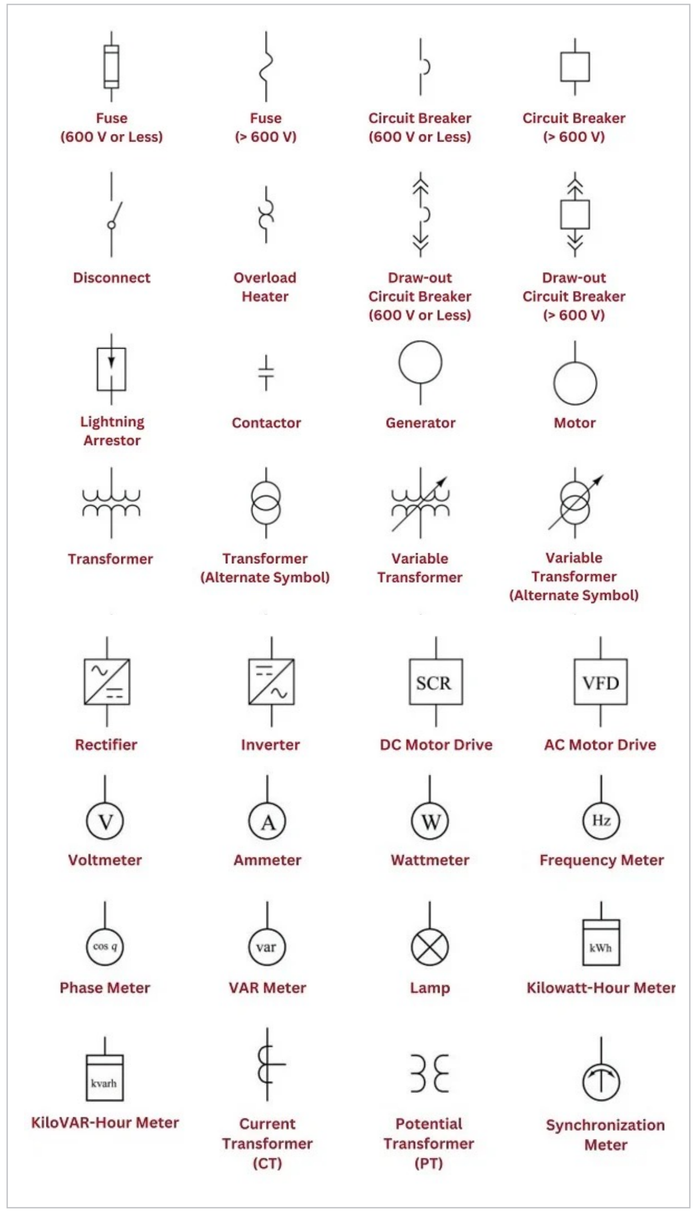

Figure D-1. Legend for single-line wiring diagram.

[16] IEEE, IEEE Standard for Graphic Symbols for Electrical and Electronics Diagrams (Including Reference Designation Letters), IEEE/ANSI 315-1975 (IEEE, 1975).

[17] ANSI, American National Standard Graphic Symbols for Electrical Wiring And Layout Diagrams Used In Architecture And Building Construction, IEEE/ANSI Y32.9-1972 (ANSI, 1972).

[18] Canadian Standards Association, Graphic Symbols for Electrical and Electronics Diagrams, CSA Z99-1975 (Canadian Standards Association, 1975).

Reviewing Figure D-2, notice four descriptive labeling characteristics for the highlighted circuit breaker. It has an equipment identification/location number (BL-C23-A-03D-N1), the manufacturer of the breaker (SQD, which indicates Square D), the frame of the breaker (FAL), and the rating of the breaker (100 A). Additionally, the highlighted transformer in Figure D-2 shows similar descriptive labels, including equipment identification/location number (C23-A-03D-N1 TX), the rating of the transformer (50 kVA), the voltage of the transformer (0.48 to 0.24 kV) and the percent impedance of the transformer as a percentage of rated voltage (5.8%). The SLD also shows that the connection of the transformer is delta-wye. Therefore, although the symbols can provide information of the type of equipment in the facility, the descriptive labeling can be very beneficial in understanding the location of the equipment and its ratings that will assist in identifying the physical equipment out in the facility

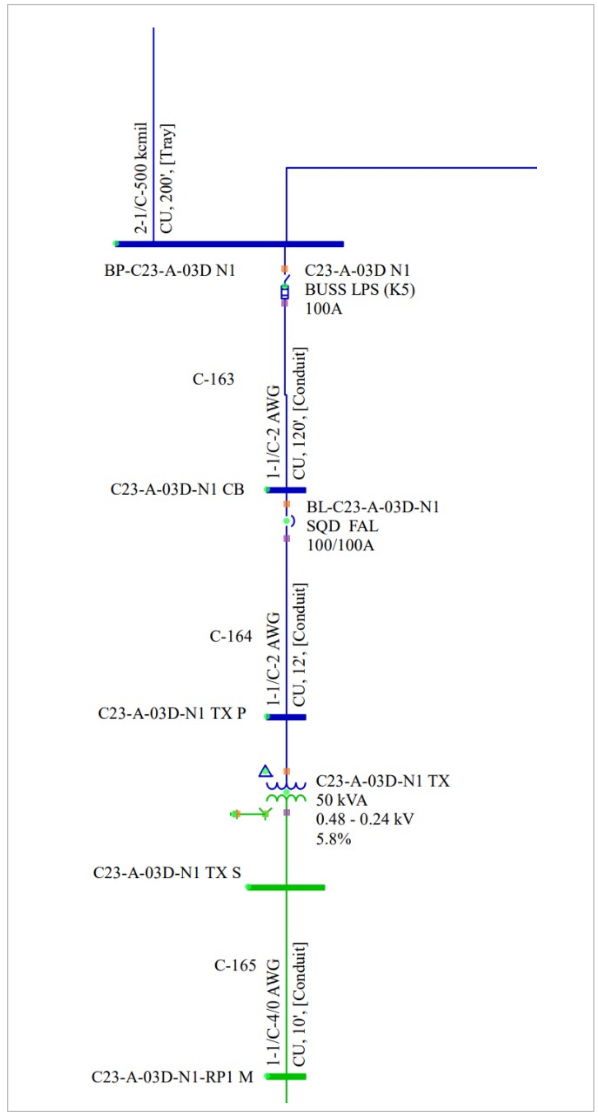

Figure D-2. Labeling example in an SLD.

Step 3: Trace the Flow of Power from Source to End-Use Load

One of the primary purposes of SLDs is to assist in the analysis of how power flows between different elements of the electrical system. To properly read an SLD, such as that in Figure D-3, consider the following steps:

- First, identify the power source at the top of the SLD. This is where the utility supply enters the facility through the utility transformer.
- Next, follow the single line down the diagram to the next level of components. You should see where the power flows through a main fused switch through another transfer switch to an area that includes a motor control center (MCC) or other switchgear.
- From the MCC, the power distributes to various loads through fused switches in the MCC. Additional downstream breakers and other facility-side transformers reach the proper operating voltage of the different end-use loads.
- Finally are areas where other distribution panels within the facility or end-use loads such as motors are identified.

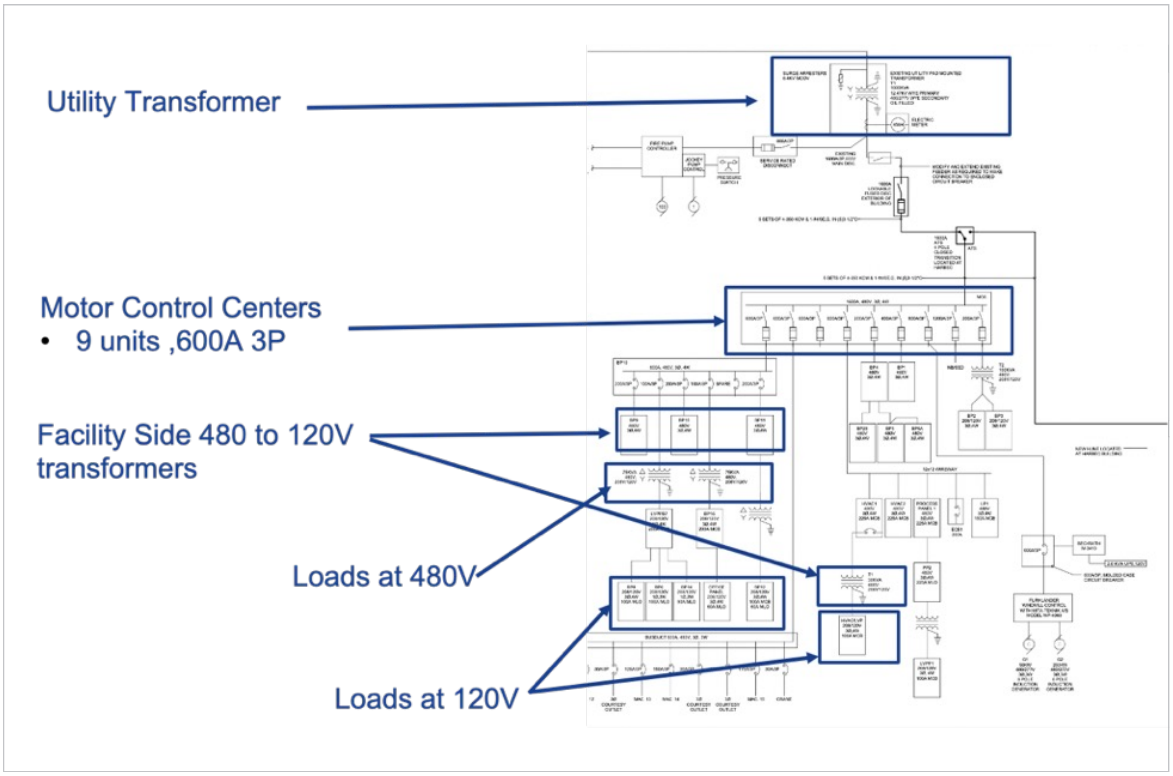

Figure D-3. Example Single Line diagram with major components

Step 4: Identify the Rated Capacity of the Components in the Electric Distribution System

An SLD will help determine the facility's available capacity and how upgraded capacity from the utility may affect the system. The following details relating to the electric distribution system are critical in making this assessment. An SLD assists in identifying the rated capacity of loads associated with process heating equipment, HVAC, and other motor loads. An SLD identifies available spare capacity in the form of circuit breakers and their voltage and current ratings located in an MCC or distribution panel for potential use in new equipment installations.

The Electrification Readiness Worksheet provided in Appendix A provides a step-by-step template to evaluate a facility's electrification readiness, and the information identified in the SLD can be used to assist in providing the required inputs.

Reviewing a Single-Line Diagram—Example

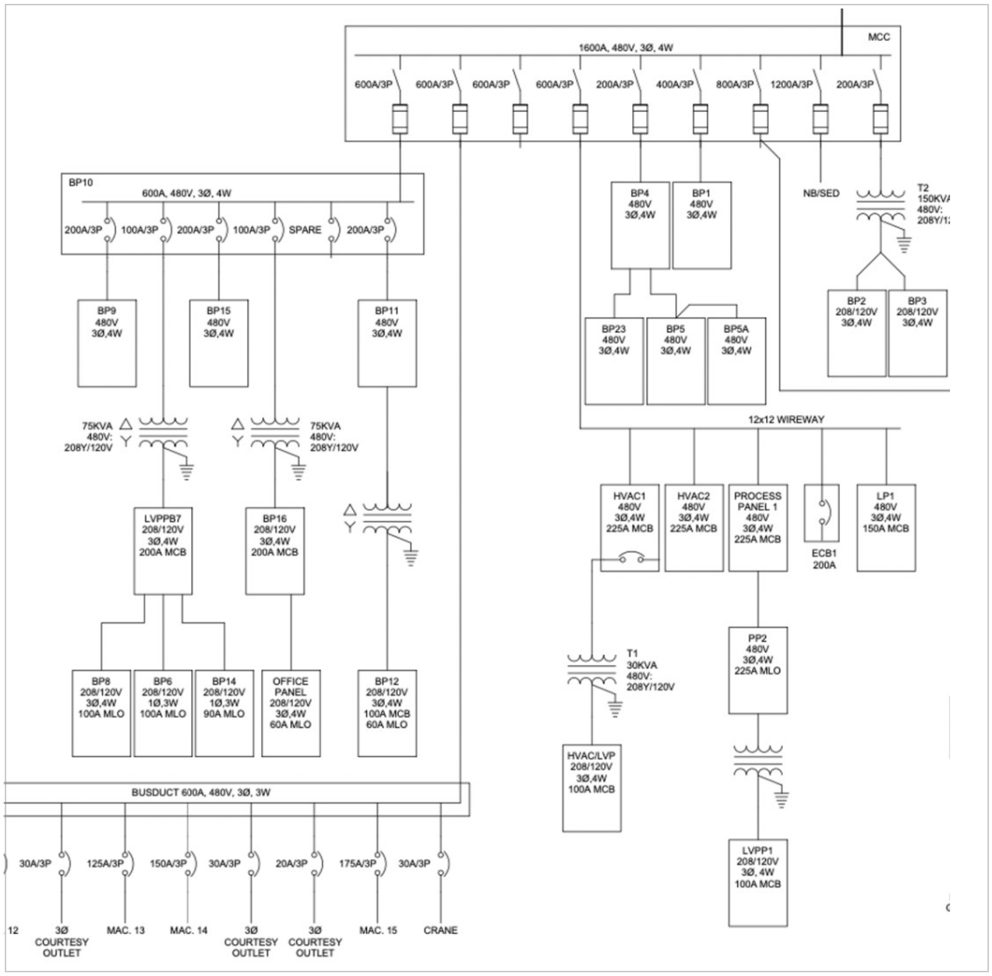

Figure D-4. Using an SLD to assist with filling out the Electrification Readiness Worksheet.

A. Starting from the top, the figure shows an MCC rated at 1,600 A with 10 sets of fused switches at various voltage and current ratings. Of these 10 fused switches, the MCC has one spare 600 A, three-phase slot.

B. Further down and to the left of the SLD is a distribution panel (BP10) that holds six three-phase circuit breakers, of which one is a spare. No rating is on this spare circuit breaker, which likely indicates that the slot is open but no breaker is installed.

C. Additionally, a 600 A bus duct is fed from an MCC fused switch, which feeds various circuit breakers to the end-use loads, which include a crane, three three-phase courtesy outlets, and several machines notated by MAC.13, MAC.14, and MAC.15.

When moving forward in analyzing an electrical system, SLDs can contribute to understanding how loads are fed within the plant. As equipment is upgraded or additional loads are added, consult electrical contractors and your facility's local utility representative to understand impacts and constraints new loads may have on the plant.

APPENDIX E: UTILITY BILL ANALYSIS

Utility bill analysis is a great tool for understanding how much energy a facility uses and when it is used. In addition to helping find ways to save money and energy, it also helps in planning and prioritizing projects for electrification. Figure E-1 shows a simple guide on how to perform this analysis.

Steps to Analyze Utility Bills

Collect energy data: Start by gathering the facility's energy usage data, particularly focusing on natural gas and other fuels. Ideally, data should be collected from the past 12 to 24 months to cover seasonal variations in production and weather.

Understand the link between production and energy use: Typically, the more a facility produces, the more energy is used. Also, the facility's energy use might change with the weather, especially if gas is used for heating. For example, a facility will use more energy in the colder months when heaters and boilers are running more often.

Visualize Energy Use Patterns: Once data are obtained, create charts to visualize how energy usage varies over time along with production levels and weather conditions. This can help to identify patterns, such as increased gas use in colder months.

Example: In the example in Figure E-2, the months with higher heating degree days exhibit a stronger demand for natural gas associated with building space heating. The heating degree day falls to a local minimum in the summer months when natural gas consumption decreases, reaching a minimum in June. This time marks the cooling season minimum and will be reflected as a peak demand season for electric power consumption owing to the additional load from air-conditioning compressor drives. This minimum natural gas usage is established as the facility's baseline natural gas consumption associated with the temperature-independent process heating load. Thus, the high-level utility data review helps to break down the weather-dependent loads and production-dependent energy use at the facility.

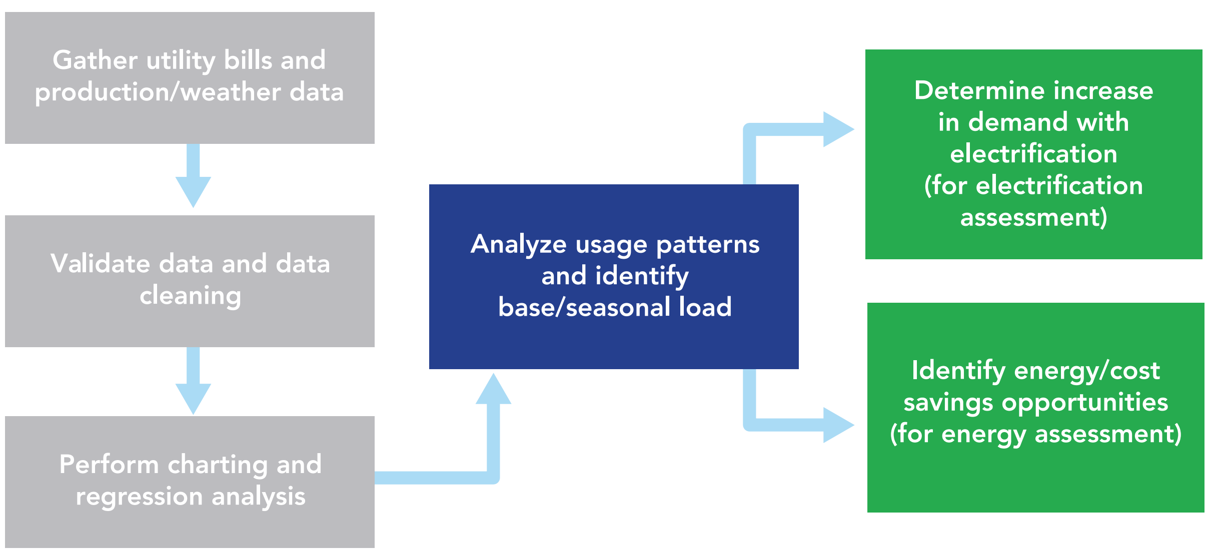

Figure E-1. Steps to performing a utility bill analysis.

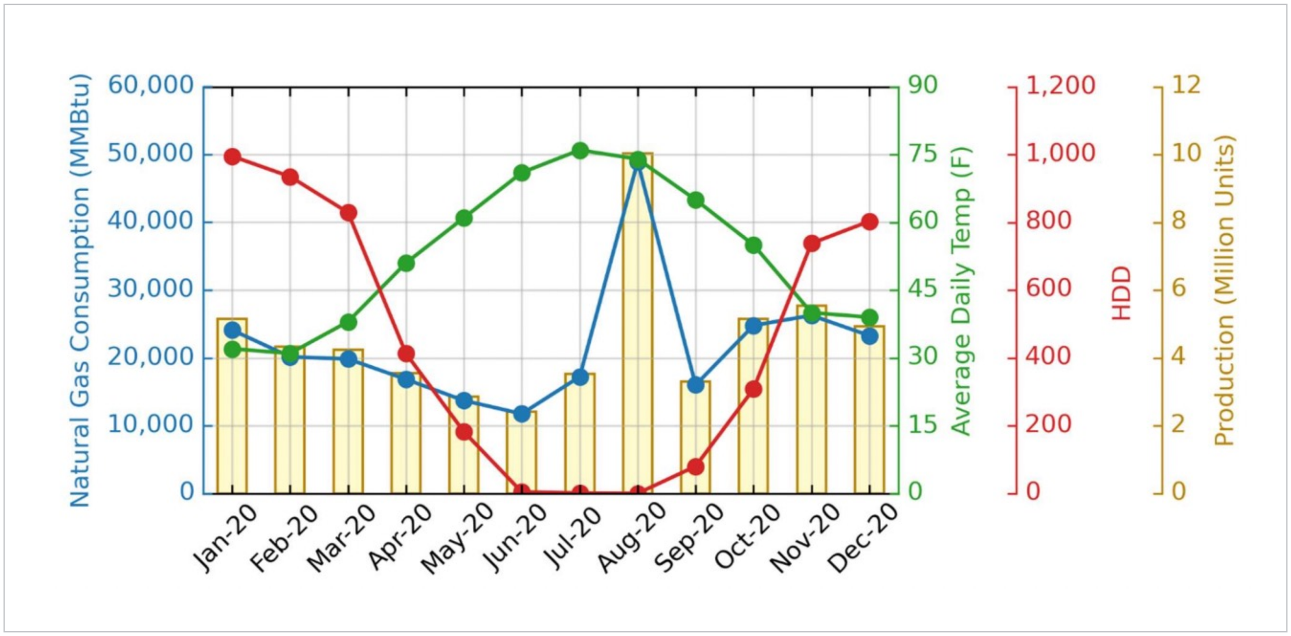

Figure E-2. Example natural gas use (blue) data plotted over a year, along with the weather (red) and production parameters. (yellow bar)

Estimate future energy needs: A regression-based model can provide deeper insights into the energy use of a facility. Regression-based approaches normalize for differences in energy consumption by accounting for all relevant variables; these approaches help make more accurate estimations for the energy use breakdown. This breakdown of weather versus production-dependent loads can then be extended to the equipment level by considering the relative size and operation of the different equipment.

From a detailed regression analysis, a facility estimates the extra electricity needed if switching from gas to electric systems. This information can help in understanding whether the current electrical setup can handle the new demand. The VERIFI tool[19] allows users to quickly explore and analyze their utility data at facility and corporate levels. VERIFI can perform advanced regression-based analysis for tracking consumption and can generate visualizations.

For more information on regression analysis, please refer to the E*nergy Intensity Baselining and Tracking Guidance*.[20] For further details on understanding energy bills and opportunities within a rate structure, refer to *Understanding Your Utility Bills*,[21] available in the U.S. Department of Energy's Better Plants resources library.

[19] DOE VERIFI Tool. https://betterbuildingssolutioncenter.energy.gov/better-plants/software-tools

[20] Chris R. Price, Sachin U. Nimbalkar, and Thomas J. Wenning, 2020. *Energy Intensity Baselining and Tracking Guidance,* ORNL/SPR-2020/1566 (Oak Ridge, Tennessee: Oak Ridge National Laboratory, 2020). DOI: https://doi.org/10.2172/1649123.

[21] Christopher Price, Alexandra Botts, Senthil Sundaramoorthy, Subodh Chaudhari, and Thomas Wenning, Understanding Your Utility Bills: / Electricity, ORNL/SPR-2021/1839 (Oak Ridge, Tennessee: U.S. Department of Energy, 2021). DOI: https://doi.org/10.2172/1833978.

APPENDIX F: COMPONENTS OF A FACILITY'S ELECTRIC INFRASTRUCTURE

The common elements or components of a facility's electric distribution system (Figure F-1) include plant and utility substations, transformers, feeders, step-down transformers, and distribution panels.

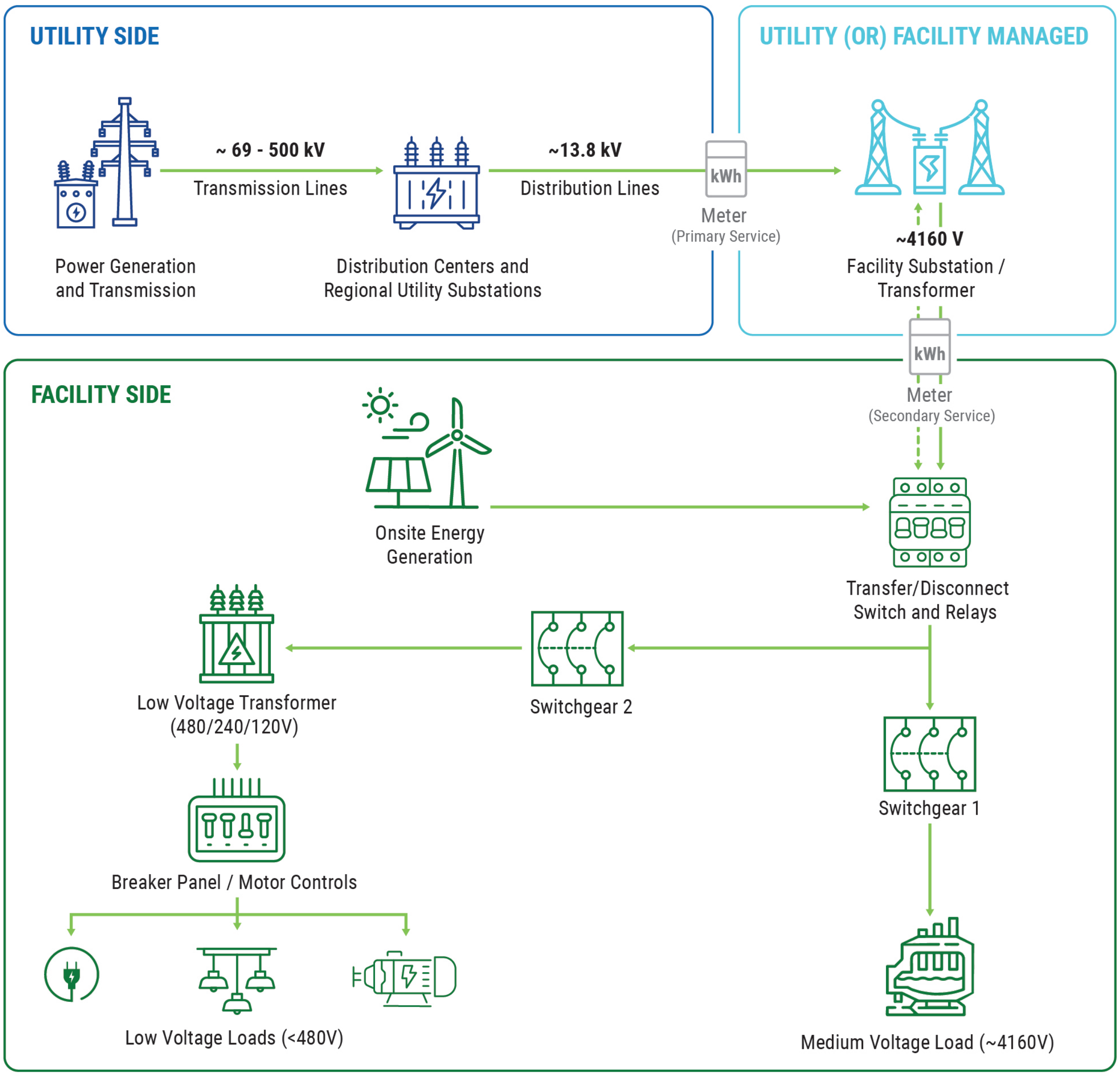

Figure F-1. Components of a facility's electric infrastructure.

Figure F-1 depicts an electrical distribution system, detailing the flow of electricity from generation to consumption at an industrial facility. Initially, electricity is generated and transmitted at high voltages ranging from 69 to 500 kV along transmission lines. This high-voltage electricity is then reduced to a medium voltage of approximately 13.8 kV at **regional utility substations** for easier distribution.

At the point of entry into the industrial facility, this medium-voltage power is further stepped down through the **facility transformer** to about 4,160 V, which is suitable for industrial applications. However, it's important to note that larger electric equipment, such as electrode boilers or high-capacity electric furnaces, may require operating at higher voltages due to their significant energy demands. Industrial facilities typically have one or more dedicated transformers that step down the voltage. Depending on the contractual agreement with the utility, these transformers can be owned and maintained either by the utility or the facility. The type of service (primary or secondary) is also typically dictated based on the ownership of these assets. **Feeders** are conductors that connect the main transformers to the areas within the facility where power is to be distributed. They ensure a constant current along their length and may use induction regulators to maintain a constant voltage.

Within the facility, electricity can be directed through two paths: directly to medium-voltage loads (around 4,160 V) or further reduced using **low-voltage facility transformers**. These transformers are typically owned by the facility and play a crucial role in adapting the power to the specific voltage requirements of different machinery and equipment. **Switchgears** receive electricity from the transformers and further distribute it to various electronic devices and distribution boards within the facility. They comprise a centralized collection of circuit breakers, fuses, and switches (circuit protection devices) that function to protect, control, and isolate electrical equipment. **Motor control centers and switchboards** are typically downstream of switchgears and are the distribution point for other loads. Although switchgears act as the first node in the electric distribution system from the facility transformer, in some cases, the motor control centers can be connected and draw power directly from the main facility transformers.

Better Plants Industrial Electrification Assessment Framework

Published April 2025 | ORNL/SPR-2025/3852