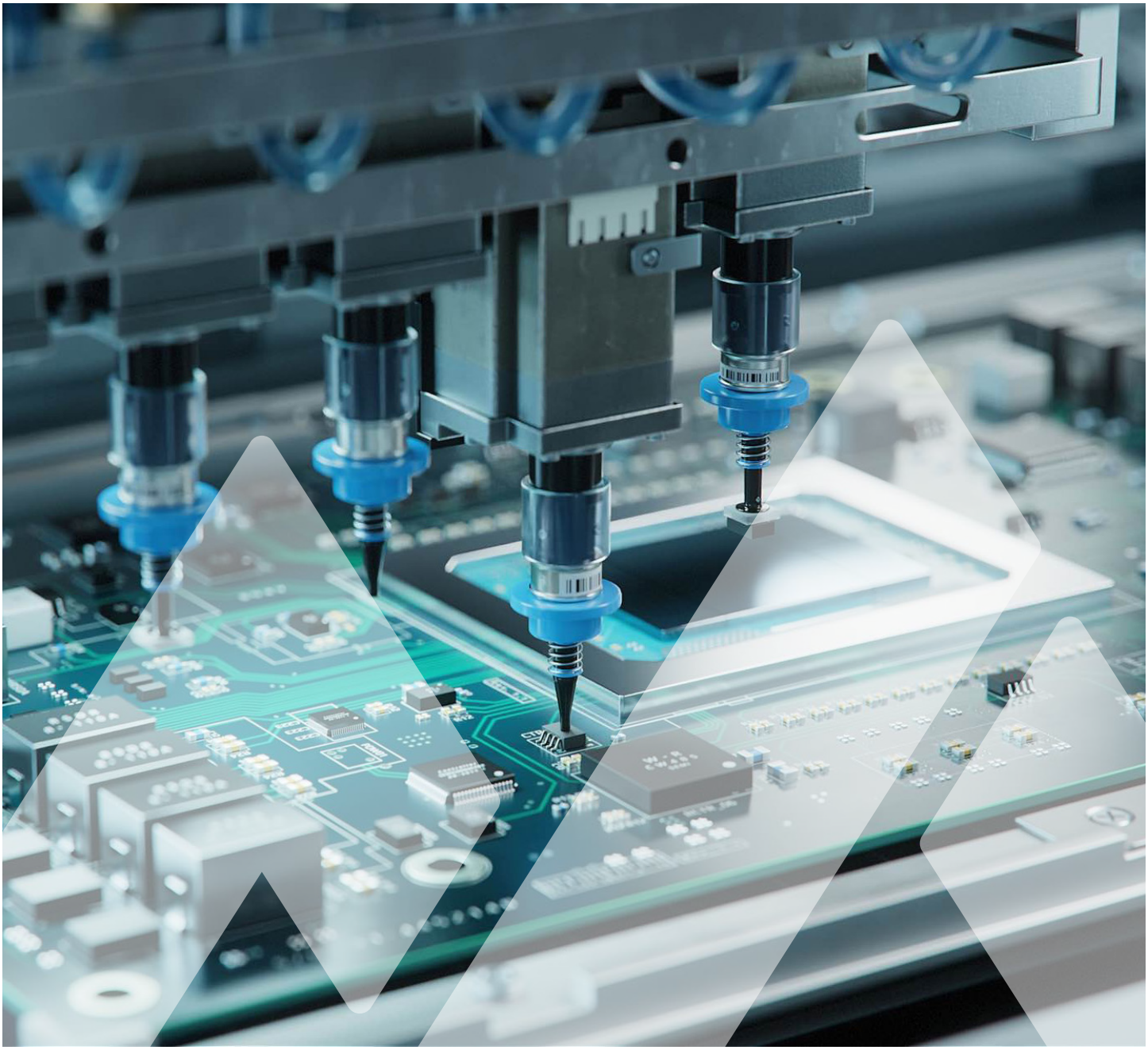
Towards Net-Zero Electronics

Unlocking the power of energy efficiency in manufacturing facilities



Report / April 2025



About RMI

RMI is an independent nonprofit, founded in 1982 as Rocky Mountain Institute, that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut climate pollution at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; Abuja, Nigeria; and Beijing, People's Republic of China.

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1. Why Supply Chain Energy Management Matters in the Electronics Manufacturing Industry

The electronics manufacturing industry is experiencing rapid growth, driven by the global shift toward digitization, automation, and technologies such as 5G, the Internet of Things, and artificial intelligence (AI). The global electronics market was valued at $1.275 trillion in 2023 and is growing at a rate of 7.5%, with the Asia–Pacific region and North America driving demand.[1] In China, the electronics manufacturing industry was the top industry in terms of revenue from 2013 to 2023. China's supply-chain market reached RMB 37.72 trillion (US$5.2 trillion) in 2023, with about 41,200 electronics manufacturing companies.[2]

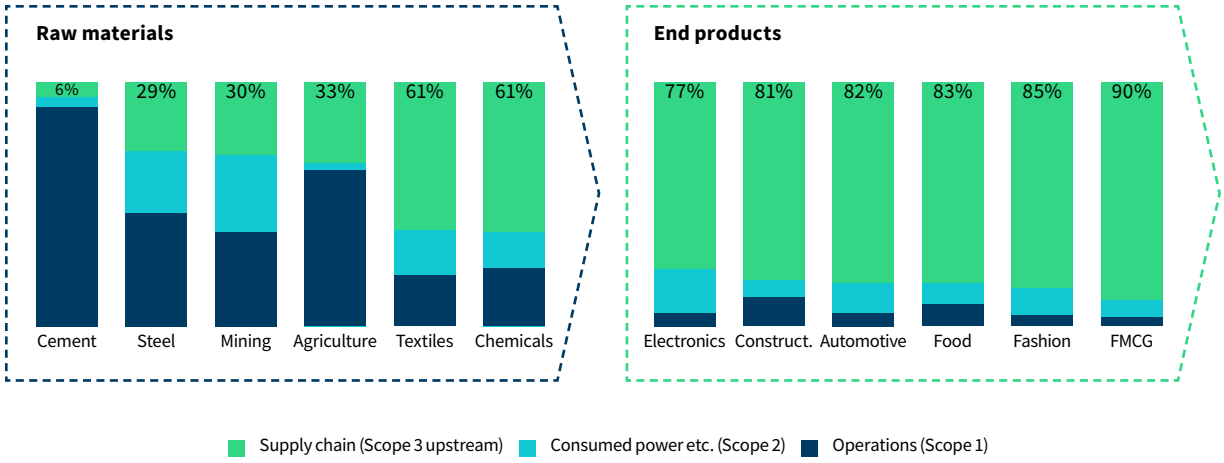
The electronics industry plays a critical role in the global energy transition and efforts to combat climate change; as demand for electronic products increases, so does the sector's environmental impact, particularly in terms of energy consumption and emissions. The electronics industry is estimated to be responsible for more than 4% of global greenhouse gas emissions.[3] By driving innovation in energy technologies, the sector is helping reduce greenhouse gas emissions and moving toward a more sustainable, low-carbon economy.

Energy efficiency is a key pillar in the global energy transition and the fight against climate change because it directly reduces energy demand, greenhouse gas emissions, and the need for fossil fuels. The International Energy Agency (IEA) calls energy efficiency the "first fuel" for achieving climate goals and says it can deliver more than 40% of the emissions reductions needed by 2040 in the IEA's Sustainable Development Scenario.[4] Improving energy efficiency in a wide range of manufacturing applications not only reduces energy consumption but also enhances the viability of renewable energy sources, increases energy security, and lowers energy costs. Research conducted by McKinsey & Company shows potential energy savings of 25% to 30% in fabrication facilities with neither loss of quality nor worker-safety compromises and little new investment.[5]

Importance of supply chain energy efficiency in the electronics manufacturing industry

Supply chain carbon emissions management is critical in the electronics manufacturing industry. Consumer electronics suppliers, including semiconductor manufacturers, display manufacturers, and final assemblers, account for over 77% of the electronics industry's total emissions (see Exhibit 1). This highlights the significant impact that upstream activities within the supply chain have on the overall carbon footprint. Effective management of energy use across these supply-chain stages is essential for the industry to progress toward net-zero emissions. This data underscores the necessity of addressing Scope 3 emissions, which include all indirect emissions that occur in the value chain, from raw material extraction to the production of final goods.

Exhibit 1 Emissions split in Scopes 1, 2, and 3 upstream for selected industries (CO_2e, 2019)

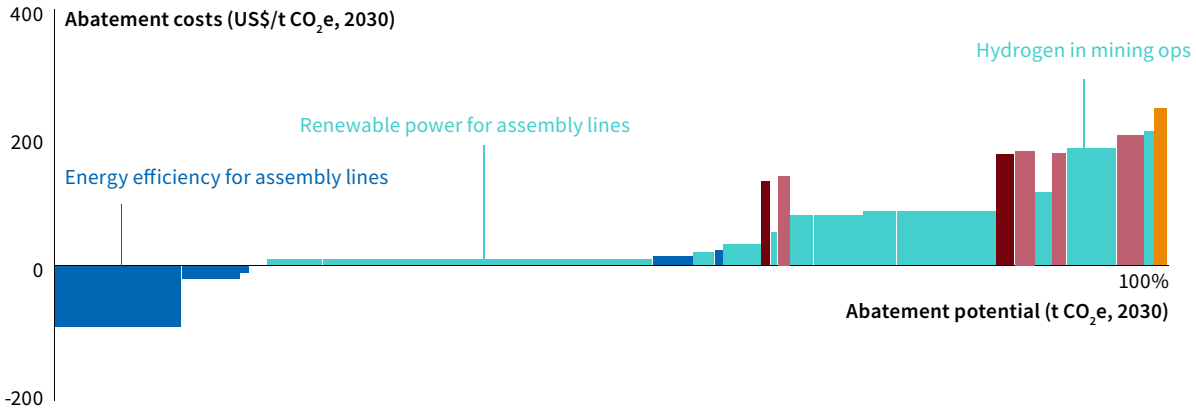


Note: Top companies were selected based on the number of reported Scope 3 upstream categories and industry fit. FMCG means fast-moving consumer goods. CO_2e means carbon dioxide equivalent.

RMI Graphic. Source: Carbon Disclosure Project; Boston Consulting Group; *Net-Zero Challenge: The Supply Chain Opportunity*, World Economic Forum, 2021

Energy efficiency is a crucial lever for reducing emissions in the electronics manufacturing industry. A substantial portion of these emissions can be eliminated at little to no cost through the implementation of energy-efficiency measures (EEMs). As shown in Exhibit 2, energy-efficiency improvements in assembly lines can reduce overall supply chain emissions by up to 20%, with abatement costs ranging from approximately -US$100 to US$0 per ton of CO_2e by 2030.[i] Business cases from leading electronics companies demonstrate that EEMs can achieve up to 30% energy savings in existing facilities, significantly reducing energy demand. This cost-effective opportunity represents one of the most impactful strategies electronics manufacturers can use to address their Scope 3 emissions.

Exhibit 2 Abatement costs vs. abatement potential in the electronics supply chain



RMI Graphic. Source: *Net-Zero Challenge: The Supply Chain Opportunity*, World Economic Forum, 2021

i Negative abatement costs indicate opportunities to reduce emissions while achieving a net economic gain.

In addition, energy efficiency can significantly lower costs for manufacturers by reducing energy consumption and optimizing production processes. By investing in energy-efficient equipment such as advanced motors, lighting systems, and automated controls, manufacturers can reduce their overall energy consumption, resulting in lower utility bills. In addition, energy-efficient machines often last longer and require less maintenance, reducing downtime and costs for repairs. According to IEA, most EEMs in its Net Zero Scenario are already cost-effective, meaning that the energy cost savings are greater than the investment required.[6] According to the US Department of Energy, the average energy cost savings identified by an energy-efficiency audit of a single energy-intensive system within a manufacturing company is US$1.4 million; for small and midsized manufacturing companies, the average energy cost savings is US$165,000 per audit.[7]

Managing energy efficiency in final assembly, testing, and packaging (FATP) facilities

An FATP facility is a manufacturing plant where the final stages of product assembly take place, including assembling components, testing the product to ensure it functions properly, and packaging it for shipment. FATP facilities are often associated with electronics manufacturing, for instance, of smartphones and computers. Although FATP facilities do not represent the most energy- and emissions-intensive stage of the electronics manufacturing process, they are important for energy management in several ways, including:

- Experience gained from addressing energy efficiency at an FATP facility can easily be scaled up to other facilities with standardized systems. An FATP facility typically has several standardized systems, such as those for compressed dry air (CDA) and heating, ventilation, and air conditioning (HVAC), that are commonly used in other manufacturing processes and facilities. For example, CDA systems are major energy consumers in the industrial sector, accounting for about 10% of industrial electricity consumption in the European Union and China, and 9% in the United States, Malaysia, and South Africa.[8]

- FATP is the stage at which an original equipment manufacturer (OEM) has direct control. FATP facility owners can therefore form better energy-efficiency collaborations and programs with OEMs and achieve optimal efficiency results, compared with more upstream (indirect) suppliers, which OEMs typically cannot directly manage.

Electricity is the main source of energy consumed by FATP. Energy consumption in these facilities is dominated by three major systems: production, HVAC, and process air (see Exhibit 3):

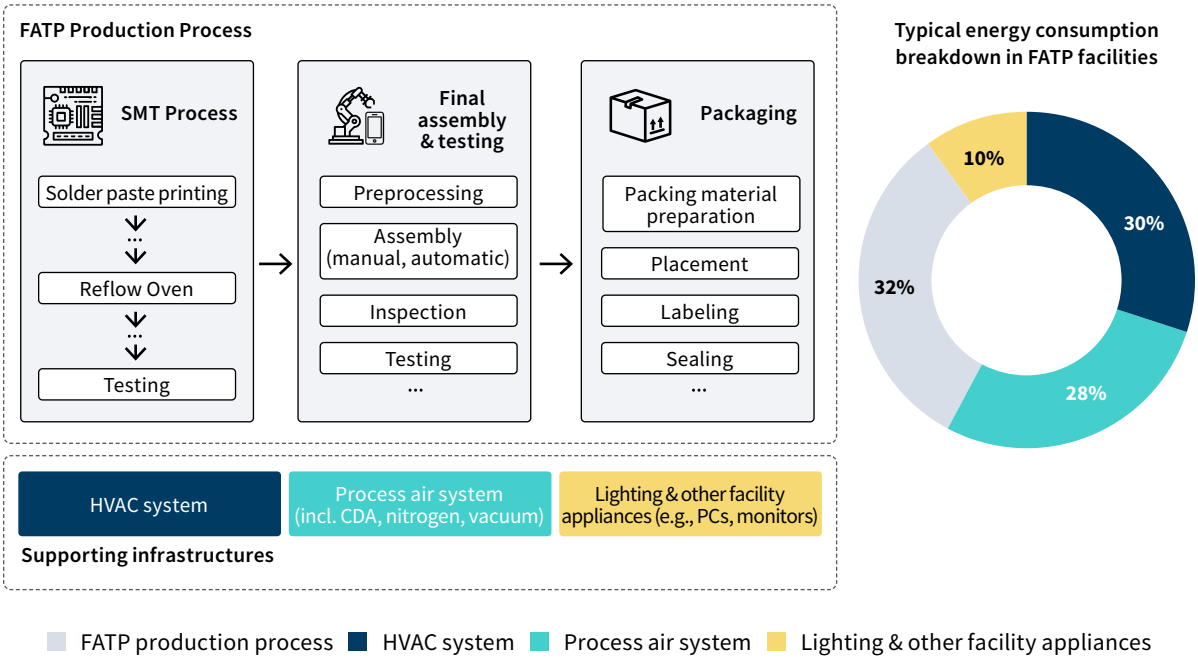
- **The production system** is the largest energy consumer at 32%. In FATP facilities, this includes the final assembly of electronics (e.g., surface mount technology [SMT] and through-hole assembly), testing, and packaging of devices. These operations require substantial energy for powering production machinery (e.g., a reflow oven) and testing equipment.

- **The HVAC system**, accounting for about 30% of total energy consumption, includes air conditioning, ventilation, and temperature control across the facility. It ensures optimal working conditions by regulating temperature and humidity, as well as the number of particles, particularly in critical areas like production lines and office spaces.

- **The process air system** consists of CDA, nitrogen, and other gases essential for production processes, accounting for 28% of the facility's energy consumption. These systems are necessary for various support operations, such as surface treatment, spraying, and blowing.

The remaining 10% covers other systems, such as lighting, office operations, and support services, which are essential for daily facility operations but contribute less to overall energy demand.

Exhibit 3 Typical energy consumption breakdown in FATP facilities



RMI Graphic. Source: RMI analysis

Improving energy efficiency in FATP facilities faces several challenges. The complexity of these facilities, which include diverse operations and equipment, complicates the integration of energy-efficient technologies without disrupting ongoing processes. Additionally, the high costs associated with upgrading machinery and implementing energy-saving measures make it difficult to justify investments and demonstrate a clear return on investment. Moreover, optimizing processes to enhance energy efficiency while maintaining high product quality and adhering to regulatory standards adds another layer of difficulty. Addressing these challenges requires a strategic approach that balances technological advancements, cost considerations, and operational efficiency.

2. Retrofitting Existing Facilities for Energy Efficiency

For existing FATP facilities, enhancing energy efficiency is increasingly critical. Many of the world's largest FATP facilities, particularly those built in China 10–20 years ago, face urgent needs for comprehensive energy upgrades and equipment modernization. This urgency is amplified by the growing commitment of OEMs to carbon neutrality within the electronics industry, including the decarbonization of their Scope 3 emissions. Additionally, tightening global and local standards and regulations are imposing stricter energy-efficiency requirements (see Exhibit 4). Internationally, standards such as ISO 50001 and ISO 50004 outline best practices for implementing an effective energy management system (EMS). In China, updated national and industry-specific standards reflect more stringent design requirements for factories. Regional or local governments have also proposed incentive policies, such as awards for efficiency projects and action plans, to catalyze implementations by local manufacturers.

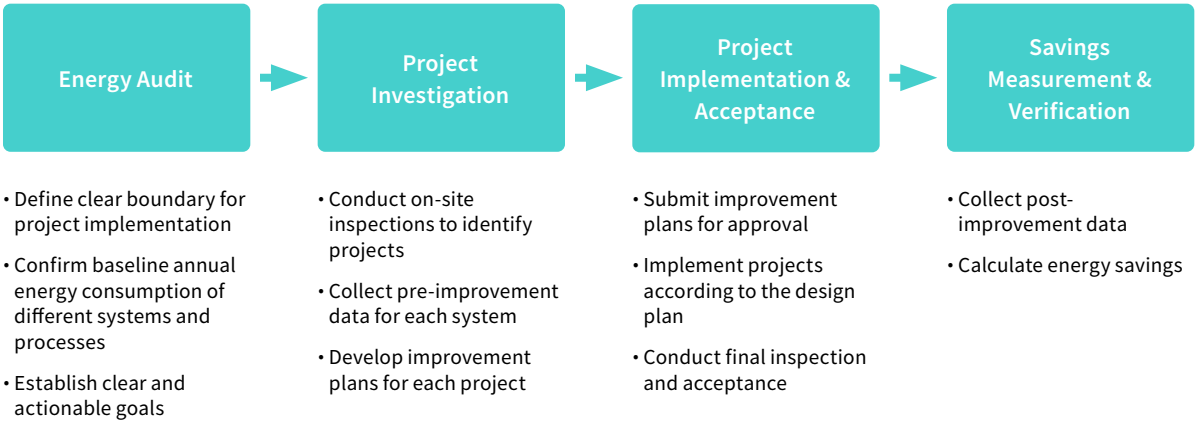
Exhibit 4 **Existing standards for energy management and green factories**

	Name	Description
Global	ISO 50001: 2018	EMS — requirements with guidance for use: international standard that provides a framework for establishing, implementing, maintaining, and improving an EMS
	ISO 50004: 2020	Guidance for the implementation, maintenance, and improvement of an ISO 50001 EMS: provides practical advice and strategies on how to effectively implement, maintain, and improve an energy management system based on ISO 50001
China's national standards & policies	GB/T 23331-2020	Chinese version of ISO 50001: 2018
	GB 51245 - 2017	Unified standard for energy efficiency design of industrial buildings
	GB/T 36132 -2018	General principles for assessment of green factories
	GB/T 50878-2013	Evaluation standard for green industrial buildings
Association standards in China	SJ/T 11744-2019	Guideline for assessment of green factories in electronic information products manufacturing (issued by Ministry of Industry and Information Technology on November 11, 2019)
	T/AIAC 003-2023	Evaluation standard of zero-carbon factories (issued by Investment Association of China on May 28, 2023)
	T/CIECCPA 030 -2023	General principles for implementation and assessment of zero-carbon factories (issued by China Industrial Energy Conservation and Clean Production Association on July 25, 2023)
	T/CECA-G 0171-2022	Evaluation specification of zero-carbon factories (issued by China Energy Conservation Association on 2022-6-1)

RMI Graphic. Source: RMI analysis

Optimizing the energy efficiency of existing FATP facilities involves a structured process consisting of several key steps (see Exhibit 5). The first step is to conduct an energy audit to confirm baseline electricity consumption and define project boundaries. This is followed by a project investigation, in which on-site inspections are conducted to identify and document potential improvement projects and collect baseline data for each proposed improvement. The next phase is project implementation and acceptance, during which project proposals are evaluated, retrofit plans are submitted, and projects are executed according to the established schedule. Finally, savings measurement and verification are performed to collect post-implementation data and calculate the actual energy savings achieved. This structured process was developed with reference to the ISO 50001 and aligns with the Plan-Do-Check-Act framework, ensuring that energy-efficiency improvements are systematically planned, implemented, monitored, and continuously optimized for long-term impact.

Exhibit 5 **General process for optimizing energy efficiency for existing FATP facilities**



RMI Graphic. Source: RMI analysis

Key considerations in an energy audit

Before initiating any retrofit work, establishing a clear energy baseline through a comprehensive energy audit of the FATP facility is essential. This audit provides a critical understanding of current energy consumption situations and identifies improvement opportunities. Key considerations for an effective energy audit include:

- **Comprehensive coverage of key energy consumers:** The audit must encompass all major energy-consuming elements of the facility, including production lines, processes, and equipment. Employing advanced diagnostic tools, such as thermal imaging and real-time energy monitoring, enhances the accuracy and depth of the audit. These tools help uncover hidden inefficiencies and establish a detailed baseline for subsequent energy-efficiency improvements.

- **A focus on energy-intensity mapping:** Energy consumption can vary significantly based on the product, process, and external factors, such as climate. Therefore, the audit should emphasize energy intensity, which is the amount of energy consumed per unit of production. This focus allows for precise comparisons and better identification of areas where energy efficiency can be improved.

- **Stakeholder engagement:** Engaging key stakeholders, including facility operators, maintenance teams, and management, is crucial. This involvement helps identify nontechnical barriers, such as operational practices and staff behavior, and ensures that the proposed EEMs are practical and have strong support for implementation.

Clearly outlining the boundaries for the audit and specifying which systems and processes will be evaluated is essential for a successful energy audit. Depending on the facility's needs, energy assessments can vary in scope and depth, ranging from quick assessments that identify major opportunities, to detailed assessments of specific systems (e.g., HVAC, CDA, lighting), or comprehensive plant-wide audits. While quick or system-specific assessments may be appropriate in certain situations, a plant-wide energy audit is highly recommended whenever possible. This comprehensive approach not only measures the energy consumption of individual systems but also maps the energy flow between different components within the facility, uncovering broader opportunities for efficiency improvements.

By analyzing the interactions between systems, the audit can identify additional energy-saving opportunities that might otherwise be overlooked. For instance, assessing the potential for heat recovery and reuse between production processes and HVAC systems can reveal significant efficiency gains that would be missed if the HVAC or production systems were audited separately. A facility-wide audit also ensures that energy losses at system boundaries are captured and that the potential synergies among various processes — such as using waste heat from CDA systems for water heating — are fully realized.

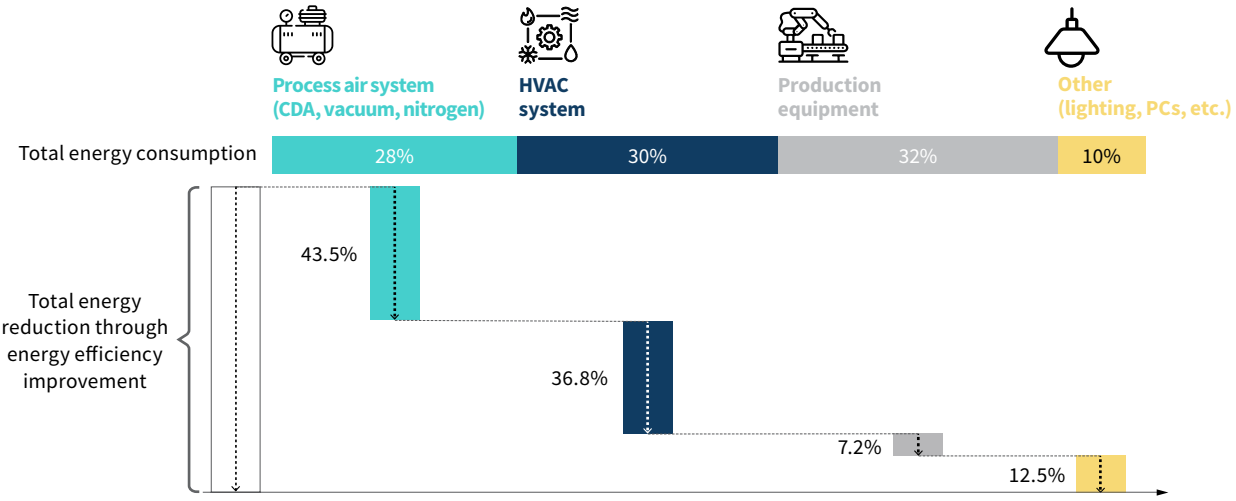
In addition, after completing the energy audit, it is essential to establish clear, actionable goals for the energy-efficiency project. These goals should be designed to not only achieve energy and cost savings but also to deliver broader, lasting benefits to the facility and organization. Key advantages of such goals include enhancing the company's financial stability and improving its competitive position. Moreover, the energy-efficiency project should be implemented in a manner that maintains operational security, ensuring seamless integration with existing production processes without causing disruptions. This careful approach allows the facility to sustain energy-efficiency improvements while safeguarding production quality and operational continuity.

Systems investigation for optimal energy-saving potential

Based on the energy intensity mapping results, the next step is to identify and evaluate EEMs for the most energy-intensive systems within the FATP facility. This includes a detailed assessment of potential improvements for key energy-consuming systems, such as HVAC systems, process air systems (including CDA, nitrogen, and vacuum), production processes, and other supporting equipment like lighting and personal computers (PCs).

RMI's analysis of verified energy-saving data from over 30 China-based FATP facilities in the consumer electronics sector (e.g., smartphones, laptops) reveals that the process air and HVAC systems present the highest potential for energy savings, accounting for an average of 43.5% and 36.8% of total energy reduction through EEM implementation, respectively. Although production equipment is the largest energy consumer, the potential for energy-efficiency improvements is comparatively limited. Significant energy-savings potential also exists in other equipment, contributing to an average of 12.5% of total energy savings, despite accounting for only about 10% of total energy consumption (as shown in Exhibit 6).

Exhibit 6 Energy consumption breakdown and subsystems' contribution to total energy reduction in FATP facilities



Note: The data analyzed represents averaged values across more than 30 FATP facilities. Actual energy-savings potential may vary significantly because of differences in production lines, facility construction years, equipment specifications, and other operational factors across individual facilities.

RMI Graphic. Source: RMI analysis.

When considering energy-efficiency improvements, FATP facility owners should assess several critical factors: (1) the potential energy savings of each measure, (2) the payback period to determine whether the investment is financially viable, and (3) the operational impact to ensure that the measures minimally affect the production processes. By carefully evaluating these aspects, FATP facility owners can make informed decisions that enhance energy efficiency while maintaining operational effectiveness.

Process air system

The process air system at an FATP facility, which includes CDA, vacuum, and nitrogen, is a significant energy consumer, accounting for approximately 30% of the facility's total electricity consumption. The process air system is also the most common area for energy-efficiency improvement, according to RMI's interviews with several companies. This system is critical to various manufacturing processes, providing essential functions, such as powering pneumatic tools, maintaining controlled environments, and supporting critical operations. Given its integral role in the production process, it is important to carefully balance EEMs with the need to ensure production reliability (see Exhibit 7, page 14).

1. CDA system:

- **Compressor:** The compressor is the central component of the CDA system. Upgrading from low-efficiency compressors to high-efficiency models can substantially reduce energy consumption, with a payback period extending up to seven years. Alternatively, recovering waste heat from compressors is a more cost-effective measure, offering a payback period of under three years.[ii]

- **Dryers and valves:** Implementing lossless dryers and drains can lower site energy consumption by up to 1.4%, with a payback period of less than three years. Additionally, installing an aftercooler before air dryers in refrigerated systems and extending dryer regeneration times through precise dew point control are cost- effective EEMs because of their minimal initial investment and substantial long-term savings.

- **Air inlet and outlet:** Optimizing air intake by repositioning and resizing suction ports can reduce compression energy consumption with minimal up-front investment. Furthermore, employing energy-saving air guns can cut unnecessary energy use with a payback period of less than one year.

- **Pipeline:** Detecting and repairing leaks, replacing pipeline connectors, and optimizing piping layouts (such as creating loop connections) are cost-effective, easily implemented EEMs. These improvements typically offer a payback period of less than six months, making them an attractive option for immediate energy savings.

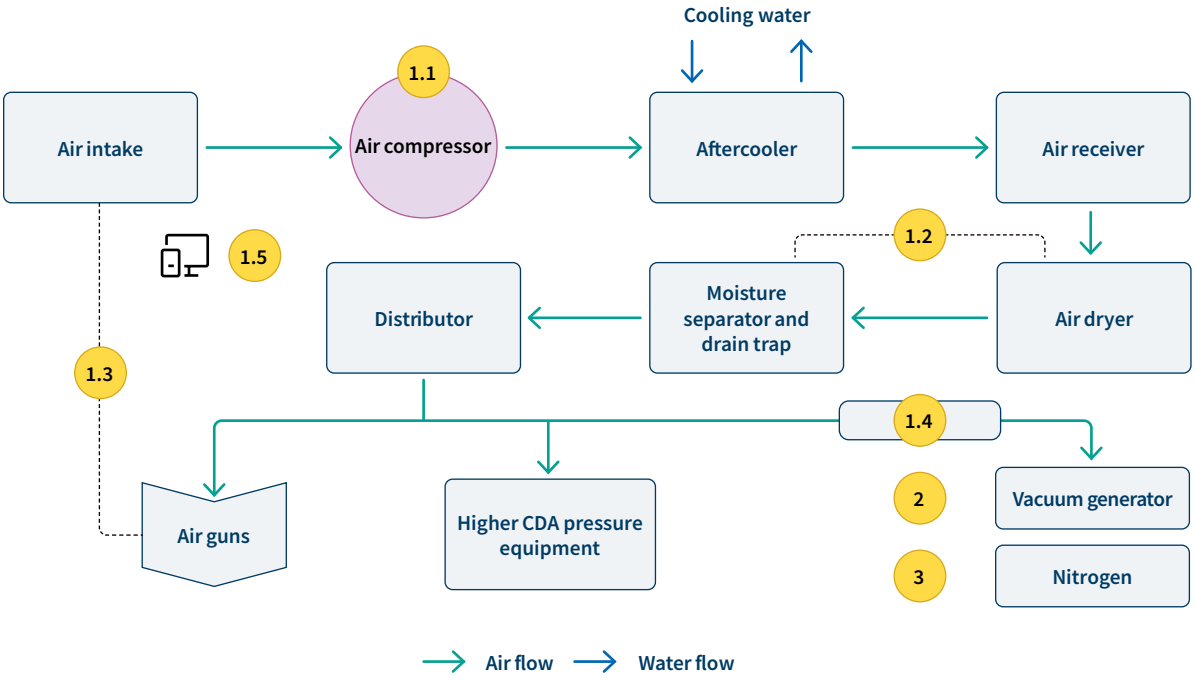
- **Control:** Improving the control strategy of the CDA system is key to enhancing efficiency. Key measures include minimizing system pressure, optimizing compressor cycles, and implementing multiple-compressor controls. Variable frequency drives (VFDs) can further reduce energy waste by adjusting air output to real-time demand. Installing local boosters for equipment requiring higher pressure helps avoid raising system-wide pressure. Additionally, interlocking dryers with compressors and shutting down unloaded compressors can reduce operational hours. These control strategies can cut site energy consumption by up to 1.5%, with a payback period of under two years.

2. **Vacuum system:** Upgrading from vacuum generators to vacuum pumps and adopting more energy-efficient vacuum generators can significantly reduce energy consumption, with a typical payback period of less than two years. Furthermore, decreasing vacuum usage by reducing operational hours or replacing vacuum functions with mechanical alternatives, such as grippers, enhances efficiency and generates additional energy savings.

3. **Nitrogen system:** Detecting and repairing leaks within the nitrogen system is essential for maintaining operational efficiency and preventing unnecessary energy consumption. Additionally, optimizing programmable logic controller settings ensures that the nitrogen system operates only as required, thereby reducing overall energy use.

ii All payback period data and estimates are based on practical experience from real-world cases. In individual cases, the actual payback time can vary significantly, as it depends on various factors, such as electricity prices, heat recovery potential, and other site-specific conditions.

Exhibit 7 System diagram and energy-efficiency measures for a process air system



System		EEMs
1. CDA system	1.1 Air compressor	– Replace low-efficiency air compressors – Recover waste heat from air compressors
	1.2 Dryers and valves	– Install lossless dryers & drain valves – Install aftercooler before air dryer (for refrigerated dryers) – Prolong dryers' regeneration time (e.g., implement dew point control)
	1.3 Air inlet & outlet	– Reposition and resize suction port – Use energy-saving air guns
	1.4 Pipeline	– Detect and repair leakage – Replace pipeline connectors – Optimize pneumatic network
	1.5 Control	– Adjust system pressure (install booster pump for higher pressure when needed) – Install VFD to regulate screw compressor – Reduce running hours (e.g., interlock dryers with compressor, shut down unloaded compressor, reduce CDA usage)
2. Vacuum		– Replace vacuum generators with vacuum pumps – Use more efficient vacuum generators – Reduce vacuum usage (e.g., reduce running hours, replace with grippers)
3. Nitrogen		– Detect and repair leakage – Optimize programmable logic controller (PLC) for nitrogen production

RMI Graphic. Source: RMI analysis

HVAC system

The HVAC system is another major energy consumer in FATP facilities, typically accounting for approximately 30% of total electricity consumption. This figure can escalate considerably if the system is not properly configured and controlled. The HVAC system is crucial for maintaining optimal environmental conditions within the facility, such as temperature, humidity, and air quality, which are essential for ensuring the reliability and quality of production processes. Given the HVAC system's significant energy use and critical role in production, it is important to implement key EEMs for each subsystem (see Exhibit 8, page 16).

1. **Chiller:** The chiller is a pivotal component of the HVAC system, significantly influencing overall energy efficiency. Upgrading from low-efficiency to high-efficiency chillers can substantially improve system performance, although the initial investment may result in a payback period ranging from two to over ten years. Conversely, regular cleaning of heat exchangers is a cost-effective measure that generally yields a payback period of less than two years. Additionally, selecting chillers with low global warming potential and ozone-depleting potential helps reduce life-cycle environmental impacts.

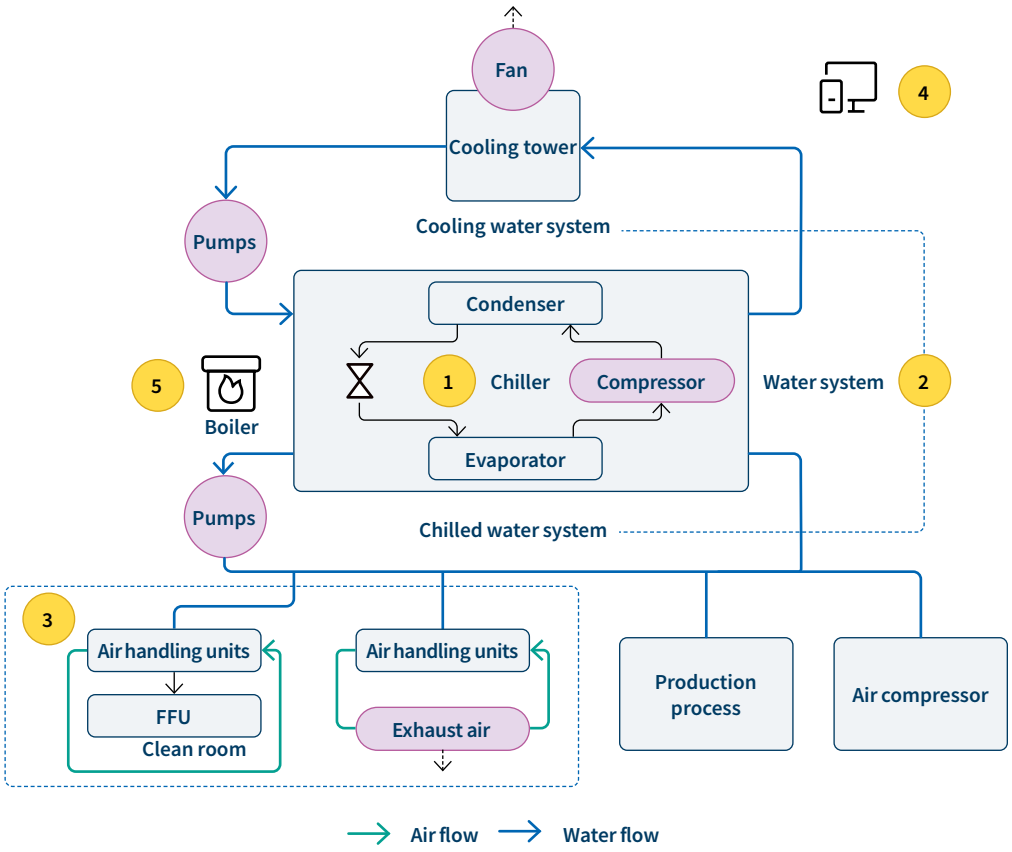
2. **Chilled and cooling water system:** Over 20% of HVAC energy consumption is allocated to water transmission. Implementing straightforward and economical EEMs, such as insulating pipelines, increasing chilled water temperatures, and making hydraulic adjustments, can enhance efficiency. Additionally, using cooling towers for free cooling during colder months proves to be highly cost-effective, with a payback period of under two years. Upgrading to efficient VFDs for pumps typically results in a payback period of less than three years.

3. **Air-handling system:** The air-handling system is particularly energy-intensive because of the stringent air-quality requirements necessary for electronics manufacturing. Cost-effective EEMs, including adjusting fresh air intake, regularly cleaning or replacing coils, and upgrading fan-filter units (FFUs) from AC to DC motors, usually offer a payback period of less than two years. Although exhaust-air heat recovery can be highly beneficial, the payback period may extend to four years or more, depending on specific conditions. Replacing steam humidifiers with spray or ultrasonic humidifiers is another effective measure, with a payback period of less than three years.

4. **Control system:** In FATP facilities, where cooling demands fluctuate and system interactions are complex, the control system is essential for optimizing component efficiency and adapting to real-time needs. Installing VFDs on pumps and fans and employing time switches to reduce operational hours are straightforward measures with a typical payback period of under three years. Although implementing centralized control through an EMS involves a higher level of complexity, it can greatly optimize HVAC operations across the facility, offering a payback period of less than two years because of significant energy savings.

5. **Boilers:** FATP facilities in colder climates often use boilers for space and water heating. Recovering waste heat from these systems can result in significant energy savings, provided that suitable heat sinks, such as dormitories or low-temperature processes, are identified for effective use. Other EEMs for boilers include installing flue gas sensors and controls to optimize combustion and replacing leaking steam traps. Improving boiler efficiency can reduce energy consumption by up to 30%, with payback periods of less than two years. Furthermore, transitioning from fossil-fueled boilers to electric heat pumps can significantly lower direct CO_2 emissions and provide additional benefits, such as reduced local air pollution (SO_x, NO_x) and lower insurance costs. Thanks to the excellent energy efficiency of heat pumps and the decreasing electricity prices relative to fossil fuels, the initial investment in heat pump technology can typically be recouped within five years.

Exhibit 8 System diagram and energy-efficiency measures for HVAC systems



System	EEMs
1. Chiller	– Replace low-efficiency chillers with high-efficiency models – Clean heat exchanger
2. Water system	– Optimize cooling water quality (e.g., add disincrustant, change filters) – Install temperature sensors on cooling towers for on/off control – Use cooling towers for free cooling, where feasible – Increase the chilled water temperature – Optimize the hydraulic system – Replace less efficient pumps
3. Air-handling system	– Adjust the volume of the fresh air intake – Clean or replace fan coils – Upgrade clean room FFUs from AC to DC motors – Incorporate heat recovery from exhaust air – Replace steam humidifiers with spray or ultrasonic humidifiers – Replace less efficient fans (including exhaust fans, fans in AHU, etc.)
4. Control	– Install VFD controls on pumps and fans – Implement centralized control through an EMS – Reduce running hours (e.g., by using time switches)
5. Boiler	– Recover waste heat (install economizer, add heat recovery units for flue gas and condensate water) – Install flue gas sensor and controller in boiler – Replace leaking steam traps – Replace boilers with heat pumps
6. Passive measures	– Add insulation to chilled water pipes – Insulate or reposition heat-generating equipment (e.g., oven exhaust gas ducts)

RMI Graphic. Source: RMI analysis

Production system

The production process accounts for approximately 30% of total electricity consumption for FATP facilities. This process is critical as it has a direct impact on the manufacture of electronic components and the overall efficiency of manufacturing operations. However, the implementation of EEMs in this area is often driven by OEM specifications, which limit the flexibility of suppliers to make changes.
In addition, because much of the energy consumption in this process is closely tied to production activities, introducing EEMs could disrupt operations or introduce uncertainty. Despite these challenges, several strategies can improve energy efficiency in the manufacturing process (see Exhibit 9, page 18).

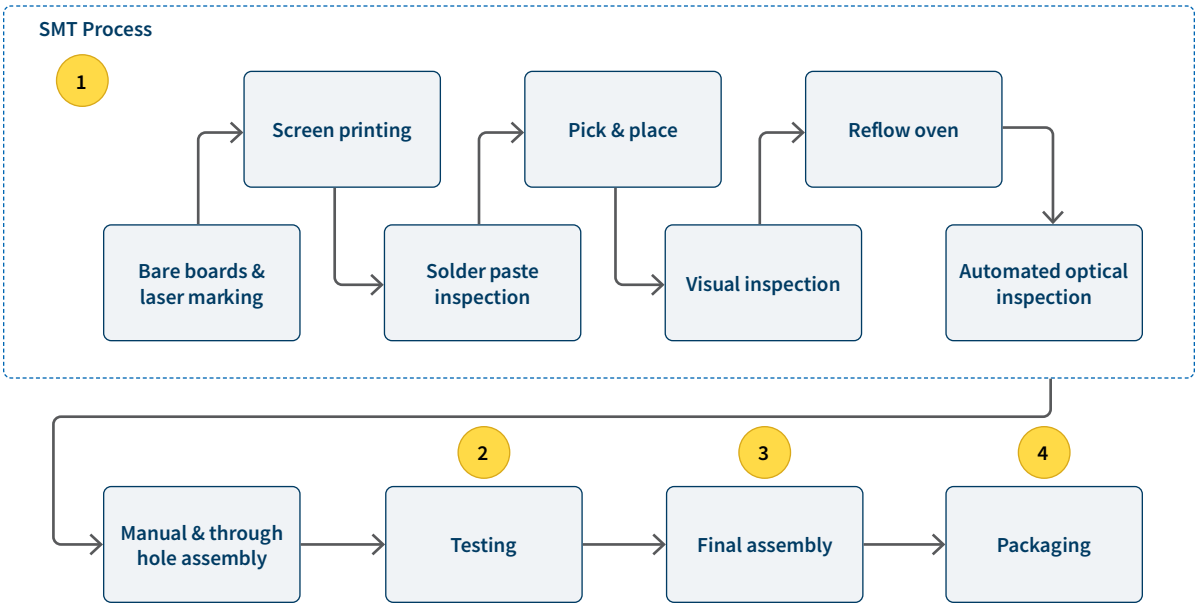
- **Standby mode optimization:** Production processes are not continuous, and research shows that 30% of energy consumption by machine tools comes from standby operation during production pauses or equipment idle periods.[9] Optimized energy-saving modes can help avoid unnecessary energy waste by automatically reducing power consumption when equipment is not in active use. This measure is highly cost-effective, as it typically requires little to no up-front investment while delivering immediate energy savings.

- **Insulation:** Many production processes generate excess heat that is often lost to the environment. Properly insulating equipment and heat-emitting areas helps retain this heat, reducing the workload on HVAC systems. This measure requires minimal up-front investment while delivering considerable energy savings; the payback period is typically less than six months.

- **Process automation:** Process automation can enhance overall efficiency by optimizing workflows, reducing manual intervention, and minimizing energy use across various stages of production. For instance, replacing pneumatic systems with servo motors could offer greater precision and efficiency, as well as reduce the CDA system's energy consumption. Although automation requires up-front investment, the energy savings, along with improved productivity and reduced manual labor costs, result in a higher return on investment over time.

In addition, replacing outdated, less efficient monitors used on production lines presents an often-overlooked opportunity for substantial energy savings. Newer, energy-efficient monitors consume significantly less power during active use and offer enhanced energy-saving modes that automatically reduce energy consumption when not in use. This dual benefit — lower energy consumption in active and standby phases — can yield considerable energy savings across the facility, especially in high-density production environments with numerous operating monitors.

Exhibit 9 **Main FATP production processes and energy-efficiency measures**



System	EEMs
1. SMT process	– Use central chilled water for reflow oven cooling – Improve reflow oven insulation – Introduce or optimize energy-saving mode for production equipment
2. Testing	– Replace less efficient split air conditioners for burn-in test – Replace less efficient testing equipment
3. Final assembly	– Replace less efficient robot grippers – Introduce or optimize energy-saving mode
4. Packaging	– Replace shrink wrap with rip cord – Improve shrink wrap machine insulation
5. Overall	– Replace less efficient monitors used on production lines

RMI Graphic. Source: RMI analysis

Lighting and other facility appliances

Lighting is typically the next largest energy-consuming activity in FATP facilities, following HVAC systems, air systems, and production processes. Because of its widespread use across the facility, lighting presents significant opportunities for energy savings. Common EEMs include installing high-efficiency LED fixtures and integrating controls such as motion sensors and time switches to ensure lights are activated only when necessary. Additionally, implementing task lighting in specific areas, such as testing zones, can reduce the need for general overhead lighting throughout the facility, thereby enhancing overall efficiency. These lighting EEMs are generally cost-effective, often resulting in a payback period of less than two years.

Other facility appliances include office devices such as PCs, monitors, split air conditioners, and drinking water dispensers, as well as supporting equipment like elevators. Although these appliances are not the primary energy consumers in FATP facilities, notable energy savings can be achieved by replacing inefficient equipment with high-efficiency models and minimizing unnecessary use, such as turning off monitors and drinking water heaters during off-hours (Exhibit 10). Although these behavioral EEMs require minimal investment, they do require staff training, education, and communication.

Exhibit 10 **Energy efficiency measures for lighting and other facility appliances**

System	EEMs
Lighting	– Replace less-efficient lamps with high-efficiency LEDs – Install lighting sensors and time switches – Evaluate and optimize lighting for specific areas
Other facility appliances	– Replace less efficient split air conditioners (e.g., split air conditioners for offices or testing) – Replace less efficient PCs and monitors – Turn off drinking water machines during off-hours

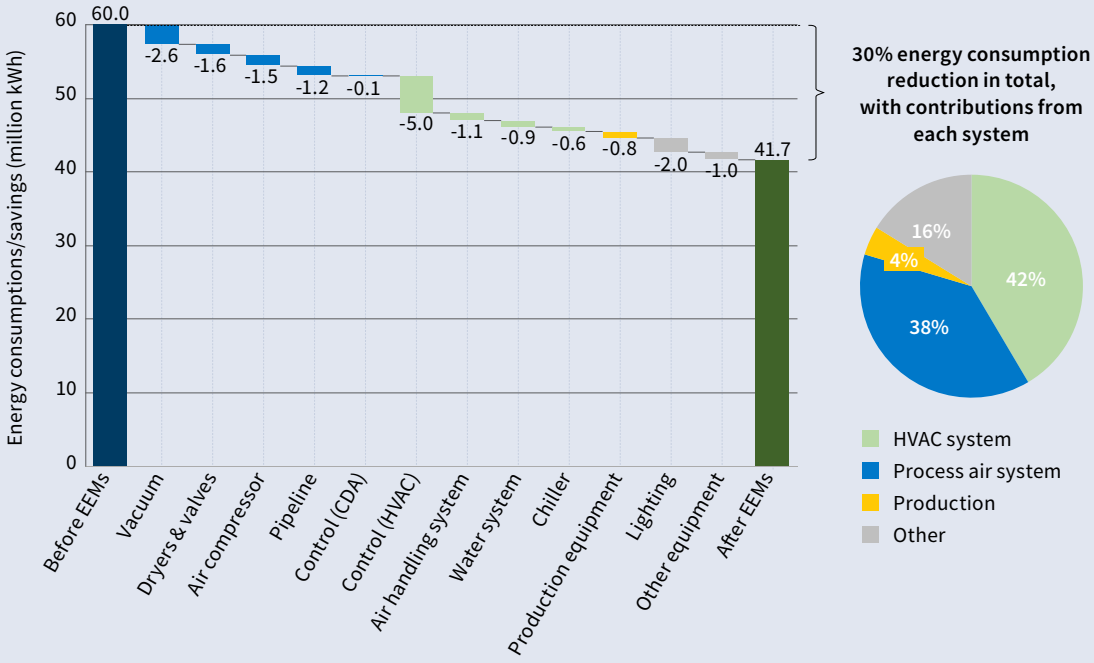
RMI Graphic. Source: RMI analysis

Case Study: Achieving over 30% energy savings through EEM implementation in an FATP facility

A comprehensive energy-efficiency program enabled a leading electronics manufacturer to achieve over 30% energy savings in one of its FATP facilities (see Exhibit 11). HVAC system optimizations led the way, contributing nearly 42% of total energy savings, with control enhancements — such as VFDs for pumps and fans and an EMS — saving approximately 5 million kilowatt-hours (kWh) annually (over 25% of total energy savings).

Process air system improvements were the second-largest contributor, delivering 38.1% of total savings. Notably, replacing vacuum generators with vacuum pumps alone saved 2.6 million kWh annually, or 15% of the total energy saved in the facility. Lighting upgrades, mainly through illumination management, saved nearly 2 million kWh, while production processes offered smaller savings, contributing 4.2% (0.8 million kWh) of the total energy savings. This case study underscores the significant energy-saving potential of EEMs in FATP facilities, with HVAC and process air systems having the greatest impact.

Exhibit 11 **Contribution of different EEMs to total energy savings in an FATP facility**



RMI Graphic. Source: RMI analysis

Project implementation and acceptance

When implementing energy-efficiency projects in FATP facilities, several challenges need to be addressed. These include variations in project implementation times, the potential impact on production schedules, and the high up-front investment required for some EEMs. To overcome these challenges and ensure effective project execution, it is essential to focus on the following three key aspects:

- **Strategically sequence the EEMs:** Start by implementing simple and proven measures that are typically easy and cost-effective, providing quick wins and establishing a solid foundation for more complex upgrades.

- **Find the right time for hard-to-implement projects:** Schedule EEMs that require longer installation times and may disrupt production during periods that minimize production downtime, such as public holidays. Introducing high-efficiency equipment toward the end of the current product life cycle can maximize economic returns. Aligning new product introductions with system upgrades can also help optimize energy efficiency.

- **Leverage financial support:** For larger projects, seek financial assistance through public funding, policy incentives, and energy performance contracting. These resources can help offset initial costs, making it more feasible to implement ambitious energy-saving measures. In a real-world case, leveraging government subsidies and recycling incentives reduced the initial cost of replacing low-efficiency motors by up to 65%.

After the implementation, a rigorous acceptance phase is vital for confirming the success of the EEMs and ensuring sustained energy savings. This phase should involve thorough commissioning to verify that the newly installed systems integrate effectively with existing processes and meet performance expectations. Installing measurement devices during the retrofit process is also crucial for accurate future savings verification, ensuring that the benefits of the implemented measures are accurately tracked and maintained.

Proactively seeking collaboration with OEMs can provide valuable support, especially when addressing complex implementation challenges. Suppliers are encouraged to work closely with OEM expert teams, who can offer on-site assistance and insights into best practices. This collaboration can be instrumental in building internal capabilities, from developing specialized skills and forming dedicated teams to setting up robust systems and adopting proven methodologies. By leveraging OEM guidance and resources, FATP facilities can streamline project execution, overcome potential obstacles, and achieve lasting gains in energy efficiency throughout the project life cycle.

Case Study: OEM and supplier collaborate for a successful energy-efficiency project

A leading consumer electronics OEM collaborated with its FATP supplier to undertake a comprehensive three-year energy-efficiency improvement project at the supplier's facility. During the preparatory phase, the two organizations established an ambitious target of achieving 30% energy savings. This goal was informed by the supplier's thorough energy intensity mapping, the OEM's previous successes in energy-efficiency retrofits, and insights from external energy-efficiency experts. This initiative reflected a shared commitment to sustainability and continuous improvement from both parties.

In the implementation phase, a joint working group was formed to facilitate technical support and training for the effective execution of the EEMs. The supplier created an internal team dedicated to securing essential resources, including funding and personnel, to ensure the project's success. The focus was placed on critical areas such as HVAC systems, process air management, and the SMT production process. Key actions included the installation of group control systems for chillers and air compressors, VFDs for motors and pumps, and energy-efficient cooling systems for reflow ovens.

As a result of their strong collaboration and the effective implementation of EEMs, the project achieved a remarkable 35% reduction in energy consumption, surpassing the initial target. The OEM's sustainability commitment to supply chain decarbonization served as the primary motivation for initiating the project, further strengthened by the close collaboration between the OEM and the supplier. For the supplier, the project reinforced its own sustainability goals while delivering operational efficiency improvements and significant cost savings. These benefits provide a compelling case to scale energy-efficiency initiatives both within the company and across the wider industry.

Savings verification

A rigorous measurement and verification (M&V) process is crucial to the success of suppliers' energy-efficiency programs, ensuring that energy savings are accurately quantified, validated, and sustained across the supply chain.

Implementing a standardized yet tailored M&V process is vital for accurately assessing the impact of EEMs. This process should be grounded in the International Performance Measurement and Verification Protocol (IPMVP) and should be recognized and agreed upon by all relevant stakeholders, including OEMs, suppliers, external verifiers, and M&V experts. Aligning all parties on the methodology ensures that the M&V process serves as a dependable tool for validating energy savings and demonstrating the effectiveness of the implemented measures.

Maintaining the credibility of the M&V process necessitates defining acceptable deviation thresholds to ensure results fall within an agreed-upon range of accuracy. This precision is essential for correctly attributing observed energy savings to the implemented measures, thereby avoiding misinterpretation due to external factors or measurement errors. Establishing clear accuracy requirements helps maintain the integrity of the M&V process and ensure reliable outcomes.

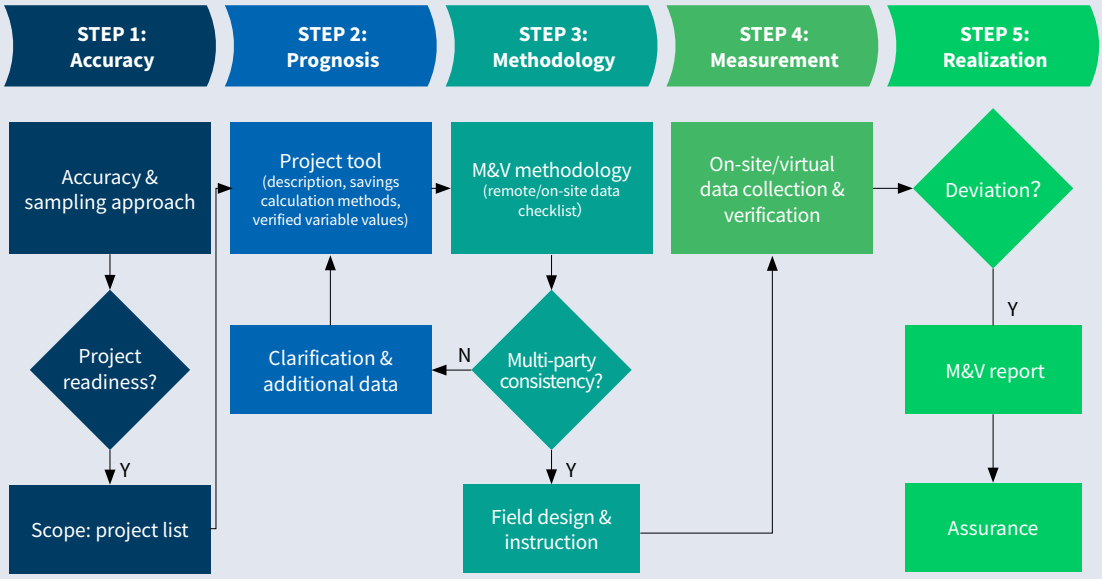
Engaging external auditors to independently verify the M&V results adds an additional layer of credibility and reliability to the energy-efficiency program. External assurance not only validates the findings but also enhances the defensibility and scalability of the energy savings across the supply chain. By incorporating independent verification, the program can gain greater trust and support from all stakeholders involved.

Case Study: Using a rigorous M&V process to strengthen reputation and enable further improvements

A leading consumer electronics OEM collaborated with its FATP supplier to implement an IPMVP-based, high-accuracy, five-step approach to verify energy savings from an energy-efficiency project involving the installation of VFD controls. The initial energy savings measurement was performed by the supplier's facility management team. Following this, a third-party verifier was engaged to conduct a thorough remeasurement, resulting in a detailed verification report that outlined the project specifics, the M&V methodology employed, and the confirmed energy savings. To ensure the reliability of these findings, the results were subsequently reviewed by another third-party verifier, with all parties — including the supplier, the OEM, and both verifiers — collectively approving the rigorously validated results.

This consensus on the energy savings not only facilitated the broader implementation of the energy-efficiency project but also positioned it as a highlight in the company's ESG report, thereby enhancing its social and environmental reputation and increasing attractiveness to investors. Additionally, the comprehensive M&V process allowed the supplier to uncover further energy-saving opportunities within the FATP facility, setting the stage for ongoing improvements in energy efficiency and reinforcing the commitment to sustainability.

Exhibit 12 **IPMVP-based, five-step, high-accuracy approach to an M&V process**



Note: "Deviation" under Step 5 refers to the difference between expected and actual energy savings. Significant deviations should be explained in the M&V report.
RMI Graphic. Source: RMI analysis

3. Planning for Optimum Energy Efficiency in New Facilities

Retrofitting existing FATP facilities unlocks substantial energy-efficiency improvements and provides valuable lessons for designing new FATP facilities. Although all the EEMs discussed in the retrofitting section apply to new facilities, constructing a new facility offers additional opportunities to achieve optimal energy efficiency from the outset. Starting with a clean slate enables a holistic design approach, incorporating the latest energy-saving technologies and seamlessly integrating systems to maximize energy performance across the facility. Unlike retrofits, which often focus on incremental upgrades, new facilities can be designed for comprehensive, long-term energy efficiency.

An integrated design approach is crucial in this context, as it allows for a holistic consideration of the facility's systems and processes. By treating the facility as a unified entity rather than a collection of disparate components, integrated design ensures that all elements work cohesively to maximize energy efficiency. This approach not only reduces energy consumption significantly but also enhances operational effectiveness and reduces waste, setting the foundation for sustainable operations in new FATP facilities.

Key principles for new FATP facilities with an integrated design approach

The design of a new FATP facility necessitates the collaboration of diverse stakeholders, including architects, engineers, environmental consultants, and operational managers. Establishing a set of shared principles for integrated designing is crucial for harmonizing these varied perspectives and expertise. This alignment ensures that all parties are oriented toward common goals of sustainability and efficiency, streamlining the decision-making process and enhancing the effectiveness of energy-efficiency strategies. The principles (see Exhibit 13) serve as a foundational guide to foster this collaborative approach and drive the successful implementation of effective and cohesive energy-efficiency solutions.

Exhibit 13 **Key principles for integrated design for new energy-efficient FATP facilities**



RMI Graphic. Source: RMI analysis

- **Select energy-efficient and electric equipment**

Selecting energy-efficient equipment is essential for optimizing energy performance in a new FATP facility. Choosing advanced, energy-efficient, and all-electric components — such as heat pumps, air compressors, reflow ovens, and chillers with VFDs — can significantly reduce energy consumption and eliminate direct emissions. For example, an air compressor with an energy-efficiency rating of 1 is approximately 20% more efficient than one with a rating of 3.[iii] Given that compressed air systems account for about 30% of total energy consumption in FATP facilities, this efficiency improvement translates into substantial energy savings.

- **Prioritize passive technology**

Passive technologies reduce a facility's energy demand by harnessing natural resources, making them a key component of integrated design. By optimizing the building's architecture, passive strategies enable natural heating, cooling, and lighting, thereby reducing dependence on mechanical systems. Research indicates that passive strategies can reduce cooling loads by 31% on average, significantly lowering energy demand.[10] Additionally, the use of passive technologies cuts life-cycle costs by allowing for smaller, less energy-intensive equipment. For instance, air-conditioning systems with 30% lower cooling capacity, made possible through passive design, are typically 10% cheaper, offering both up-front cost savings and long-term energy-efficiency benefits.

- **Deploy automation and smart controls**

The integration of automation and smart controls is a cornerstone of dynamic energy management within an integrated design approach. For instance, deploying smart HVAC controls that adjust heating and cooling based on real-time occupancy and demand can significantly reduce energy consumption during nonpeak periods. Best practices show that combining VFDs with smart controls can reduce a chiller's annual energy use by up to 30%.[11] Furthermore, equipping production equipment with smart sensors and automated controls for standby and idle modes can optimize energy usage during production downtime, leading to additional efficiency gains. In one FATP facility, for instance, implementing an energy-saving mode for production equipment like reflow ovens resulted in a 1% reduction in the facility's total energy consumption.

- **Adopt modular and scalable equipment**

Designing facilities with modular and scalable equipment provides significant flexibility and adaptability in response to changing production requirements. For example, employing modular clean room, air-handling systems that can be expanded or contracted based on production demand helps prevent unnecessary energy consumption. Similarly, modular power distribution systems and scalable compressed air systems in FATP facilities enable use of only the energy necessary for current production loads, thereby reducing overall energy waste.

- **Integrate emerging technologies**

Early integration of emerging technologies, such as AI-driven energy management platforms and advanced cryogenic nitrogen generation systems, places new FATP facilities at the forefront of energy

iii Analysis is based on China's national standard "minimum allowable values of energy efficiency and energy-efficiency grades for displacement air compressors (GB 19153—2019)". Data for an oil-injected, rotary air compressor with a nominal discharge pressure of 0.7 MPa and nominal motor power of 22 kW is used for comparison.

efficiency. Case studies show that AI technology can enable energy-efficiency improvement of 20%–40% in the chemical industry.[12] Within an integrated design framework, these technologies provide continuous energy usage optimization, crucial for maintaining long-term energy efficiency. By embedding these advanced technologies from the outset, the facility is equipped to continually adapt and improve its energy strategies.

- **Recover and reuse energy**

Incorporating energy recovery systems into new FATP facilities exemplifies integrated design by linking heat sources and sinks to maximize efficiency. This approach captures waste heat from production equipment for other needs, such as preheating HVAC intake air or providing hot water in canteens and dormitories. By repurposing otherwise wasted heat, these systems reduce overall energy consumption and costs. For example, 70%–80% of the electricity used by air compressors is converted to heat and released into the environment; capturing this waste heat for hot water could save about 0.6% of the facility's total energy consumption.

Case Study: Designing new energy-efficient FATP facilities

A leading electronic components manufacturer adopted an integrated design approach to constructing a new FATP facility, emphasizing key principles for maximizing energy efficiency. Central to the design was the selection of energy-efficient equipment, which included high-performance chillers, air compressors, and motors rated at level 2 efficiency or higher.[iv] This strategic choice not only minimizes energy consumption but also enhances operational throughput, particularly through the deployment of energy-efficient pick-and-place machines in SMT processes. Additionally, the facility's architecture incorporated advanced passive technologies, such as an optimized building envelope, which significantly reduces heat loss and maximizes natural lighting, thus lowering overall energy demand.

The facility's design further prioritized automation and smart controls to facilitate dynamic energy management. Extensive smart control systems were integrated, including VFDs for pumps and motors, along with occupancy sensors and timers for lighting and HVAC systems. This ensures that energy consumption is closely aligned with actual demand, minimizing waste during nonpeak periods. A centralized EMS seamlessly integrates these components, enabling intelligent sequencing and real-time monitoring to optimize energy usage across the facility.

A standout feature of the new FATP facility is its robust heat recovery system, designed to effectively use waste heat from air compressors for heating needs, such as hot water and mixed air units. By incorporating energy recovery systems from the outset, the facility exemplifies the essence of integrated design, maximizing efficiency through the interconnectedness of various systems. These comprehensive energy-saving measures have not only resulted in the facility's achieving LEED Gold certification for the entire manufacturing campus but also China's Green Factory certification, showcasing the manufacturer's commitment to sustainability and operational excellence.

iv Level 2 is the second highest (out of three) energy efficiency rating under China's national standards for various equipment types, such as chillers (GB 19577-2024) and air compressors (GB 19153-2019).

Implementing integrated design: Key considerations for energy efficiency in new FATP facilities

Implementing an integrated design approach in new FATP facilities involves prioritizing energy efficiency through cohesive workflows. This approach requires a thorough understanding of the facility's energy needs and the implementation of innovative solutions to meet those requirements. Traditional methods often treat essential energy needs — such as heating, cooling, lighting, and process air —through separate, stand-alone systems, which can lead to missed opportunities for synergy and increased inefficiencies. By adopting an integrated design approach that harmonizes building layout with operational processes, energy demands can be met more effectively and sustainably.

This section will focus on three critical workflows essential to achieving energy efficiency:

- **Building and facility layout design,** which optimizes the physical configuration to enhance energy performance. This workflow is normally led by architects and building designers.

- **System and equipment design,** which strategically selects and arranges technologies to minimize energy consumption while maximizing production efficiency. This workflow is normally led by mechanical engineers.

- **Control and monitoring systems**, which leverage advanced technologies to continuously manage and refine energy usage. This workflow is normally led by electrical engineers.

Working together, these workflows exemplify the integrated design approach, ensuring that all aspects of the facility's design and operation work synergistically. This method not only addresses individual energy needs but also fosters a comprehensive strategy that significantly enhances the facility's overall energy efficiency and sustainability.

Building and facility layout

The integrated design approach at the building design stage is essential for maximizing energy efficiency in FATP facilities by aligning physical spaces with energy needs and collaborating with other workflows. Strategic design decisions can greatly reduce energy consumption across various operational demands, enhancing the overall effectiveness of this holistic method. By considering the layout and functionality of the facility from the outset, designers can create an environment that supports optimal energy performance.

In managing process air, the facility layout should position air compressors close to their points of use to minimize distance, thereby reducing pressure drops and leakage. This design optimization not only cuts down on the energy required for air distribution but also integrates seamlessly with heating and cooling. Suggested steps include:

- Implementing effective passive measures — such as optimizing building orientation and shade, and using high-performance thermal insulation. This can significantly lower heating and cooling loads, directly affecting the energy demand on HVAC systems.

- Implementing an efficient piping layout to minimize the energy required for distributing heated or cooled air, water, or recovered heat, thereby reducing pumping energy consumption.

- Maximizing natural daylight through strategic window placements and skylights so that facilities can reduce reliance on artificial lighting, while reflective surfaces — such as light-colored walls and ceilings — can improve the distribution of natural light throughout the space, further minimizing the need for artificial lighting.

- Additionally, optimizing workstation layouts and minimizing transportation distances between production stations, which can directly reduce electricity consumption for motion and transportation, leading to more efficient operations.

System and equipment

Selecting systems and equipment with high energy-efficiency ratings is critical for achieving the operational needs of new FATP facilities while maximizing energy efficiency. An integrated design approach during this selection process ensures that each system not only fulfills its functional requirements but also enhances overall energy use across interconnected workflows. Measures include:

- Using high-efficiency air compressors and related equipment in the process air system to reduce energy use significantly.

- Selecting high-efficiency chillers, boilers, and pumps for heating and cooling is essential. Additionally, using recovered heat from processes like air compressors and reflow ovens can effectively meet heating and cooling demands while minimizing energy waste.

- Employing centralized chilled water systems for critical processes that require cooling, such as reflow oven operations. This is recommended because of their higher efficiency compared with split systems.

- Choosing energy-efficient production equipment, including reflow ovens and packaging machines. Additionally, using robotic grippers instead of vacuum systems where feasible can save energy otherwise consumed in vacuum generation. Furthermore, insulating heat-generating equipment such as reflow ovens improves the equipment's efficiency while also reducing unnecessary cooling demand.

- Using LED fixtures along with targeted lighting layouts to ensure that illumination is directed precisely where it is needed.

Control and monitoring

A centralized EMS serves as the core of a new energy-efficient FATP facility, effectively coordinating the interactions among various systems and processes to maximize the energy-saving potential of each piece of equipment. This advanced system enables real-time energy monitoring, allowing for continuous optimization of energy use and the identification of inefficiencies across the facility. By integrating dedicated controls for specific systems — such as occupancy-based lighting switches — this approach provides targeted energy savings at the process level, ensuring comprehensive management and persistent optimization of energy consumption throughout all facility operations. Recommendations include:

- Implementing intelligent controls, including VFDs and automatic on/off control to improve the energy efficiency of process air systems. Advanced monitoring systems should track air pressure and temperature to optimize airflow and ensure that equipment operates only when needed.

- Installing a centralized control system equipped with VFDs, compressor group controls, and advanced valves for air and water flow management to significantly enhance overall heating and cooling efficiency. These controls intelligently adjust based on real-time heating and cooling demands, thereby improving the facility's energy performance.

- Integrating lighting controls with sensors — such as motion detectors and daylight sensors —which can significantly enhance efficiency by automatically adjusting light levels based on occupancy and natural light availability. Centralized control systems further optimize lighting management by allowing for facility-wide adjustments.

- Incorporating energy-saving modes for idle equipment and prioritizing the use of efficient motors during operation to substantially reduce electricity consumption. These measures ensure that energy is used only when truly needed, contributing to overall efficiency.

Key considerations for implementing integrated design for energy efficiency in new FATP facilities are summarized in Exhibit 14 (page 30). Major energy consumers — HVAC systems, process air systems, manufacturing systems, and lighting systems — are interrelated and can either complement or hinder one another's efficiency, depending on how they are designed and integrated. By adopting an integrated design approach that considers the entire facility, FATP manufacturers can optimize energy efficiency, reduce operating costs, and advance sustainability goals.

Exhibit 14 **Integrated system design considerations for energy-efficient FATP facilities**

What can be optimized when designing new FATP facilities \ Energy-dependent operational needs in FATP facilities		Gas or district heating	Electricity		
		Heating/Cooling	Lighting	Process air (including CDA, nitrogen, vacuum)	Electricity used by production equipment
Buildings and Facility Layout	Production Hall Design	• Optimize building orientation and shade • Use thermal insulation and airtight envelope	• Design for natural light (orientation, window, reflective surfaces)		• Optimize workstation and facility layout to reduce energy use for motion and transportation
	Facility Layout Design (entire complex, including production halls, warehouses, dormitories, canteen)	• Optimize facility layout to reduce pump energy (e.g., cooling water & recovered heat transmission)		• Optimize facility layout to reduce air distribution energy	
Systems and Equipment	HVAC System	• Use high-efficiency equipment (compressors, pumps, fans, FFUs) • Configure the quantity and capacity of chillers for optimal working efficiency • Consider heat pumps when heating and cooling demand both exist • Reuse waste heat from exhaust air (e.g., for fresh-air pre-conditioning)			
	Lighting		• Use high-efficiency LEDs with smart sensors • Optimize lighting layout		
	Process Air System (including CDA-system, vacuum and nitrogen generation and supply)	• Recover waste heat from air compressor • Use recovered heat for air dryers • Use high-efficiency cooling equipment for aftercooler		• Use high-efficiency equipment (compressor, dryers, air guns, vacuum pumps) • Set system pressure properly • Optimize pneumatic network for less air leakage • Position air inlet correctly for better air quality	
	Production Process	• Insulate heat-generating equipment (e.g., reflow oven) • Recover waste heat (e.g., from forming, molding process) • Use centralized chill water for reflow oven cooling		• Use robot gripper instead of vacuum, when possible	• Use high-efficiency equipment (e.g., reflow oven, packaging machine) • Streamline the production process to reduce energy use (lean manufacturing)
Control and Monitoring Systems (e.g., EMS)		• Install centralized control system (incl. VFD control, compressor group control, valves for water/air volume control)	• Integrate lighting control systems (timer, occupancy, etc.)	• Install intelligent compressor system (including VFD control, on/off control)	• Optimize energy-saving mode when equipment is idling

RMI Graphic. Source: RMI analysis

Endnotes

1 *Consumer Electronics Market, Research and Markets*, 2024.
2 *2024 China Electronics Industry Supply Chain Development Report*, China Federation of Logistics and Purchasing, 2024.
3 *Sustainable Electronics Manufacturing*, 2023–2033, IDTech, 2022.
4 *How Energy Efficiency Will Power Net Zero Climate Goal*s, IEA, 2021.
5 Steve Chen, Apoorv Gautam, and Florian Weig, *Bringing Energy Efficiency to the Fab*, McKinsey & Company, 2013.
6 *The Value of Urgent Action on Energy Efficiency*, IEA, 2022.
7 *Energy-Saving Opportunities for Manufacturing Enterprises*, US Department of Energy, 2011.
8 J. J. Cabello Eras, A. Sagastume Gutiérrez, V. Sousa Santos, and M. J. Cabello Ulloa, "Energy Management of Compressed Air Systems. Assessing the Production and Use of Compressed Air in Industry," *Energy* 213, 2020.
9 *Energy Efficiency in Production: Future Action Fields*, Fraunhofer Gesellschaft.
10 M. Hu, K. Zhang, Q. Nguyen, and T. Tasdizen, "The Effects of Passive Design on Indoor Thermal Comfort and Energy Savings for Residential Buildings in Hot Climates: A Systematic Review," *Urban Climate* 49, 2023.
11 *VSD Chillers Deliver Energy Savings under Real World Operation*, Chiller and Cooling Best Practices, 2017.
12 Rohit Kochar, "AI Will Transform Chemical Industries for Better Energy Management", *Chemical Industry Digest*, 2023.

Wei Li, Guangxu Wang, and Meng Wang, *Towards Net-Zero Electronics: Unlocking the power of energy efficiency in manufacturing facilities*, RMI, 2025, **https://rmi.org/insight/towards-net-zero-electronics/**.

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