Energy Efficiency and Cost Saving Opportunities for Breakfast Cereal Production

An ENERGY STAR® Guide for Energy & Plant Managers

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Cover photograph of a cereal oven courtesy of Post Consumer Brands.

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Overview

This Guide provides information to identify cost-effective practices and technologies to increase energy efficiency in the breakfast cereal production industry. It focuses on the most important systems, processes, and practices that account for the bulk of energy consumption. The information found in this Guide will help energy and plant managers identify energy reduction opportunities in their facility as well as improve the quality of breakfast cereal operations. For additional information on breakfast cereal production and associated processes and their energy consumption, please consult Appendix A and B of this Guide.

For breakfast cereal producers, raw material costs dominate over energy costs. However, increasing energy and water efficiency can generate significant economic benefits and will improve your profit margins. Energy waste is found in all plants, and improving energy efficiency goes right to the bottom line and protects the environment. Following the procedures outlined in this Guide can help reduce your energy costs (and dollars spent) per ton[1] of breakfast cereal produced while improving your environmental performance as well as image in the community. This Guide is organized as follows:

- **Chapter One** – the value of energy management in a breakfast cereal production facility,
- **Chapter Two** – information on energy costs and energy efficiency opportunities in ready-to-eat and traditional breakfast cereal production,
- **Chapters Three through Fifteen** – step-by-step best practices to save energy and reduce costs in breakfast cereal making and reduce waste water generation, and,
- **Appendices** – explanation on how energy is used in the industry and in various processes along with a variety of assessments, standards and guidelines for additional reference.

Prior to implementation, assess the economics, actual energy savings and improved product quality that each measure found in this Guide can provide to individual plants.

EPA offers tools and resources to help companies build strategic energy management programs that span all operations. Begin online at www.energystar.gov/industry with "Get Started with ENERGY STAR." Helpful resources can be found throughout the site to support an organization-wide energy program at no charge to your company. Further, EPA invites companies that operate breakfast cereal plants to participate in the ENERGY STAR Focus on Energy Efficiency in Breakfast Cereal, a group of breakfast cereal producing companies that work together to share best energy practices and to build unique and helpful energy management tools specific to the breakfast cereal industry. If you have questions or need assistance with building a corporate energy program, contact energystrategy@energystar.gov.

[1] In this Guide, weight is reported in short tons and is simply referred to as tons.

Chapter One: Why Energy Management is Good for Your Business

Energy management programs control long-term energy risks and build stability into the business by reducing energy costs by 3 to 10% annually, protecting the environment, and reducing waste and expensive emissions such as greenhouse gases and other air pollutants.[2]

Well-run energy programs attract new talent to your company, improve its reputation within communities, and create value for the corporate brand.

DID YOU KNOW?

Energy savings from improving energy efficiency go directly to a company's bottom line! Many companies can save 3-10% annually.

Although energy and water expenses account for a smaller share of overall production costs than material costs, significant gains can be achieved by increasing energy and water efficiency, which can also improve product quality. To withstand future price fluctuations and remain competitive, new plants should be evaluated for their ability to employ energy-efficient state-of-the-art technologies while older and more inefficient plants should be assessed for retrofitting opportunities. Energy efficiency improvements can reduce the energy cost per unit of product – a practical method for increasing profit margins. To see financial returns from energy management, regularly assess energy performance and implement steps to increase energy efficiency in areas where you will get the most efficiency for dollars spent. Turn your company into a high-performance organization that improves your bottom line and environmental performance by:

- Actively managing energy;
- Adopting a structured energy management approach;
- Establishing policies and procedures that will achieve long-term results;
- Enlisting senior management's support;
- Allocating staff and resources to energy management;
- Establishing goals;
- Developing management structures that empower staff to address energy efficiency issues;
- Identifying and implementing energy savings; and,
- Building a culture of continuous improvement.

[2] See EPA's report "Energy Strategy for the Road Ahead" at www.energystar.gov/energystrategy.

Chapter Two: Where to Look for Energy Savings

By looking strategically at how energy is currently used throughout breakfast cereal manufacturing, energy managers can assess the most cost-effective strategies for improving energy efficiency. With a general overview of energy use trends, you will not only save time by focusing on areas and processes where the greatest efficiency can be generated, but also save on operational costs. This chapter looks at where energy is consumed as well as trends in energy consumption.

DID YOU KNOW?

If you don't manage energy, your business is giving money away to the utility.

The U.S. breakfast cereal industry has undergone major process and product quality improvements along with new product developments over the past 20 years. Yet, breakfast cereal manufacturers consume significant amounts of energy. In 2014, the U.S. breakfast cereal plants spent \$53 million in fuels and about \$80 million in electricity (U.S. Census, 2016a).

How is this money spent?

- Natural gas is the primary fuel, which is consumed for cooking, drying and toasting the cereal products.
- The highest energy cost is for the electricity used to drive equipment, such as motors, pumps, and air compressors.
- Water consumption is another significant utility expense. Breakfast cereal plants use between 300-1,200 gallons of water per ton of product produced.

Energy Consumption within the Breakfast Cereal Industry

The production of breakfast cereal involves several processes, including grinding, mixing, cooking, extruding, puffing, shredding, etc. to produce a variety of products. Fuel use in breakfast cereal facilities, primarily natural gas, ranges from 0.7 to 5.7 MMBtu/ton. Electricity use ranges from 330-440 kWh/ton of product (Jeswani et al., 2015). It is estimated that in 2014, the U.S. breakfast cereal plants consumed 9.8 TBtu of natural gas and 4.1 TBtu of electricity.

So where are the best opportunities to save energy and reduce costs given the trends in overall energy consumption?

First, plants use energy for common equipment such as motors, pumps, and compressors. These important components require regular maintenance, good operation and replacement, when necessary. Thus, a critical element of plant energy management involves the efficient control of equipment that powers the production process of a plant. A second and equally important area is the proper and efficient operation of the manufacturing process. Process optimization and ensuring the use of the most efficient technology is key to realizing energy savings in a plant's operation. Finally, throughout a plant, there are many processes that run simultaneously. Process integration may offer further opportunities.

For information on energy use in the U.S. breakfast cereal industry, please see Appendix B.

Energy Efficiency Opportunities

Many of the energy efficiency measures discussed in this Guide require either a small investment or none at all. The majority of the energy efficiency measures discussed have payback periods of four years or less.

DID YOU KNOW?

If the energy required per unit of product is reduced, you can grow your market share!

"Common" plant systems are those that are found in most manufacturing plants regardless of the industry and they are described in Table 1 of this Guide. Table 2 describes energy efficiency measures specific to breakfast cereal manufacturing by end-use category. Table 3 lists measures for increased water efficiency. Generally, each chapter begins with a description of the topic, a checklist for quick reference, and a description of best practices starting with the easier-to-implement measures.

If reading this Guide online, you may click on the chapter titles listed in Table 1 through Table 3 to be taken directly to these chapters. Refer to these tables as a reference tool for your energy management program.

Table 1. Summary of general energy efficiency measures.

Chapter 3: Energy Management Programs and Systems	
Build an energy management Program	Apply the principles for developing energy management programs and systems
Use the ENERGY STAR tools and resources	
Chapter 4: Motor Systems	
Create a motor management plan	Select and purchase motors strategically
Perform ongoing maintenance	Properly size motors
Employ motor labeling	Automate motors
Use adjustable speed drives	Correct power factor
Minimize voltage imbalances	Use soft starters
Chapter 5: Compressed Air Systems	
Maintain systems	Monitor effectively
Reduce leaks	Turn off unnecessary compressed air
Modify system instead of increasing pressure	Replace compressed air with other energy sources
Minimize pressure drops	Maximize allowable pressure dew point at air intake
Improve load management	Reduce inlet air temperature
Use compressor controls	Properly size pipe diameters
Recover heat for water preheating	Use natural gas-driven air compressors
Chapter 6: Fan Systems	
Maintain systems properly	Properly size fans
Use adjustable speed drives and improved controls	Install high efficiency belts
Employ direct drive fans	Repair duct leaks

Chapter 7: Pump Systems	
Maintain pump systems	Monitor pump system
Minimize pump demand	Install controls
Install high efficiency pumps	Properly size pumps
Use multiple pumps for variable loads	Install adjustable speed drives
Trim impellers	Avoid throttling valves
Replace belt drives	Properly size piping
Use precision castings, surface coatings or polishing	Maintain proper seals
Reduce leakage through clearance reduction	
Chapter 8: Steam Systems	
Integrate the process	Perform total site pinch analysis
Steam Supply - Boiler	
Match steam demand	Control boiler allocation
Install boiler flue shut-off dampers	Perform maintenance
Improve insulation	Reduce fouling
Optimize boiler blowdown rate	Reduce excessive flue gas
Reduce excess air	Monitor flue gas
Install turbulators	Use an economizer
Recover heat from boiler blowdown	Reduce standby losses
Recover condensate	
Combined Heat and Power (CHP)	
Gas turbines	Steam turbines
Reciprocating engines	Waste heat-to-power
Waste to power	
Steam distribution	
Shut off excess distribution lines	Properly size pipes
Insulate	Check and monitor steam traps
Use thermostatic steam traps	Shut off steam traps
Reduce distribution pipe leaks	Recover low-pressure waste steam through vapor recompression
Recover flash steam	
Chapter 9: Lighting	
Turn off lights in unoccupied Areas	Use occupancy sensors and other lighting controls
Upgrade exit signs	Replace magnetic ballasts with electronic ballasts
Replace T-12 tubes with T-8 or T-5 tubes	Use LED lighting
Replace linear fluorescent lights with LED lights	Replace high wattage fluorescent, metal halide and high-pressure sodium lights with LED lights
Reduce lighting system voltage	Use daylighting
Chapter 10: HVAC Systems	
Employ an energy-efficient system design	Consider recommissioning before replacing
Install energy monitoring and control systems	Adjust non-production setback temperatures
Repair leaking ducts	Consider variable air volume systems
Install adjustable speed drives	Consider heat recovery systems
Modify your fans	Use ventilation fans
Install efficient exhaust fans	Add building insulation
Place good dock door seals	Employ solar air heating
Modify building reflection	Install low-emittance windows

Table 2. Summary of energy efficiency measures specific to breakfast cereal production.

Chapter 11: Weighing and Blending Processes	
Weigh with accuracy	Optimize blending
Combine weighing and blending	Use adjustable speed drives
Chapter 12: Cooking Process	
Employ continuous cooking	Use direct fired hot water heaters
Use improved cooking vessel designs	Use PLC and computer controls
Perform maintenance	Insulate
Employ continuous steam pre-cooking	
Chapter 13: Drying and Toasting Processes	
Optimize the moisture content of the cooked product	Maximize the drying gas temperature drop
Choose the right capacity	Keep cooling prior to drying to the minimum
Improve airflow distribution	Improve product distribution
Use adjustable speed drives	Select and install efficient equipment
Place equipment in the right area	Insulate
Limit drafting	Use ovens with operational flexibility
Reduce pre-heating times	Create a temperature profile
Utilize waste heat	Use energy efficient burners
Perform maintenance	Employ overall system controls
Adopt heat pump drying	
Chapter 14: Forming Process	
Extrusion	
Improve cutting	Operate at design speed
Correct motor size	Control temperature
Insulate the barrel	Optimize standby operations
Minimize cooling	Conduct cooling carefully
Lower the cooking temperature	Optimize single-screw extrusion operation
Consider the use of twin-screw extruders	Employ preconditioning
Adopt automated process control	Adopt statistical process control
Gun-puffing	
Use advanced puffing guns	
Flaking	
Preheat rolls	Use the optimal roll temperature
Employ cooling before tempering	

Table 3. Summary of water sanitation and recycling measures.

Chapter 15: Water Use	
General water efficiency measures	
Create a strategic water management program	Practice good housekeeping
Use X-ray sorting for foreign material removal	Recycle product wastes as animal feed
Use water-efficient building fixtures	Use small diameter hoses
Use automated start/stop controls	Control flow rates
Reduce steam and hot water demand	Reduce cooling tower bleed-off
Cleaning and sanitation	
Dry clean equipment and surfaces	Use release and process aids
Employ high-pressure, low-volume sprays	Optimize the cleaning process
Employ low-pressure foam cleaning	Pre-soak floors and equipment
Monitor and control water temperatures	

Chapter 15: Water Use	
Reuse and recycle	
Replace once-through cooling systems with cooling towers	Recycle evaporator condensate
Reuse compressor cooling water	Use membrane filtration technologies
Install a membrane bioreactor	Install a membrane biofilm reactor

Chapter Three: Energy Management Programs and Systems

In this chapter:	
Build an energy management program	Apply the principles for developing energy management programs and systems
Use the ENERGY STAR tools and resources	

Building an energy management program is the first step to increase energy efficiency and save money. EPA has seen companies that successfully manage energy achieve consistent savings over time. Further, a corporate culture that encourages energy efficiency enhances the reputation of a company as one that cares for the environment.

Energy Savings Checklist: Energy Management

Energy Management Checklist	✓
Understand your energy use.	
Set goals.	
Assess plants for energy savings.	
Set a plan for improvement.	
Develop good operations and maintenance practices.	
Track and benchmark energy use.	
Encourage behavior changes and engage employees.	
Recognize and reward energy achievements.	

Best Practices for Energy Management Programs and Systems

- **Build an energy management program**. By constructing an energy management program, you can assess your energy consumption, motivate energy teams to manage energy across all facilities, and continuously benchmark and improve your company's energy performance.
- **Apply the principles for developing energy management programs and systems.** ENERGY STAR Guidelines for Energy Management can inform the development of your program through key actions for success.
- **Use the ENERGY STAR tools and resources.** ENERGY STAR offers a variety of assessment tools, guides, communication materials, and other resources to support your energy program.

Build an energy management program.

Successful energy management goes beyond installing energy-efficient equipment. Build a solid foundation for a company-wide energy program by following the ENERGY STAR Guidelines for Energy Management and make energy one of the top items managed by your business.

Next, institute sound energy management practices into your program, including: (1) energy assessments, (2) energy teams and (3) energy tracking, measurement, and benchmarking.

1) Assess the energy efficiency of your plant(s).

Assessing the energy used in plants helps determine how, how much and where energy is consumed. This information enables the identification of steps to improve the facility's energy efficiency and save money. Assessments may be focused on the whole site or specific systems and processes.

Assessments may be conducted by company staff, the local electric and gas utility, contractors, or government programs:

- Staff teams. If company employees perform the plant assessment, include staff from various departments across the facility. This brings together a spectrum of experience and knowledge on the plant and its processes. Facilities of any size can successfully use this method. ENERGY STAR provides guidance for a type of assessment that uses employee teams, the Energy Treasure Hunt (see www.energystar.gov/treasurehunt for more information).
- Electric and gas utility programs. Local utility companies work with their industrial clients to achieve energy savings in existing facilities and in the design of new facilities. Check with your local utility to see what assistance it provides. Utilities sometimes offer specific programs for improving plant systems such as lighting or motors.
- Federal government programs. The U.S. DOE supports plant assessments through the Industrial Assessment Center (IAC) program. IACs are designed to help small- and medium-size enterprises. Universities that participate in the program offer free assessments performed by students.

DID YOU KNOW?

The cost of paying one employee to lead an energy management program should be more than recovered by potential energy savings!

2) Build an energy team.

Establishing an energy team is an important part of making a commitment to energy management because a team can accomplish much more than a single person can accomplish alone. The energy team is responsible for planning, implementing, benchmarking, monitoring, and evaluating the organizational energy management program. The team's duties also include delivering training, communicating results, and providing recognition.

The ENERGY STAR Teaming Up to Save Energy guide is designed to help organizations develop effective energy teams. The guide provides advice, checklists and examples for starting an energy program, organizing an energy team, building capacity, sustaining the team, and maintaining momentum (see also Appendix F).

3) Monitor your energy systems.

Every company should compile, track, and benchmark energy data. Reliable energy data helps you manage energy and interpret energy efficiency trends over time so you can take corrective action when necessary.

Here are a few reasons it's important to monitor energy:

- Identifies increased use and costs that could be caused by operational inefficiencies.
- Supports participation in emergency demand response programs where utility companies provide financial incentives to customers who reduce their energy loads during peak demand times.
- Provides data useful for corporate greenhouse gas accounting initiatives.

Data on energy use can be found in utility bills, fuel purchase receipts, and from self-installed meters. Using an energy monitoring system is ideal. The use of meters in plant facilities, production lines and energy-intensive equipment offers information on how much energy is actually consumed. This real-time information can be used to assess and optimize the facility and equipment operation and identify opportunities for energy savings. (Parker et al., 2015)

While meters cannot conserve energy, the use of meters in combination with a supporting system that analyzes the data obtained from the meters enables managers and operators to establish an energy/flow conservation plan whose successful implementation will reduce plant costs. Developing a better understanding of energy use in the various facilities/departments will help staff identify areas for improvement (Tutterow et al., 2011), create a benchmark of the facility's energy use and verify actual savings that an energy efficiency measure will have.

Appendix C shows some common natural gas flow meters along with the most important criteria that should be considered for their selection. Costs of flow meters have come down overtime and currently it is possible to install accurate flow meters at low costs.

Energy monitoring systems include submeters at key areas in a plant to strategically track and manage energy. Submetering production departments can provide improved metrics and enables quick pinpointing of areas where energy problems may exist. The meters' data should be managed with a data management tool; a simple spreadsheet may be sufficient or tailored software is also available.

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In its simplest form, an energy monitoring system should be based on:

- Monthly utility billing and energy-use data for the past 12 to 24 months.
- Monthly production figures.

A simple spreadsheet may be used to plot graphs for visually understanding the relationship between energy use and production as well as to identify any trends. Graphs can be made for fuel and electricity separately, as well as for total energy use (showing both in the same units, such as megajoules or British thermal units) and costs. For example:

- Graphs of energy use and production over time.
- Graphs of energy costs and production over time.
- Graphs of energy use on vertical axis against production on horizontal axis.
- Graphs of energy use divided by production (showing specific energy consumption).

Often the analysis will show periods of good performance and poor performance. This information helps with setting targets for energy consumption based on expected production volumes. Tracking energy use by entering new data and re-evaluating it regularly will help identify problems and improve energy savings.

The ENERGY STAR Energy Tracking Tool is available at no cost to companies and sites for use in tracking energy.

CASE STUDY: The General Mills breakfast cereal plant in Albuquerque, New Mexico, adopted a comprehensive energy management program and reduced the energy use by 2.6 million kWh annually through better operational and management practices. These practices include shutting down dryers, eliminating compressed air cooling in the packaging facility, turning off office lights, and adjusting of heating and cooling controls. (General Mills, 2013)

Apply the principles for developing energy management programs and systems.

An organization-wide energy management program is the best way to save energy and money. It doesn't matter whether you company is big or small…any company can do it! Simply apply the following basic principles:

1) Make energy a priority.

Everyone in the company*, especially senior management,* must recognize that reducing energy use is an important business objective that must be a part of decision making.

2) Commit to save energy.

Every level of the organization must support the commitment to improve energy efficiency.

3) Assign responsibility.

Someone must be assigned responsibility for managing energy across the company. The annual pay for a corporate energy manager is more than covered by the costs of the energy you will save. An energy team with roles assigned to each member is a practical way to share the load across all facilities.

4) Look beyond your initial costs.

You get what you pay for. Energy-efficient equipment and products may cost more initially but the long-term savings will surpass the initial costs.

5) Make energy management a continuous process.

Effective energy management is more than just executing projects. It requires monitoring performance, identifying new opportunities, and ensuring saving measures are implemented.

Use the ENERGY STAR tools and resources.

EPA offers tools and resources to help companies build a strategic energy management program that spans all operations. Begin online at www.energystar.gov/industry with "Get Started with ENERGY STAR." Helpful resources can be found throughout the site, which is designed to walk you through the main steps of building an organization-wide energy program at no charge to your company.

To assess how well your company manages energy currently, use the ENERGY STAR Energy Program Assessment Matrix, located within the ENERGY STAR Guidelines for Energy Management and Appendix E of this guide.

EPA works with thousands of companies to identify the basics of an effective energy management program by using the ENERGY STAR Guidelines for Energy Management. If your company has questions or needs assistance with building a corporate energy program, contact energystrategy@energystar.gov.

Chapter Four: Motor Systems

In this chapter:	
Create a motor management plan	Select and purchase motors strategically
Perform ongoing maintenance	Properly size motors
Employ motor labeling	Automate motors
Use adjustable speed drives	Correct power factor
Minimize voltage imbalances	Use soft starters

Considering energy efficiency improvements to motor from a “systems approach” analyzes both the energy supply and energy demand sides of motor systems as well as how these interact to optimize total system performance, which includes not only energy use but also system uptime and productivity.

A systems approach involves the following steps.

- Locate and identify all applications of motors in a facility.
- Document the conditions and specifications of each motor in a current systems inventory.
- Assess the needs and the actual use of the motor systems to determine if motors are properly sized and how well each meets the needs of its driven equipment.
- Collect information on potential repairs and upgrades to the motor systems, including the economic costs and benefits of implementing repairs and upgrades to inform decisions.
- Monitor performance of the upgraded motor systems to determine the actual costs savings when upgrades are completed (SCE, 2003).

Systems Approach

A systems approach strives to optimize the energy efficiency of entire motor systems (i.e., motors, drives, driven equipment such as pumps, fans, and compressors, and controls), not just the energy efficiency of motors as single components.

The motor system energy efficiency measures below reflect important aspects of this systems approach, including matching motor speeds and loads, proper motor sizing, and upgrading system components.

Energy Savings Checklist: Motor Systems

To achieve energy efficiency improvements to motor systems, it is important to address the energy efficiency of the entire motor system. Use the checklist below to find new ways to save energy and money with motor system improvements.

Replacing a motor with a more efficient one can achieve energy savings of 5-10%.

Motor Checklist	✓
Are motors properly sized?	
Are motors maintained?	
Can adjustable or variable speed drives be installed?	
Can older, less efficient motors be replaced?	
Do you have a motor management program?	

Best Practices for Energy-Efficient Motor Systems

- **Create a motor management plan.** A motor management plan can help companies realize energy savings and ensure that system failures are handled quickly and cost-effectively.
- **Select and purchase motors strategically**. Considering life cycle costs and motor efficiency can reduce motor system life-cycle costs.
- **Perform ongoing maintenance**. Motor maintenance prolongs motor life and helps foresee motor failure.
- **Properly size motors**. Replacing oversized motors with properly sized motors saves U.S. industry, on average, 1.2% of total motor system electricity consumption.
- **Employ motor labeling.** Motors not in use should be identified and powered off.
- **Automate motors.** Running motors only when needed saves energy and does not significantly affect the lifetime of the motor.
- **Use Adjustable Speed Drives (ASDs).** Adjustable-speed drives better match speed to load requirements for motor operations and ensure that motor energy use is optimized to a given application.
- **Correct power factor.** Reducing the magnitude of reactive power in the system can reduce power consumption.
- **Minimize voltage imbalances**. Monitor voltages and minimize imbalances to increase of motor efficiency.
- **Use soft starters.** Soft starters reduce power use during motor start up.

Create a motor management plan.

A motor management plan is an essential part of a plant's energy management strategy. A motor management plan helps companies realize long-term motor system energy savings and ensures that motor failures are handled quickly and cost effectively. The Motor Decisions Matter℠ Campaign suggests the following key activities for a sound motor management plan (MDM, 2012):

- Create a motor survey and tracking program.
- Develop guidelines for proactive repair/replace decisions.
- Prepare for motor failure by creating a spare motor inventory.
- Develop of a purchasing specification.

- Develop of a repair specification.
- Develop and implement a predictive and preventive maintenance program.

It is important to develop a motor purchasing policy and to stock a selection of preferred premium efficiency motors to replace existing motors at failure. Otherwise, it is likely and common that the motors will be replaced by less efficient alternatives.

The Motor Decisions Matter[SM] Campaign's *Motor Planning Kit* contains further details on each of these elements (MDM, 2012).

Select and purchase motors strategically.

Several factors are important when selecting a motor, including motor speed, horsepower, enclosure type, temperature rating, efficiency level, and quality of power supply. When selecting and purchasing a motor, it is also critical to consider the life-cycle costs of that motor rather than just the price of its initial purchase and installation. Life cycle costing (LCC) is an accounting framework that enables calculation of the total costs of ownership for different investment options, leading to a sound evaluation of competing options in motor purchasing and repair or replacement decisions. A specific LCC guide has been developed for pump systems (Fenning et al., 2001), which also provides an introduction to LCC for motor systems.

Motor Selection

Up to 95% of a motor's costs can be attributed to the energy it consumes over its lifetime, while only around 5% of a motor's costs are typically attributed to its purchase, installation, and maintenance (MDM, 2012).

The selection of energy-efficient motors is an important strategy for reducing motor system life cycle costs. Energy-efficient motors reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. With proper installation, energy-efficient motors can also run cooler (which may help reduce facility heating loads) and have higher service factors, longer bearing life, longer insulation life, and less vibration.

To be considered energy-efficient in the United States, a motor must meet performance criteria published by the National Electrical Manufacturers Association (NEMA). See Appendix D for more information.

The choice of installing a premium efficiency motor depends on motor operating conditions and the life cycle costs associated with the investment. In general, premium efficiency motors are most economically attractive when replacing motors with annual operation exceeding 2,000 hours/year. However, software tools such as MotorMaster+ (see Appendix G) can help identify attractive applications of premium efficiency motors based on the specific conditions at a given plant.

Sometimes, even replacing an operating motor with a premium efficiency model may have a low payback period. According to data from the Copper Development Association, the upgrade to high-efficiency motors, as compared to motors that achieve the minimum efficiency as specified by EPACT, can have paybacks of less than 15 months for 50 hp motors (CDA, 2001). *Given the quick payback time, it usually makes sense to buy the most efficient motor available* (U.S. DOE and CAC, 2003).

NEMA, the Consortium for Energy Efficiency and other organizations created the Motor Decisions Matter[SM] campaign to help industrial and commercial customers evaluate their motor repair and replacement options, promote cost-effective applications of NEMA Premium[R] motors and "best practice" repair, and support the development of motor management plans before motors fail.

In some cases, it may be cost-effective to rewind an existing energy-efficient motor, instead of purchasing a new motor. As a rule of thumb, when rewinding costs exceed 60% of the costs of a new motor, purchasing the new motor may be a better choice (MDM, 2012). When rewinding a motor, it is important to choose a motor service center that follows best practice motor rewinding standards in order to minimize potential efficiency losses. An ANSI-approved recommended best practice standard has been offered by the Electric Apparatus Service Association (EASA) for the repair and rewinding of motors (EASA, 2006). When best rewinding practices are implemented, efficiency losses are typically less than 0.5 to 1% (EASA, 2003). However, poor quality rewinds may result in larger efficiency losses. It is therefore important to inquire whether the motor service center follows EASA best practice standards (EASA, 2006).

Perform ongoing maintenance.

Motor maintenance prolongs motor life and helps anticipate motor failure. Motor maintenance measures can be categorized as either preventative or predictive. Preventative measures, which prevent unexpected downtime of motors, include electrical consideration, voltage imbalance minimization, load consideration, and motor ventilation, alignment, and lubrication. The purpose of predictive motor maintenance is to observe ongoing motor temperature, vibration, and other operating data to identify when it becomes necessary to overhaul or replace a motor before failure occurs (Barnish et al., 1997). The savings associated with an ongoing motor maintenance program are significant, and could range from 2 to 30% of total motor system energy use (Efficiency Partnership, 2004).

Properly size motors.

Inappropriately sized motors cause unnecessary energy losses. Where peak loads on driven equipment can be reduced, motor size can also be reduced. Replacing oversized motors with properly sized motors saves, on average for U.S. industry, 1.2% of total motor system electricity consumption (Xenergy, 1998). Higher savings can often be realized for smaller motors and individual motor systems.

Properly sizing a motor depends on the following: load on the motor, operating efficiency of the motor at that load point, the full-load speed of the motor to be replaced, and the full-load speed of the replacement motor. The U.S. DOE provides a range of technical assistance, tip sheets and software tools for decision making on motor systems.

Employ motor labeling.

Motors not in use should be powered off. This can be done through automated systems (see below), or motors can be labeled to show the typical use, e.g. continuous operation (365/24/7), production days, during production, or when an operator is present. Toyota and Bodine Casting have successfully introduced (colored) labeling for motor systems in a number of plants.

Automate motors.

Motors should only run when needed. Though some people are concerned that frequent motor start-ups will negatively affect a motor's lifetime, as long as the frequency of motor start-ups is not excessive, the lifetime will not be significantly affected (U.S. DOE, 2008a). NEMA (2001) gives the maximum number of allowable motor start-ups per hour and the duration of rest time between start-ups, for various horsepower motors and synchronous speed ratings.

> **Motor Automation**
>
> **A 10% reduction in motor operating time can save more energy than replacing a conventional motor with a NEMA Premium® efficiency motor (U.S. DOE, 2008a). Therefore, automatic shutdown of motors that would otherwise be left idling can reduce energy costs without requiring high investment.**

Use adjustable speed drives (ASDs).[3]

Adjustable-speed drives better match speed to load requirements for motor operations, and therefore ensure that motor energy use is optimized to a given application. Adjustable-speed drive systems are offered by many suppliers and are available worldwide. Worrell et al. (1997) provide an overview of savings achieved with ASDs in a wide array of applications; typical energy savings are shown to vary between 7 and 60%.

Correct power factor.

Inductive loads like transformers, electric motors, and HID lighting may cause a low power factor, which may result in increased power consumption and increased electricity costs. The power factor can be corrected by minimizing idling of electric motors (a motor that is turned off consumes no energy), replacing motors with premium efficiency motors (see above), and installing capacitors in the AC circuit to reduce the magnitude of reactive power in the system.

Minimize voltage imbalances.

A voltage unbalance degrades the performance and shortens the life of three-phase motors. A voltage unbalance causes a current unbalance, which will result in torque pulsations, increased vibration and mechanical stress, increased losses, and motor overheating, which can reduce the life of a motor's winding insulation. Voltage unbalances may be caused by faulty operation of power factor correction equipment, an unbalanced transformer bank, or an open circuit. A rule of thumb is that the voltage unbalance at the motor terminals should not exceed 1%. Even a 1% unbalance will reduce motor efficiency at part load operation while a 2.5% unbalance will reduce motor efficiency at full load operation. See http://www.energy.gov/eere/amo/downloads/eliminate-voltage-unbalance.

For a 100 hp m*otor operating 8,000 hours per year, a correction of the voltage unbalance from 2.5 to 1% will result in el*ectricity savings of 9,500 kWh or almost $500 at an electricity rate of $0.05/kWh (U.S. DOE, 2005a).

By regularly monitoring the voltages at the motor terminal and through regular thermographic inspections of motors, voltage unbalances may be identified. It is also recommended to verify that single-phase loads

[3] Several terms are used in practice to describe a motor system that permits a mechanical load to be driven at variable speeds, including adjustable speed drives (ASDs), variable speed drives (VSDs), adjustable frequency drives (AFDs), and variable frequency drives (VFDs). The term ASD is used throughout this Guide for consistency.

are uniformly distributed and to install ground fault indicators as required. Another indicator that a voltage unbalance may be a problem is 120 Hz vibration, which should prompt an immediate check of voltage balance (U.S. DOE, 2005a). The typical payback period for voltage controller installation on lightly loaded motors in the United States is about 2 years (IAC, 2017).

Use soft starters.

Soft starters are special devices, which allow the gradual speed acceleration of the motor, and limit the electrical stresses associated with motor start-up (U.S. DOE, 2003). With the use of soft starters, power use during motor start-up can be reduced.

Chapter Five: Compressed Air Systems

In this chapter:	
Maintain systems	Monitor effectively
Reduce leaks	Turn off unnecessary compressed air
Modify system instead of increasing pressure	Replace compressed air with other energy sources
Minimize pressure drops	Maximize allowable pressure dew point at air intake
Improve load management	Reduce inlet air temperature
Use compressor controls	Properly size pipe diameters
Recover heat for water preheating	Use natural gas-driven air compressors

Compressed air systems consist of a supply side, which includes compressors and air treatment, and a demand side, which includes distribution and storage systems and end-use equipment. According to the U.S. DOE, a properly managed supply side will result in clean, dry, stable air being delivered at the appropriate pressure in a dependable, cost-effective manner. A properly managed demand side minimizes waste air and uses compressed air for appropriate applications (U.S. DOE, 2003).

Energy Savings Checklist: Compressed Air

Compressed air is often the most expensive form of energy available in a plant because of its poor efficiency. However, there are several possible steps to improve the energy efficiency of compressed air. Use the checklist below to find new ways to save energy and costs.

Compressed Air Checklist	Potential Gains	✓
Reduce system header pressure.	A 2-3 psi discharge pressure reduction results in a 1% energy decrease.	
Is a compressed air program in place to minimize air leaks?	Typically 15-25% of air usage is air leaks, if no compressed air program is in place.	
Are the pumps and fans sequenced with ASD?	If there is no sequencing in place, there is potential for a 15-25% energy reduction.	
Is waste heat being captured?	Every 100 CFM of rejected hear equates to 50,000 Btu's of available heat.	
Are all air compressors on a master controller?	Use of master system controller results in energy savings of 10-20%.	
Can the temperature of air intake be reduced?	For every 5-10 degree reduction there is a resulting 1% energy savings.	
Have you sized your system properly?		

Best Practices for Energy-Efficient Compressed Air

- **Maintain systems.** Proper maintenance can reduce leakage, pressure variability, and increase efficiency.
- **Monitor effectively.** Use measures such as temperature and pressure gauges and flow meters to save energy and money.
- **Reduce leaks.** Leak maintenance can reduce leak rates to less than 10%.

- **Turn off unnecessary compressed air.** Save energy by ensuring no air is flowing to unused parts of the system.
- **Modify system instead of increasing pressure.** Modify equipment instead of raising the pressure of the entire system to reduce cost.
- **Replace compressed air with other energy sources.** Other sources of energy can be more economical and more efficient than compressed air.
- **Minimize pressure drops.** Use a systems approach to minimize pressure drop, reduce energy consumption and increase system performance.

Pressure Reductions

As a rule of thumb, every 2-3 pound reduction in header pressure yields one percent in energy savings.

- **Maximize allowable pressure dew point at air intake.** Use a dryer with a floating dew point to maximize efficiency.
- **Improve load management.** Use two-stage compressors or multiple smaller compressors to save energy. Large compressors consume more electricity when they are unloaded than do multiple smaller compressors with similar overall capacity.
- **Reduce inlet air temperature.** Reduce air temperature to reduce energy used by the compressor and increase compressor capacity.
- **Use compressor controls.** Compressor controls shut off unneeded compressors and can save up to 12% in energy costs annually.
- **Properly size pipe diameters.** Increasing pipe diameters can minimize pressure losses and leaks, reduce system-operating pressures, and reduce energy consumption by 3%.
- **Recover heat for water preheating.** A heat recovery unit can recover thermal energy and save up to 20% of the energy used in compressed air systems annually for space heating.
- **Use natural gas-driven air compressors.** Gas-driven compressors can have lower operating costs.

Maintain systems.

Poor maintenance lowers compression efficiency and increases air leakage or pressure variability, leading to increased operating temperatures, poor moisture control, and excessive contamination. Improved maintenance reduces these problems and saves energy. Proper maintenance includes the following (U.S. DOE and CAC, 2003; Scales and McCulloch, 2007):

- *Keep the compressor and intercooling surfaces clean and foul-free.* Blocked filters increase pressure drop. Inspect and periodically clean filters to reduce pressure drop. Use filters with just a 1 psig pressure drop over 10 years. The payback period for filter cleaning is usually under 2 years (Ingersoll-Rand, 2001). Fixing improperly operating filters will also prevent contaminants from entering tools and causing them to wear out prematurely. Generally, when pressure drop exceeds 2 to 3 psig, replace the particulate and lubricant removal elements. Inspect all systems at least annually. Consider adding filters in parallel that decrease air velocity and, therefore, decrease air pressure drop. A 2% reduction of annual energy consumption in compressed air systems is projected when filters are replaced frequently (Radgen and Blaustein, 2001).

- *Keep motors properly lubricated and cleaned*. Poor motor cooling can increase motor temperature and winding resistance, shorten motor life and increase energy consumption. Compressor lubricant should be changed every 2 to 18 months and checked to make sure it is at the proper level. In addition to energy savings, this can help avoid corrosion and degradation of the system.

- *Inspect drain traps* periodically to ensure they are not stuck in the open or closed positions and are clean. Some users leave automatic condensate traps partially open at all times to allow for constant draining. This practice wastes substantial energy and has no role in a properly maintained system. Instead, install simple pressure driven valves. Malfunctioning traps should be cleaned and repaired, and not left open. Some auto drains, such as float switch or electronic drains, do not waste air. Inspecting and maintaining drains typically has a payback of less than 2 years (U.S. DOE, 2004a).

- *Maintain the coolers* on the compressor so that the dryer gets the lowest possible inlet temperature (U.S. DOE and CAC, 2003).

- *Check belts for wear* and adjust them. A good practice is to adjust after every 400 hours of operation.

- *Replace air lubricant separators* according to specifications or sooner. Rotary screw compressors generally start with their air lubricant separators having a 2 to 3 psid pressure drop at full load. When this increases to 10 psid, change the separator (U.S. DOE and CAC, 2003).

- *Check water cooling systems* for water quality (pH and total dissolved solids), flow, and temperature. Clean and replace filters and heat exchangers per manufacturer's specifications.

- *Check for excess pressure, duration, and volume* in applications that require compressed air. Applications not requiring maximum system pressure should be regulated, either by production line sectioning or by pressure regulators on the equipment itself. Using more pressure than required wastes energy and can shorten equipment life and add maintenance costs.

Monitor effectively.

Effective monitoring systems save energy and money and typically include the following (CADDET, 1997):

- Pressure gauges on each receiver or main branch line and differential gauges across dryers, filters, etc.

- Temperature gauges across the compressor and its cooling system to detect fouling and blockages.

- Flow meters to measure the quantity of air used.

- Dew point temperature gauges to monitor the effectiveness of air dryers.

- Kilowatt-hour meters and hours run meters on the compressor drive.

- Checking of compressed air distribution systems after equipment has been reconfigured to be sure that no air is flowing to unused equipment or to obsolete parts of the compressed air distribution system.

- Checking for flow restrictions of any type in a system, such as an obstruction or roughness, which can unnecessarily raise system operating pressures. As a rule of thumb, every 2 psi pressure rise resulting from resistance to flow can increase compressor energy use by 1% (U.S. DOE and CAC, 2003). The highest pressure drops are usually found at the points of use, including undersized or leaking hoses, tubes, disconnects, filters, regulators, valves, nozzles and lubricators (demand side), as well as air/lubricant separators, after-coolers, moisture separators, dryers and filters.

- Checking for compressed air use outside production hours.

Reduce leaks.

A typical plant that has not been well maintained will likely have a leak rate equal to 20 to 50% of total compressed air production capacity (U.S. DOE and CAC, 2003). Leak maintenance can reduce this number to less than 10%. Overall, a 20% reduction of annual energy consumption in compressed air systems is projected for fixing leaks (Radgen and Blaustein, 2001).

> **Leak Reductions**
>
> **The payback period for leak reduction efforts is generally shorter than five months (IAC, 2017).**

Estimations of leaks vary with the size of the hole in the pipes or equipment. A compressor operating 2,500 hours per year at 87 psi with a leak diameter of 0.02 inches (½ mm) is estimated to lose 250 kWh per year; 0.04 inches (1 mm) to lose 1,100 kWh per year; 0.08 inches (2 mm) to lose 4,500 kWh per year; and 0.16 in. (4 mm) to lose 11,250 kWh per year (CADDET, 1997).

In addition to increased energy consumption, leaks can make air tools less efficient and adversely affect production, shorten the life of equipment, lead to additional maintenance requirements and increase unscheduled downtime. In the worst case, leaks can add unnecessary compressor capacity.

> **Continuing Programs**
>
> **Leak detection and correction programs should be ongoing efforts.**

The most common areas for leaks are couplings, hoses, tubes, fittings, pressure regulators, open condensate traps and shut-off valves, pipe joints, disconnects, and thread sealants. A simple way to detect leaks is to apply soapy water to suspect areas. Another simple way is a bleed down test (Bayne, 2011). In a bleed down test the plant air system is brought to full pressure and then shut down. By recording the system pressure while compressed air is not used anywhere in the plant, any pressure losses can be attributed to existing leaks. The best way to detect leaks is to use an ultrasonic acoustic detector, which can recognize the high frequency hissing sounds associated with air leaks. After identification, leaks should be tracked, repaired, and verified. Leak detection and correction programs should be ongoing efforts.

Turn off unnecessary compressed air.

Equipment that is no longer using compressed air should have the air turned off completely using a simple solenoid valve. Compressed air distribution systems should be checked when equipment has been reconfigured to ensure that no air is flowing to unused equipment or to obsolete parts of the compressed air distribution system.

Modify system instead of increasing pressure.

For individual applications that require a higher pressure, instead of raising the operating pressure of the whole system, special equipment modifications should be considered, such as employing a booster, increasing a cylinder bore, changing gear ratios, or changing operation to off peak hours.

Replace compressed air with other energy sources.

Many operations can be accomplished more economically and efficiently using energy sources other than compressed air (U.S. DOE, 2004b; U.S. DOE, 2004c). Various options exist to replace compressed air use, including:

- Cool electrical cabinets with air conditioning fans instead of compressed air vortex tubes.
- Create a vacuum with a vacuum pump instead of compressed air venturi methods.
- Cool, aspirate, agitate, mix, or inflate packaging with blowers.
- Clean parts or remove debris with brushes, blowers, or vacuum pump systems.
- Move parts with blowers, electric actuators, or hydraulics.
- Special case tools or actuators: electric motors should be considered because they are more efficient than using compressed air (Howe and Scales, 1995). However, it has been reported that motors can have less precision, shorter lives, and lack safety compared to compressed air. In these cases, using compressed air may be a better choice.

Based on numerous industrial case studies, the average payback period for replacing compressed air with other applications is about 1 year (IAC, 2017).

Minimize pressure drops.

Excessive pressure drop results in poor system performance and excessive energy consumption. Flow restrictions of any type in a system, such as an obstruction or roughness, result in higher operating pressures than needed. Resistance to flow increases the drive energy on positive displacement compressors by 1% of connected power for each 2 psi of differential (U.S. DOE and CAC, 2003). The highest pressure drops are usually found at the points of use, including undersized or leaking hoses, tubes, disconnects, filters, regulators, valves, nozzles, and lubricators (demand side), as well as air/lubricant separators on lubricated rotary compressors and after-coolers, moisture separators, dryers, and filters (supply side).

Minimizing pressure drop requires a systems approach in design and maintenance. Air treatment components should be selected with the lowest possible pressure drop at specified maximum operating conditions and best performance. Manufacturers' recommendations for maintenance should be followed, particularly in air filtering and drying equipment, which can have damaging moisture effects like pipe corrosion. Finally, minimize the distance the air travels through the distribution.

Maximize allowable pressure dew point at air intake.

Choose the dryer that has the maximum allowable pressure dew point, and best efficiency. A rule of thumb is desiccant dryers consume 7 to 14% of the total energy of the compressor, whereas refrigerated dryers consume 1 to 2% as much energy as the compressor (Ingersoll-Rand, 2001). Consider using a dryer with a floating dew point.

Improve load management.

Because of the large amount of energy consumed by compressors, whether in full operation or not, partial load operation should be avoided. For example, unloaded rotary screw compressors still consume 15 to 35% of full-load power while delivering no useful work (U.S. DOE and CAC, 2003).

Air receivers can be employed near high demand areas to provide a supply buffer to meet short-term demand spikes that can exceed normal compressor capacity. In this way, the number of required online compressors may be reduced. Multi-stage compressors theoretically operate more efficiently than single-stage compressors. Multi-stage compressors save energy by cooling the air between stages, reducing the volume and work required to compress the air. Replacing single-stage compressors with two-stage compressors typically provides a payback period of two years or less (Ingersoll-Rand, 2001). Using multiple smaller compressors instead of one large compressor can save energy as well. Large compressors consume more electricity when they are unloaded than do multiple smaller compressors with similar overall capacity. An analysis of U.S. case studies shows an average payback period for optimally sizing compressors of about 1.5 years (IAC, 2017).

Another efficient way to operate on partial loads is with the use of adjustable speed drives (ASDs). ASDs adjust the drive motor speed to match the variable pressure demand with an almost direct one to one relationship to full load power consumption (U.S. DOE and CAC, 2015). However, at or near full-output capacity, compressors equipped with ASDs will use more power than a comparable fixed speed compressor due to the inherent drive losses. In addition, at low speeds the efficiency of adjustable speed compressors decreases. For efficient use, adjustable speed compressors should not operate for too long at full or minimum speeds. The best efficiencies are achieved when the system operates between 30 and 80% speed during most of its life (U.S. DOE and CAC, 2015).

Reduce inlet air temperature.

Reducing the inlet air temperature reduces energy used by the compressor. In many plants, it is possible to reduce inlet air temperature to the compressor by drawing fresh air from outside the building. Importing fresh air can have paybacks of 2 to 5 years (CADDET, 1997). As a rule of thumb, each 5°F (3°C) will save 1% compressor energy use (CADDET, 1997; Parekh, 2000). In addition to energy savings, compressor capacity is increased when cold air from outside is used. Industrial case studies have found an average payback period for importing outside air of less than 1 year (IAC, 2017), but costs can vary significantly depending on facility layout.

Use compressor controls.

The primary objectives of compressor control strategies are to shut off unneeded compressors and to delay bringing on additional compressors until needed. Energy savings for sophisticated compressor controls have been reported at around 12% annually (Radgen and Blaustein, 2001). An excellent review of compressor controls can be found in Compressed Air Challenge® *Best Practices for Compressed Air Systems* (Second Edition) (Scales and McCulloch, 2007). Common control strategies for compressed air systems include:

- *Start/stop (on/off) controls*, in which the compressor motor is turned on or off in response to the discharge pressure of the machine. Start/stop controls can be used for applications with very low duty cycles and are applicable to reciprocating or rotary screw compressors. The typical payback for start/stop controls is one to two years (CADDET, 1997).

- *Load/unload controls*, or constant speed controls, which allow the motor to run continuously but unloads the compressor when the discharge pressure is adequate. In most cases, unloaded rotary screw compressors still consume 15 to 35% of full-load power while delivering no useful work (U.S. DOE and CAC, 2003). Hence, load/unload controls can be inefficient.
- *Modulating or throttling controls*, which allow the output of a compressor to be varied to meet flow requirements by closing down the inlet valve and restricting inlet air to the compressor. Throttling controls are applied to centrifugal and rotary screw compressors.
- *Single master sequencing system controls*, which take individual compressor capacities on-line and off-line in response to monitored system pressure demand and shut down any compressors running unnecessarily. System controls for multiple compressors typically offer a higher efficiency than individual compressor controls.
- *Multi-master controls*, which are the latest technology in compressed air system control. Multi-master controls are capable of handling four or more compressors and provide both individual compressor control and system regulation by means of a network of individual controllers (Martin et al., 2000). The controllers share information, allowing the system to respond more quickly and accurately to demand changes. One controller acts as the lead, regulating the whole operation. This strategy allows each compressor to function at a level that produces the most efficient overall operation. The result is a highly controlled system pressure that can be reduced close to the minimum level required (U.S. DOE and CAC, 2003). According to Nadel et al. (2002), such advanced compressor controls are expected to deliver energy savings of about 3.5% where applied.

In addition to energy savings, the application of controls can sometimes eliminate the need for some existing compressors, allowing extra compressors to be sold or kept for backup. Alternatively, capacity can be expanded without the purchase of additional compressors. Reduced operating pressures will also help reduce system maintenance requirements (U.S. DOE and CAC, 2003).

Properly size pipe diameters.

Increasing pipe diameters to the greatest size that is feasible and economical for a compressed air system can help to minimize pressure losses and leaks, which reduces system operating pressures and leads to energy savings. Increasing pipe diameters typically reduces compressed air system energy consumption by 3% (Radgen and Blaustein, 2001). Further savings can be realized by ensuring other system components (e.g., filters, fittings, and hoses) are properly sized.

Recover heat for water preheating.

As much as 80 to 93% of the electrical energy used by an industrial air compressor is converted into heat. In many cases, a heat recovery unit can recover 50 to 90% of this available thermal energy for space heating, industrial process heating, water heating, makeup air heating, boiler makeup water preheating, industrial drying, industrial cleaning processes, heat pumps, laundries or preheating aspirated air for oil burners (Parekh, 2000). It's been estimated that approximately 50,000 Btu/hour of energy is available for each 100 cfm of capacity (at full load) (U.S. DOE and CAC, 2003). Paybacks are typically less than one year (Galitsky et al., 2005a).

Heat recovery for space heating is not as common with water-cooled compressors because an extra stage of heat exchange is required and the temperature of the available heat is lower. However, with large water cooled compressors, recovery efficiencies of 50 to 60% are typical (U.S. DOE and CAC, 2003). Implementing this measure saves up to 20% of the energy used in compressed air systems annually for space heating (Radgen and Blaustein, 2001).

Use natural gas-driven air compressors.

Gas engine-driven air compressors can replace electric compressors with some advantages and disadvantages. Gas engine-driven compressors are more expensive and can have higher maintenance costs, but may have lower overall operating costs depending on the relative prices of electricity and gas. Operating costs can be lower due to the current low gas prices, however in general, natural gas-driven compressors use more energy than electric-driven ones.

Variable-speed capability is standard for gas-fired compressors, offering a high efficiency over a wide range of loads. Heat can be recovered from the engine jacket and exhaust system. However, gas engine-driven compressors have some drawbacks: they need more maintenance, have a shorter useful life, and sustain a greater likelihood of downtime.

Chapter Six: Fan Systems

In this chapter:	
Maintain systems properly	Properly size fans
Use adjustable speed drives and improved controls	Install high efficiency belts
Employ direct drive fans	Repair duct leaks

Considerable opportunities exist to upgrade the performance and improve the energy efficiency of fan systems. For fans in particular, concerns about failure or underperformance have led to many fans being oversized for their particular application (U.S. DOE, 2003). Oversized fans do not operate at optimal efficiency and therefore waste energy. However, the efficiencies of fan systems vary considerably across impeller types.

Best Practices for Energy-Efficient Fan Systems

- **Maintain systems properly.** A proper maintenance program can improve system performance, reduce downtime, minimize repair costs, and increase system reliability.
- **Properly size fans.** Properly sized fans have lower capital, maintenance, and energy costs.
- **Use adjustable speed drives (ASD's) and improved controls.** Retrofitting fans with ASD's can save up to 49% in energy costs.
- **Install high efficiency belts (cog belts).** Replace standard V-belts with cog belts to save energy and money.
- **Employ direct drive fans.** Consider the use of direct drive fans with ASDs and increase system efficiency.
- **Repair duct leaks.** Installing duct insulation and performing regular duct inspection and maintenance reduce system leaks and save significant amounts of energy.

Maintain systems properly.

As for most energy using systems, a proper maintenance program for fans can improve system performance, reduce downtime, minimize repair costs, and increase system reliability. The U.S. DOE recommends establishing a regular maintenance program for fan systems, with intervals based on manufacturer recommendations and experience with fans in similar applications (U.S. DOE, 2003). Additionally, the U.S. DOE recommends the following important elements of an effective fan system maintenance program (U.S. DOE, 2003):

- *Inspect Belts*. In belt-driven fans, belts are usually the most maintenance-intensive part of the fan assembly. Belts wear over time and can lose tension, reducing their ability to transmit power efficiently. Regularly inspect and tighten belts, especially for large fans given the potential size of the power loss.
- *Clean fans*. Many fans experience a significant loss in energy efficiency due to the build-up of contaminants on blade surfaces. Build-up can create imbalance problems that reduces performance and contributes to premature wear of system components. Fans that operate in particulate-laden or high-moisture airstreams are particularly vulnerable and should be cleaned regularly.

- *Inspect and repair leaks.* Leakage in a fan duct system decreases the amount of air that is delivered to the desired end use, which can significantly reduce the efficiency of the fan system. Inspect ductwork on a regular basis and repair leaks as soon as possible. In systems with inaccessible ductwork, use temporary pressurization equipment to determine if the integrity of the system is adequate.

- *Lubricate bearings.* Worn bearings can lead to premature fan failure, as well as create unsatisfactory noise levels. Monitor and frequently lubricate fan bearings based on manufacturer recommendations.

- *Replace motors.* Eventually, all fan motors will wear and will require repair or replacement. The decision to repair or replace a fan motor should be based on a life cycle cost analysis, as described in the motor systems section.

Properly size fans.

Conservative engineering practices often result in the installation of fans that exceed system requirements. Such oversized fans lead to higher capital costs, maintenance costs, and energy costs than fans that are properly sized for the job (U.S. DOE, 2003). However, other options may be more cost effective than replacing an oversized fan with a smaller fan (U.S. DOE, 2002). Other options include (U.S. DOE, 2003):

- Decreasing fan speed using different motor and fan sheave sizes (may require downsizing the motor).

- Installing an ASD or multiple-speed motor (see below).

- Using an axial fan with controllable pitch blades.

Use adjustable speed drives (ASDs) and improved controls.

Significant energy savings can be achieved by installing adjustable speed drives on fans. Savings may vary between 14 and 49% when retrofitting fans with ASDs (U.S. DOE, 2002).

Install high efficiency belts (cog belts).

Belts make up a variable, but significant portion of the fan system in many plants. It is estimated that about half of the fan systems use standard V-belts, and about two-thirds of these could be replaced by more efficient cog belts (U.S. DOE, 2002). Standard V-belts tend to stretch, slip, bend and compress, which lead to a loss of efficiency. Replacing standard V-belts with cog belts can save energy and money, even as a retrofit. Cog belts run cooler, last longer, require less maintenance and have an efficiency that is about 2% higher than standard V-belts. Typical payback periods will vary from less than one year to three years.

Employ direct drive fans.

There are two main types of drive systems: belt drive and direct drive systems. Gear drive systems are also available but are less used. In direct drive systems, the fan is directly mount to the motor shaft. This close contact of the motor and the shaft, with no intermediate linkages as in belt drive systems, creates a highly efficient system. However, the fan speed flexibility is lower compared to a belt drive system.

If the initial speed estimates are incorrect or if the fan speed requirements change, the use of belts allows for fan speed adaptations. In direct drive fan systems, speed adaptations are also possible when an ASD is employed. Especially for fans that operate over a range of conditions direct fan systems with ASDs are considered an efficient option (U.S. DOE, 2003), especially given the reduced costs of ASDs.

Repair duct leaks.

Duct leakage can waste significant amounts of energy in fan and ventilation systems. Measures for reducing duct leakage include installing duct insulation and performing regular duct inspection and maintenance, including ongoing leak detection and repair. For example, according to studies by Lawrence Berkeley National Laboratory, repairing duct leaks in industrial and commercial spaces could reduce HVAC energy consumption by up to 30% (Galitsky et al., 2005a).

Because system leakage can have a significant impact on fan system operating costs, the U.S. DOE recommends considering the type of duct, the tightness and quality of the fittings, joint assembly techniques, and the sealing requirements for duct installation as part of the fan system design process as proactive leak prevention measures (U.S. DOE, 2003).

Chapter Seven: Pump Systems

In this chapter:	
Maintain pump systems	Monitor pump system
Minimize pump demand	Install controls
Install high efficiency pumps	Properly size pumps
Use multiple pumps for variable loads	Install adjustable speed drives
Trim impellers	Avoid throttling valves
Replace belt drives	Properly size piping
Use precision castings, surface coatings or polishing	Maintain proper seals
Reduce leakage through clearance reduction	

Pumping systems consist of a pump, a driver, piping systems, and controls (such as ASDs or throttles). There are two main ways to increase pump system efficiency, aside from reducing use. These are reducing the friction in dynamic pump systems (not applicable to static or "lifting" systems) or upgrading/adjusting the system so that it draws closer to the best efficiency point on the pump curve (Hovstadius, 2007). Correct sizing of pipes, surface coating or polishing and ASDs, for example, may reduce the friction loss, increasing energy efficiency. Correctly sizing the pump and choosing the most efficient pump for the applicable system will push the system closer to the best efficiency point on the pump curve. Furthermore, pump systems are part of motor systems, and, thus, the general “systems approach” to energy efficiency described in Chapter 4 for motors applies to pump systems as well.[4]

Energy Savings Checklist: Pump Systems

Energy is typically the most significant cost associated with the life cycle of a pump system, accounting for up to 95% of the lifetime costs of the pump. Use the checklist below to find new ways to save energy and money.

Pump Systems Checklist	✓
Can you minimize pump demand by better matching pump requirements to end use loads?	
Is a control system in place to automatically shut off pumps when demand is reduced?	
Is older, inefficient technology being used?	
Are pumps properly sized, including the use of multiple pumps for variable loads?	
Are adjustable-speed drives (ASDs) being used?	
Is the impeller properly sized or trimmed?	
Replace v-belt with energy-efficient belt (i.e. cog belt).	

[4] The U.S. DOE’s Advanced Manufacturing Office provides a variety of resources for improving the efficiency of industrial pumps, which can be consulted for more detailed information on many of the measures presented in this chapter. The U.S. DOE’s *Improving Pumping System Performance: A Sourcebook for Industry* is a particularly helpful resource (U.S. DOE, 2006a). For a collection of tips, tools, and industrial case studies on industrial pump efficiency, visit the DOE’s website at: http://energy.gov/eere/amo/pump-systems.

Opportunities for Energy Efficiency

Initial costs are only a fraction of the lifetime cost of a pump system. Energy expenditures, and sometimes operations and maintenance expenditures, are much more important. In general, for a pump system with a lifetime of 20 years, the initial capital expense of the pump and motor make up merely 2.5% of the total costs of ownership (Best Practice Programme, 1998). Depending on the pump application, energy outlays may comprise about 95% of the lifetime expenses of the pump. Hence, the initial choice of a pump system should be highly dependent on energy cost considerations rather than on initial costs such as the price of the pump and related parts.

Optimization of the design of a new pumping system should focus on optimizing the lifecycle expenditures. Hodgson and Walters (2002) discuss software developed for this purpose and several case studies in which they show large reductions in energy use and lifetime costs of a complete pumping system. Typically, such an approach will lead to energy savings of 10-17%.

Best Practices for Energy-Efficient Pump Systems

- **Maintain pump systems.** A maintenance program keeps pumps running optimally and can save up to 7% in energy.
- **Monitor pump system.** Monitoring and maintenance can detect problems and determine solutions to increase the efficiency of the system.
- **Minimize pump demand.** Reducing demand through holding tanks and elimination of bypass loops can save up to 20% in energy.
- **Install controls.** Control systems increase efficiency of pump systems and significantly reduce costs.
- **Install high efficiency pumps.** New high efficiency pumps can result in up to 10% in energy savings.
- **Properly size pumps.** Replacing oversized pumps with properly sized ones can reduce electricity by up to 25%.
- **Use multiple pumps for variable loads.** Using multiple pumps in parallel is a cost-effective and energy-efficient method for pump systems with variable loads.
- **Install adjustable speed drives (ASDs).** Including modulation features like ASD's can save an estimated 20 to 50% of pump energy consumption.
- **Trim impellers.** Reducing an impeller's diameter reduces energy added to the pump system.
- **Avoid throttling valves.** Pump demand reduction, controls, impeller trimming, and multiple pump strategies (all previously discussed in this section) are more energy-efficient flow management strategies than throttling valves.
- **Replace belt drives.** Replacing belt drives with cog belts saves energy and money.
- **Properly size piping.** Increasing pipe diameters as part of a system retrofit reduces pumping energy.

- **Use precision casting, surface coatings, or polishing.** Using castings, coatings, or polishing reduces pump surface roughness and increases energy efficiency.
- **Maintain proper seals.** Use gas barrier seals, balanced seals, and no-contact labyrinth seals to decrease seal losses.
- **Reduce leakage through clearance reduction.** Use hard construction materials such as chromium steel to reduce the wear rate of the clearance between the impeller suction and pressure sides.

Maintain pump systems.

Inadequate maintenance can lower pump system efficiency, cause pumps to wear out more quickly, and increase pumping energy costs. A pump system maintenance program will help to avoid these problems by keeping pumps running optimally. Furthermore, improved pump system maintenance can lead to energy savings from 2 to 7% (U.S. DOE, 2002). A solid pump system maintenance program will generally include the following tasks (U.S. DOE, 2006a; 2002):

- Replacement of worn impellers, especially in caustic or semi-solid applications.
- Inspection and repair of bearings.
- Replacement of bearing lubrication on an annual or semiannual basis.
- Inspection and replacement of packing seals. Allowable leakage from packing seals is usually between 2 to 60 drops per minute.
- Inspection and replacement of mechanical seals. Allowable leakage is typically 1 to 4 drops per minute.
- Replacement of wear ring and impeller. Pump efficiency degrades by 1 to 6% for impellers less than the maximum diameter and with increased wear ring clearances.
- Check pump/motor alignment.
- Inspection of motor condition, including the motor winding insulation.

Monitor pump system.

Monitoring in conjunction with operations and maintenance can be used to detect problems and determine solutions to create a more efficient system. Monitoring can determine clearances that need adjustment, indicate blockage, impeller damage, inadequate suction, operation outside of preferences, clogged or gas-filled pumps or pipes, or worn out pumps. Monitoring should include:

- Specific energy consumption, i.e. electricity use/flow rate (Hovstadius, 2007).
- Wear monitoring.
- Vibration analyses.
- Pressure and flow monitoring.
- Current or power monitoring.

- Differential head and temperature rise across the pump (also known as thermodynamic monitoring).
- Distribution system inspection for scaling or contaminant build-up.

Minimize pump demand.

An important component of the systems approach is to minimize pump demand by better matching pump requirements to end use loads. Two effective strategies for reducing pump demand are the use of holding tanks and the elimination of bypass loops. Holding tanks can be used to equalize pump flows over a production cycle, which can allow for more efficient operation of pumps at reduced speeds and lead to energy savings of 10 to 20% (U.S. DOE, 2002). Holding tanks and can also reduce the need to add pump capacity. The elimination of bypass loops and other unnecessary flows can result in energy savings of 10 to 20% (U.S. DOE, 2002). Other effective strategies for reducing pump demand include lowering process static pressures, minimizing elevation rises in the piping system, and lowering spray nozzle velocities.

Install controls.

Control systems can increase the energy efficiency of a pump system by shutting off pumps automatically when demand is reduced, or, alternatively, by putting pumps on standby at reduced loads until demand increases.

Install high efficiency pumps.

It has been estimated that up to 16% of pumps in use in U.S. industry are more than 20 years old (U.S. DOE, 2002). Considering that a pump's efficiency may degrade by 10 to 25% over the course of its life, replacement of aging pumps can lead to significant energy savings. The installation of newer, higher efficiency pumps typically results in energy savings of 2 to 10% (Elliott, 1994).

A number of high efficiency pumps are available for specific pressure head and flow rate capacity requirements. Choosing the right pump often saves both operating and capital costs. For a given duty, selecting a pump that runs at the highest speed suitable for the application will generally result in a more efficient selection as well as the lowest initial cost (U.S. DOE, 2001a).

Properly size pumps.

Pumps that are oversized for a particular application consume more energy than is necessary (see also "avoiding throttling valves" below). Replacing oversized pumps with pumps that are properly sized can often reduce the electricity use of a pumping system by 15 to 25% (U.S. DOE, 2002). Where peak loads can be reduced through improvements to pump system design or operation (e.g., via the use of holding tanks), pump size can also be reduced. If a pump is dramatically oversized, often its speed can be reduced with gear or belt drives or a slower speed motor. The typical payback period for the above strategies can be less than one year (Galitsky et al., 2005a).

Use multiple pumps for variable loads.

The use of multiple pumps installed in parallel can be a cost-effective and energy-efficient solution for pump systems with variable loads. Parallel pumps offer redundancy and increased reliability, and can often reduce pump system electricity use by 10 to 30% for highly variable loads (U.S. DOE, 2002). Parallel pump arrangements often consist of a large pump, which operates during periods of peak demand, and a small pump (or "pony" pump), which operates under normal, more steady-state conditions. Because the pony pump is sized for normal system operation, this configuration operates more efficiently than a system that relies on a large pump to handle loads far below its optimum capacity.

Install adjustable speed drives (ASDs).

ASDs better match speed to load requirements for pumps whereas for motors, energy use is approximately proportional to the cube of the flow rate[5]. Hence, small reductions in flow rates that are proportional to pump speed may yield large energy savings for friction dominated pump systems. However, in static head dominated systems, the energy use might increase when using ASDs if the speed is turned down too much. New installations may result in short payback periods. In addition, the installation of ASDs improves overall productivity, control and product quality, and reduces wear on equipment, thereby lowering future maintenance costs.

According to inventory data collected by Xenergy (1998), 82% of pumps in U.S. industry have no load modulation feature (or ASD). Similar to being able to adjust load in motor systems, including modulation features with pumps is estimated to save between 20 and 50% of pump energy consumption, at relatively short payback periods, depending on application, pump size, load and load variation (Xenergy, 1998; Best Practice Programme, 1996). The savings depend strongly on the system curve. As a rough rule of thumb, unless the pump curves are exceptionally flat, a 10% regulation in flow should produce pump savings of 20%, and 20% regulation should produce savings of 40% (Best Practice Programme, 1996).

Trim impellers.

Impeller trimming refers to the process of reducing an impeller's diameter via machining, which will reduce the energy added by the pump to the system fluid. According to the U.S. DOE (2006b), one should consider trimming an impeller when any of the following conditions occur:

- Many system bypass valves are open, indicating that excess flow is available to system equipment.
- Excessive throttling is needed to control flow through the system or process.
- High levels of noise or vibration indicate excessive flow.
- A pump is operating far from its design point.

Trimming an impeller is slightly less effective than buying a smaller impeller from the pump manufacturer, but can be useful when an impeller at the next smaller available size would be too small for the given pump load. The energy savings associated with impeller trimming are dependent upon pump power, system flow, and system head, and are roughly proportional to the cube of the diameter reduction (U.S. DOE, 2006a). An additional benefit of impeller trimming is a decrease in pump operating and maintenance

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[5] This equation applies to dynamic systems only. Systems that solely consist of lifting (static head systems) will accrue no benefits from ASDs (but often will become more inefficient) because pump efficiency usually drops when speed is reduced in such systems. A careful choice of operating points can to some extent overcome this problem. Similarly, systems with more static head will accrue fewer benefits than systems that are largely dynamic (friction) systems. More careful calculations must be performed to determine actual benefits, if any, for these systems.

costs. Care has to be taken when an impeller is trimmed or the speed is changed so that the new operating point does not end up in an area where the pump efficiency is low.

Avoid throttling valves.

Throttling valves and bypass loops are indications of oversized pumps as well as the inability of the pump system design to accommodate load variations efficiently, and should always be avoided (Tutterow et al., 2000). Pump demand reduction, controls, impeller trimming, and multiple pump strategies (all previously discussed in this section) should always be more energy-efficient flow management strategies than throttling valves. Several industrial case studies from the IAC database suggest that the replacement of throttling systems with ASDs has an average payback period of 2 years (IAC, 2017).

Replace belt drives.

Most pumps are directly driven. However, inventory data suggests 4% of pumps have V-belt drives (Xenergy, 1998). Standard V-belts tend to stretch, slip, bend and compress, which leads to a loss of efficiency. Replacing standard V-belts with cog belts can save energy and money, even as a retrofit. It is better to replace the pump by a direct driven system, resulting in increased savings of up to 8% and payback periods as short as 6 months (Studebaker, 2007).

Properly size piping.

Pipes that are too small for the required flow velocity can significantly increase the amount of energy required for pumping, in much the same way that drinking a beverage through a small straw requires a greater amount of suction. Where possible, pipe diameters can be increased to reduce pumping energy requirements, but the energy savings due to increased pipe diameters must be balanced with increased costs for piping system components. A lifecycle costing approach is recommended to ensure positive economic benefits when energy savings, increased material costs, and installation costs are considered. Increasing pipe diameters will likely only be cost effective during greater pump system retrofit projects. The U.S. DOE estimates typical industrial energy savings in the 5 to 20% range for this measure (U.S. DOE, 2002).

Use precision castings, surface coatings or polishing.

The use of castings, coatings, or polishing reduces pump surface roughness that in turn, increases energy efficiency. It may also help maintain efficiency over time. This is more effective on smaller pumps. One case study in the steel industry analyzed the investment in surface coating on the mill supply pumps (350 kW pumps). It was determined that the additional cost of coating, $1,200, would be paid back in 5 months by energy savings of $2,700 (or 36 MWh, 2%) per year (Hydraulic Institute and Europump, 2001). Energy savings for coating pump surfaces are estimated to be 2 to 3% over uncoated pumps (Best Practice Programme, 1998).

Maintain proper seals.

Seal failure accounts for up to 70% of pump failures in many applications (Hydraulic Institute and Europump, 2001). The sealing arrangements on pumps will contribute to the power absorbed. Often the use of gas barrier seals, balanced seals, and no-contacting labyrinth seals decrease seal losses.

Reduce leakage through clearance reduction.

Internal leakage losses are a result of differential pressure across the clearance between the impeller suction and pressure sides. The larger the clearance, the greater is the internal leakage causing inefficiencies. The normal clearance in new pumps ranges from 0.014 to 0.04 inches. (0.35 to 1.0 mm) (Hydraulic Institute and Europump, 2001). With wider clearances, the leakage increases almost linearly with the clearance. For example, a clearance of 0.2 inches (5 mm) decreases the efficiency by 7 to 15% in closed impellers and by 10 to 22% in semi-open impellers. Abrasive liquids and slurries, even rainwater, can affect the pump efficiency. Using very hard construction materials (such as high chromium steel) can reduce the wear rate.

Chapter Eight: Steam Systems

In this chapter:	
Integrate the process	Perform total site pinch analysis
Steam Supply – Boiler	
Match steam demand	Control boiler allocation
Install boiler flue shut-off dampers	Perform maintenance
Improve insulation	Reduce fouling
Optimize boiler blowdown rate	Reduce excessive flue gas
Reduce excess air	Monitor flue gas
Install turbulators	Use an economizer
Recover heat from boiler blowdown	Reduce standby losses
Recover condensate	
Combined Heat and Power (CHP)	
Gas turbines	Steam turbines
Reciprocating engines	Waste heat-to-power
Waste to power	
Steam distribution	
Shut off excess distribution lines	Properly size pipes
Insulate	Check and monitor steam traps
Use thermostatic steam traps	Shut steam traps
Reduce distribution pipe leaks	Recover low-pressure waste steam through vapor recompression
Recover flash steam	

While the exact size and use of a modern steam system varies greatly, there is an overall pattern that steam systems follow (see Figure 1). Treated cold feed water is fed to the boiler, where it is heated to form steam. Chemical treatment of the feed water is required to remove impurities, because impurities would otherwise collect on the boiler tube walls. Even though the feed water has been treated, some impurities remain and can build up in the boiler water. Thus, water is periodically drained from the bottom of the boiler in a process known as blow down. The generated steam travels along the pipes of the distribution system to get to the process where the heat will be used. Sometimes the steam is passed through a pressure reduction valve if the process requires lower pressure steam. In steam transport, the steam cools down, and some of it is condensed. The condensate is removed by a steam trap that allows condensate to pass through, but blocks the passage of steam.

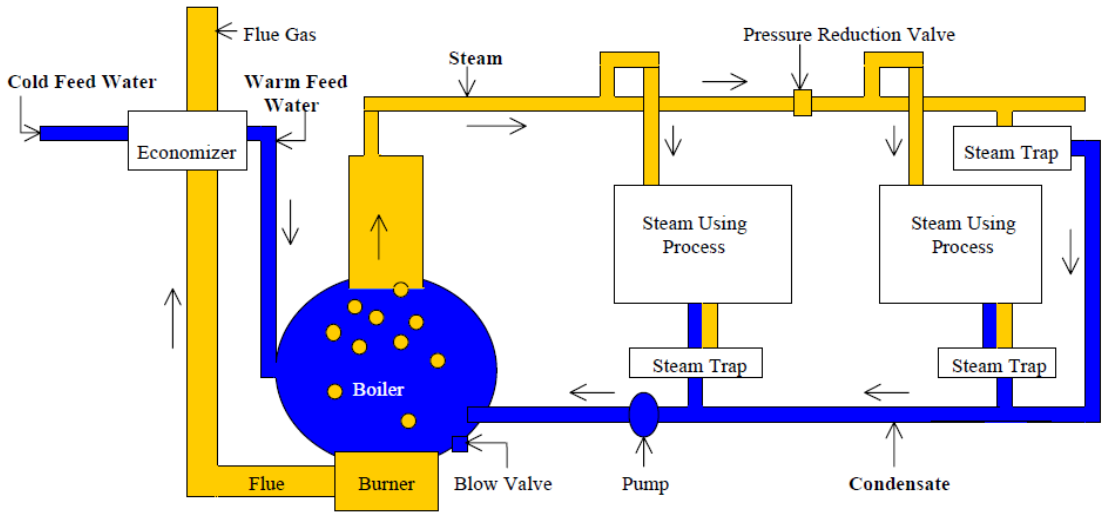

Figure 1: Schematic presentation of a steam production and distribution system.

Steam flow meters are commonly used to help evaluate the performance of the steam system. They retrieve information on the boiler performance, calculate boiler efficiency and determine the amount of steam needed by the system (U.S. DOE, 2012). In addition, their use can facilitate benchmarking the steam system and help identify opportunities for energy efficiency improvements.

There are two basic steam flow meter types (Parker et al., 2015):

- *differential pressure meters* that rely on the relationship between the pressure difference through an element used in the steam flow to define steam velocity. Main types are the Orifice, Annubar, and spring-loaded variable.
- *velocity meters* that directly measure the velocity of the steam flow. Main types are the Turbine and Vortex-Shedding meters. Because velocity meters directly measure the velocity of the flow, they are more accurate than differential pressure meters.

Table 4 shows some common metering technologies with key characteristics. The Orifice differential pressure meter is the steam meter most widely used in the U.S. industry. However, many of these meters are being neglected and need to be recalibrated in order to obtain correct readings (U.S. DOE, 2005b).

Table 4. Common steam metering technologies and key criteria (Parker et al., 2015).

Goal	Orifice	Annubar	Turbine	Vortex Shedding
Accuracy	Moderate	Good	Good	Good
Turndown Ratio	<5:1	5:1	10:1	20:1
Repeatability	Good	Good	Low	Very good
Installation Ease	Easy	Easy	Challenging	Moderate
Pressure loss	Moderate	Low	Moderate	Low
Recalibration Needs	Frequent	Infrequent	Frequent	Infrequent
Capital Cost	Low	Low	Moderate	Moderate
Installed Cost	Low	Low	Moderate	Moderate
Maintenance Cost	High	Low	Moderate	Low

For accurate readings, proper maintenance is crucial. Differential pressure systems should be checked monthly for properly connected and sealed pressure taps. Annual maintenance should include a thorough checkup of the state of the orifice and pressure taps. In the case of velocity meters, annual maintenance should include the checkup of the impeller blades and the bearings for any wear or damage (Parker et al., 2015).

Energy Savings Checklist: Steam Systems

Steam Systems Checklist	✓
Are steam flow meters properly maintained?	
Is the whole system properly maintained?	
Does the burner use the proper fuel to air ratio?	
Is the system (e.g. boiler size, distribution lines) properly sized?	
Is waste heat recovered and reused?	
Are heat losses minimized?	
Do the steam turbines operate under optimum condition?	
Is the energy embodied in the pressure drop utilized?	

Best Practices for Energy-Efficient Steam Systems

- **Integrate the process.** Exploit potential synergies in systems with multiple components for heating and cooling and use pinch analysis techniques to decrease energy use.
- **Perform total site pinch analysis.** Identify optimum side-wide utility levels by integrating the demands for heating and cooling and reduce the energy consumption by 20-30%.

Steam Supply - Boiler

- **Match steam demand.** Use the right size boilers in the high-fire setting to improve energy efficiency.
- **Control boiler allocation.** Employ automatic controllers for all boilers in systems that use multiple boilers to shift the loads and maximize efficiency. Install automatic flow valves to shut off unused boilers.
- **Install flue shut-off dampers.** Reduce hot air losses by fitting fully closing stack dampers.
- **Perform maintenance.** Properly maintain the burner and condensate return systems to reduce the energy consumption by 10%.
- **Improve insulation.** Improve insulation and heater circuit controls and reduce the energy use by 6-26%.
- **Reduce fouling.** Remove scale deposits built on the water side of the boiler to improve heat transfer and reduce fuel use by up to 5%.

Maintenance

Unmaintained steam systems can cost 20-30% of initial energy efficiency over 2-3 years.

- **Optimize boiler blowdown rate.** Optimize the blowdown rate to reduce energy losses, makeup water and chemical treatment costs.
- **Reduce excessive flue gas quantities.** Repair leaks in the boiler and the flue that can lead to excessive flue gases.
- **Reduce excess air.** Check the burner fuel to air ratio on a regular basis to reduce the amount of wasted heat. Controlling the combustion process digitally can improve energy efficiency by 3-5%.
- **Monitor flue gas.** Adopt flue gas monitoring to optimize the fuel to air ratio and detect scale deposition to improve efficiency.
- **Install turbulators on two- and three-pass firetube boilers.** Place turbulators into the boiler tubes to improve heat transfer and improve boiler efficiency.
- **Use an economizer.** Preheat boiler feed water from flue gases in an economizer and reduce fuel use by 5-10%.
- **Recover heat from boiler blowdown.** Use the heat from boiler blow down for space heating or feed water preheating to improve energy efficiency.
- **Reduce standby losses.** Reduce the losses from keeping boilers on standby. By installing an automatic control system, full capacity can be reached within 12 minutes.
- **Recover condensate.** Install a condensing economizer and improve overall heat recovery and system efficiency by up to 10%.

Reducing excess air

As a rule of thumb, boiler efficiency can increase by 1% for each 15% reduction in excess air.

Steam Supply – Combined Heat and Power (CHP, see also below)

- **Gas turbines.** Install a gas turbine to meet your power needs and recover the gas turbine exhaust to generate high-pressure steam or use it in heating or drying applications.
- **Steam turbines.** Use high-pressure steam in steam turbines to drive the process compressors and extract part of intermediate pressure steam to utilize in other equipment or processes.
- **Reciprocating engines.** Use modern reciprocating engines to generate electricity and recover the heat from the engine exhaust, cooling water, and lubricating oil to generate steam or to heat water.
- **Waste heat-to-power.** Capture discarded process heat to generate electricity.
- **Waste to power.** Utilize high strength waste streams for bio-energy production and decrease energy costs.

Steam Distribution

- **Shut off excess distribution lines.** Reduce steam distribution losses in a cost-effective way by shutting off excess lines.

- **Properly size pipes.** When designing new steam distribution systems, account for the velocity and pressure drop and avoid high heat losses, pressure drops and erosion.
- **Insulate.** Reduce energy use by properly insulating the distribution system and by regularly inspecting and repairing worn insulation.
- **Check and monitor steam traps.** Adopt a scheme of regular steam trap checkups and follow up maintenance to save up to 10% of energy.
- **Use thermostatic steam traps.** Install thermostatic element steam traps and reduce energy use while improving reliability.
- **Shut off steam traps.** Shut off steam traps on superheated lines when not in use and save energy.
- **Reduce distribution pipe leaks.** Create a program of leak detection and maintenance on distribution pipes to decrease losses.
- **Recover low-pressure waste steam through vapor recompression.** Compress low-pressure waste steam to higher pressures so that it can be reused. Recompression will only need 5-10% of the energy required to raise an equivalent amount of steam in a boiler.
- **Recover flash steam.** Use a heat exchanger to recover the heat in flash steam to use it for space heating or feed water preheating.

Integrate the process.

Process integration exploits potential synergies that are inherent in any system that consists of multiple components working together. In plants that have multiple heating and cooling demands, the use of *pinch analysis* techniques may significantly improve efficiencies. Developed in the early 1970's, pinch analysis is now a well-established methodology for continuous processes (Linnhoff et al., 1992). The methodology involves the linking of hot and cold streams in a process in a thermodynamically optimal way (i.e. not over the so-called 'pinch'). Process integration is the art of ensuring that the components are well suited and matched in terms of size, function and capability. Pinch analysis takes a systematic approach to identifying and correcting the performance limiting constraint (or pinch) in any manufacturing process (Linnhoff, 1993). The pinch approach has been extended to resource conservation in general, whether the resource is capital, time, labor, electrical power, water or a specific chemical compound such as hydrogen.

The critical innovation in applying pinch analysis was the development of "composite curves" for heating and cooling, which represent the overall thermal energy demand and availability profiles for the process as a whole. When these two curves are drawn on a temperature enthalpy graph, they reveal the location of the process pinch (the point of closest temperature approach), and the minimum thermodynamic heating and cooling requirements. These are called the energy targets. The methodology involves first identifying the targets and then following a systematic procedure for designing heat exchanger networks to achieve these targets. The optimum approach temperature at the pinch is determined by balancing the capital-energy tradeoffs to achieve the desired payback. The procedure applies equally well to new designs as well as to retrofit of existing plants.

The analytical approach to this analysis has been well documented (Smith, 1995; Shenoy, 1994). The energy savings potential using pinch analysis far exceeds that from well-known conventional techniques such as heat recovery from boiler flue gas, insulation and steam trap management. Pinch analysis, and competing process integration tools, have been developed further in recent years. The most important developments in the energy area are the inclusion of alternative heat recovery processes such as heat pumps and heat transformers, as well as the development of pinch analysis for batch processes (or in other words bringing in time as a factor in the analysis of heat integration). Furthermore, pinch analysis should be used in the design of new processes and plants, as process integration goes beyond optimization of heat exchanger networks (Hallale, 2001). Even in new designs additional opportunities for energy efficiency improvement can be identified. Pinch analysis has also been extended to the areas of water recovery and efficiency, and hydrogen recovery.

Perform total site pinch analysis.

Total Site Pinch Analysis has been applied by many chemical sites around the world to find optimum site-wide utility levels by integrating heating and cooling demands of various processes, and by allowing the integration of combined heat and power (CHP) into the analysis. Process integration analysis of existing processes should be performed regularly, as continuous changes in product mix, mass flows and applied processes can provide new or improved opportunities for energy and resource efficiency.

Typical savings identified in site-wide analyses are around 20-30%. Savings of 10-15% are achievable under normal economic investment criteria (Linnhoff-March, 2000). Total site pinch analysis has been applied at over 100 sites in many industries on all continents.

Steam Supply – Boiler

Match steam demand.

A boiler is more efficient in the high-fire setting. Since heating demands may change over time, situations can occur in which a boiler is operating beneath its optimum efficiency. Also, boilers may have been oversized because of anticipated additions or expansions that never occurred, or equipment later may have been replaced or discarded from the boiler. Energy conservation or heat recovery measures may also have reduced the heat demand. As a result, a facility may have multiple boilers, each rated at several times the maximum expected load (U.S. DOE, 2006b). Another common problem with oversized boilers is boiler "short cycling," which occurs when an oversized boiler quickly satisfies process or space heating demands, and then shuts down until heat is again required.

Fuel savings can be achieved by adding a smaller boiler to a system, sized to meet average loads at a facility, or by re-engineering the power plant to consist of multiple small boilers. Multiple small boilers offer reliability and flexibility to operators to follow load swings without over-firing and short cycling. Facilities with large seasonal variations in steam demand should operate small boilers when demand drops, rather than operating large boilers year-round.

Measures to run boilers on the high-fire setting have an average payback time of slightly more than 1 year. Installation of smaller boilers to increase the high-fire duty cycle has an average payback time of less than 2 years (IAC, 2017).

Control boiler allocation.

Systems containing multiple boilers offer energy-saving opportunities by using proper boiler allocation strategies. This is especially true if multiple boilers are operated simultaneously at low-fire conditions.

Automatic controllers determine the incremental costs (change in steam cost/change in load) for each boiler in the facility, and then shift loads accordingly. This maximizes efficiency and reduces energy costs. If possible, loads should be scheduled to optimize boiler system performance.

The efficiency of hot water boilers can be improved through the use of automatic flow valves. Automatic flow valves shut off boilers that are not being used, preventing hot water from the fired boiler from cooling as it passes through unused boilers in the system. Where valves are left open, the average flow temperature is lower than designed for and more fuel is used (CADDET, 2001b).

Install flue shut-off dampers.

Where boilers are regularly shut down due to load changes, heat loss to the chimney can be significant. A solution to stop hot air loss is to fit fully closing stack dampers, which only operate when the boiler is not required. Another alternative is to fit similar gas tight dampers to the fan intake (CADDET, 2001b).

Perform maintenance.

In the absence of a good maintenance system, the burners and condensate return systems can wear or go out of adjustment. These factors can end up costing a steam system up to 20-30% of initial efficiency over 2-3 years (U.S. DOE, 2001b). A simple maintenance program ensures that all components of the boiler are operating at peak performance and can result in substantial savings and reduce air pollutant emissions. On average, energy savings are estimated at 10% (U.S. DOE, 2001b). Establishing a maintenance schedule for boilers has an average payback time of 0.5 years (IAC, 2017).

Improve insulation.

The shell losses of a well-maintained boiler should be less than 1%. New insulation materials insulate better and have a lower heat capacity. As a result, the output temperature is more vulnerable to temperature fluctuations in the heating elements. Improved control is required to maintain the output temperature range of the old firebrick system. Savings of 6-26% can be achieved by combining improved insulation with improved heater circuit controls (Caffal, 1995).

Reduce fouling.

Fouling of the fireside of the boiler tubes and scaling waterside of the boiler should be controlled. Tests show that a soot layer of 0.03 inches (0.8 mm) reduces heat transfer by 9.5%, while a 0.18 inch (4.5 mm) layer reduces heat transfer by 69% (CIPEC, 2001). Scale deposits occur when calcium, magnesium, and silica, commonly found in most water supplies, react to form a continuous layer of material on the waterside of the boiler heat exchange tubes. Tests show that for water-tube boilers, 0.04 inches (1 mm) of buildup can increase fuel consumption by 2% (CIPEC, 2001). In fire-tube boilers scaling can lead to a fuel waste up to 5% (U.S. DOE, 2006b). Moreover, scaling may result in tube failures.

Scale removal can be achieved by mechanical means or acid cleaning. The presence of scale can be indicated by the flue gas temperature (see flue gas monitoring) or be determined by visual inspection of the boiler tubes when the unit is shut down for maintenance. Fouling and scaling are more of a problem with coal-fed boilers than natural gas or oil-fed units. Boilers that burn solid fuels like coal should be checked more often as they have a higher fouling tendency than liquid fuel boilers (U.S. DOE, 2006b).

Optimize boiler blowdown rate.

Insufficient blowdown may lead to carryover of boiler water into the steam, or the formation of deposits. Excessive blowdown wastes energy, water, and chemicals. The optimum blowdown rate is determined by various factors including the boiler type, operating pressure, water treatment, and quality of makeup water.

Blowdown rates typically range from 4% to 8% depending on boiler feed water flow rate, but can be as high as 10% when makeup water has a high solids content (U.S. DOE, 2006b). Minimizing blowdown rate can substantially reduce energy losses, makeup water and chemical treatment costs. The reduction of the blowdown rate has an average payback time of 1 year (IAC, 2017).

Optimum blowdown rates can be achieved with an automatic blowdown-control system. In many cases, the savings due to such a system can provide a simple payback of 1 to 3 years (U.S. DOE, 2006b).

Reduce excessive flue gas quantities.

Often, excessive flue gas results from leaks in the boiler and the flue, reducing the heat transferred to the steam, and increasing pumping requirements. These leaks are often easily repaired. This measure consists of a periodic repair based on visual inspection or on flue gas monitoring which is discussed below.

Reduce excess air.

The more air used to burn the fuel, the more heat is wasted to unnecessarily heat excess air. Air slightly in excess of the ideal stoichiometric fuel/air ratio is required for safety, to reduce NO_x emissions, and depends on the type of fuel. Poorly maintained boilers can have up to 140% excess air leading to excessive amounts of waste gas. An efficient natural gas burner requires 2% to 3% excess oxygen, or 10% to 15% excess air in the flue gas, to burn fuel without forming carbon monoxide. A rule of thumb is that boiler efficiency can be increased by 1% for each 15% reduction in excess air (U.S. DOE, 2006b). Fuel-air ratios of the burners should be checked regularly. On average the analysis and adjustment of proper air/fuel mixture had a payback time of 0.6 years.

An efficient burner provides the proper air-to-fuel mixture throughout the full range of firing rates, without constant adjustment. Traditionally, this mixture was controlled by using linkages or cables to position the air and fuel valves. These are subject to wear, repeatability difficulties and a limited amount of adjustment. Modern burners are an alternative to complex linkage designs and are increasingly using servomotors with parallel positioning to independently control the quantities of fuel and air delivered to the burner head. These controls provide consistent performance and repeatability as the burner adjusts to different firing rates (U.S. DOE, 2006b). Implementing a digital system results in greater control of the combustion process and leads to an improvement i energy efficiency of 3-5% (CADDET, 2001b). Replacement of inefficient obsolete burners averages a payback period of about 2.5 years (IAC, 2017).

Using a combination of CO and oxygen readings, it is possible to optimize the fuel/air mixture for high flame temperature (and thus the best energy efficiency) and low emissions (see flue gas monitoring).

Monitor flue gas.

The oxygen content of exhaust gas is a combination of excess air (which is deliberately introduced to improve safety or reduce emissions) and air infiltration (air leaking into the boiler). By combining an oxygen monitor with an intake airflow monitor, it is possible to detect small leaks. Using a combination of carbon monoxide (CO) and oxygen readings, it is possible to optimize the fuel/air mixture for high flame temperature, best energy efficiency, and low emissions. The payback of installing flue gas analyzers to determine proper air/fuel ratios on average is about 0.7 years (IAC, 2017).

Monitoring flue gas temperature can also help to indicate scaling, since the flue gas temperature is an indirect indicator of scale or deposit formation. If the flue gas temperature rises (with boiler load and excess air held constant), the effect is likely due to the presence of scale.

The percentage of oxygen in the flue gas can be measured by inexpensive gas-absorbing test kits. More expensive hand-held, computer-based analyzers (ranging in cost from $500 to $1,000) display percentage of oxygen, stack gas temperature, and boiler efficiency. They are a recommended investment for any boiler system with annual fuel costs exceeding $50,000 (U.S. DOE, 2006b).

Install turbulators on two- and three-pass firetube boilers.

The packaged firetube boiler is the most common boiler design used to provide heating or process steam in industrial and heavy commercial applications. In a firetube boiler, hot combustion gases pass through long, small-diameter tubes where heat is transferred to water through the tube walls. These gases enter the tubes in a turbulent flow regime. Within a few feet laminar flow begins and a boundary layer of cooler gas forms along the tube walls. This layer serves as a barrier, retarding heat transfer. Turbulators, which consist of small baffles, angular metal strips, spiral blades, or coiled wire, may be inserted into the boiler tubes to break up the laminar boundary layer (U.S. DOE, 2006b). This increases the turbulence of the hot combustion gases and the convective heat transfer to the tube surface. The result is improved boiler efficiency. Turbulator installers can also balance gas flow through the tubes by placing longer turbulators in the uppermost tubes. This practice increases the effectiveness of the available heat-transfer surface by eliminating thermal stratification and balancing the gas flow through the firetubes.

The cost of installing turbulators is about $10 to $15 per boiler tube and the average payback time is slightly more than 1 year (IAC, 2017). A manufacturing facility installed 150 turbulators into its firetube boiler. Tests conducted both before and after turbulator installation indicated a reduction in the stack gas temperature of 130°F (55°C). More combustion heat was being transferred into the boiler water. Each 40°F (22°C) reduction in the boiler flue gas temperature results in a 1% boiler-efficiency improvement, so overall boiler efficiency was improved by about 3.3%, while fuel costs decreased by approximately 4%.

Preheat boiler feed water with heat from flue gas (economizer).

Heat from flue gases can be used to preheat boiler feed water in an economizer. By preheating the water supply, the temperature of the water at the inlet to the boiler is increased, reducing the amount of heat necessary to generate steam and save fuel. While this measure is common in large boilers, there often is the potential to increase heat recovery.

The limiting factor for flue gas heat recovery is the economizer wall temperature that should not drop below the dew point of acids in the flue gas. Traditionally this is done by keeping the flue gases at a temperature significantly above the acid dew point. However, the economizer wall temperature is more dependent on the feed water temperature than on the flue gas temperature because of the high heat transfer coefficient of water. As a result, it makes more sense to preheat the feed water to close to the acid dew point before it enters the economizer. This allows the economizer to be designed so that the flue gas exiting the economizer is just above the acid dew point.

Generally, boiler efficiency can be increased by 1% for every 40°F (22°C) reduction in flue gas temperature. By recovering waste heat, an economizer can often reduce fuel requirements by 5% to 10% and pay for itself in less than 2 years (U.S. DOE, 2006b).

CASE STUDY: Kellogg's Battle Creek, Michigan plant installed an economizer to recover the heat from flue gas to preheat hot water and boiler make-up water. The project's annual cost savings were $411,000 with a return on investment slightly higher than 22%. (DeYoung and Kaiser, 2017)

Recover heat from boiler blowdown.

When the water is blown from the high-pressure boiler tank, the pressure reduction often produces substantial amounts of steam. Up to 80% of the heat in the discharge is recoverable by using flash vessels and heat exchangers (CADDET, 2001b). The recovered heat can subsequently be used for space heating and feed water preheating, increasing the efficiency of the system. Any boiler with continuous blowdown exceeding 5% of the steam rate is a good candidate for the introduction of blowdown waste heat recovery. If there is a non-continuous blowdown system, then consider the option of converting it to a continuous blowdown system coupled with heat recovery (U.S. DOE, 2006b). Larger energy savings occur with high-pressure boilers. The use of heat from boiler blowdown on average has payback period of about 1.8 years (IAC, 2017).

Reduce standby losses.

Often, one or more boilers are kept on standby in case of failure of the operating boiler. By modifying the burner, combustion air supply and boiler feedwater supply, steam production at standby can be reduced to virtually zero. By installing an automatic control system, the boiler can reach full capacity within 12 minutes. Energy savings up to 85% of the standby boiler are achieved by installing the control system and modifying the boiler. Actual figures depend on the use pattern of the boiler (Worrell and Galitsky, 2005).

Recover condensate.

By installing a condensing economizer, companies can improve overall heat recovery and steam system efficiency by up to 10% (U.S. DOE, 2007a). Many boiler applications can benefit from additional heat recovery. Condensing economizers require site-specific engineering and design, and a thorough understanding of the effect they will have on the existing steam system and water chemistry.

Hot condensate can be returned to the boiler to save energy and reduce the need for treated boiler feed water since condensate, being condensed steam, is extremely pure and has high heat content. Increasing the amount of returned condensate has an average payback period is slightly more than 1 year (IAC, 2017). Condensate has also been used to provide for hot water supply. This measure had an average payback period of 1.1 years (IAC, 2017). Care should be taken to prevent the forming of corrosion. Corrosion in condensate systems can limit the quality or quantity of returned condensate, may contain iron and copper corrosion products, and can deposit on boiler heat transfer surfaces, reducing heat transfer efficiency. In addition, corrosion may cause steam leaks. As a result, corrosion increases maintenance and equipment costs.

Steam Supply - Combined Heat and Power (CHP)

Combined heat and power (CHP) is an efficient and clean approach to generating electric power and useful thermal energy from a single fuel source. CHP is used either to replace or supplement conventional separate heat and power (SHP). Instead of purchasing electricity from the local utility and burning fuel in an on-site furnace or boiler to produce thermal energy, facilities can use CHP on-site to provide both energy services in one energy-efficient process. In this way, and by avoiding distribution losses, CHP can achieve total efficiencies of over 80 percent, compared to 50 percent for conventional technologies (i.e., grid-supplied electricity and an on-site boiler).

Applications with steady demand for electricity and thermal energy are potentially good economic targets for CHP deployment. Industrial applications, particularly in industries with continuous processing and high steam requirements, tend to be the most economic and represent the majority of existing CHP capacity (U.S. EPA, 2015). While in general, breakfast cereal plants use more heat than electricity, they depend on electricity to run the compressors, refrigerators, fans, lights and a number of process equipment such as mixers and packaging units.

Properly sized and configured CHP systems can effectively insulate facilities from a grid failure, providing continuity of critical operations. The design elements necessary so that a CHP system can be isolated from the grid – i.e. operate in "island" mode – are system-specific and include additional controls and switchgear equipment (ORNL, 2013)

The cost benefits of power export to the grid will depend on the regulation where the industry is located, but can provide a major economic incentive. Not all states allow wheeling of power (i.e. sales of power directly to another customer using the grid for transport) and for the states that do allow wheeling, regulations may also differ with respect to the tariff structure for power sales to the grid operator.

Most CHP systems consist of several individual components – prime mover (heat engine), generator, heat recovery, and electrical interconnection – configured into an integrated system. The type of equipment that drives the overall system (i.e., the prime mover) typically identifies the CHP system (U.S. EPA, 2015). 97 percent of the CHP projects in place today and 99 percent of the total installed CHP electric capacity is represented by five technologies: reciprocating engines, gas turbines (that include gas turbine/steam turbine combined cycles), boiler/steam turbine, microturbine and fuel cells (U.S. EPA, 2015).

CHP systems are classified as either as topping-cycle or bottoming-cycle CHP. In topping-cycle CHP systems, fuel is used to generate electricity. Waste heat from the prime mover is then recovered and used for steam, hot water, process heating, and/or cooling applications. In bottoming cycle CHP systems, high-temperature thermal energy is first used for industrial applications, such as metal smelting furnaces, and the waste heat is then recovered and used to drive a turbine to produce electric power.

Smaller CHP systems have been developed that are pre-engineered, pre-packaged and pre-tested. The capacity range is 55-400 kWe for systems running with natural gas and 60-350 kWe for systems running with biogas (Duffy and Purani, 2012). These systems include all components, such as the prime mover, generator, heat exchangers and process and emission controls. This reduces installation and engineering costs and offers an improved return on investment. The food industry is considered one of the many industrial applications where the pre-packaged systems can achieve great energy savings potentials. The low and stable natural gas prices in combination with the lower installation and engineering costs of such systems has improved the return on investment with payback periods claimed to be as low as three years (ESC, 2013).

Micro-CHP plants are systems that can provide up to 50 kWe. Similarly to small-scale CHP plants they are delivered as complete units including all components. Instead of internal combustion engines micro-turbines or Stirling engines can be used. The average investment costs of packaged CHP units in 2008 were 2,000/kWe for micro-CHPs (5 kWe), 1,250/kWe for small CHPs (50 kWe) and 800/kWe for bigger CHPs (1MWe) but are now expected be lower (Carbon Trust, 2010).

The technology choice for a CHP facility depends on available fuel and the amount of generating capacity needed (EIA, 2012).

CASE STUDY: Kellogg's Manchester UK plant uses a natural gas fueled 4.9 MWe CHP plant to supply 85% of steam demand and 50% of electricity demand. The adoption of the CHP unit reduced CO_2 emissions by 12% along with NOx emissions reductions. (Gardiner, 2011)

CASE STUDY: Breakfast cereal producer Nordgetreide GmbH & Co. KG in Falkenhagen, Germany, installed a CHP system with an electrical output rated at 835 kW. When operated at full load, the CHP unit can cover the plant's total electricity demand. The unit also produces 1,322 lbs of steam per hour which allowed the plant to avoid purchasing a new boiler for hot water production. (2G. Energy Inc., 2015)

Gas turbines.

Gas turbines are used to meet many different power needs, including propulsion, direct drive, and stationary electricity generation. Gas turbines are well suited for industrial CHP applications because the high temperature gas turbine exhaust can be used to generate high-pressure steam, or it can be used directly for heating or drying applications. Some industrial CHP systems use gas turbine exhaust to heat the input of a furnace or to preheat combustion air. This option may require replacing existing furnaces, since the radiative heat transfer from gas turbine exhaust gases is much smaller than from combustion gases, due to their lower temperature (Worrell et al., 1997).

Gas turbines can range from 1 MW to hundreds of megawatts, and they can be utilized as simple cycle turbines or as part of a combined cycle where recovered steam is used to power a secondary steam turbine. Some recent designs use a Cheng cycle which injects steam directly into the gas turbine to boost power output. Electric efficiencies for simple cycle gas turbines can approach 40 percent (HHV), but efficiency degrades quickly as the load is decreased, so gas turbines are best-suited for applications where the system operates at near-constant full load.

Steam turbines.

Steam turbines have been used for electricity production since the 1880s, and most of the electricity generated in the U.S. is produced by steam turbines at central station power plants. Steam turbines only require a source of heat sufficient to produce high-pressure steam, so any type of fuel (or high-temperature heat source) can be used to produce power. Other than central station power, steam turbines are commonly paired with boilers for CHP applications at industrial manufacturing facilities. Steam turbines can come in all sizes, from under 100 kW to over 200 MW.

The efficiency of steam turbines is determined by the inlet steam pressure and temperature as well as the outlet pressure. Each turbine is designed for a certain steam inlet pressure and temperature, and operators should make sure that the steam inlet temperature and pressure are optimal. An 18°F decrease in steam inlet temperature will reduce the efficiency of the steam turbine by 1.1% (Patel and Nath, 2000).

In industrial CHP applications, some steam is used for on-site thermal processes, and some is used to generate electricity. Most industrial steam turbine configurations use back-pressure or extraction turbines to produce steam at specific pressures for industrial processes, filling the role of pressure reduction valves.

In recent decades, steam turbine technology has improved significantly (e.g. materials, blade types, integration). Older steam turbines may be retrofitted to enhance their performance. Based on existing projects efficiency improvements of between 2.5-10% are to be expected. The higher end of the savings potential is applicable to older turbines (in the range of 30 years). The retrofit would lead to an increase in the capacity of the steam turbine while fuel use would remain the same. The payback time of the steam turbine upgrade is usually in the order of 1 year. Costs can be reduced by including the upgrade in the normal turn-around schedule.

Reciprocating engines.

There are two primary reciprocating engine designs relevant to stationary power generation applications – the spark ignition Otto-cycle engine and the compression ignition Diesel-cycle engine. For baseload power and CHP applications, spark ignition natural gas-fueled engines tend to be used, with capacities ranging from 10 kW to 10 MW.

Reciprocating engines represent over 50 percent of all installed CHP systems, with engines fueled by natural gas and other gaseous fuels accounting for most of the installed capacity. Modern reciprocating engines are some of the most efficient CHP technologies, reaching over 40 percent electric efficiency and 80 percent total CHP efficiency (HHV). Thermal energy can be recovered from three sources: 1) engine exhaust, 2) cooling water, and 3) lubricating oil. Steam can be produced from the exhaust of some larger engines, but thermal energy from cooling water and lubricating oil can only be used to produce hot water (or chilled water with an absorption chiller).

Waste heat to power.

Waste heat to power (WHP) is the process of capturing heat discarded by an existing industrial process and using that heat to generate power (U.S. EPA, 2012). Energy-intensive industrial processes—such as those occurring at refineries, steel mills, glass furnaces, and cement kilns—all release hot exhaust gases and waste streams that can be harnessed with well-established technologies to generate electricity.

Waste heat streams can be used to generate power in what is called bottoming cycle CHP. In this configuration, fuel is first used to provide thermal energy in an industrial process, such as a furnace, and the waste heat from that process is then used to generate power. The key advantage of this type of WHP systems is that they utilize heat, produced at necessary high temperatures from existing thermal processes, which would otherwise be wasted, to produce electricity or mechanical power, as opposed to directly consuming additional fuel for this purpose.

Most WHP systems use the Rankine cycle, either with steam or with an organic fluid when the waste heat sources have a lower boiling point. The working fluid is pumped to a heat recovery boiler where the fluid is evaporated, passed through a turbine to generate power, and then condensed and returned to the boiler.

The working fluid for WHP systems is chosen based on the temperature and characteristics of the waste heat source. Steam can only be used with high-temperature (>700^{o}F) heat sources, while heat sources from 300 to 700^{o}F can use other organic working fluids (typically different types of refrigerants).

Waste to power.

Unavoidable food waste generated in breakfast cereal plants, as in other food processing industries, can be used for bio-energy production, either with the use of CHP plants or through anaerobic digestion. Food manufacturing facilities generate high strength waste streams characterized by high Chemical Oxygen Demand (COD) and high solids loading making them well-suited for biogas generation with anaerobic digestion.

The food waste (ingredients and cereals) generated from all the different processes involved in breakfast cereal making, are about 8% of production and are usually used as animal feed. Other process wastes, such as cardboards, are recycled (Jeswani et al., 2015).

Significant amounts of waste water can be generated in breakfast cereal plants mainly from cleaning the various equipment (e.g. cookers, mixers, conveyors, rollers, extruders), and the water from the scrubbers and the utilities on-site (Judd, 2014). According to Jeswani et al., (2015) about 2.7 kgs of wastewater are generated for every kg of breakfast cereal produced. The typical Total Suspended Solids (TSS) range is between 300-500 mg/L while the COD is typically between 2,000-3,000 mg/L, however for certain facilities the value can be 2-3 times higher if there are significant product losses, if sweetener coatings are applied and if frequent product changes take place that involve more regular cleaning (Judd, 2014).

Digestion is commonly used to treat waste and can be either aerobic (air-feed provided) or anaerobic (air-tight vessel). The aerobic systems commonly used can be disadvantageous due to the high power requirements (Cheremicinoff, 2002). With anaerobic digestion organic compounds in the wastewater can be turned into biogas that can be used to provide heat or cogenerate electricity and heat onsite. These systems are feasible if the influent concentration is approximately 1 kg of BOD/m^3 (UNEP, 1996).

Certain waste, such as oat hulls can be used for energy production.

CASE STUDY: General Mills' Cheerios® plant in Fridley, Minnesota, converts oat hulls generated from milling into energy. About 80,000 tons are burned annually which covers 90% of the steam needed to heat the plant and produce the oat flour. Annual energy cost savings were estimated at $390,000. (General Mills, 2010)

CASE STUDY: Quaker Oats provides 40,000 tons of oat hulls to Iowa University for energy generation. (Quaker Oats, 2017)

Steam Distribution

Shut off excess distribution lines.

Installations and steam demands change over time, which may lead to under-utilization of steam distribution capacity, and extra heat losses. It may be too expensive to optimize the system for changed steam demands. Still, checking for excess distribution lines and shutting off those lines is a cost-effective way to reduce steam distribution losses.

Properly size pipes.

When designing new steam distribution systems, it is very important to account for the velocity and pressure drop. This reduces the risk of oversizing a steam pipe, which is not only a cost issue but would also lead to higher heat losses. A pipe that is too small may lead to erosion and increased pressure drop (Van de Ruit, 2000).

Insulate.

Insulation can typically reduce energy losses by 90% and help ensure proper steam pressure at plant equipment (U.S. DOE, 2006b). The application of insulation can lead to significant energy cost savings with relatively short payback periods. For instance, the average payback period of insulation on steam and hot water lines, condensate lines, and feedwater tanks is 2.3, 1.1 and 1.1 years respectively (IAC, 2017). The improvement of existing insulation can often lead to further savings. This measure consists of applying more or better insulating material. Crucial factors in choosing insulating material include: low thermal conductivity, dimensional stability under temperature change, resistance to water absorption, and resistance to combustion. Other characteristics of insulating material may also be important depending on the application, e.g. tolerance of large temperature variations and system vibration, and compressive strength where insulation is load bearing (Baen and Barth, 1994).

Some types of insulation can become brittle, or rot. As a result, energy can be saved by a regular inspection and maintenance program (CIBO, 1998). The repair of faulty insulation has an average payback time of 0.8 years (IAC, 2017).

During maintenance, insulation that covers pipes, valves, and fittings is often damaged or removed and not replaced. This can be avoided by using removable and reusable insulating pads which are available to cover almost any surface (U.S. DOE, 2006b).

Check and monitor steam traps.

A simple program of checking steam traps to ensure proper operation can save significant amounts of energy. If the steam traps are not maintained for 3 to 5 years, 15-30% of the traps can be malfunctioning, thus allowing live steam to escape into the condensate return system. In systems with a regularly scheduled maintenance program, leaking traps should account for less than 5% of the trap population (U.S. DOE, 2006b). The repair and replacement of steam traps has an average payback time of about 0.5 years (IAC, 2017). Energy savings for a regular system of steam trap checks and follow-up maintenance is estimated to be up to 10% (Jones, 1997; Bloss et al., 1997). Attaching automated monitors to steam traps in conjunction with a maintenance program can save even more energy, without significant added cost. Such a system is an improvement over steam trap maintenance alone, because it gives quicker notice of steam trap malfunctioning or failure. Using automatic monitoring is estimated to save an additional 5% over regular steam trap maintenance, with a payback of about 1 year.

Use thermostatic steam traps.

Using modern thermostatic element steam traps can reduce energy use while improving reliability. The main advantages offered by these traps are that they open when the temperature is close to that of the saturated steam (within 0.6°F (2°C)), purge non-condensable gases after each opening, and are open on startup to allow a fast steam system warm-up. These traps are also very reliable, and useable for a large range of steam pressures (Alesson, 1995). Energy savings will vary depending on the steam traps installed and the state of maintenance.

Examples of thermostatic traps are pinch traps. In these traps, a modulator automatically closes off flow as a chemically resistant elastomer around the modulator expands with the passage of hot condensate. As the condensate builds up and cools, the elastomer around the modulator contracts, allowing the orifice to open and create flow. It automatically responds to condensate temperature, has no live steam losses and uses energy in the steam line at maximum efficiency (Kane et al., 1998).

Shut off steam traps.

Energy savings can come from shutting off steam traps on superheated steam lines when they are not in use. This measure has an immediate payback (IAC, 2017).

Reduce distribution pipe leaks.

As with steam traps, the distribution pipes themselves often have leaks that go unnoticed without a program of regular inspection and maintenance. On average leak repair has a payback period of 0.3 years (IAC, 2017).

Recover low-pressure waste steam through vapor recompression.

Low-pressure steam exhaust from industrial operations is usually vented to the atmosphere or condensed in a cooling tower. Simultaneously, other plant operations may require intermediate-pressure steam at 20 to 50 psig. Instead of letting down high-pressure steam across a throttling valve to meet these needs, low-pressure waste steam can be mechanically compressed or boosted to a higher pressure so that it can be reused. Recovery of the latent heat content of low-pressure steam reduces the boiler load, resulting in energy and fuel cost savings. Low-pressure steam potential uses include driving evaporation and distillation processes, producing hot water, space heating, producing a vacuum, or chilling water.

Vapor recompression relies upon a mechanical compressor or steam jet ejector to increase the temperature of the latent heat in steam to render it usable for process duties. It is noted that the steam jet ejector is known for its simple construction, insensitivity to fouling, easy installation, low capital and installation costs, easy maintenance with no moving parts, and long useful operating lives.

Recompression typically requires only 5% to 10% of the energy required to raise an equivalent amount of steam in a boiler. Vapor recompression can be used in steam distribution systems to boost system pressures that have dropped to unacceptably low levels (U.S. DOE, 2006b).

Recover flash steam.

When a steam trap purges condensate from a pressurized steam distribution system to ambient pressure, flash steam is produced. Depending on the pressures involved, the flash steam contains approximately 10% to 40% of the energy content of the original condensate. This energy can be recovered by a heat exchanger and used for space heating or feed water preheating (Johnston, 1995; U.S. DOE, 2006b). The potential for this measure is site dependent, as it is unlikely that a plant will build an entirely new system of pipes to transport this low-grade steam, unless it can be used close to the steam traps. Sites using multi-pressure steam systems can route the flash steam formed from high-pressure condensate to reduced pressure systems.

The flashing of high-pressure condensate can regenerate low-pressure steam. Low-pressure process steam requirements are usually met by throttling high-pressure steam, but a portion of the process requirements can be achieved at low cost by flashing high-pressure condensate. Flashing is particularly attractive when it is not economically feasible to return the high-pressure condensate to the boiler. The economics of heat recovery projects are most favorable when the waste steam heat content is high and the flow continuous. Seasonal space heating is not the most desirable end use. Flashing of high-pressure condensate to regenerate low-pressure steam has an average payback period of 1 year (IAC, 2017).

Chapter Nine: Lighting

In this chapter:	
Turn off lights in unoccupied areas	Use occupancy sensors and other lighting controls
Upgrade exit signs	Replace magnetic ballasts with electronic ballasts
Replace T-12 tubes with T-8 or T-5 tubes	Use LED lighting
Replace linear fluorescent lights with LED lights	Replace high wattage fluorescent, metal halide and high-pressure sodium lights with LED lights
Reduce lighting system voltage	Use daylighting

Lighting is used either to provide overall ambient lighting throughout the manufacturing, storage and office spaces or to provide low bay and task lighting to specific areas. Many of the lighting technologies employed in the residential, commercial, and industrial sectors are similar. However, because the industrial sector operates lights for many hours a day and requires high light outputs, lights with high efficacy and long lifetimes that have low life cycle costs, such as linear fluorescent and High Intensity Discharge (HID) lights (U.S. DOE, 2016b), and increasingly LEDs are of preference.

In the U.S. industries, about 92% of the energy used for illumination is for linear fixture and low- and high-bay applications. In 2015, the lighting installations used for low- and high- bay applications were 5% LED, 13% Metal Halide (MH), 13% high-pressure sodium (HPS) and about 68% high wattage fluorescent lamps (i.e. 14% T-12, 38% T-8 and 16% T-5; see below). Historically, the low- and high- bay market was dominated by (HID) sources, including MH, HPS and mercury vapor lamps. Lately, fluorescent lamps, and T-5 in particular, have become a major player in this area primarily due to their lumen maintenance and improved control options (U.S. DOE, 2016b). Mercury vapor ballasts are no longer available for purchase in the U.S. (EPACT 2005) and are currently only used in very limited quantities.

Energy Savings Checklist: Lighting

Lighting is a significant energy use and cost for many manufacturers and is an area with numerous opportunities for savings. Use the checklist below to find new ways to save energy and costs with lighting changes.

Lighting Checklist	✓
Are unoccupied areas lit?	
Are lights left on during non-work hours?	
Are parts of the facility overlit?	
Is older, inefficient technology in use?	
Are exit lights using old technology?	
Can daylighting be used?	
Are lighting controls in use?	
Is there a periodic review of lighting technology to ensure the most efficient technology is in use?	

Opportunities for Energy Efficiency

There are many options and choices for providing appropriate lighting for specific settings. When the opportunity to install new or replace and upgrade existing lighting presents itself, understanding the various energy requirements, lifetime, uses, etc. for the numerous types of lighting sources can be an important part of energy management and savings in a manufacturing facility. Table 5 shows the mean performance of conventional lighting sources used in industries. Table 6 shows the efficacy range of LED products for industrial applications according to the latest LED Lighting Facts® database[6].

Appendix H lists the purchasing prices (lamp, ballast, fixture) of the various lighting sources.

Table 5. Mean[1] performance of conventional industrial sector lighting sources (U.S. DOE, 2016b).

Industrial Sector Markets	Mean Lamp Wattage (W)[2]	Mean Efficacy (Lumen/watt)[3]	Typical Lifetime (hours)
A-Type			
Incandescent Omni	46	16	2,000
Halogen Omni	29	15	2,000
CFL Omni	11	54	10,000
Directional			
Incandescent	65	10	3,000
Halogen	48	13	3,000
CFL	16	43	10,000
Linear Fixtures			
T-12 < 4ft	41	49	15,000
T-8 < 4ft	24	73	20,000
T-12 4ft	39	72	20,000
T-8 4ft	30	79	24,000
T-5 4ft	56	85	30,000
T-12 > 4ft	84	78	12,000
T-8 > 4ft	62	83	18,000
Low and High Bay			
T-12	75	72	12,000
T-8	57	79	18,000
T-5	68	85	30,000
Metal Halide	424	77	20,000
High-Pressure Sodium	295	106	24,000
Other			
CFL Pin	44	70	12,000
Metal Halide	424	77	20,000
High-Pressure Sodium	295	106	24,000

[1] Values are mean performance. Actual performance of individual lighting sources will vary.
[2] Ballast losses are accounted for in the lamp wattage assumptions for ballasted technologies (i.e. linear fluorescent and HID lamps).
[3] System lifetime assumptions for ballasted technologies (i.e. linear fluorescent and HID lamps) are also included.

[6] LED Lighting Facts® is a program launched in 2008 by the U.S. Department of Energy to assure consumers that the performance of LED products is accurately represented (http://lightingfacts.com/). The LED Lighting Facts® database is an online, free access product list that summarizes verified product performances (for both luminaires and retrofit kits) allowing buyers to make comparisons and identify the best product for their application (http://www.lightingfacts.com/products).

Table 6. Range of 2016 LED product efficacies for industrial applications (U.S. DOE, 2017a).

Application	Product Type	LED Replacement Description	2016 LED Efficacy Range (lm/W)		
			5th percentile	Average	95th percentile
Linear Fixtures	Lamp	Linear tube replacements	101	118	142
	Retrofit Kit Luminaire	Panels and recessed/surface-mounted troffer retrofit kits and luminaires	70	91	118
Low/High Bay	Lamp	High wattage lamp replacements	76	103	131
	Luminaire	High and low bay luminaires	80	107	136

Best Practices for Energy-Efficient Lighting

- Turn off lights in unoccupied areas. An easy and effective measure is to encourage personnel to turn off lights in unoccupied building spaces.

- Use occupancy sensors and other lighting controls. Lights can be shut off during non-working hours by automatic controls, such as occupancy sensors which turn off lights when a space is unoccupied.

- Upgrade exit signs. Energy costs can be reduced by switching from incandescent lamps to light emitting diodes (LED's) or radium strips in exit sign lighting.

- Replace magnetic ballasts with electronic ballasts. Electronic ballasts require 12 to 30% less power than magnetic ballasts.

- Replace T-12 tubes with T-8 or T-5 tubes. Replace T-12 lamps with T-8 or T-5 lamps and lower the energy use.

- Use LED lighting. LED lights can use far less energy to emit the same lumens of light, and typically have a long lifetime.

- Replace linear fluorescent lights with LED lights. Use high efficacy LED lightings to reduce energy use significantly.

- Replace high wattage fluorescent, metal halide and high-pressure sodium lights with LED lights. Using LED lighting for low- and high-bay applications can offer significant energy savings.

- Reduce lighting system voltage. Voltage controllers reduce voltage and save energy in HID or fluorescent lighting systems without losing light.

- Use daylighting. Increasing levels of daylight within rooms can reduce electrical lighting loads by up to 70%.

Turn off lights in unoccupied areas.

An easy and effective measure is to encourage personnel to turn off lights in unoccupied building spaces. An energy management program that aims to improve the awareness of personnel with regard to energy use can help staff get in the habit of switching off lights and other equipment when not in use.

Use occupancy sensors and other lighting controls.

Lights can be shut off during non-working hours by automatic controls, such as occupancy sensors, which turn off lights when a space is unoccupied. Manual controls can also be used in addition to automatic controls to save additional energy in smaller areas. Numerous case studies throughout the United States suggest that the average payback period for occupancy sensors is approximately 1.5 years (IAC, 2017).

Manual controls can be used in conjunction with automatic controls to save additional energy in smaller areas. One of the easiest measures is to install switches that allow occupants to control lights. Other lighting controls include daylight controls for indoor and outdoor lights, which adjust the intensity of electrical lighting based on the availability of daylight. Figure 2 shows lighting placements and controls.

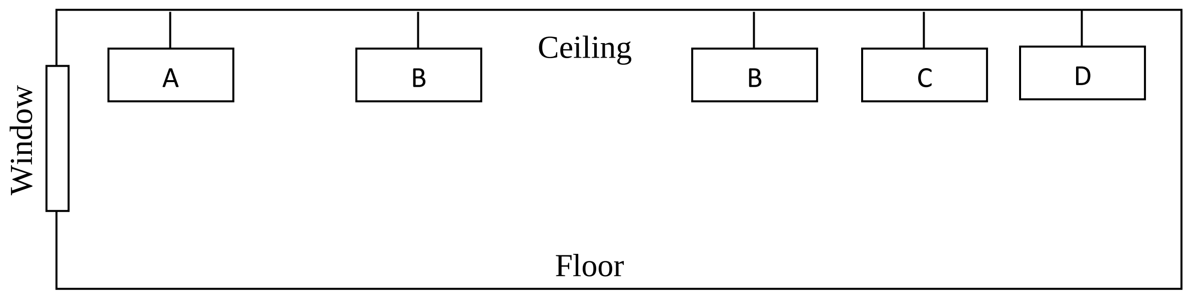

Figure 2: Lighting Placement and Controls.

Upgrade exit signs.

Energy costs can be reduced by switching from incandescent lamps to light emitting diodes (LEDs) or radium strips in exit sign lighting. An incandescent exit sign contains one or two lamps and consumes about 40 W, while LED signs use less than 5 W (average use around 3 W), reducing electricity use by about 90% (U.S. EPA, unknown date; 2009). Fluorescent exit signs consume about 13 W. The lifetime of an LED exit sign is about 25 years, compared to 1 year for incandescent signs, which can reduce exit sign maintenance costs considerably. In addition to exit signs, LEDs are increasingly being used for path marking and emergency way finding systems. Their long life and cool operation allows them to be embedded in plastic materials, which makes them well suited for such applications (LRC, 2001).

New LED exit signs are inexpensive, with prices typically at around $40 (U.S. EPA, 2009). Tritium powered exit signs are an alternative to LED exit signs. Tritium signs are self-luminous and thus do not require an external power supply. The advertised lifetime of these signs is around 10 years and prices typically start at around $160 per sign (U.S. EPA, 2009).

Replace magnetic ballasts with electronic ballasts.

A ballast is a mechanism that regulates the amount of electricity required to start a lighting fixture and maintain a steady output of light. Electronic ballasts can require 12 to 30% less power than their magnetic predecessors (Cook, 1998; Galitsky et al., 2005a). New electronic ballasts have smooth and silent dimming capabilities, in addition to longer lives (up to 50% longer), faster run-up times, and cooler operation than magnetic ballasts (Eley et al., 1993; Cook, 1998). New electronic ballasts also have automatic switch-off capabilities for faulty or end-of-life lamps.

Replace T-12 tubes with T-8 or T-5 tubes.

Linear fluorescent lights, due to their low cost, high efficiency and long lifetimes, have found wide application in industrial and commercial facilities.

In the industry, T-12 lights have been typically used. The designation T-12 refers to tubular fluorescent lamps with a diameter of 1/8 inch increments (T-12 means 12/8 inch or 3.8 cm diameter tubes). The initial output for these T-12 lights is high, but energy consumption is also high. They also have extremely poor efficacy, lamp life, lumen depreciation, and color rendering index. Due to this, T-12 lamps are being replaced with the smaller diameter T-8 lamps approximately doubling the efficacy of the former. Typical energy savings from the replacement of a T-12 lamp by a T-8 lamp are around 30% (Galitsky et al., 2005a).

T-5 lamps can also replace T-12 lamps and offer higher light output with a lower energy consumption. However, as T-5 lamps do not come in equivalent lengths to the T-12, new fixtures or a retrofit kit is needed (U.S. DOE, 2010).

Use LED lighting.

Light emitting diode (LED) lights are the latest generation of energy-efficient lighting. In typical florescent lighting, electrical arcs are used to excite mercury and phosphorous compounds, which then emit light. LED lights are semiconductor diodes that use far less energy to emit the same lumens of light. Several new LED light products that are compatible with current linear and low- and high-bay light fixtures have emerged on the market, and prices for LED lighting have decreased substantially in the last few years.

To determine the efficiency of LED lighting, the efficiency of the whole lighting system, both LED lamp and fixture (luminaire efficiency), needs to be assessed, as the fixture design affects the energy use. Also, due to their sensitivity to thermal and electrical conditions, they need to be carefully integrated with existing lighting fixtures to be able to achieve high energy efficiencies.

The long lifetime of LEDs is, next to energy efficiency, a key advantage, as it strongly reduces maintenance costs as well as energy costs. Including these cost savings in the investment decision generally will make a sound business case for LED lighting. This report focuses mainly on LED lighting efficacies and lumen output. Prior to adopting a new LED lighting source, several other important aspects will need to be examined related to light distribution, lamp color, lumen maintenance, glare, dimmability and restrike issues, ballast noise, durability, and flicker (U.S. DOE, 2017b).

There is a wide variety of LED lighting products that can be used in industrial facilities, with some having some of the highest efficiencies of today's white lighting sources. Although many products outperform their counterpart linear florescent, high wattage fluorescent, MH and HPS lighting systems, their efficiency and performance varies widely. The following two paragraphs address the main two types of LED applications in industries; linear lighting fixtures and low- and high-bay lighting applications based on Department of Energy's Lighting Facts Database.

Replace linear fluorescent lights with LED lights.

The lamps mostly used for linear applications are the T-8 type. The use of T-12 lamps has been limited in recent years, mainly due to the new efficacy requirements for fluorescent lamps (10 CFR 430.2).

TLEDs > 100 lm/W

For a luminance compared to a typical fluorescent system, LED lighting systems need to have an efficacy of at least 100 lm/W to achieve energy savings.

Linear LED lamps, also known as TLEDs, can be used to replace linear fluorescent fixtures. They offer an attractive retrofit solution as they can reduce power use for lighting by up to 60%. Due to technological advancements in the past few years, lighting efficacies as high as 190 lm/W have been achieved. According to the LED Lighting Facts® database, the maximum efficacy in 2012 was much lower at 120 lm/W (U.S. DOE, 2016a), demonstrating the progress in LED development.

When evaluating the performance of TLEDs, note that their efficacy will decrease when installed in a luminaire. The luminaire efficiency of TLEDS with a troffer is about 75% to 85%. In addition, as the number of LED lamps increases, the efficiency of the luminaire slightly declines. In general, the efficacies of bare TLED products (when adjusted for the efficiency reduction of a typical luminaire - troffer) are lower than the efficacies of the LED retrofit kits and LED luminaires (U.S. DOE, 2016a).

Of the tens of thousands of LED products listed in the LED Lighting Facts® database, more than 100 products had an efficacy of 150 lm/W. However, the median efficacy was at 92 lm/W (U.S. DOE, 2016a). Although TLED lamps have some of the highest efficacies (190 lm/W), the efficacy of the various products varies drastically, with some having a lower efficacy than linear fluorescent lamps. Modern efficient fluorescent lighting systems (both lamp and ballast) can offer efficacy of up to 108 lm/W and at a low price of about $4/klm (U.S. DOE, 2017a). In 2016, the price of a TLED lamp for linear fixture applications was $8/klm. That is about five times the price of a linear fluorescent lamp. The price of LED retrofit kits and LED luminaires was considerably higher, at $30/klm (2016 price) (U.S. DOE, 2017a).

Due to significant variations among different LED products, the impact their use can have on illumination levels and energy consumption should be carefully evaluated. Significant energy savings can be achieved when LED lighting systems with efficacies on the highest range (95^{th} percentile) are adopted (see Table 6).

Industrial LED products are more efficient than other LED products and more efficient than their fluorescent and metal halide counterpart products.

Replace high wattage fluorescent, metal halide and high-pressure sodium lights with LED lights.

Only recently, and due to the ongoing technological and cost improvements, did industrial facilities begin to replace fluorescent lights with LEDs in both low-bay (ceilings less than 20 feet high) and high-bay (ceilings more than 20 feet high) applications. For low-bay applications, luminaires should typically emit 15,000 to 20,000 lumens per fixture, and for high-bay 15,000 to 100,000 lumens per fixture. The breakdown of the technologies used for such applications currently in the U.S. industry is as follows: 68% tubular fluorescent, 13% MH, 13% HPS and 5% LEDs (U.S. DOE, 2016b).

There are many industrial LED lights that emit the same lumens and have higher efficacies than high wattage fluorescent, MH and HPS. While five years ago very few LED fixtures could reach the required lumen output for low- and high-bay applications, today there are more than 8,000 products listed, of which more than 55% emit more than 15,000 lumens. About 23% of the products have an efficacy of more than 130 lm/W, and 5% exceed 150 lm/W. One product has an efficacy of 210 lm/W (U.S. DOE, 2017b).

CASE STUDY: Kellogg's Battle Creek, Michigan plant replaced about 1,900 inefficient light fixtures (mostly 400-watt metal halide lamps) with fluorescent lamps with high performance ballasts, saving $176,000 annually. The return on investment was about 26%. (DeYoung and Kaiser, 2017)

Because optical, form and color constraints are not as strict as in other LED applications (e.g. linear, troffer, roadways), industrial LED lights are characterized by higher efficacies (U.S. DOE, 2017b). LED retrofit lamps have become available as direct replacements for fluorescent lights. Prices for LED high-wattage lamps has dropped to $14/klm (2016 price), approximately four times that of high-wattage linear fluorescent lamps. LED retrofit kits and LED luminaires that can be used for direct replacement of fluorescent lamps are more expensive, at about $19/klm (2016 price) (U.S. DOE, 2017a).

Reduce lighting system voltage.

Reducing lighting system voltage can also save energy. A Toyota production facility installed reduced-voltage HID lights and realized a 30% reduction in lighting energy consumption (Galitsky et al., 2005a). Commercial products are available that attach to a central panel switch (controllable by computer) and constrict the flow of electricity to lighting fixtures, thereby reducing voltage and saving energy, with an imperceptible loss of light. Voltage controllers work with both HID and fluorescent lighting systems and are available from multiple vendors.

Use daylighting.

Daylighting involves the efficient use of natural light to minimize the need for artificial lighting in buildings. Increasing levels of daylight within rooms can reduce electrical lighting loads by up to 70% (CADDET, 2001a; IEA, 2000). Unlike conventional skylights, an efficient daylighting system may provide evenly dispersed light without creating heat gains, which can reduce the need for cooling compared to skylights.

Daylighting differs from other energy efficiency measures because its features are integral to the architecture of a building; therefore, it is applied primarily to new buildings and incorporated at the design stage. However, existing buildings can sometimes be cost-effectively refitted with daylighting systems.

Daylighting can be combined with lighting controls to maximize its benefits. Because of its variability, daylighting is almost always combined with artificial lighting to provide the necessary illumination on cloudy days or after dark. Daylighting technologies include properly placed and shaded windows, atria, clerestories, light shelves, and light ducts. Clerestories, light shelves, and light ducts can accommodate various angles of the sun and redirect daylight using walls or reflectors. More information on daylighting can be found at the website of the Daylighting Collaborative led by the Energy Center of Wisconsin (http://www.daylighting.org/).

CASE STUDY: General Mills' Rooty Hill, Australia plant installed high efficiency lighting estimated to save 865,000 kWh per year. This improvement could reduce the plant's GHG emissions by 1,000 tons of CO_2 and save $133,000 (US$) annually. (General Mills, 2013)

Chapter Ten: Building HVAC

In this chapter:	
Employ an energy-efficient system design	Consider recommissioning before replacing
Install energy monitoring and control systems	Adjust non-production setback temperatures
Repair leaking ducts	Consider variable air volume systems
Install adjustable speed drives	Consider heat recovery systems
Modify your fans	Use ventilation fans
Install efficient exhaust fans	Add building insulation
Place good dock door seals	Employ solar air heating
Modify building reflection	Install low-emittance windows

HVAC stands for heating, ventilation, and air conditioning and refers to the equipment, distribution network, and terminals used either collectively or individually to provide fresh filtered air, heating, cooling, and humidity control in a building. The main goals of HVAC are to provide comfort and indoor air quality.

Energy Savings Checklist: HVAC Systems

HVAC systems can be a significant energy load, so it is important to ensure that these systems are operating efficiently. Use the checklist below to identify new ways to save energy and costs with HVAC system changes.

HVAC Checklist	✓
Are temperature set points turned back during non-production hours?	
Are temperature set points at the right level?	
Is duct work leaking?	
Is the building well insulated?	
Are HVAC systems programmed correctly and operating according to manufacturer's instructions?	
Are coils cleaned regularly?	
Are air filters changed appropriately and regularly?	
Is older, inefficient technology being used?	
Are economizer control and models functioning properly?	
Have burners been maintained properly and calibrated annually?	
Have v-belts been replaced with energy-efficient belts (i.e. cog belt)?	

Best Practices for Energy-Efficient HVAC Systems

- **Employ an energy-efficient system design.** Sizing equipment properly and designing energy efficiency into a new facility minimizes energy consumption and operational costs of HVAC systems from the outset.

- **Consider recommissioning before replacing.** Recommissioning identifies problem areas that may be reducing building efficiency, and can help avoid the cost of new equipment.
- **Install energy monitoring and control systems.** These systems monitor, control, and track energy consumption to optimize consumption and help identify system problems.
- **Adjust non-production setback temperatures.** Adjusting temperatures during periods of non-use can significantly reduce HVAC energy consumption.
- **Repair leaking ducts.** Repairing duct leaks can reduce HVAC energy consumption up to 30%**.**
- **Consider variable air volume systems.** These systems match HVAC load to heating and cooling demands and reduce energy use.
- **Install adjustable speed drives (ASDs).** ASD's minimize consumption based on system demand to save energy.
- **Consider heat recovery systems.** These systems reduce the energy required to heat or cool intake air.
- **Modify your fans.** Changing the size or shape of the sheaves of a fan optimizes fan efficiency and airflow and reduces energy consumption.
- **Use ventilation fans.** Ventilation fans reduce the load on heating systems and lead to better air circulation.
- **Install efficient exhaust fans.** Impeller exhaust fans are up to 25% more efficient than centrifugal fans.
- **Add building insulation.** Insulation is an easy and effective way to reduce utility bills.
- **Place good dock door seals.** Add heavy duty weather-stripping to insulate dock doors and decrease energy consumption due to reduced heat losses.
- **Employ solar air heating.** These systems use solar radiation for insulation and provide clean, fresh air.
- **Modify building reflection.** Use reflective roofing, "green" roofing or shading/windbreaks to increase energy efficiency.
- **Install low-emittance (Low-E) windows.** Insulating ability is increased through these windows.

Employ an energy-efficient system design.

For HVAC systems in new industrial facilities, the greatest opportunities for energy efficiency arise at the design stage. Sizing equipment properly and designing energy efficiency into a new facility generally minimizes the energy consumption and operational costs of HVAC systems from the outset. This practice often saves money in the long run, as it is generally less expensive to install energy-efficient HVAC equipment during construction than it is to upgrade an existing building with an energy-efficient system later on, especially if those upgrades lead to downtime.

Consider recommissioning before replacing.

Before replacing HVAC system components to improve energy efficiency, explore the possibility of HVAC system recommissioning. Recommissioning is essentially the same process as commissioning, but it is applied to a building's existing HVAC, controls, and electrical systems (U.S. EPA, 2008).

Commissioning is the process of verifying that a new building functions as intended and communicating the intended performance to the building management team. This usually occurs when a new building is turned over for occupancy. In practice, commissioning costs are not included in design fees and often compete with other activities, so commissioning is seldom pursued properly. To ensure that energy performance and operational goals are met, however, the building must be commissioned. To achieve this, ENERGY STAR recommends the following:

- Communicate your energy performance goals during commissioning to ensure that the design target is met. Encourage energy use tracking so that performance comparisons are made over time.
- Specify detailed commissioning activities in project contracts. Seek separate funding for commissioning work, to ensure that it will get done and be done well.
- Hire building commissioning experts. Include the commissioning firm as part of the design team early in the project.
- Finalize and transfer a set of technical documents, including manufacturers' literature for systems and components. Supplement technical literature with summaries of how to operate and manage the systems. Provide additional explanation for innovative design features.

Recommissioning involves a detailed assessment of existing equipment performance and maintenance procedures. This is compared to the intended or design performance and maintenance procedures in order to identify and fix problem areas that might be hampering building energy efficiency. Recommissioning can be a cost-effective retrofit in itself, sometimes generating more savings than the cost of the retrofit measure. For example, recommissioning may help avoid the need to install new or additional equipment, leading to savings in capital investments.

The U.S. EPA's ENERGY STAR Building Upgrade Manual (U.S. EPA, 2008) recommends a stepwise approach to recommissioning, in which a series of strategically ordered building "tune up" strategies are pursued. First, lighting and supplemental loads should be assessed, then the building envelope, followed by controls, testing, adjusting and balancing, heat exchange equipment, and finally heating and cooling systems. Most of these steps relate to HVAC system components or factors that will directly affect HVAC system energy consumption (such as building envelope and lighting). For more information, consult the manual.

Install energy monitoring and control systems.

An energy monitoring and control system supports the efficient operation of HVAC systems by monitoring, controlling, and tracking system energy consumption. Such systems continuously manage and optimize HVAC system energy consumption while also providing building engineers and energy managers with a valuable diagnostic tool for tracking energy consumption and identifying potential HVAC problems. Several projects indicate that the average payback period for HVAC control systems is about 1.3 years.

CASE STUDY: Kellogg's Battle Creek plant performed a series of HVAC modifications that saved $387,000. These improvements included updating and adding new controls and zone pressure monitoring on air handling units, eliminating heating and cooling air systems by installing recirculation pumps and smart sequencing, and installing a system to reduce pressure fluctuations when operations are turned on and off. (DeYoung and Kaiser, 2017)

Adjust non-production setback temperatures.

Setting back building temperatures (i.e. adjusting building temperatures down in the winter or up in the summer) during periods of non-use, such as weekends or non-production times, can significantly reduce HVAC energy consumption.

Repair leaking ducts.

Leaking air ducts can waste significant amounts of energy. Install duct insulation and perform regular duct inspection and maintenance, including ongoing leak detection and repair. According to a study by Lawrence Berkeley National Laboratory, repairing duct leaks in industrial and commercial spaces can reduce HVAC energy consumption by up to 30%. The study also showed that duct tape should not be used for leak repair; aerosol sealants are preferred.

Consider variable air volume systems.

Variable-air-volume systems adjust the rate of air flow into a room or space based on the current air flow requirements of that room or space. Variable-air-volume systems therefore work to more closely match HVAC load to heating and cooling demands, which reduces energy use.

Install adjustable speed drives (ASDs).

Adjustable speed drives can be installed on variable-volume air handlers and recirculation fans to match precisely the flow and pressure requirements of air handling systems. Energy consumed by fans can be lowered considerably since they do not constantly run at full speed. Adjustable speed drives can also be used on chiller pumps and water systems pumps to minimize power consumption based on system demand.

Consider heat recovery systems.

Heat recovery systems reduce the energy required to heat or cool facility intake air by recovering the thermal energy of the exhaust air. Common heat recovery systems include heat recovery wheels, heat pipes, and run-around loops. Heat pipes recover about 45 to 65% of the exhaust heat, while the efficiency of run-around loops can be in the 55 to 65% range.

Modify your fans.

Changing the size or shape of the sheaves of a fan can help to optimize fan efficiency and airflow, reducing energy consumption. Toyota optimized the sheaves of its fans instead of installing adjustable speed drives (ASDs) on fans, finding better savings and payback periods than expected.

Use ventilation fans.

Ventilation fans installed in the ceilings of work areas can help de-stratify workspace air, leading to better circulation of cool air in summer and warm air in winter, as well as more even temperature distributions from floor to ceiling. Such fans can help reduce the load on building heating systems by helping to “push down” warm air that rises during heating months.

Install efficient exhaust fans.

Exhaust fans are standard components in any HVAC system. Mixed flow impeller exhaust fans offer an efficient alternative to traditional centrifugal exhaust fans. They are typically 25% more efficient than centrifugal fans and can be cheaper to install and maintain. The expected payback period is about two years (Tetley, 2001).

Add building insulation.

Adding insulation will reduce utility bills. Older buildings are likely to use more energy than newer ones, leading to very high heating and air conditioning bills. However, even in new buildings, adding insulation may reduce utility bills enough to pay for itself within a few years.

Various states have regulations and guidelines for building insulation—for example, California’s Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24). Going beyond regulated insulation levels may be economically beneficial and should be considered as part of a new building’s design, as well as for reconstruction of existing buildings. For refrigerated warehouses, much higher levels of insulation are preferred.

Place good dock door seals.

Heat losses are significant when the loading dock doors are unsealed. Reduce heat transfer and energy for heating (or cooling) the building by insulating dock doors with heavy duty weather-stripping such a vinyl or wood pile, neoprene bulb or neoprene baffle (NREL, 2011).

Employ solar air heating.

Solar air heating systems, such as Solarwall®, use conventional steel siding painted black to absorb solar radiation for insulation. Fresh air enters the bottom of the panels where it is heated as it passes over the warm absorber, and fans distribute the air. Using this technology, the Ford Motor Company’s Chicago Stamping Plant turned its south wall into a huge solar collector (CREST, 2001). Energy savings were estimated to be over $300,000 per year compared to conventional natural gas air systems. Capital costs were $863,000 (about $15 per square foot, including installation), resulting in a payback period of less than three years. In addition to energy savings, the system was reported to provide clean fresh air for employees. The technology has been applied for various types of buildings (e.g. warehouse, office, hospital) in countries around the world. This measure is best applied in cold climates; potential benefits must be analyzed for each site’s local conditions.

Modify building reflection.

Reflective roofing. Use of a reflective coating on the roof of buildings in sunny, hot climates can save on air conditioning costs inside. Using reflective roofs, two medical offices in Northern California reduced air conditioning demand; one by 8% and the other by 12%. For colder climates, the heat lost due to cool roofs (in winter, for example) needs to be considered, as it could negate savings. In addition to location and weather, other primary factors (such as roof insulation, air conditioning efficiency, and building age) also influence energy savings. Reflective roof materials are available in different forms and colors.

"Green" roofs. Roof gardens on a flat roof improve the insulation of buildings against both hot and cold by providing heat in winter and air conditioning in summer. In winter, "green" roofs can freeze, so they carry a slight heating penalty but still often yield net energy savings. In addition, a roof garden can increase the lifetime of the roof, reduce runoff to local storm drains, and lower air pollution and dust.

Shading and windbreaks. Shade trees reduce the need for cooling in hot climates. Shade trees should be deciduous (providing shade in the summer and none in the winter) and planted on the west and southwest sides of the building (based on the path of the summer sun). Trees planted on the north side of the building in cold climates can reduce heating in winter by shielding the building from the wind. Vines can provide both shade and wind shielding.

Install low-emittance (Low-E) windows.

Low-emittance windows are another effective strategy for improving building insulation. Low emittance windows can lower the heat transmitted into a building to increase its insulating ability. There are two types of Low-E glass: high solar transmitting (for regions with higher winter utility bills) and low solar transmitting (for regions with higher summer utility bills). The U.S. DOE supports the development of new window and glazing technology. The ENERGY STAR website includes a selection of rated Low-E windows. New window and glazing technology is being developed worldwide (see for example www.efficientwindows.org).

Chapter Eleven: Weighing and Blending Processes

In this chapter:	
Weigh with accuracy	Optimize blending
Combine weighing and blending	Use adjustable speed drives

Producing breakfast cereal begins with accurately measuring ingredients that are later blended to make specific recipe mixes. Dry ingredients and liquid ingredients are measured and blended separately. For weighing dry ingredients, weighbelt and screw feeders are commonly used (Fast, 2001).

For blending the dry materials, batch ribbon blenders, also known as horizontal batch mixers, are used (Caldwell et al., 2000b). For liquid blending, steam jacketed kettles are primarily used as the mixing vessel. In liquid blending, the ingredients (i.e., liquid sucrose, dry salt, liquid malt extract) are mixed with water in a kettle equipped with agitation and a steam jacket. The mix is heated to 125°F (52°C) (Fast, 2001). The blending of the dry mix with the liquid mix takes place in continuous mixers (either single- or double-shafted) or in simple cut-flight screw conveyors (Caldwell et al., 2000b).

Best Practices for Efficient Weighing and Blending

- **Weigh with accuracy.** Accurately weigh all ingredients used in the recipe to obtain uniform final products and reduce waste.

- **Optimize blending.** Improve blending efficiency and decrease the mixing duration by using the right level of ingredients in each mixer.

- **Combine weighing with blending.** Increase throughput by using a combined weighing and blending system.

- **Use adjustable speed drives.** Improve mixing with the use of ASDs that offer high levels of control and flexibility.

Weigh with accuracy.

The accurate batch weighing of dry and liquid ingredients is crucial to obtaining uniform products with the desired characteristics. Sensing the ingredient flows via loss-in weight from feed hoppers controlled by PLC programs needs to be in place, resulting in less energy use for making batches and avoiding product (and energy) loss due to bad batches.

Optimize blending.

To achieve uniform blending using ribbon blenders, the level of the ingredients during mixing should not exceed the height of the ribbons (Caldwell et al., 2000b). For optimum blending in the shortest time, the blenders should be between 50-75% filled (Fast, 2001). Overloading the mixers to achieve higher outputs leads to incomplete blending since the top part of the mix is in a dead mixing zone.

Combine weighing with blending.

Loading the mixer from a receiver decreases the loading time, thereby increasing the number of batches that can be processed per hour by the mixer (Caldwell et al., 2000b). Mounting the whole blending system on load cells allows it to serve as both the weigh hopper vessel and a receiver (Fast, 2001).

Use adjustable speed drives.

Mixers with adjustable speed drives (ASDs) offer high levels of control and flexibility. ASD mixers can operate at different speeds, accelerations, and durations to enhance the mixing. ASD mixers experience less wear and tear as motor and drive component speeds can be ramped up and down instead of undergoing abrupt on and off as with a two-speed motor.

Chapter Twelve: Cooking Process

In this chapter:	
Employ continuous cooking	Use direct-fired hot water heaters
Use improved cooking vessel designs	Use PLC and computer control
Perform maintenance	Insulate
Employ continuous steam pre-cooking	

Traditionally, breakfast cereals were cooked in batch cooking processes, for example by boiling whole grains in hot water or in steam pressure cookers. Today, continuous cooking has generally replaced batch cooking (Caldwell et al., 2000b). Due to recent developments in extruder technology, there has been a trend towards extrusion cooking (continuous cooking). In this Guide, measures for efficient extrusion cooking are listed in Chapter 15 along with extrusion forming.

Best Practices for Energy-Efficient Cooking

- **Employ continuous cooking**. Consider using extrusion cooking, if final product characteristics allow, to decrease the overall energy use and energy costs.
- **Use direct-fired hot water heaters.** Consider using direct-fired hot water heaters and reduce the energy use due to improved efficiencies.
- **Use improved cooking vessel designs.** Promote better mixing and avoid material overcooking by using vessels with improved designs, and thus avoid wasting energy.
- **Use PLC and computer controls.** Electronically control the cooker to improve the overall cooking process and product uniformity, and reduce cooking times to reduce energy use.
- **Perform maintenance.** Regularly maintain the cooker components to ensure efficient operations.
- **Insulate.** Properly insulate the batch cooking vessels to decrease heat losses.
- **Employ continuous steam pre-cooking.** In continuous cooking systems, steam pre-cooking can improve product quality and cut down on energy costs.

Employ continuous cooking.

Continuous cooking is more energy efficient than batch cooking because the materials/mix can have a lower moisture content (e.g., in extrusion cooking the mix is less moist) and improved energy transfer. In addition, continuous cooking allows for better process control. A disadvantage is the higher potential for inconsistent product if processing steps following cooking are slowed down or held up. Since the processes that succeed cooking, such as flaking and drying, are also continuous, any issues with the product flow may require holding the cooked product for a certain period of time before entering the next process, which results in uneven processing. The holding time could be reduced by adopting a continuous-batch system process (Caldwell et al., 2000b).

Because of advancements in twin-screw extruders, there is now a trend towards extrusion cooking. Twin-screw extruders eliminate shear issues that produced undesired “grey” grains. Modern twin-screw extrusion systems provide greater flexibility in screw speed and heat input which provides greater cooking control.

Main advantages of extrusion cooking for breakfast cereal production are (Riaz, 2010; Miller and Mulvaney, 2000):

- **Greater process adaptability:** The extrusion process is highly flexible. By changing the minor ingredients and the extruder operating conditions, a large variety of products can be manufactured using one system.
- **Increased product characteristics:** Products with a large variety in forms, shapes, textures and colors can be generated that are not usually possible with other cooking techniques.
- **Greater process compatibility:** Extrusion cooking tends to be more compatible with subsequent continuous processes.
- **Reduced process steps:** Process steps such as lump breaking are no longer needed.
- **Energy efficient:** Compared to other cooking methods, the moisture content in extrusion cooking is low, thereby reducing the energy requirements for re-drying.
- **Cost efficient:** Production costs are lower for extrusion cooking. Raw material costs, labor costs and investment costs can be reduced by 19%, 14% and 44%, respectively.
- **Compact:** Compared to other cooking processes, extrusion cooking requires less space.

In spite of the developments in extrusion technology, batch cooking and extrusion cooking do not produce identical products. The final choice of cooking technology will depend on the desired final finished product.

CASE STUDY: The Nacional breakfast cereal facility in Trofa, Portugal, adopted extrusion techniques and started the production of a variety of products. By using the extrusion process, the production efficiency increased as several process steps were combined into a single continuous process unit. (Food Processing Technology, 2004)

Use direct-fired hot water heaters.

An indirect-fired water heater is composed of two units: a furnace or a boiler that heats the fluid circulated through a coil (heat exchanger), and a water tank in which the coil is placed. It is an efficient system when used with an efficient boiler and a well-insulated storage tank. To fire these systems, a variety of fuels (natural gas, oil, electricity, solar energy and propane) is used.

Direct water heaters, on the other hand, allow the flue gases to come in direct contact with the water that needs to be heated. In these heaters, water is sprayed on the top of a hollow vertical chamber. The upper of the hollow chamber is filled with stainless steel balls, used to provide a large heat transfer area for the heat from exhaust gases of the burner to be conducted into the water. The burner is placed either directly under the heat transfer area (in the path of the falling water) or in a burner chamber (on the side of the falling water) (Parker and Walker, 2009). They are usually fueled with natural gas, propane or oil.

Direct contact heaters are very efficient. When operating with a water inlet temperature between 60 and 65°F, the efficiency ranges between 97.7 and 99.7% (Parker and Walker, 2009). Although they are efficient at providing heat at moderate temperatures, at higher temperatures they are not as efficient. They are also not able to produce steam. Direct water heaters have found many applications in food processing plants where moderate temperature water is needed.

Use improved cooking vessel designs.

During cooking, the mix is agitated or mixed for uniform cooking and flavoring. Cooking in vessels with straight shells requires the use of internal flights or wings that are attached to the shell for product agitation and discharging (Caldwell et al., 2000b). However, the use of flights can result in product overcooking (Fast, 2001).

By using vessels with improved designs that promote mixing, the use of flights and thereby overcooking can be eliminated. This is achieved by using vessels with a spherical or conical shape that promote mixing as the product gravitates to the center (Caldwell et al., 2000b). The horizontal diameter at the center is larger than the diameter at the end of the cylinder by about 15%. In addition, the sides of the vessel are not flat (Fast, 2001).

Use PLC and computer controls.

Batch cookers should be automated. The cookers can be automatically positioned for charging and discharging, and lids can be automatically opened and closed, increasing the operators' safety. In addition, adding sensors to monitor important parameters such as steam pressures, temperature and moisture content ensure proper operation and provide data that can be recorded and analyzed for further adjustments (Caldwell et al., 2000b).

Electronically controlling cooker operation, such as the steam injection and mix agitation, can improve cooking. In some designs, steam injection and exhaust alternate from the one side of the cooking vessel to the other on a pre-programmed basis. In this way, the steam exhaust port screens are continuously cleaned. Such advancements have led to more accurate cooking times and improved uniformity of grain cooking (Fast, 2001).

Perform maintenance.

The cooking vessels need to be thoroughly cleaned at regular intervals. How frequently these intervals should occur is determined by the materials used.

Batch cookers and pressure vessels need to be properly maintained in order to operate efficiently. For example, seals need to be inspected on a regular basis, in particular the charge-discharge lid seal. Other parts that need to be properly maintained are valves, gauges, vents, and drains (Caldwell et al., 2000b).

Monitoring that regular maintenance is conducted can help ensure that equipment will operate efficiently.

Insulate.

In general, heat losses in continuous cooking equipment are not very significant due to the small ratio of surface area to throughput. In batch cooking vessels, however, the heat losses can be significant (Caldwell et al., 2000b). Use new materials, such as ceramic fibers, that both insulate better and have a lower heat capacity (thus allowing for more rapid heating).

Employ continuous steam pre-cooking.

Steam cooking is usually conducted in batches. However, it can be used in a continuous process to pretreat raw materials going into extruders. Hydrating and partially cooking the raw material prior to feeding it into the extruder helps to reduce energy use and associated costs in the extrusion process. Additionally, product quality generally increases with longer and gentler cooking times since starch damage is minimized. Energy costs can be lowered by replacing more expensive electricity with steam (Miller, 1994). Although the energy requirements for extrusion decrease, it is not clear how the total energy use, pretreatment plus extrusion, is affected.

Chapter Thirteen: Drying and Toasting Processes

In this chapter:	
Optimize the moisture content of the cooked product	Maximize the drying gas temperature drop
Choose the right capacity	Keep cooling prior to drying to the minimum
Improve airflow distribution	Improve product distribution
Use adjustable speed drives	Select and install efficient equipment
Place equipment in the right area	Insulate
Limit drafting	Use ovens with operational flexibility
Reduce preheating time	Create a temperature profile
Utilize waste heat	Use energy efficient burners
Perform maintenance	Employ overall system controls
Adopt heat pump drying	

Drying

Drying is used to remove additional water from the cooked mix to obtain specific product properties needed for further processing. These properties include formability, viscosity, flavor, and moisture content. While some of the property changes result from lowering the moisture content, others are related to the drying temperature (Miller and Gillespy, 2000).

After cooking is completed, the mix's grains contain about 25-30% water. Drying decreases the moisture content to 9-17%. There is a variety of types of dryers used in the breakfast cereal industry, including rotary dryers, turbo dryers, single-pass conveyor dryers, and multi-pass conveyor dryers. However, the most widely used are the single-pass and the multi-pass conveyor dryers.

Toasting

Toasting provides important product characteristics such as flavor, color and texture. There are several types of toasting ovens used, such as fluidized bed ovens, rotary ovens, impingement ovens, and radiant heating ovens. The most commonly used ovens are rotary ovens. In general, the toasting temperatures for wheat and oat cereals range between 350-450°F (175-230°C), while rice and corn flakes are toasted between 450-600°F (230-315°C).

To minimize the sensitivity of the initial change in moisture content of the product, ovens usually have an additional tempering stage at a temperature lower than the toasted product temperature. At this stage, products with high initial moisture content will continue to dry, while products with low initial moisture content will not.

Dryers often consume two to three times the thermodynamically minimum amount of energy required to remove a pound of water from the product. Ovens are typically even less energy efficient, consuming five or more times as much energy as thermodynamically required to heat the product. The majority of this extra energy is lost as heat to the outdoor environment through the oven or dryer stack. The type of heating element selected for use in an oven or dryer also greatly affects the thermal efficiency of the system. For example, gas burners are 85 to 95% efficient, while steam heat systems are 70 to 80% efficient.

Best Practices for Energy-Efficient Drying and Toasting

- **Optimize the moisture content of the cooked product.** Control the steam input and output during cooking to ensure that the product has the required moisture content and limit the requirements for drying.
- **Maximize the drying gas temperature drop.** Consider increasing the inlet gas temperature to minimize the volume of inlet gas usage without negatively affecting product requirements.
- **Choose the right capacity.** Make careful estimates of production volumes to better choose the dryer capacity for efficient use.
- **Keep cooling prior to drying to a minimum.** Because the product temperature needs to be raised during drying, minimize cooling prior to drying.
- **Improve airflow distribution.** For improved drying, match the specific product requirements to the airflow needed.
- **Improve product distribution.** Ensure uniform product distribution to improve the drying efficiency.
- **Use adjustable speed drives.** Optimize the drying times of different products with the use of adjustable speed drives employed to adjust each conveyor pass.
- **Select and install efficient equipment.** Carefully select efficient ovens/dryers with improved designs and flexible production throughputs.
- **Place equipment in the right area.** Install ovens and dryers in well-ventilated areas away from processes that require a cooler environment.
- **Insulate.** Insulate the ovens and other bare equipment to limit heat losses.
- **Limit drafting.** Fix leaks and control the operating pressures in dryers to limit the cool air of the surroundings from infiltrating.
- **Use ovens with operational flexibility.** Choose ovens designed with operational flexibility that can accommodate changing production loads.
- **Reduce pre-heating times.** Identify the optimum oven warm-up period to become more energy efficient.
- **Create a temperature profile.** Improve the oven/dryer efficiencies and product quality by creating temperature profiles that can reveal temperature imbalances. Full climate controls in dryers can be used to adjust dampers and valves to improve the process.
- **Utilize waste heat.** Utilize waste heat in a number of ways: directly at the oven or dryer, or for hot water production to increase the facility's overall efficiency.
- **Use energy-efficient burners.** Ensure burners are not out of specification by properly maintaining them, and replace damaged or obsolete burners with more efficient ones.
- **Perform maintenance.** Properly maintain ovens and dryers to ensure energy-efficient operation.

- **Employ overall system controls.** Improve operations of ovens and other systems by integrating the controls for the entire process.

- **Adopt heat pump drying.** Consider using heat pumps in conjunction with dryers for increased energy efficiency and enhanced product quality.

Optimize the moisture content of the cooked product.

In general, cooked pellets intended for flaking enter the dryer at 30-33% moisture content and exit the dryer at 16-22%. Cooked pellets intended for puffing enter the dryer at 30-32% moisture content and exit at 10-12% (Miller and Gillespy, 2000). If the cooked pellets enter the dryer with higher moisture content than required, the drying needs will increase, resulting in increased energy use.

A good energy-saving technique is thereby not to load the dryer with a product that has higher moisture content than required (APV, 2000). Controlling the steam input and output and the moisture content during cooking should ensure that the product is not overcooked and the moisture content is at the desired levels (Caldwell et al., 2000b).

Maximize the drying gas temperature drop.

Apart from some preheating, the steam exiting the dryer cannot be easily reused. It is therefore important to minimize the volume of inlet gas usage. The higher the inlet gas temperature, the lower the gas volumes needed. However, there are important temperature limitations that determine the maximum inlet and exit air temperatures (APV, 2000).

Choose the right capacity.

If the plant often operates under lower production volumes, avoid using dryers that cannot vary the mass airflow, such as fluidized bed dryers, which are less energy efficient. This is because the hot airflow has dual functions: it not only dries the product, but also acts as the conveying medium for the transportation of the product. As the mass of the airflow needs to remain constant, even under low throughputs, the only way to bring down the dryer would be to lower the inlet air temperature, which results in lower energy efficiencies. The efficiency can drop by 20% when operating at 60% of the designed capacity. This highlights the importance of making reasonable estimates of production volumes and choosing the right dryer capacity (APV, 2000).

Keep cooling prior to drying to the minimum.

Cooking can cause grits to attach to each other, which forms lumps. To break the lumps apart, the product must go through a delumping process before entering the dryer. In some cases, it may be necessary to perform cooling first, and then delumping. Cooling is used to stop the product from cooking further and to eliminate stickiness, thereby assisting delumping. Because the temperature needs to be raised again during drying, cooling should be kept to a minimum (Fast, 2000).

Improve air flow distribution.

The conveyors should be designed to provide a uniform air flow. Look for designs where the air velocity and the size of the perforators provide resistance that makes the airflow more uniformly distributed (Miller and Gillespy, 2000).

Fans and dampers are often used to control the airflow. By equipping fans with adjustable speed drives, the airflow can be carefully controlled and accurately matched to specific product requirements, thereby reducing energy use (Miller and Gillespy, 2000).

Improve product distribution.

For efficient drying, the product should be uniformly dispersed on the dryer conveyor. Several devices are used to ensure uniform bed coverage and depth. The product should be initially dispersed on the belt by a properly designed discharger, followed by a plow, rake or sweep to level the product. Within the dryer, rotary pickers can be used to re-arrange the product for different airflow orientations and to ensure a uniform bed depth and distribution (Miller and Gillespy, 2000).

Use adjustable speed drives.

In multipass dryers, the product is reoriented from pass to pass, which varies exposure to the drying air and results in a more uniform moisture distribution. When adjustable speed drives are used on each conveyor pass, the drying curve (the three different phases of drying) for each different product can be optimized or adjusted based on the product's features (Miller and Gillespy, 2000).

Select and install efficient equipment.

Ovens are a major capital investment. They typically operate for well over ten years. Considering the operating costs of an oven, procuring an energy efficient one should be an important purchasing decision. Modern ovens are significantly more energy efficient than they were even five years ago (McMullen, 2010). Therefore, upgrading an oven may help reduce operating costs.

Heating methods for ovens come in many forms, such as radiant, convective, and impingement (Rigik, 2009). Additionally, there are alternative baking and drying technologies, such as infrared units. For breakfast cereal toasting, rotary ovens are mainly used. This oven type is characterized by high-convective heat transfer when the product is falling and low-convective heat transfer when the product is in a packed moving bed that moves upwards (Caldwell et al., 2000b).

Careful maintenance, control, and operation of ovens and dryers can greatly improve the overall energy efficiency. While large, direct energy efficiency savings can be found by improving the efficiencies of technologies such as motors and equipment insulation, indirect benefits can be realized by improving oven and dryer design, production throughput, decreasing downtime, and optimizing production processes.

Place equipment in the right area.

When installed, ovens should be placed in a well-ventilated space away from other processes that require a cooler environment such as cooling racks, ingredient storage areas, and mixers. Oven isolation can also be improved by using simple Teflon™ curtains and proper ventilation.

Insulate.

Ensuring the oven is properly insulated will increase the energy efficiency of the oven by reducing heat loss. In addition to insulating the oven itself, insulation of other bare equipment such as exhaust stacks should be considered. Insulation of the oven typically has an average payback period of about 0.9 years, while other equipment insulation projects have an average payback period of 1.2 years (IAC, 2017).

Limit drafting.

A common flaw in some oven designs allows large quantities of air to infiltrate, which causes drafting. The warm conditions inside an oven produce a natural convection that can draw in cooler air from the facility into the oven and out the stack. This results in a loss of excess conditioned air and decreases the oven's efficiency (Malovany, 2010). Ventilation doors that span multiple rooms need to be controlled to reduce drafts that can pass through the oven and affect temperature levels/gas usage.

Dryers typically operate under a slightly negative pressure to provide safety from the high temperatures and to ensure that the hot air supply moves through the beds (Miller and Gillespy, 2000). This can cause cool air from the surroundings to infiltrate into the dryer, resulting in high energy losses as the cool air will be heated and released through the exhaust. By fixing leaks and controlling the operating pressures, the efficiency can be improved (U.S. DOE, 2008b).

Use ovens with operational flexibility.

Ovens that are designed with operational flexibility can accommodate expanding or shifting production better than ovens built only for one type of product. Two primary considerations for evaluating oven flexibility include a balance of radiant and convection heat in different oven sections, and the ability to use open mesh, closed mesh, or a solid steel belt (Whitaker, 2012a).

Reduce pre-heating times.

Preheating of ovens should be kept as short as possible. The minimum pre-heating time should be evaluated and standardized and must consider the potential impact to product quality and required toasting schedule. Two methods for establishing a minimum pre-heating time are (CoA, 2001):

1. Record how long after start-up the oven temperature sensors indicate a desired toasting/baking temperature. This value is the minimum pre-heating time and is the absolute minimum time needed before product enters the oven.
2. Starting with the current operating parameters, gradually delay the oven start-up time (e.g., 15 minutes at a time) over several days until you find the shortest time needed to start the oven while ensuring all products are baked. Decreasing the start-up time by small amounts will ensure you achieve energy efficiencies without adversely affecting your product quality. This method helps to set an upper bound on time for more efficient pre-heating, but does not identify the absolute minimum pre-heating time.

Create a temperature profile.

Oven temperature profiling can assist in oven tuning and product optimization. Temperature profilers are fitted with multiple thermocouple temperature sensors mounted along the width of the belt on a pan. The sensors travel through the oven capturing a picture of the oven's thermal profile and reveal issues such as left/right temperature differences and cold and hot spots (Whitaker, 2012c). Some more advanced profiler devices can also read and record oven airflow and moisture levels.

Once a temperature profile has been created, temperature imbalances across the width of the oven should be investigated and corrected. Corrective action may include adjustment, repair, or replacement of burner elements, and adjusting insulation. These measures can help improve the oven's fuel efficiency as well as identify issues that could potentially impact product quality (CoA, 2000).

In dryers, full climate control systems measure the temperature and air humidity, which is used to inform the control system's activation of dampers and valves that control heat input, exhaust, and airflow. Humidity and dew point sensors can be used to measure the humidity inside the dryers to ensure that the drying air is at minimum humidity needed to ensure product quality. This results in efficient fuel use as well as improved product quality (Fast, 2001).

Utilize waste heat.

Waste heat can be used in a number of ways, either directly at the oven or dryer, or for water heating. Water heating with waste heat is addressed in Chapter Eight.

In general, before hot air in the oven or dryer is vented or captured through a heat exchanger, it should be re-circulated, if possible. Air re-circulation reuses a portion of the hot exhaust and transfers it to a lower temperature section of the oven. However, this measure may be limited by the required dryness of the product and the moisture content of the hot exhaust (APV, 2000).

Installing an air-to-air heat exchanger on oven and dryer exhaust vents allows for the recovery of waste heat to improve oven and dryer efficiency. A heat exchanger can be used to pre-heat the air required by the burner for combustion, which lowers fuel consumption. The warmer air raises the temperature of the flame in the radiant section and increases the heat transfer. The result is a lower temperature in the exhausting stack gases and lower fuel consumption. Installation of heat exchangers has a payback of two to four years depending on fuel costs (CoA, 2000).

CASE STUDY: Kellogg's Battle Creek, Michigan plant recovered heat from an oven to preheat product going into another oven, which reduced energy costs by $75,000. The return on investment was 18%. (DeYoung and Kaiser, 2017)

Use energy-efficient burners.

Efficient oven burners are a critical component. Burners should be checked based upon a predictive maintenance plan. Stack emissions should be analyzed to ensure burners are not out of specification. Proper burner maintenance will help plants that operate with air quality permits ensure their stack emissions are within permitted levels and avoid fines. Damaged or obsolete burners should be replaced with more efficient ones. This action typically has a payback period of 2.5 years (IAC, 2017).

When first installed, burners should be adjusted and commissioned for efficient operation, an action with an average payback period of 8 months (IAC, 2017). As a part of commissioning, a stack sample should be taken for reference. Periodic stack sampling can be performed, as differences in stack exhaust levels will indicate problems with one or more of the burners. An oxygen or combustion analyzer, along with stack temperature measurements, can be used to determine a host of potential energy inefficiencies. If the combustion efficiency is lower than when the oven was commissioned, corrective strategies should be taken to improve this efficiency (CoA, 2000). Common outcomes and corrective actions from stack gas analysis include:

- Excess air: Adjust and maintain the air/fuel ratio so that it is optimized for the operating load condition of the oven. Adding an oxygen trim control may be needed where combustion inefficiencies cannot be managed by air/fuel ratio adjustments. Oxygen trim controllers cost between $6,000 and $10,000 to install, but will reduce time required to assess efficiency and maintain oven efficiency in the future.

- High stack temperatures: As discussed in the previous section, energy wasted as stack heat can be recovered and either used in other parts of the facility or used to preheat combustion air for the oven. This action reduces flue temperature and improves combustion efficiency. This action may cost on the order of $8,000 with typical payback of two to four years.

- Incomplete combustion: A lack of adequate combustion air will lead to incomplete combustion. This will result in unburned or partially burned fuel being released from the oven, wasting fuel and potentially violating air permits. Possible fixes include burner control adjustment and burner maintenance or replacement (CoA, 2000).

Perform maintenance.

Ovens and dryers should be well maintained. Part of regular oven and dryer maintenance should include looking for air leaks. Air leaking into the dryer or oven results in increased energy consumption, as the infiltrating air must be heated to ensure oven temperatures. Air leakage out of the oven is a source of wasted energy, resulting in heating the surrounding air and not the product. Repairing air leaks is cost effective and typically has a payback period of less than one year (IAC, 2017).

Oven and dryer controllers should be tested and calibrated to ensure accurate and efficient operation. These devices should be checked regularly based upon manufacturer specification or when production and energy data indicates a potential issue with the devices.

Employ overall system controls.

Control measures can be used just on an oven or by integrating oven controls into other process controls. Controls help to ensure ongoing optimization as conditions within the plant and process change.

Controls on oven exhaust ducting can be used to minimize the energy required to expel combustion exhaust safely while preventing ambient air from entering through the exhaust system. Exhaust controls use external pressure, wind, and temperature data to control adjustable speed motors. These types of systems can result in 5 to 20% energy savings. Exhaust control systems can also be coupled with heat exchangers to produce hot water (Exhausto). Additionally, self-adjusting dampers on air intakes will prevent migration of outside air into the oven during pre-purge and gas exhausts. Removal of barometric dampers from forced draft ovens can also reduce the amount of cooler plant air being sucked into the oven while preventing outside air from being drawn in through the exhaust while the oven is not running.

Controls on dampers help adjust air velocity, an important parameter for good oven operation. For effective baking, four general parameters need to be well controlled: temperature, air velocity, baking duration and exhaust (Caldwell et al., 2000b). For shredded cereals, high air velocities at the beginning of the oven can dry the product too quickly and negatively impact taste. High air velocities can also cause burning and affect product expansion.

Control systems can be used to greatly expand the usefulness of an oven. A centralized controller can adjust how the oven is being heated to accommodate different product types as well as minimize start up and shut down energy requirements (Whitaker, 2011). Centralized control allows plants to utilize a multiple zoned approach that promotes product flexibility. Product can be tracked throughout the production process and oven settings can be adjusted based upon known product changes that will soon be ready for toasting. Working with the controller, a direct spark ignition system can provide oven flexibility by changing burner firing as the type of product entering the oven changes. A direct spark ignition system controls each individual burner separately, allowing for individual burners to be turned on and off in various configurations depending upon the needs of the product entering the oven. By linking the system to a central controller, these settings can be automatically changed based upon product type (Malovany, 2010; Whitaker, 2011; 2012b).

Controllers also provide real time information to operators on equipment issues, recipes, toasting temperature, time, steam, convection, pan size, up- and downstream production issues and other information. Operators can use this data to see real time production statistics and compare to historic trends. Recorded data can be used in many ways, including to create custom reports, trending, or maintenance personnel troubleshooting.

Adopt heat pump drying.

Heat pumps have several applications in industrial processes, where they can be used to recover process heat, heat process water, and provide space heating and cooling.

The use of heat pumps in combination with dryers can improve energy efficiency by utilizing recovered heat. Additionally, these systems can provide precision drying that preserves the natural ingredients of heat sensitive materials, resulting in improved product quality.

Several studies have shown that there is a significant energy efficiency improvement from using heat pumps for drying a variety of products (Chua et al., 2002; Chu and Chua, 2006). For example, one study looking at drying herbs found that less energy was used to dry plants with higher moisture content due to the higher availability of latent heat for recovery (Chou and Chua, 2006). Another study found that drying herbal and medicinal crops with heat pumps reduced energy use by 22% and retention time by 66% compared to conventional dryer systems (Adapa and Schoenau, 2005). Compared to conventional electrical systems, convective drying in combination with heat pumps can reduce the energy use by 60% (Butz and Schwarz, 2004). A preliminary study of a gas-driven heat pump drying system used for food drying showed that the heat gained from heat recovery can be provided by 30% of the heating capacity of the system (Hepbasli et al., 2009).

Unlike other innovative drying systems that require new processes and large capital investments, a heat pump drying system can be retrofitted onto existing systems. The main components of retrofit heat pump systems are an expansion valve, two heat exchangers (evaporator and condenser), a compressor, and the dryer system. The evaporator is used to remove the humidity from the drying air and the condenser to increase the air temperature (Moses et al., 2014).

A heat pump system can be fitted to any type of dryer that uses convection as the primary heat transfer mode. This is independent of whether other secondary modes of heat transfer are used. Although the majority of existing heat pump systems are fitted to batch dryers, they can also be used in combination with other dryer types such as continuous fluid bed dryers and rotary dryers. Table 7 shows the key advantages of using a heat pump drying system in comparison to conventional drying, vacuum drying and freeze drying. Key advantages are the high Specific Moisture Extraction Ratio (SMER), since heat is extracted from the high moisture air, and the improved product quality as drying takes place at lower temperatures (Chua et al., 2010).

Table 7. Heat pump drying in comparison to vacuum drying and hot air-drying (Mujumdar, 2006).

Parameter	Hot air drying	Vacuum drying	Heat pump drying	Freezer drying
SMER (gallons H_2O/kWh)	0.03-0.34	0.18-0.32	0.26-1.06	0.11 and lower
Drying efficiency (%)	35-40	Up to 70	Up to 95	Very low
Operating temperature (°F)	104 to very high	86-140	14-176	-31 to >120
Operating humidity % RH range	Varies depending on temperature	Low	10-80	Low
Capital cost	Low	High	Moderate	Very high
Operating cost	High	Very high	Low	Very high
Control	Moderate	Good	Very good	Good

The main advantages of heat pump dryer systems are improved energy efficiency, the better control of the drying conditions (air temperature, air moisture and air flow rate) and improved product quality. The main potential limitations of a heat pump drying system are (Jangam and Mujumdar, 2012):

- **Environmental impact.** The environmental impact of refrigerants can be limited with the use of environmentally friendly HCFCs and natural refrigerants.
- **Cost.** Heat pump dryers are more expensive than simpler drying systems. The most expensive aspects of the technology are the heat exchangers, compressor and controllers.
- **Maintenance.** For efficient operation, all components will need to be maintained regularly.
- **Potential for refrigerant leaks.** This can be a serious problem that can result in recurring repair costs. Loss of refrigerant will undermine the system and can result in significant repair costs.

Chapter Fourteen: Forming Process

In this chapter:	
Extrusion	
Improve cutting	Operate at design speed
Correct motor size	Control temperature
Insulate the barrel	Optimize standby operations
Minimize cooling	Conduct cooling carefully
Lower the cooking temperature	Optimize single-screw extrusion operation
Consider the use of twin-screw extruders	Employ preconditioning
Adopt automated process control	Adopt statistical process control
Gun-puffing	
Use advanced puffing guns	
Flaking	
Preheat rolls	Use the optimal roll temperature
Employ cooling before tempering	

A large percentage of breakfast cereals, including flaked and gun-puffed cereals, are formed by extrusion and in some cases they are also extrusion cooked (Miller, 1994). The cereal extrusion process involves the forcing of the ingredients mix through one or more process steps of mixing, heating, and shearing through dies to form and/or puff-dry the ingredients (Riaz, 2010). There are several cereal extruder types available in the market and can be generally divided into two main categories: single-screw and twin-screw.

The extrusion process primarily uses electricity, with most used by motors and drives. For energy efficiency improvements in motor, air compressor, fan and pump systems see Chapters Four, Five, Six and Seven of this Guide. Operating the extruder screws in an efficient way is an important strategy for improving energy performance.

Best Practices for Energy-Efficient Forming

Extrusion

- **Improve cutting.** Use advanced blade designs to improve cutting.
- **Operate at design speed**. Identify the most efficient screw speed the extruder can run without compromising product quality.
- **Correct motor size.** Match the size of the motors to the torque needed by the screws to increase energy efficiency.
- **Control temperature.** Determine the optimal temperature needed for extrusion to limit the energy being wasted.
- **Insulate.** Insulate the barrel to reduce heat losses.
- **Optimize standby operations.** Save energy by determining and using standby conditions for equipment operation.

- **Minimize cooling.** Identify and employ the maximum allowable extrudate temperature after extrusion to reduce the water cooling requirements.
- **Conduct cooling carefully.** Conduct cooling with care to avoid uneven processing, thereby reducing product waste and, indirectly, energy waste.
- **Lower the cooking temperature.** Decrease the cooking temperature and allow the warm product to continue cooking on the way to the forming extruder.
- **Optimize single-extruder operation.** The efficiency of single-screw extruders can increase by pre-mixing and pre-conditioning the feed material.
- **Consider the use of twin-screw extruders.** Twin-screw extruders are highly versatile and are characterized by high efficiencies and increased productivity. Evaluate if employing twin-screw extrusion makes financial sense as well.
- **Employ preconditioning.** Add a preconditioning step to increase the extruder efficiency.
- **Adopt automated process control.** Optimize the extrusion process, minimize waste generation and increase production efficiency with the use of automated process control.
- **Adopt statistical process control.** Track the overall process to minimize waste generation and improve energy use.

Gun-puffing

- **Use advanced puffing guns.** Upgrade to more efficient automatic puffing guns.

Flaking

- **P**reheat rolls. Reduce waste production by preheating the rolls prior to operation.
- **Use the optimal roll temperature.** Determine and use the optimal surface roll temperature for improved flaking.
- **Employ cooling before tempering.** Improve product quality and decrease holding times by cooling the grains before tempering.

Extrusion

Improve cutting.

Improved blades with spring-loaded mountings allow the blade to come into direct contact with the die, making clearer cuttings and thereby reducing the production of faulty products (Fast, 2001).

Operate at design speed.

Run the extruder at its most efficient speed, normally close to the maximum design speed (European Commission, 2006b). The screw speed should be controlled and adjusted to deliver an extrusion rate as close to the design rate without compromising product quality (Tangram, 2010). For energy-efficient operation, motors should run close to their designed rated load.

Correct motor size.

Extruder motors should be correctly sized to match the torque needed by the screw (European commission, 2006b). Operating the extruder at the optimum speed can maximize the heat generated from mechanical work and decrease the power consumption to the minimum required level. Doubling the rotational speed of the extruder can decrease the energy use by 50%, provided that downstream equipment does not create limitations (Tangram, 2010).

Control temperature.

Accurate temperature control is needed for good extrusion and to reduce energy waste from excess heat (Tangram, 2010).

Insulate the barrel.

Barrel insulation decreases heat losses and has a payback period of less than one year. In addition, it also reduces air current fluctuations (Tangram, 2010).

Optimize standby operations.

While on standby, large amounts of energy are still consumed from several types of equipment such as barrel heaters and water coolers. By identifying the minimum standby settings and letting machines operate in standby mode under certain conditions can help save energy (Tangram, 2010).

Minimize cooling.

Identify the maximum allowable extrudate temperature after extrusion to determine if cooling water temperature set points can be reduced (Tangram, 2010). When machines are idling, turn the cooling water off.

Control cooling carefully.

In extrusion forming, cooling the feeder is usually done to improve the feeding efficiency. Due to the poor mixing properties of single-screw extruders, the cooling must be done carefully to avoid uneven processing or hot spots in the product (Miller and Mulvaney, 2000).

Intensive cooling of the barrel in single-screw extruders reduces the temperature, raises the material friction and improves processing performance. In single-screw extrusion, when more friction is generated, material spinning reduces and material transfer improves. However, this strategy should be tested to ensure that product quality is not compromised (Mościcki and Zuilichem, 2011).

Lower the cooking temperature.

In some cooking extruder designs, the cooking extruder is connected to the die extruder with a "pipe" die connection. Such designs can allow the cooking temperature to be decreased since the product continues to cook in the large diameter pipe that transfers product to the forming extruder (Miller and Mulvaney, 2000).

Optimize single-screw extruder operation.

Single-screw extruders have a relatively simple design. Their role is to carry, compress, melt and plasticize the material, and to force it through small die holes to form the extruded product. Single-screw extrusion is suitable for materials with a high friction coefficient such as corn grains and corn grits (Mościcki and Zuilichem, 2011).

The main disadvantages of single-screw extruders are poor mixing and reduced efficiency of the extrusion process in multi-ingredient mixture processing. Therefore, mixing needs to be performed at an earlier step (Mościcki and Zuilichem, 2011) and, in some cases, preconditioners need to be installed for better mixture preparation prior to feeding, which can improve the process efficiency and increase the capacity (Mościcki and Zuilichem, 2011; Riaz, 2010).

Consider the use of twin-screw extruders.

Twin-screw extruders are highly versatile as they can handle a large variety of products, including viscous and hard materials. Due to the high operating speeds, increased productivity and good material mixing properties, they have gained popularity (Mościcki and Zuilichem, 2011). Co-rotating twin-screw extruders have a better heat transfer efficiency, improved pumping and lower heat generation than single-screw extruders. Additionally, they are self-cleaning, so no material remains between the barrel and the screws.

However, they are more expensive (Miller and Mulvaney, 2000). Twin-screw extruders are 1.5 times more expensive than single-screw extruders of the same capacity (Riaz, 2010). For products that do not require twin-screw extrusion, the use of single-screw extrusion is more cost efficient as the investment costs and the operational and maintenance costs are lower (Riaz, 2010; Bouvier, 2010; Mościcki and Zuilichem, 2011). Due to the high investment costs, it is more economical to install twin-screw extruders as integrated units that conduct both cooking and forming (Miller and Mulvaney, 2000).

Employ preconditioning.

Before the extrusion step, a preconditioning step can be employed to supply the extruder with a uniform and hydrated mixture. Preconditioners are typically categorized as atmospheric or pressurized. The cereals industry mostly uses the atmospheric type. The preconditioner consists of a rotating screw or paddle enclosed in a barrel in which the moisture content of materials is increased via steam injection. Single, double or differential double screws can be used (Frame, 1994).

Main advantages of preconditioning are improved material hydration, shorter retention times in the extruder, increased throughput, reduced wear of extruder parts, and reduced energy expenses. The advantages of preconditioning, such as increased throughput, are minimized when the amount of water that can be added is low (Fast, 2000). Preconditioning is usually applied when the materials have moisture contents of 20-30% and require long residence times (Rao and Thejaswini, 2015).

Adopt automated process control.

The automation of food extrusion control is complicated mainly due to limited knowledge on the impacts that operational changes have on the material properties of the mix. As opposed to the plastics extrusion industry, developments towards fully automated food extrusion have only in recent years become noticeable (Mościcki and Moster, 2011).

Due to the lack of appropriate sensors, extrusion cooking is controlled to great extent by simple circuit breakers (Mościcki and Moster, 2011). However, great efforts are made to better control the process in many cases with the use of microprocessors. Start up and shut down are the most difficult operations in terms of automation. Measurable factors that can give an indication of the extrudate quality are mechanical energy consumption per kilogram of product, product temperature, head pressure, residence time, treatment temperature, torque and screw rotation.

The cost of an on-demand process control system is equal to about 10-15% of the cost of the equipment (Mościcki and Moster, 2011). Available extruder controls enable process optimization, production efficiency and waste minimization. The overall performance improves by adjusting the process temperature and material feeding and by monitoring all processes. In automated operations, the torque is monitored and important process parameters are regulated.

Adopt statistical process control.

In generating high quality products and minimizing waste generation, it is important to control the whole production process, from the selection of the right raw ingredients for the purpose, to the processing conditions of all stages. Statistical process control (SPC) uses statistical methods to monitor and control the main parameters that can influence final product specifications.

They key tools used in SPC applications are control charts. Control charts show the results from raw materials/mix/product inspections that are taken at regular intervals. If the mean value lies within certain limits, the process is considered to be on target; however, when the mean value is outside the limits, action needs to be taken (Peterson, 2004).

Statistical methods have been used for many years in the process industry to evaluate whether final products meet certain specifications. Usually, however, the data were analyzed after the process had been completed. The main drawback with analyzing data after the end of the process is that, before identifying and solving the problem, many substandard products have been generated that need to be either discarded or further processed (Keller, 2017). Rather than identifying problems after the process has been completed, SPC that applies statistical methods during the production process informs whether the process will start producing products below specifications. As the formation of defects due to process variations is prevented, less waste is generated and less energy is consumed.

Gun-puffing

The use of gun-puffing processes has been declining since all process steps (cooking, extrusion forming, drying, tempering) that precede gun-puffing can be replaced with twin-screw extrusion (Fast, 2001).

Use advanced puffing guns.

In advanced puffing guns, the grains are pre-heated in a chamber pressurized by direct steam injection before entering a heated gun. The hot, cooked, pressurized grains are then released through an opening valve that fires at 40 times per hour instead of six times per hour (the rate of older puffing guns) (Fast, 2001).

Flaking

Preheat rolls.

Preheating the rolls to running temperatures before the product starts to flow limits or even eliminates the need for later temperature adjustments to compensate for a change in roll temperature. This results in reduced product waste (Fast, 2001).

Use the optimal roll temperature.

For having good grit handling, it is important to carefully control the surface temperature of the rolls. If the temperature is too low, the grits will not be pulled by the rolls; if the temperature is too high, the grits will stick to the rolls. Optimal surface roll temperatures range between 110-115°F (Whalen, et al., 2000).

Employ cooling before tempering.

To ensure that grains exiting the dryers have a uniform moisture distribution, a tempering step is sometimes introduced before drying. During tempering, the mix is held in collection bins until the grain particles are case hardened.

Cooling the grains before tempering can considerably improve the quality of the product. Drying the grains to a moisture content of 17% for flaking and holding them at elevated temperatures results in a darker grain color. Cooking grains to a 30% moisture content for shredding and holding them in bins at elevated temperatures results in a sticky product difficult to shred (Caldwell et al., 2000b).

Chilling cooked wheat to 34-54°F (1-4°C) reduced the holding times before shredding (Fast, 2001). Similar improvements are expected for all types of cereals.

Chapter Fifteen: Water Use

In this chapter:	
General water efficiency measures	
Create a strategic water management program	Practice good housekeeping
Use X-ray sorting for foreign material removal	Recycle product wastes as animal feed
Use water-efficient building fixtures	Use small diameter hoses
Use automated start/stop controls	Control flow rates
Reduce steam and hot water demand	Reduce cooling tower bleed-off
Cleaning and sanitation	
Dry clean equipment and surfaces	Use release and process aids
Employ high-pressure, low-volume sprays	Optimize the cleaning process
Employ low-pressure foam cleaning	Pre-soak floors and equipment
Monitor and control water temperatures	
Reuse and recycle	
Replace once-through cooling systems with cooling towers	Recycle evaporator condensate
Reuse compressor cooling water	Use membrane filtration technologies
Install a membrane bioreactor	Install a membrane biofilm reactor

Best Practices for Water Use

Water is a resource that can be just as critical and costly as energy in the production process. Water preparation, transport, and disposal also uses large amounts of energy. Depending on the types of products manufactured, the breakfast cereal plants can be very water intensive. Reported values on water use range from 300 to 1,160 gallons per ton of product (Jeswani et al., 2015). The largest water uses include preparing and blending of ingredients, cooling systems, and cleaning of equipment.

This chapter provides a brief overview of basic, proven water efficiency measures applicable to typical breakfast cereal plants. In addition to reducing water costs, improved water efficiency can reduce energy consumption needed for water pumping and treatment systems, and lower wastewater discharge volumes and associated sewer and treatment costs. Furthermore, the recovery and recycling of water can provide opportunities for energy recovery, which helps to further cut energy costs and reduce chemical requirements. Water efficiency also reduces loads on local fresh water supplies and wastewater treatment plants, which provides indirect energy savings in the industrial water supply chain.

The water efficiency measures discussed in this chapter are grouped into three major categories: (1) general water efficiency measures, (2) cleaning and sanitation, and (3) reuse and recycle.

Best Practices for Efficient Water Use

General water efficiency measures

- **Create a strategic water management program.** Ensure that cost-effective ways to reduce water use are successfully implemented by creating an organization-wide water management program.

- **Practice good housekeeping.** Make sure that water supply systems and end uses operate properly and are regularly maintained to secure water efficiency.

- **Use X-ray sorting for foreign material removal.** Use X-ray machines instead of washers to detect foreign material in wheat and reduce water and energy use and limit food waste.

- **Recycle product wastes as animal feed.** Reduce water use by manually reclaiming solid waste that would otherwise be discharged in the wastewater streams.

- **Use water-efficient building fixtures.** Install water-efficient building fixtures and reduce water use.

- **Use small diameter hoses.** Reduce the volume of water used for certain tasks with the use of small diameter hoses.

- **Use automated start/stop controls.** Supply water only when required with the use of sensors.

- **Control flow rates.** Use control devices such as valves to control the water flow and reduce water use and associated costs.

- **Reduce steam and hot water demand.** Reducing the demand for hot water and steam not only reduces energy consumption but also water use and chemical use.

- **Reduce cooling tower bleed-off.** Find the optimal balance between bleed-off and make-up water concentrations, and reduce water use.

Cleaning and sanitation

- Dry clean equipment and surfaces. Before applying water, try to manually clean equipment and surfaces to reduce water use.

- Use release and process aids. Add process and release aids to stop product from sticking on equipment, and decrease food waste and water needed for cleaning.

- Employ high-pressure, low-volume sprays. Reduce water use by using high-pressure, low-volume spraying systems for cleaning.

- **Optimize the cleaning performance.** Use only the amount of water and detergent required for cleaning a particular piece of equipment.

- **Employ low-pressure foam cleaning.** Before rinsing surfaces with low-pressure water, spray cleaning foam and reduce water and energy use.

- **Pre-soak floors and equipment.** Use less water for cleaning by pre-soaking floors and equipment to loosen the accumulated dirt.

- **Monitor and control water temperatures.** Install mixing valves to deliver water at the desired temperature and reduce the volumes of cleaning water and cleaning detergents used.

Reuse and recycle

- **Replace once-through cooling systems with cooling towers.** Recycle cooling water with the use of a cooling tower and significantly reduce the water use.

- **Recycle evaporator condensate.** Reuse evaporator condensate in low-grade applications such as equipment pre-rinsing and surface pre-soaking, and reduce water use.

- **Reuse compressor cooling water.** Cooling water from compressors can be reused as seal water in vacuum pumps or for equipment pre-soaking.

- **Use membrane filtration technologies.** Clean wastewater with membrane filtration to recover water for recycling in various facility applications.

- **Install a membrane bioreactor.** Combine biological treatment with membrane filtration and reuse water in non-potable facility applications.

- **Install a membrane biofilm bioreactor.** Use a biofilm reactor to clean wastewater and reuse water in non-potable facility applications.

General water efficiency measures

Create a strategic water management program.

Similar to a strategic energy management program, a strategic, organization-wide water management program can be one of the most successful and cost-effective ways to bring about lasting water efficiency improvements. Strategic water management programs help to ensure that water efficiency improvements do not just happen on a one-time basis, but rather are continuously identified and implemented in an ongoing process of continuous improvement.

Establishing and maintaining a successful industrial water management program generally involves the following key steps (NCDENR, 2009; CDWR, 1994; NHDES, 2001):

1. **Establish commitment and goals**. Goals for water savings should be qualitative and included in statements of commitment and company environmental policies. A commitment of staff, budget, and resources should be established at the outset of the water management program to ensure success.

2. **Line up support and resources.** Internal and external staff and resources should be identified and secured, including a water program manager, with buy in from senior level management. Many of the recommendations for establishing an Energy Team are applicable at this stage.

3. **Conduct a water audit.** A facility water audit should be performed to identify and document all end uses of water, daily or hourly water consumption rates for all end uses, and water efficiency practices already in place.

4. **Identify water management opportunities**. Based on the results of the audit, opportunities for the elimination, reduction, and reuse of water applicable to each end use should be identified.

5. **Prepare an action plan and implementation schedule**. Cost-benefit analyses on all identified opportunities can be performed to determine the most practical ways for meeting the established goals for water efficiency. An action plan with specific goals, timelines, and staff responsibilities for water efficiency updates should be established to implement all feasible opportunities.

6. **Track results and publicize successes**. Progress toward established water efficiency goals should be tracked and publicized as a means of highlighting successes and educating personnel on water efficiency. Successes should be acknowledged and awarded on a regular basis.

Practice good housekeeping.

A general housekeeping program for facility water systems can ensure that water supplies and end uses continue to operate at optimal efficiency and that potential maintenance issues are identified and addressed promptly. In general, good housekeeping for water efficiency involves the following actions (Envirowise, 2001; NCDENR, 2009):

- Inspection of all water connections, piping, hoses, valves, and meters regularly for leaks, with prompt repair of leaks when found.
- Inspection and replacement of faulty valves and fittings.
- Switching off water sprays and hoses when not in use.
- Keeping spray nozzles free of dirt and scale.
- Installing water meters on equipment to better enable monitoring and reduction of water consumption.
- Disconnecting or removing redundant pipework.

CASE STUDY: Kellogg's Omaha, Nebraska plant reduced water use by 9% after shutting down one of the two boilers, repairing failing water valves, installing reduced flow-spray nozzles for washing the conveyors, and installing sinks with low-flow hand washing. (Atkinson, 2013)

Use X-ray sorting for foreign material removal.

The wheat received needs to be freed of all foreign material such as dust and stones prior to its use. The cleaning procedure involves a number of equipment and cleaning stages. Typically, wheat cleaning stages include a magnet, a screener, an aspirator, a disc separator, a washer, a centrifuge, and a drier all mounted in a single unit (Ortega-Rivas, 2012).

X-ray sorting can be used to replace wheat washers. This will lower water consumption and help reduce process variations that will reduce food waste and energy use (Armstrong, 2017). In addition, effluent generation and needs for treatment will also decrease.

X-rays are able to identify dense bodies such as glass, metal, stones, calcified bones and some plastics (Stier, 2017) but also product density variations (U.S. FDA, 1998). When foreign material or a defective product is identified, a signal is transmitted and the material is removed from the stream by a reject mechanism (e.g., mechanical finger, paddle, or a carefully timed burst of air) to a reject conveyor or bin (Stein, 2015).

Recycle product waste as animal feed.

Instead of discharging solid wastes into the wastewater stream, they can be reclaimed (often manually by using brooms and shovels, or by using screens on drains) and used as animal feed. This measure can reduce the use of water because often product wastes are discarded by the hosing down or rinsing of surfaces. Additionally, this measure can reduce the need for manufacture of animal feed from raw materials, leading to indirect energy and water savings in the animal feed supply chain (European Commission, 2006a).

Use water-efficient building fixtures.

For building fixtures such as toilets, showers, and faucets, water-efficient designs can be installed that lead to significant water savings. For example, low-flow toilets typically require only 1.6 gallons per flush, compared to 3.5 gallons per flush required for standard toilets (Galitsky et al., 2005b). Additional options include low-flow shower heads, aerating faucets, self-closing faucets, and proximity sensing faucets that turn on and off automatically.[7]

Use small diameter hoses.

All applications of hoses should be assessed and, where feasible, the smallest possible diameter hoses should be installed. Small diameter hoses provide a low-flow, high-pressure condition, which can reduce the volume of water required for a given task (Lom and Associates, 1998).

Use automated start/stop controls.

For end uses of water with intermittent demand, sensors (e.g., photocells) can be employed to detect the presence of materials and to supply water only when it is required by the process. Such sensors will turn off water supplies automatically when not required, also during non-production periods, thereby saving water (European Commission, 2006b).

Control flow rates.

Use flow controls to reduce water use and the associated costs. The most common flow control devices are valves that can be operated either manually or with automatic control systems. Valves can also control pressures. Examples of flow control valves include simple fixed or variable orifices and flow regulators to

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[7] For additional information on water-saving fixtures and appliances, visit the U.S. EPA's WaterSense website at https://www.epa.gov/watersense and the U.S. DOE's Federal Energy Management Program Water Efficiency website at https://energy.gov/eere/femp/best-management-practices-water-efficiency water consumption.

highly sophisticated electrohydraulic valves that automatically adjust to changes in temperature and pressure (Hydraulics and Pneumatics, 2012).

Reduce steam and hot water demand.

Reducing the demand for steam and hot water not only saves energy but also reduces the need for treated boiler water. Typically, fresh water must be treated to remove contaminants that might accumulate in the boiler, so reducing demand not only decreases boiler water use, but can also reduce the amount of purchased chemicals for boiler water treatment (Galitsky et al. 2005b). The combined energy, water, and chemicals savings associated with reducing steam and hot water demand make it a particularly attractive measure. Steam and hot water demand can be reduced through the general steam system energy efficiency strategies discussed in Chapter Eight of this Guide, as well as through process specific modifications. For example, where feasible, dry caustic peeling methods can be employed in lieu of wet caustic peeling or steam-based peeling methods to reduce process water.

CASE STUDY: A breakfast cereal plant in Germany installed a new boiler to reduce the water consumption. The result was a significant reduction in water and natural gas use. (CEEREAL, 2012)

Reduce cooling tower bleed-off.

Cooling tower "bleed-off" refers to water that is periodically drained from the cooling tower basin to prevent the accumulation of solids. Bleed-off volumes can often be reduced by allowing higher concentrations of suspended and dissolved solids in the circulating water, which saves water. The challenge is to find the optimal balance between bleed-off and make-up water concentrations (i.e., the concentration ratio) without forming scales, which reduces the energy efficiency. The water savings associated with this measure can be as high as 20% (Galitsky et al., 2005b).

Cleaning and sanitation

Dry clean equipment and surfaces.

Residual ingredient wastes, product wastes and residues should be removed manually from floors and equipment before the application of cleaning water to reduce water consumption. Dry cleaning can be done using brushes, squeegees, brooms, shovels, and vacuums. Often, solid and liquid wastes are chased down floor drains using a hose; a better practice is to use brooms or shovels and to dump wastes into a container designated for solid waste (European Commission, 2006a).

Use release and process aids.

Process and release aids can be used on conveyor belts, transition plates, dryer flights, etc. to decrease stickiness. This will reduce product waste and water needs for cleaning the equipment (Armstrong, 2017). Vegetable oils, emulsifiers and shortenings (fat made of vegetable oils) are regularly used to decrease stickiness and improve cellular structure and expansion in extruders (Seker, 2012).

Employ high-pressure, low-volume sprays.

In applications such as truck, container, surface, and floor cleaning, total water consumption can be reduced by using high-pressure, low-volume spray systems, which employ small diameter hoses and/or flow restricting spray nozzles. Such systems can also be fitted with manual triggers, which allow personnel to regulate use, or automatic shut-off valves to further reduce water consumption (European Commission, 2006a; RACCP, 2001).

Optimize the cleaning performance.

Clean-in-place processes should be programmed to use only enough water and detergent to perform the desired cleaning task at a particular piece of equipment. Dry cleaning prior to clean-in-place cycles can further reduce the minimum amount of water and detergent needed (European Commission, 2006a).

CASE STUDY: The Kellogg's Rome, Georgia plant originally used 50 high-pressure water streams that sprayed 10 gallons of water per minute to remove a very sticky product from the conveyor belts. After designing and installing a more efficient cleaning system, the plant expects to reduce the water use to 2-3 gallons per minute each, saving 70-80% of water use. (Atkinson, 2013)

Employ low-pressure foam cleaning.

Traditionally, walls, floors, and some equipment are cleaned using brushes, high-pressure spray hoses, and detergents. Low-pressure foam cleaning methods, in which cleaning foam is sprayed on surfaces and allowed to settle for 10 to 20 minutes before rinsing with low-pressure water, can save both water and energy compared to high-pressure cleaning methods (RACCP, 2001; European Commission, 2006a). However, this method does not provide scouring ability and thus might not be a feasible replacement for all high-pressure cleaning applications.

Pre-soak floors and equipment.

An effective means of reducing water consumption in cleaning is to pre-soak soiled surfaces on floors and open equipment prior to cleaning. Pre-soaking can be effective at loosening dirt and hardened food residues so that less water is required in the actual cleaning operations (European Commission, 2006a).

Monitor and control water temperatures.

Monitor and control the temperature of the cleaning water and realize the required cleaning standards without the excessive use of water and cleaning agents (European Commission, 2006a).

To deliver cleaning water at a controlled temperature, a mixing valve can be used. Mixing valves combine and regulate two streams of cold and hot water into a single outlet to deliver water at the desired temperature. There are single-mixer handle, thermostatic, or tempering valves available.

Reuse and recycle

Due to the scarcity of clean water and increased pollution control, the recycling of water from wastewater is a practice widely used in the food processing industry. The type of treatment technology deployed will depend on the purity standards and on where the reclaimed water will be used. For each application, certain standards need to be met (Sethu and Viramuthu, 2008):

- **Cooling (cooling towers):** Reclaimed water used for cooling will have to be treated for suspended solids. The alkalinity, hardness and pH levels need to be adjusted as they can cause corrosion.

- **Heating (e.g., boilers, heat exchangers):** The reclaimed water to be used in boilers needs to be of very high quality. Constituents that promote scaling, such as hardness, dissolved solids, silica and aluminum oxide need to be in low levels.

- **Production process:** The reclaimed water needs to be of drinking water standards.

- **Other uses (washing, rinsing etc.):** The level of water quality depends on whether it will be in contact with food. For the washing of ingredients or equipment that comes in contact with the product such as conveyer belts, mixers and cookers, the water needs to be of drinking standards. For cleaning floors, water of low or medium quality could be used.

The U.S. Environmental Protection Agency publishes the Guidelines for Water Reuse for information on water quality standards and advances in wastewater treatment technologies.

Replace once-through cooling systems with cooling towers.

Once-through cooling systems can be replaced by cooling towers, which continuously recycle cooling water and lead to significant water savings. The U.S. DOE (2006g) estimates that to remove the same heat load, once-through cooling systems can use as much as 40 times more water than a cooling tower (operated at 5 cycles of concentration). In a cooling tower, circulating warm water is put into contact with an air flow, which evaporates some of the water. The heat lost by evaporation cools the remaining water, which can then be recirculated as a cooling medium. The U.S. DOE (2006h) offers the following guidelines for operating cooling towers at optimal water efficiency:

- Consider using *acid treatment* (e.g., sulfuric or ascorbic acid), where appropriate. Acids can improve water efficiency by controlling scale buildup created from mineral deposits.

- Install a *side stream filtration system* that is composed of a rapid sand filter or high-efficiency cartridge filter to cleanse the water. These systems enable the cooling tower to operate more efficiently with less water and chemicals.

- Consider *alternative water treatment options* such as ozonation or ionization, to reduce water and chemical usage.

- Install *automated chemical feed systems* on large cooling tower systems (over 100 tons). The automated feed system should control bleed-off by conductivity and add chemicals based on makeup water flow. Automated chemical feed systems minimize water and chemical use while optimizing control against scale, corrosion and biological growth.

CASE STUDY: The General Mills' Cedar Rapids, Iowa plant installed a filtration system that reduced water use by 190,000 cubic meters per year. The new system recirculates 75% of the water that was previously used only once. Water and sewer costs are expected to decrease by $220,000. (General Mills, 2013)

Recycle evaporator condensate.

Depending on the quality (e.g., organic content) of condensate reclaimed from products in evaporation processes, condensate water can be reused for other low-grade facility applications such as equipment pre-rinsing and surface pre-soaking. Additionally, condensate recovery systems can be fitted with heat exchangers such that hot condensate can be used for pre-heating the evaporation process input streams, which saves energy (European Commission, 2006a).

Reuse compressor cooling water.

Cooling water from compressors (e.g., in refrigeration and compressed air systems) can be reused as seal water in vacuum pumps instead of fresh water, or as secondary water for other purposes, such as equipment pre-soaking (Korsström and Lampi, 2001). Warm cooling water can also be stored in insulated tanks for later use in facility cleaning, pre-soaking, and equipment pre-rinsing applications (NDCC, 1997).

Use membrane filtration technologies.

Membrane filtration technologies have been applied in many industries to clean wastewater prior to disposal and to recover water for recycling in various facility and process applications. Membranes are basically thin films that act as barriers to the transfer of certain constituents when the wastewater passes through. The process is pressure driven.

The treatment with membranes results in higher effluent quality than with other techniques, but it is more expensive. The use of microfiltration and ultrafiltration membrane filter types is 1.5-2.0 times more expensive than surface and depth filtration due to the higher energy and equipment costs. Nanofiltration and reverse osmosis membranes are even more expensive due to the high energy use and the required specialized equipment (U.S. EPA, 2012). The potential barriers to implementation include relatively high capital costs, as well as the need for specific membranes for specific applications (Martin et al., 2000).

CASE STUDIES: In 2004, Kellogg's Manchester, England plant installed sMBR (submerged Membrane Bioreactor) technology to treat the wastewater generated on-site. The system was later expanded to include a fifth bank of membranes and the balance tank was converted into a bioreactor using pure oxygen for enhanced aeration. The upgraded system removes 99% of influent COD with permeate COD at 10-100 mg/L, and BOD values at less than 10 mg/L (Judd, 2014).

The Manchester plant installed a heat pump system to utilize the heat otherwise rejected from the treated effluent coming from the aerobic tank and supplied heated water to the hot water and CIP systems. The annual savings amounted to 2,100 MWh, while the payback period was about 3 years (European Commission, 2015).

In the General Mills' Covington, Georgia plant, a similar sMBR technology was installed to treat a comparable effluent wastewater. About 50% of the effluent is recycled for non-potable applications within the facility, such as the dust scrubbers and as feed water in boilers. The project has also reduced costs for chemicals and blow-down waste. (Judd, 2014)

CASE STUDY: In 2012, Kellogg's Manchester plant installed a reverse osmosis system to further treat water from the treatment plant. The water exiting the osmosis process is reused in scrubbers and cooling operations. The new treatment system reduced water use by 26%. (Atkinson, 2013)

Install a membrane bioreactor (MBR).

The membrane bioreactor process is the combination of biological treatment and membrane filtration in a single process in which the membrane is used to replace the clarifier in the wastewater treatment (Leiknes and Ødegaard, 2007). In the first MBR designs the membrane unit was placed outside the reactor. This configuration required high velocities for sludge recirculation, which resulted in high energy costs for pumping. In current MBR designs, the membrane is immersed in the reactor. Compared to the earlier external configurations, the membrane area is larger, the operating pressure is lower (4-8 psi) and the cross-flow velocities are also lower.

The MBR technology has found applications in many commercial and non-commercial facilities for non-potable water reuses (U.S EPA, 2012). The main advantages of MBR systems are the high-quality effluent, the good disinfection potential, the large volumetric load capabilities and the relatively small production of sludge (Nagy, 2008). A main drawback is fouling: accumulation of materials on the surface or within the membrane that is detrimental to membrane permeability.

CASE STUDY: Kellogg's Pikeville plant in Kimper, Kentucky upgraded its wastewater facility to address increased waste flows and improve effluent quality. The existing anaerobic and aerobic system was upgraded to an anaerobic membrane reactor and a membrane bioreactor system. The result was COD removal of more than 99% with an average low effluent COD of 83 mg/L. Currently the system produces biogas that is flared, but the plant plans to recover the biogas for use in the wastewater treatment plant's boiler. (Wilson, 2015)

Install a membrane biofilm reactor (BF-MBR).

In the membrane biofilm reactor treatment process, membrane filtration is combined with a biofilm reactor. Biofilms are formed in a natural process where microbial cells attach to adsorbents or form flocs and create thick layers known as biofilms (Qureshi et al., 2005). In this way, the biomass concentration in the reactor can be reduced. Although BF-MBRs are efficient in the removal of soluble organic matter and may decrease membrane fouling, in high particle loads they can be prone to clogging. An alternative process, the moving bed biofilm reactor (MBBR) can have all the benefits of the BF-MBR system while it can also handle high loads of particles (Leiknes and Ødegaard, 2007).

CASE STUDY: The Nestle Toruń, Poland plant modernized the old active sludge wastewater treatment plant with an MBR system. The main advantages of the new treatment system include doubling the effectiveness of the previous system, greater resistance to changes in wastewater flow and load, and small footprint of the system. (Veolia, 2015)

Conclusion: Why Manage Energy?

Improving energy efficiency is an important way to reduce energy costs and increase predictable earnings. Look strategically at how energy is currently used in plants, systems, and production processes. Focus on the areas where you can generate the greatest savings. This Guide provides many examples of cost-effective best practices to increase energy efficiency including:

- How to create a successful energy management program that assesses and tracks your energy performance through the use of energy teams dedicated to improving your energy savings.

- How to assess and fix energy waste in your plants, systems, and breakfast cereal production processes as well as at the organizational level.

- How to assess your company in relation to the current state of energy use in the breakfast cereal industry.

The most effective way to reduce energy costs is to cultivate a culture of energy efficiency within your organization. As you learned in Chapter Three, establishing an energy management program creates a culture of energy efficiency while assessing and tracking energy and improving savings. When your entire energy team, plant, and company is engaged in energy management, additional cost saving opportunities can be identified and create a process for continuous energy improvement within the organization.

EPA ENERGY STAR offers tools and resources to help companies develop and continuously improve their energy management programs. These tools and resources include communication materials, assessment tools and guides to help you benchmark your energy performance and energy management practices, and information about how to become an ENERGY STAR partner and participate in competitions to raise awareness about your energy management program. You may access these tools and resources at www.energystar.gov/industry. If your company has questions or needs assistance with building a corporate energy program, please contact energystrategy@energystar.gov.

Despite what efficiency measures you may have implemented in the past, there is always room for additional cost-effective energy efficiency improvements that will pay your company back tenfold and grow your bottom line!

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Any remaining errors in this Guide are the responsibility of the authors. The views expressed in this Guide do not necessarily reflect those of the U.S. Environmental Protection Agency, or the U.S. government.

Appendix A: The Breakfast Cereal Industry

The United States is one of the largest producers in the global breakfast cereal market. Other major cereal producing countries include the United Kingdom, France, Spain, Italy, and Russia. About one third of the global population consumes breakfast cereals, with the United States and the European Union being the largest consumers (Muthukumarappan and Karunanithy, 2016).

Breakfast cereals are processed grains typically eaten in combination with milk or yogurt, usually as the first meal of the day. There are two types of breakfast cereals: those that require cooking, known as “traditional cereals” or “hot cereals,” and “ready-to eat” or “cold” cereals that are not cooked.

Traditional cereals are primarily made of oats or wheat. Other grains used include corn and rice, which are used in lesser quantities. Original hot cereals require cooking before consumed, but some new hot cereal types are pre-processed and only require the addition of hot water or milk in the bowl. The cereal content (cereal grains or milled grains fractions) in hot cereals is very high, reaching 100% in many products (Caldwell et al., 2000a).

Ready-to-eat cereals (RTE) are primarily made of wheat, oats, corn, or rice with the addition of flavor and fortifying ingredients. In RTEs, the grain content is usually much lower than in traditional cereals and can drop to well below 50% in many pre-sweetened products, where sweeteners compose a significant part of mass (Caldwell et al., 2000a). RTEs are typically grouped based on their form (Fast, 2000): 1) flaked cereals (corn flakes, wheat flakes and rice flakes), including extruded flakes, 2) gun-puffed whole grains, 3) extruded gun-puffed, 4) shredded whole grains, 5) extruded and other shredded cereals, 6) oven-puffed, 7) granola, 8) extruded expanded, 9) baked 10) compressed flaked biscuits, 11) muesli type products, and 12) filled bite-sized shredded wheat.

Ready-to-eat cereals account for most of the breakfast cereal consumption. As shown in Figure 3, RTEs accounted for 79% of cereals consumption, with hot cereals accounting for the remaining 21%. The breakdown was similar in 2001, shown for comparison.

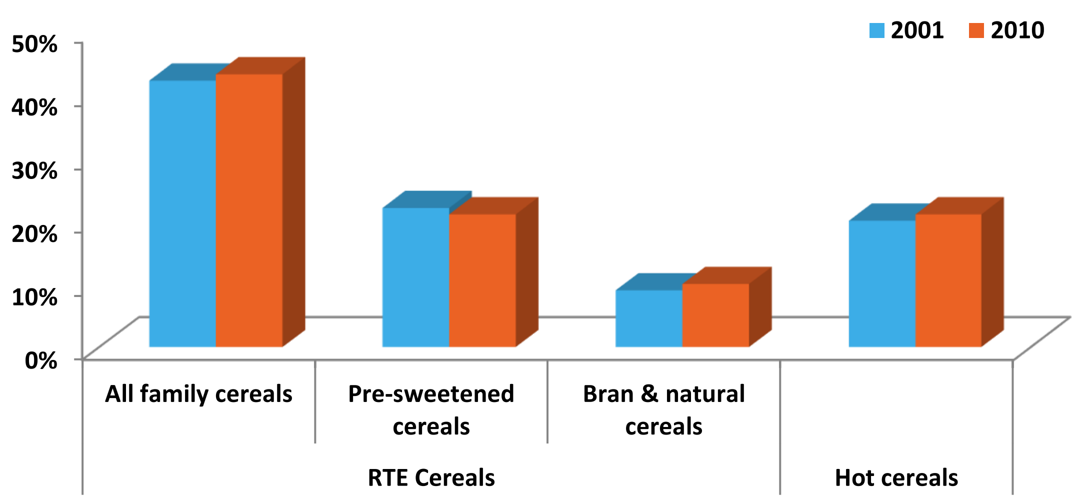


Figure 3: Breakdown of total cereal consumption per breakfast cereal type in the United States (NPD Group, 2010 as found in Agriculture and Agri-Food Canada, 2012).

The per capita average consumption of breakfast cereal has decreased within the past decade from about 5.1 kg in 2001 to 4.5 kg in 2010. According to Euromonitor (2012, as found in Muthukumarappan and Karunanithy, 2016) this trend is expected to continue as a result of the maturing cereal market, the competition with food services, and the unhealthy image of some children's breakfast cereals.

According to the Economic Census, the total value of shipments[8] was $9.8 billion in 2014, lower from $11 billion in the previous year. Figure 4 shows the trend in the value of shipments since 1997. Within the past decade, the value of shipments experienced an annual decrease of 2%.

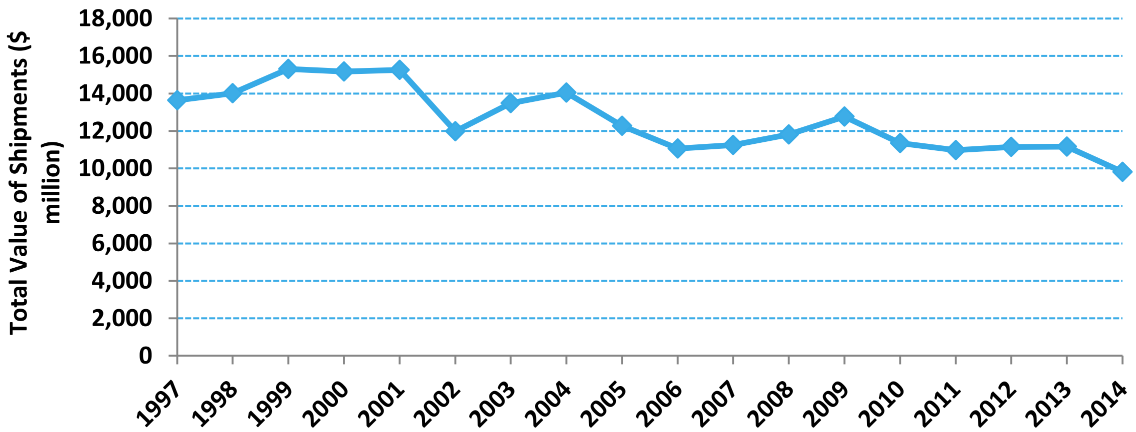


Figure 4: Total value of shipments 1997-2014 (in 2014 constant $) (United States Census Bureau, various years).

According to the U.S. Census Bureau (2011b; 2015; 2016b), in 2014, there were 82 breakfast cereal manufacturing facilities operating in the U.S. In 2009, there were 65 establishments in operation. The number of companies, on the other hand, has decreased within the last decade from 48 companies in 1997 to 37 companies in 2012 (U.S. Census Bureau, 2005; 2015a). The top RTE selling companies are the Kellogg Company and General Mills, Inc., which together account for about 62% of the U.S. market (Schroeder, 2011). Figure 5 shows the number of RTE units sold per company in the U.S.

[8] The values of shipments also include miscellaneous receipts for services and interplant transfers.

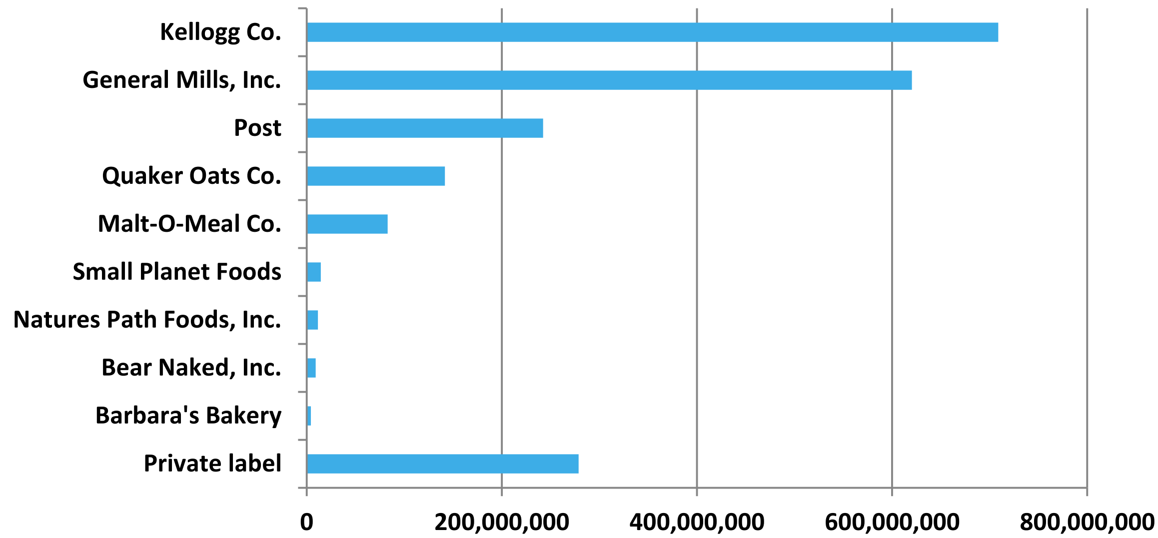


Figure 5: RTE units sales per company in the period August 2010-August 2011 (Schroeder, 2011).

The 2012 North American Industry Classification System (NAICS) code for breakfast cereal manufacturers is 311230 and is defined as establishments primarily focused on the manufacture of RTE and hot breakfast cereals. Not included are establishments engaging in the production of chocolate covered granola bars (NAICS codes: 311352 and 311352) and non-chocolate covered granola bars and other types of breakfast bars (NAICS code: 311340).

In this Guide, the production processes of traditional flaked cereals (RTE cereal type) and oat cereals (traditional cereal type) are described in detail. For other breakfast cereal types, only a short process description is given, with the similarities and differences from the main process highlighted. The description of RTE cereals is based on Fast (2000), and of traditional cereals on Caldwell et al. (2000b).

Process Description

Ready-To-Eat (RTE) Cereals

Flaked Cereals

Flaked cereals are made from whole grain kernels or parts of kernels of corn, wheat or rice. The main objective in the production of flaked cereals is to process the grain so that particles will form independent flakes. These flakable sized particles are known as flaking grits. Grain selection, intermediate size reduction, and sizing or screening are therefore very essential processes in producing flaked cereals with the desirable characteristics.

With the use of cooking extruders, flakable grits can also be produced from finer materials such as flours. The flour dough is initially cooked and is then used to form flakable grits formed at the correct size. In this way, pre-flaking size reduction and screening used in the traditional flaking process are no longer needed.

The processes involved in making flaked cereals are depicted in Figure 6.

Traditional Flaked Cereals

Preprocessing

The type of processing needed prior to cooking and flaking depends on the type of grain. For corn grains, dry milling is initially used to remove the bran and the germ. The product of dry milling[9] is broken chunks of endosperm that represent the raw material for flake production. The size needed is about half to one-third of the original kernel. In the case of wheat grains, preprocessing entails the light steaming and slight crushing of the kernels through a pair of rolls in a process called bumping. The raw material for wheat flakes is the whole wheat kernel (germ, bran and endosperm) that must be crushed in order to be able to absorb moisture and flavor. The preprocessing of rice grains entails the milling of the whole kernels to produce broken pieces of rice.

Mixing

After pre-processing, the raw grits are mixed with a flavor solution mainly composed of sugar, malt, salt and water in rotating batch cookers. Accurate proportioning is crucial for the intermediate processes and finished product quality, so batch amounts of raw grits and flavor solution must be carefully weighed. The moisture content that cooked grits should have for producing flakes should be 32% for corn, 28-30% for wheat and 28% for rice flakes.

Cooking

After the raw grits and syrup are combined, the cooking process starts with steam being directly injected under pressure (15-18 psi) into the cooker. The cooking time depends on the grain type. Corn grits are usually cooked for about 2 hours, wheat grits for 30 minutes and rice grits for 1 hour. The cooking process is complete when each grit has a light golden brown color and is soft and translucent (in the case of corn). The steam injection is then stopped and the vent is opened to release the pressure and cool down the mix. The cooker is then uncapped and the rotation is restarted. For more rapid cooling, the vents are sometimes connected to a vacuum system.

[9] If the corn wet milling process is used, use the EPA's energy guide to identify energy efficiency improvements: *Energy Efficiency Improvement and Cost Saving Opportunities for the Corn Wet Milling Industry*.

Dumping

The hot cooked mix is then dumped into conveyor belts for transfer to the dryer. To restrict the mix from continuing to cook, some processes spread the mix over large perforated air-cooled tables, while others spread the mix over wide and slow-speed conveyor belts.

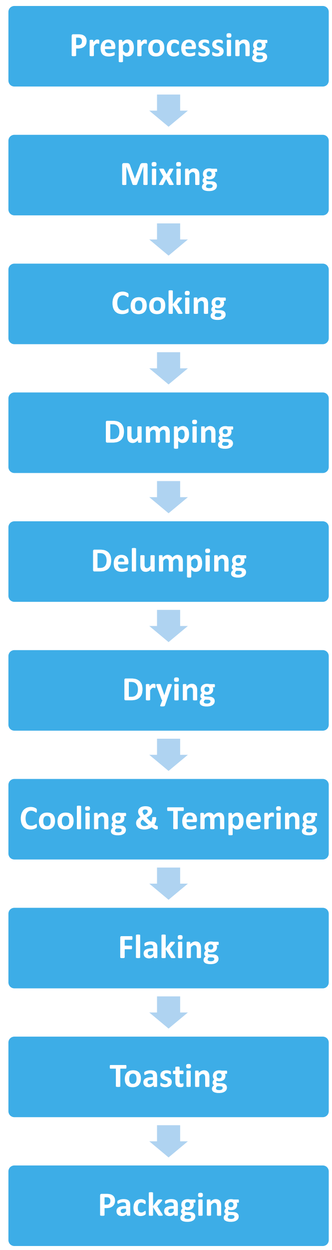


Figure 6: Cereal flake production process (based on Fast, 2000).

Delumping

Before the cooked grits are transferred to the dryer, they are sent through delumping equipment to break apart lumps of grits. To achieve a desired grit size, some processes will cool the grits and then delump. Cooling is needed to stop the product from further cooking, but also to eliminate stickiness, which assists delumping.

While corn exiting the cooker can be relatively easily separated, cooked wheat and rice exit the cooker in big lumps, which requires a different delumping system than corn. For wheat and rice, one-shaft units with intermeshing comb or two-shaft units are used to break apart the lumps.

Drying

After delumping, the grits move to the dryer. Grits are placed on a perforated conveyor and pass through a chamber in which temperature, humidity and airflow are controlled. Corn grits are dried at temperatures below 250 °F (120 °C). The moisture removal from inside the grit can be hindered due to skinning (hardening of the outside surface). With controlled humidity, skinning can be minimized and the drying time needed to reach the desired moisture content is shortened. The moisture content should be 10-14% for corn, 16-18% for wheat and 17% for rice.

Cooling and tempering

After drying, the grits need to be cooled to ambient temperature. This is commonly done using an unheated section of the dryer. In hot climates or under specific plant conditions, refrigerated air might need to be used.

After the grits are cooled down, they are placed in large bins at ambient conditions for tempering. Tempering is conducted to equalize the moisture content among all grits, as well within the grit particle. At the end of tempering, the moisture content is 10-14% for corn grits.

Flaking

After tempering, the grits are passed between pairs of very large metal rolls to produce flakes. Moisture content is an important production parameter. The ideal moisture content of corn grits is 10-14%. For this moisture content, the cooked corn grits would need to be steamed or slightly heated for them to stick on the roller surface.

Toasting

Toasting of the flakes is the final step before packaging. Instead of being laid flat on a baking furnace, the flakes are toasted by being suspended in a hot air stream within rotating perforated drums. The toasting of rice requires more heat than the toasting of corn and wheat. Depending on the grain type, the moisture content of the final product ranges between 1 and 3%.

Extruded Flake Cereals

The main difference between the traditionally flaked cereals and the extruded flake cereals is that the grits needed for flaking are formed by extruding a dough mix through a die hole and cutting it into small pellets in the desired size. The processes are similar to the ones described for flaked cereals except that extrusion replaces the cooking, dumping and delumping steps.

Extruders perform several processes consecutively. During the first stage, the dough is kneaded and the wheat is crushed. With the use of a metering pump, the flavoring is then added. A low level of heat is applied to keep the process warm, but must avoid gelatinization and cooking. After mixing is finalized, the mix moves to the center part of the extruder, where temperature levels are increased for cooking. The cooked mix then moves to the last part of the extruder where the dies are placed. The mix extrudes through the dies and is then cut by rotating knives. This is normally the coolest part of the extruder. The remaining process steps are the same as with traditional flake production.

Gun Puffed Whole Grain Cereals

Whole grains used in gun-puffing are rice and wheat. Corn and oats can also be used in gun puffs but not as whole grains. For the grains to puff they are first cooked and then exposed to a large and sudden pressure drop that causes the steam within the kernel to expand (puff). The processes involved are preprocessing, puffing, screening, drying and cooling.

For wheat puffs, unlike rice puffs, preprocessing is needed to remove the bran from the grain. This can be done either by applying saturated brine solution that helps the bran be removed from the grain when puffed or by removing the bran from the grain prior to puffing in a process called pearling. Puffing can take place in single-shot, multiple-shot or continuous-shot guns. In single-shot guns, the grains are loaded into the opening and the gun is sealed. The gun is then rotated while heated by gas burners, which turns the moisture in the cooked grains into steam. When the gun's door is opened, the steam expands, causing the grain to puff. In automated guns, the grains are preheated before entering the gun and heat is directly injected into the gun resulting in reduced heat needed for puffing and shorter heating times. After puffing, the puffs are screened and dried.

Extruded Gun-Puffed Cereals

Extruded gun-puffed cereals are not made from whole grains but from flours. Premixed dry materials are loaded in the cooking extruder where they are combined with the flavoring solution to form a dough, which is then cooked. The cooked dough exits the cooking extruder to enter the forming extruder, where it is extruded through a die. The puffing process and the steps following it are similar to the gun-puffed whole grain cereals.

Oven Puffed Cereals

Oven-puffed cereals are exclusively made from rice and/or corn grains. When the moisture content of these two grain types is at the right level, they puff in the presence of heat. The grains are initially mixed with the flavor solution and then pressure-cooked. After cooking, the grains go through cooling and sizing. The grains are then dried into two drying steps, with tempering in between to reduce the moisture content and pass through rolls that slightly flatten them. Next, the grains are dried and oven-puffed. After puffing, the cereals are cooled and packaged.

Shredded Whole Cereals

Wheat is the grain primarily used for shredded cereals. The process steps include cleaning, cooking, cooling and tempering, shredding, biscuit formation, biscuit baking and packaging. The process starts with cleaning all foreign material from the wheat. The wheat is then inserted in rotating baskets for cooking in excess water and under atmospheric pressure. The steam is directly injected into the water inside the basket. After cooking, the water is drained from the cooker and the wheat is cooled down to atmospheric temperature in cooling units to stop the cooking process. Before shredding, the wheat is left to temper in large bins. During shredding, the wheat is squeezed between two rolls. One of the rolls has a smooth surface while the other is grooved. As the wheat gets squeezed, it fills the roll grooves. A comb is used to remove the shredded wheat, which falls on a conveyor belt in layers. Typically, 10-20 rolls are needed to form a web needed for large shredded biscuits. Bite sized shredded cereals need fewer layers. After exiting the shredder, the web of layers enters the cutting unit and the individual biscuits are formed. The final steps involve baking in either a band or continuous conveyor belts, drying and packaging. In the case of filled shredded wheat biscuits, the filling is placed between shredding the wheat and forming the biscuits. After baking, coatings could be added.

Extruded and Other Shredded Cereals

Wheat, corn, rice and oat kernels, parts of kernels, or flour can be used for these types of cereals. Precooking is typically done using pressure cookers for flake production or extrusion cooking. When pressure cooking is used, the lumps formed do not have to be broken down into flakes, but instead just reduced in size for cooling and uniform feeding into the shredder. The shredding, biscuit formation, biscuit baking, drying and packaging steps are the same as for shredded whole cereals.

Granola Cereals

Granola cereals are a mix of traditional oats, either whole-rolled or quick-cooking oats, and other flavoring ingredients such as nuts, honey and dried fruit. A layer of the mix is spread on the band of a continuous dryer or oven. After drying, the layers are cut into pieces.

Extruded Expanded Cereals

Flour or meal is baked in the cooking extruder or in the cooking section of a cooking-expanding extruder. The cooked dough is then expanded when the moisture is released, the temperature is elevated, and pressure drops to ambient conditions. The shape of the final product is controlled by holes in the die at the end of the extruder. The cutting is done by rotating knives at the end of the die.

Traditional Hot Cereals

Traditional cereals require cooking prior to consumption. They are made from oats, farina (wheat), corn, rice and/or barley. About 81% of traditional cereals are made from oats and 18% from farina.

Oat Cereals

The process steps are grain receiving, cleaning, hulling, drying, groat processing, steaming and flaking. Figure 7 shows the production processes involved in making traditional cereals.

Grain receiving and cleaning

The grains received are initially sampled to check whether certain criteria are fulfilled. The acceptable grains are then cleaned to remove foreign material such as dust and stems, as well as grains not satisfactory for processing. The cleaning process uses several devices (screens, aspirators, width grader, indent cylinder and gravity table) that base their operation on the physical properties of the grains.

Hulling

First, the oats are sized and separated into long oats and short oats. Each oat stream is then fed to an impact huller to remove the hull from the groat (the part of the grain that will be further processed). The hull is removed as the grains hit the inside wall tangentially and drop at the bottom of the huller along with the groats. To separate the hulls from the groats, the mix is subjected to aspiration.

Drying

The pre-drying of the original grains (before hulling) in drying pans was commonly used in the past to achieve a nuttier flavor. However, due to the inefficiency of drying the hull, pre-drying is no longer employed. Currently, most facilities dry the groats after their separation from the hull in grain conditioners where both direct and indirect steam is applied in a process that achieves a similar flavor to pre-drying in pans.

Groat Processing

The dried groats are separated based on their size. The larger groats will move to rolling to make the traditional rolled oats. The medium and small sized oats are cut before rolling in several pieces in a groat cutter by knives mounted against a stationary surface of revolving drums. After cutting, the groat pieces are steamed and rolled to make quick-cooking oats.

Steaming

To produce satisfactory oat flakes, before rolling, the moisture content needs to increase from 8-10% to about 10-12%. Whole and cut groats go through an atmospheric steamer where live steam is injected. The groats need to stay long enough in the steamer to reach the desirable level of moisture.

Flaking

The whole and cut steamed groats exiting the steamer pass through equal speed cast iron rolls. The rolls are adjusted depending on the final product type; quick cooking oats are thinner than traditional old-fashioned flaked oats.

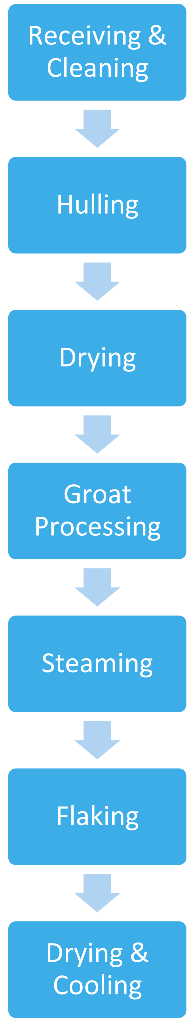


Figure 7: Traditional oat cereal production process (based on Caldwell et al., 2000b)

Drying and Cooling

Before packaging, the flakes need to be dried and cooled. For this purpose, a variety of devices can be used to draw ambient air through the flakes to dry them.

Farina Cereals

Farina hot cereals are made of ground wheat endosperm (farina) that is obtained from flour mills. The main process steps to make farina cereals are: wetting and pressure cooking, flaking, re-drying and packaging.

Appendix B: Energy Consumption in Breakfast Cereal Production

The production of cereals involves several processes, including grinding, mixing, cooking, extruding, puffing, shredding, etc. to manufacture a variety of products. These processes all require various amounts of energy.

Detailed data on the energy use and water use per process and by product are not available. Table 8 shows data on fuel, electricity, and water consumption in five different RTE breakfast cereal manufacturing plants in Europe. Each plant produces different types and mixes of products, making it impossible to easily compare energy intensities of different plants. Differences in energy and water use depict differences in products manufactured, processes used and efficiency levels.

Table 8. Fuel, electricity, and water use in European RTE manufacturing plants (adapted from Jeswani et al., 2015)

Utility	Bremen, Germany	Valls, Spain	Manchester, UK	Wrexham (portable foods), UK	Wrexham, (RTEs), UK	Weighted average
Electricity (kWh/short ton product)	363	345	327	372	435	381
Natural gas (kBtu/short ton product)	2,879	2,322	5,696	743	3,962	3,931
Water (gallon/short ton product)	419	364	1158	300	1184	853

Figure 8 shows the energy costs for breakfast cereal production in the U.S. industry. Fuel costs experienced a gradual increase during the 1997-2006 period. After 2006, total electricity expenses decreased and stabilized between $50 and 55 million. Fuel expenses have decreased substantially since 2009. Currently, the U.S. cereal manufacturing industry spends about $53 million on fuels. As natural gas prices have considerably subsided in the last few years, electricity use accounts for the greatest part of energy expenses.

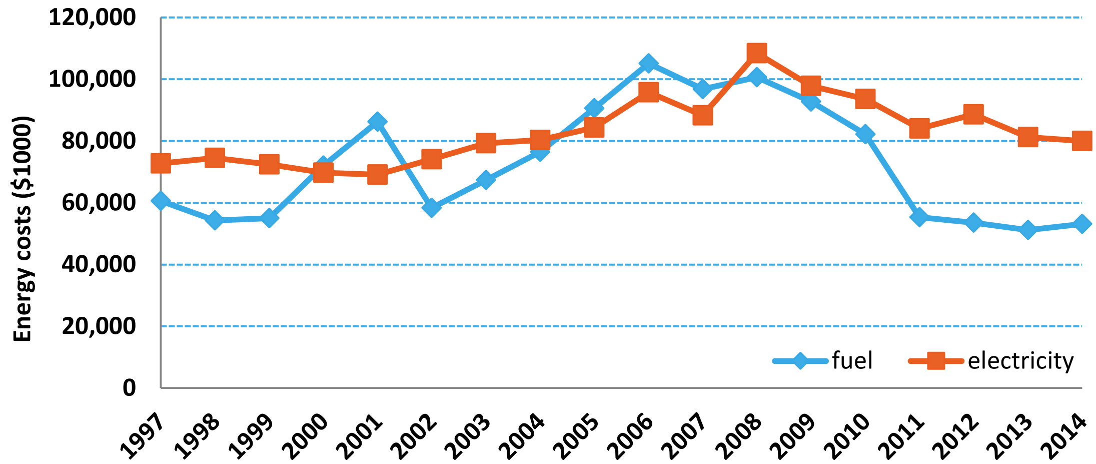


Figure 8: Fuel and electricity costs in the U.S. breakfast cereal industry (in constant 2014 $) (based on U.S. Census Bureau, various years and U.S. EIA, 2017).

In 2014, the U.S. breakfast cereal industry spent $133 million on energy. It is estimated that fuel consumption for the same year was 9,800 GBtu and the average industrial natural gas price was $3.91/1000 cu ft. For the same year, the electricity consumption was approximately 4,100 GBtu. Figure 9 shows the total fuel consumption, electricity consumption, and natural gas prices in the period 1997-2014.

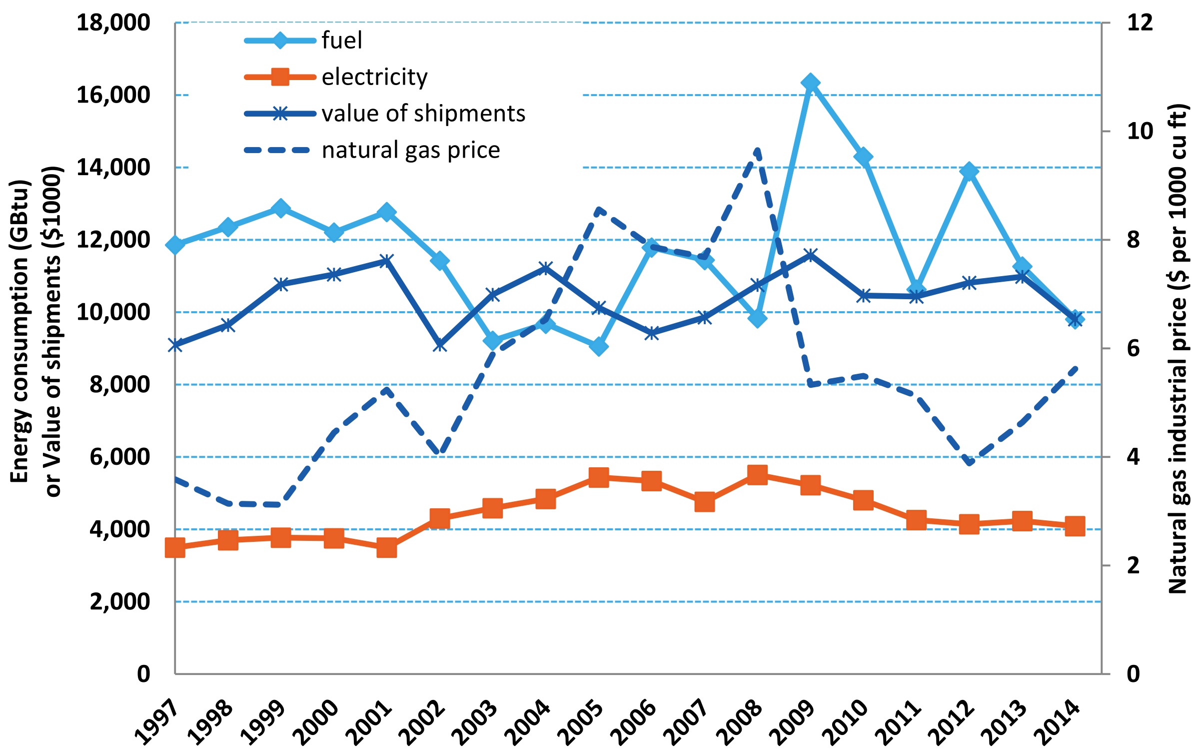


Figure 9: Development of fuel and electricity consumption in the U.S. cereals manufacturing industry in the period 1997-2014 (based on U.S. Census Bureau, various years and U.S. EIA, 2017).

The total energy consumption depends on the volumes and types of products manufactured and the energy intensity of the production processes. There is no data available on production levels of breakfast cereal, and although the value of shipments can represent the industry's activity, it cannot reflect with certainty actual physical production levels since the value of shipments reflects the price of goods.[10]

In the period 1997-2001, fuel consumption followed the increase in the value of shipments and started dropping when the value of shipments decreased in 2002. The even lower fuel consumption in 2003, while the value of shipments increased, could be the result of increasing natural gas prices, which may have driven more efficient utilization of natural gas. Between 2003 and 2008, fuel consumption fluctuated within the 9,000 to 12,000 GBtu range. Interestingly, in 2009, fuel consumption increased by 66%. Such an abrupt increase in fuel consumption cannot be justified by the relatively mild increase of 8% in shipment values, but it could be explained by the sharp decrease of industrial natural gas prices which dropped from \$9.65/cu ft in 2008 to \$5.33/cu ft in 2009. Although in the subsequent years energy consumption returned to usual levels, another steep increase in fuel consumption occurred when natural gas prices hit another historical low in 2012. This could indicate a less efficient utilization of heat in manufacturing processes in the periods of low natural gas costs.

[10] For example, an increase in the value of shipments can be the result of higher pricing for cereals rather than an increase in physical production.

Appendix C: Natural Gas Flow Meters

Table 9. Natural gas flow meters and key selection criteria (Parker et al., 2015).

Goal	Differential Pressure flow meters				Velocity flow meters		
	Positive Displacement	Orifice	Venturi	Annubar	Turbine	Vortex Shedding	Fluid Oscillation
Accuracy	Good	Moderate	Good	Good	Good	Good	Good
Turndown Ratio	10:1	<5:1	< 5:1	10:1	10:1	20:1	100:1
Repeatability	Good	Good	Good	Very Good	Low	Very good	Good
Installation Ease	Easy	Easy	Moderate	Easy	Challenging	Moderate	Easy
Pressure loss	Medium	Moderate	Low	Low	Moderate	Low	Low
Recalibration Needs	Infrequent	Frequent	Infrequent	Infrequent	Frequent	Infrequent	Infrequent
Capital Cost	Low	Low	Moderate	Low	Moderate	Moderate	High
Installed Cost	Moderate	Low	Moderate	Low	Moderate	Moderate	Low
Maintenance Cost	Low	High	Moderate	Low	Moderate	Low	Low

Appendix D: Standards for NEMA Motors

The Consortium for Energy Efficiency (CEE) has described the evolution of standards for energy-efficient motors in the United States, which is helpful for understanding "efficient" motor nomenclature (CEE, 2013):

- NEMA Energy Efficient (NEMA EE) was developed in the mid-1980s to define the term "energy efficient" in the marketplace for motors. NEMA Standards Publication No. MG-1 -2011, Table 12-11 defines efficiency levels for a range of different motors (NEMA, 2012).
- The Energy Policy Act of 1992 (EPAct) required that many commonly used motors comply with NEMA "energy efficient" ratings if offered for sale in the United States.
- In 1996, the CEE Premium Efficiency Criteria specification was designed to promote motors with higher efficiency levels than EPAct required, for the same classes of motors covered by EPAct. The CEE efficiency levels specified were generally two NEMA efficiency bands (Table 12-10, NEMA MG-1-2011) above those required by EPAct.
- In 2007, the Energy Independence and Security Act (EISA) updated the minimum energy efficiency levels set by Epact. The new levels established by EISA are equivalent to NEMA Premium® efficiency levels (Table 12-12, NEMA MG-1-2011). The EISA minimum standards took effect December 2010 (the CEE motor specification was retired June 2011).

In 2001, the NEMA Premium Efficiency Electric Motor specification was developed to address confusion with respect to what constituted the most efficient motors available in the market. This specification was developed by NEMA, CEE, and other stakeholders, and was adapted from the CEE 1996 criteria. It currently serves as the benchmark for premium energy efficient motors. NEMA Premium® also denotes a brand name for motors, which meet this specification. Specifically, this specification covers motors with the following attributes:

- Speed: 2, 4, and 6 pole.
- Size: 1-500 horsepower (hp).
- Design: NEMA A and B.
- Enclosure type: open and closed.
- Voltage: low and medium voltage.
- Class: general, definite, and special purpose.

Appendix E: Energy Management Program Assessment Matrix

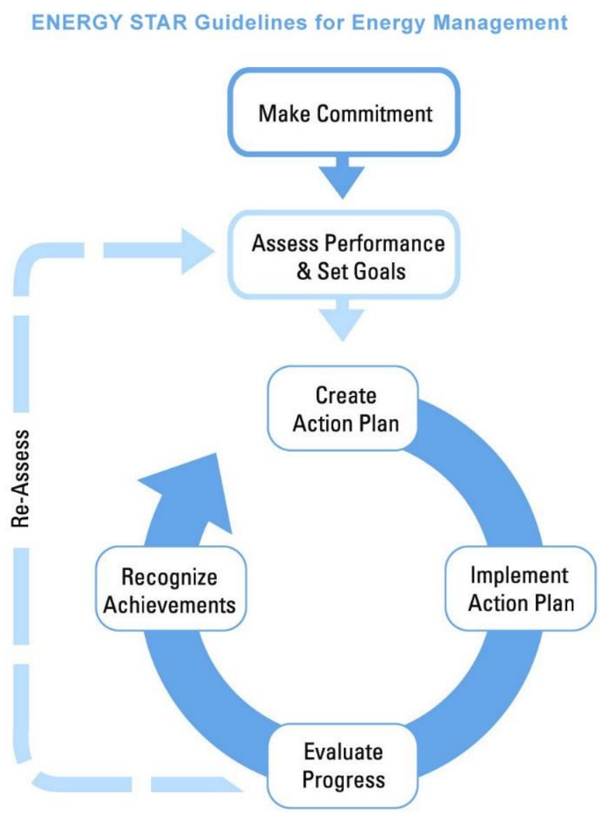
Energy Management Program Assessment Matrix

Introduction

The U.S. EPA has developed guidelines for establishing and conducting an effective energy management program based on the successful practices of ENERGY STAR partners.

These guidelines, illustrated in the graphic, are structured on seven fundamental management elements that encompass specific activities.

This assessment matrix is designed to help organizations and energy managers compare their energy management practices to those outlined in the Guidelines. The full Guidelines can be viewed on the ENERGY STAR web site – www.energystar.gov/guidelines.



How to Use the Assessment Matrix

The matrix outlines the key activities identified in the ENERGY STAR Guidelines for Energy Management and three levels of implementation:

- No evidence.
- Most elements.
- Fully Implemented.

1. Print the assessment matrix or download from www.energystar.gov/assessprogram.
2. Compare your program to the Guidelines by identifying the degree of implementation that most closely matches your organization's program.
3. Use a highlighter to fill in the cell that best characterizes the level of implementation of your program. You will now have a visual comparison of your program to the elements of the ENERGY STAR Guidelines for Energy Management.

4. Identify the steps needed to fully implement the energy management elements and record these in the Next Steps column.

Energy Management Program Assessment Matrix				
	Little or no evidence	**Some elements**	**Fully implemented**	**Next Steps**
Make Commitment to Continuous Improvement				
Energy Director	No central corporate resource Decentralized management	Corporate or organizational resource not empowered	Empowered corporate leader with senior management support	
Energy Team	No company energy network	Informal organization	Active cross-functional team guiding energy program	
Energy Policy	No formal policy	Referenced in environmental or other policies	Formal stand-alone EE policy endorsed by senior mgmt.	
Assess Performance and Opportunities				
Gather and Track Data	Little metering/no tracking	Local or partial metering/tracking/ reporting	All facilities report for central consolidation/analysis	
Normalize	Not addressed	Some unit measures or weather adjustments	All meaningful adjustments for corporate analysis	
Establish baselines	No baselines	Various facility-established	Standardized corporate base year and metric established	
Benchmark	Not addressed or only same site historical comparisons	Some internal comparisons among company sites	Regular internal & external comparisons & analyses	
Analyze	Not addressed	Some attempt to identify and correct spikes	Profiles identifying trends, peaks, valleys & causes	
Technical assessments and audits	Not addressed	Internal facility reviews	Reviews by multi-functional team of professionals	
Set Performance Goals				
Determine scope	No quantifiable goals	Short term facility goals or nominal corporate goals	Short & long term facility and corporate goals	
Estimate potential for improvement	No process in place	Specific projects based on limited vendor projections	Facility & corporate defined based on experience	
Establish goals	Not addressed	Loosely defined or sporadically applied	Specific & quantifiable at various organizational levels	
Create Action Plan				
Define technical steps and targets	Not addressed	Facility-level consideration as opportunities occur	Detailed multi-level targets with timelines to close gaps	

Energy Management Program Assessment Matrix				
	Little or no evidence	**Some elements**	**Fully implemented**	**Next Steps**
Determine roles and resources	Not addressed or done on ad hoc basis	Informal interested person competes for funding	Internal/external roles defined & funding identified	
Implement Action Plan				
Create a communication plan	Not addressed	Tools targeted for some groups used occasionally	All stakeholders are addressed on regular basis	
Raise awareness	No promotion of energy efficiency	Periodic references to energy initiatives	All levels of organization support energy goals	
Build capacity	Indirect training only	Some training for key individuals	Broad training/certification in technology & best practices	
Motivate	No or occasional contact with energy users and staff	Threats for non-performance or periodic reminders	Recognition, financial & performance incentives	
Track and monitor	No system for monitoring progress	Annual reviews by facilities	Regular reviews & updates of centralized system	
Evaluate Progress				
Measure results	No reviews	Historical comparisons	Compare usage & costs vs. goals, plans, competitors	
Review action plan	No reviews	Informal check on progress	Revise plan based on results, feedback & business factors	
Recognize Achievements				
Provide internal recognition	Not addressed	Identify successful projects	Acknowledge contributions of individuals, teams, facilities	
Get external recognition	Not sought	Incidental or vendor acknowledgement	Government/third party highlighting achievements	

Interpreting Your Results

Comparing your program to the level of implementation identified in the Matrix should help you identify the strengths and weaknesses of your program.

The U.S. EPA has observed that organizations fully implementing the practices outlined in the Guidelines achieve the greatest results. Organizations are encouraged to implement the Guidelines as fully as possible.

By highlighting the cells of the matrix, you now can easily tell how well balanced your energy program is across the management elements of the Guidelines. Use this illustration of your energy management program for discussion with staff and management.

Use the "Next Steps" column of the Matrix to develop a plan of action for improving your energy management practices.

Resources and Help

ENERGY STAR offers a variety tools and resources to help organizations strengthen their energy management programs.

Here are some next steps you can take with ENERGY STAR:

1. Read the Guidelines sections for the areas of your program that are not fully implemented.

2. Find more sector-specific energy management information at http://www.energystar.gov/industry.

3. Become an ENERGY STAR Partner, if your company is not already, to take advantage of additional resources.

Appendix F: Teaming Up to Save Energy Checklist

The following checklist can be used as a handy reference to key tasks for establishing and sustaining an effective energy team. For more detailed information on energy teams, consult the U.S. EPA's *Teaming Up to Save Energy* guide (U.S. EPA, 2006), which is available at www.energystar.gov/energyteam.

Organize Your Energy Team		√
Energy Director	Able to work with all staff levels from maintenance to engineers to financial officers. Senior-level person empowered by top management support	
Senior Management	Energy director reports to senior executive or to a senior management council. Senior champion or council provides guidance and support	
Energy Team	Members from business units, operations/engineering, facilities, and regions. Energy networks formed. Support services (PR, IT, HR).	
Facility Involvement	Facility managers, electrical personnel. Two-way information flow on goals and opportunities. Facility-based energy teams with technical person as site champion.	
Partner Involvement	Consultants, vendors, customers, and joint venture partners. Energy savings passed on through lower prices.	
Energy Team Structure	Separate division and/or centralized leadership. Integrated into organization's structure and networks established.	
Resources & Responsibilities	Energy projects incorporated into normal budget cycle as line item. Energy director is empowered to make decisions on projects affecting energy use. Energy team members have dedicated time for the energy program.	
Starting Your Energy Team		**√**
Management Briefing	Senior management briefed on benefits, proposed approach, and potential energy team members.	
Planning	Energy team met initially to prepare for official launch.	
Strategy	Energy team met initially to prepare for official launch.	
Program Launch	Organizational kickoff announced energy network, introduced energy director, unveiled energy policy, and showcased real-world proof.	
Energy Team Plans	Work plans, responsibilities, and annual action plan established.	
Facility Engagement	Facility audits and reports conducted. Energy efficiency opportunities identified.	
Building Capacity		**√**
Tracking and Monitoring	Systems established for tracking energy performance and best practices implementation.	
Transferring Knowledge	Events for informal knowledge transfer, such as energy summits and energy fairs, implemented.	
Raising Awareness	Awareness of energy efficiency created through posters, intranet, surveys, and competitions.	
Formal Training	Participants identified, needs determined, training held. Involvement in ENERGY STAR Web conferences and meetings encouraged. Professional development objectives for key team members.	
Outsourcing	Use of outside help has been evaluated and policies established.	
Cross-Company Networking	Outside company successes sought and internal successes shared. Information exchanged to learn from experiences of others.	

Sustaining the Team		√
Effective Communications	Awareness of energy efficiency created throughout company. Energy performance information is published in company reports and communications.	
Recognition and Rewards	Internal awards created and implemented. Senior management is involved in providing recognition.	
External Recognition	Credibility for your organization's energy program achieved. Awards from other organizations have added to your company's competitive advantage.	
Maintaining Momentum		√
Succession	Built-in plan for continuity established. Energy efficiency integrated into organizational culture.	
Measures of Success	Sustainability of program and personnel achieved. Continuous improvement of your organization's energy performance attained.	

Appendix G: Support Programs for Industrial Energy Efficiency Improvement

This appendix provides a list of energy efficiency support available to industry. A brief description of the program or tool is given, as well as information on its target audience and the URL for the program. Included are federal and state programs. Use the URL to obtain more information from each of these sources. An attempt was made to provide as complete a list as possible; however, information in this listing may change with the passage of time.

Tools for Self-Assessment

Steam System Modeler Tool (SSMT)
Description: Software package to evaluate energy efficiency improvement projects for steam systems. It includes an economic analysis capability.
Target Group: Any industry operating a steam system
Format: Downloadable software package
Contact: U.S. Department of Energy
URL: https://energy.gov/eere/amo/articles/steam-system-modeler.

Process Heating Assessment and Survey Tool (PHAST)
Description: Software package to identify most energy intensive equipment, evaluate energy use under various operating conditions, and test "what-if" scenarios for energy efficiency improvement projects.
Target Group: Any industry
Format: Downloadable software package (130 MB)
Contact: U.S. Department of Energy
URL: https://energy.gov/eere/amo/articles/process-heating-assessment-and-survey-tool.

MotorMaster+
Description: Energy efficient motor selection and management tool, including a catalog of over 20,000 AC motors. It contains motor inventory management tools, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting, and environmental reporting capabilities.
Target Group: Any industry
Format: Downloadable software
Contact: U.S. Department of Energy
URL: Link to download this tool is only available upon request at AMO Tools Help Desk (AMO_ToolHelpDesk@ee.doe.gov).

The 1-2-3 Approach to Motor Management
Description: A step-by-step motor management guide and spreadsheet tool that can help motor service centers, vendors, utilities, energy-efficiency organizations, and others convey the financial benefits of sound motor management.
Target Group: Any industry
Format: Downloadable Microsoft Excel spreadsheet
Contact: Consortium for Energy Efficiency (CEE), (617) 589-3949
URL: https://library.cee1.org/content/123-approach-motor-management/.

AirMaster+: Compressed Air System Assessment and Analysis Software
Description: Modeling tool that maximizes the efficiency and performance of compressed air systems through improved operations and maintenance practices.
Target Group: Any industry operating a compressed air system
Format: Downloadable software
Contact: U.S. Department of Energy
URL: https://energy.gov/eere/amo/articles/airmaster.

Fan System Assessment Tool (FSAT)
Description: The Fan System Assessment Tool (FSAT) helps to quantify the potential benefits of optimizing a fan system. FSAT calculates the amount of energy used by a fan system, determines system efficiency, and quantifies the savings potential of an upgraded system.
Target Group: Any user of fans
Format: Downloadable software
Contact: U.S. Department of Energy
URL: https://energy.gov/eere/amo/articles/fan-system-assessment-tool.

Pumping System Assessment Tool (PSAT)
Description: The tool helps industrial users assess the efficiency of pumping system operations. PSAT uses achievable pump performance data from Hydraulic Institute standards and motor performance data from the MotorMaster+ database to calculate potential energy and associated cost savings.
Target Group: Any industrial pump user
Format: Downloadable software
Contact: U.S. Department of Energy
URL: https://energy.gov/eere/amo/articles/pumping-system-assessment-tool.

Plant Energy Profiler Excel (PEPEx)
Description: The PEPEx, an excel version of former ePEP , is an online software tool provided by the U.S. Department of Energy to help industrial plant managers in the United States identify how energy is being purchased and consumed at their plant and also identify potential energy and cost savings. PEPEx is designed so that the user can complete a plant profile in about an hour.
Target Group: Any industrial plant
Format: Online software tool
Contact: U.S. Department of Energy
URL: https://energy.gov/eere/amo/downloads/plant-energy-profiler-excel.

ENERGY STAR Portfolio Manager
Description: Online software tool helps to assess the energy performance of buildings by providing a 1-100 ranking of a building's energy performance relative to the national building market. Measured energy consumption forms the basis of the ranking of performance.
Target Group: Any building user or owner
Format: Online software tool
Contact: U.S. Environmental Protection Agency
URL: http://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager.

ENERGY STAR Energy Tracking Tool
Description: Provides manufacturers with a simple means for tracking their energy performance over time and progress toward goals. This Microsoft Excel-based tool enables users to define custom energy intensity metrics, and select from a variety of reports.
Target Group: Any manufacturing plant user or owner
Format: Microsoft Excel-based tool
Contact: U.S. Environmental Protection Agency
URL: http://www.energystar.gov/ett.

Assessment and Technical Assistance

Industrial Assessment Centers (IACs)
Description: Small- to medium-sized manufacturing facilities can obtain a free energy and waste assessment. The audit is performed by a team of engineering faculty and students from 30 participating universities in the U.S. and assesses the plant's performance and recommends ways to improve efficiency.
Target Group: Small- to medium-sized manufacturing facilities with gross annual sales below $75 million and fewer than 500 employees at the plant site.
Format: A team of engineering faculty and students visits the plant and prepares a written report with energy efficiency, waste reduction and productivity recommendations.
Contact: U.S. Department of Energy
URL: http://energy.gov/eere/amo/industrial-assessment-centers-iacs.

Manufacturing Extension Partnership (MEP)
Description: MEP is a nationwide network of not-for-profit centers in over 400 locations providing small- and medium-sized manufacturers with technical assistance. A center provides expertise and services tailored to the plant, including a focus on clean production and energy-efficient technology.
Target Group: Small- and medium-sized plants
Format: Direct contact with local MEP Office
Contact: National Institute of Standards and Technology, (301) 975-5020
URL: http://www.nist.gov/mep/.

Small Business Development Center (SBDC)
Description: The U.S Small Business Administration (SBA) administers the Small Business Development Center Program to provide management assistance to small businesses through 58 local centers. The SBDC Program provides counseling, training and technical assistance in the areas of financial, marketing, production, organization, engineering and technical problems and feasibility studies, if a small business cannot afford consultants.
Target Group: Small businesses
Format: Direct contact with local SBDC
Contact: Small Business Administration, (800) 8-ASK-SBA
URL: https://www.sba.gov/tools/local-assistance/sbdc.

ENERGY STAR – Selection and Procurement of Energy-Efficient Products for Business
Description: ENERGY STAR identifies and labels energy-efficient office equipment. Look for products that have earned the ENERGY STAR. They meet strict energy efficiency guidelines set by the EPA. Office equipment included such items as computers, copiers, faxes, monitors, multifunction devices, printers, scanners, transformers and water coolers.
Target Group: Any user of labeled equipment.

Format: Website
Contact: U.S. Environmental Protection Agency
URL: http://www.energystar.gov/products?s=mega.

Federal, State, Local, and Utility Incentives

Government and utilities sponsor incentives to assist businesses in assessing or financing energy-efficient process technology or buildings. Please contact your utility, state and local government to determine what tax benefits, funding grants, or other assistance they may be able to provide your organization.

Database of State Incentives for Renewables & Efficiency (DSIRE)
Description: DSIRE is a comprehensive source of information on state, local, utility, and federal incentives and policies that promote renewable energy and energy efficiency. Established in 1995, DSIRE is an ongoing project of the NC Solar Center and the Interstate Renewable Energy Council funded by the U.S. Department of Energy.
Target Group: Any industry
URL: http://www.dsireusa.org/.

Appendix H: Purchase Prices of Conventional Lighting Systems

Industrial Sector Markets	Mean Lamp Wattage (W)	Mean Efficacy (Lumen/watt)	Typical Lifetime (hours)	Lamp Price ($)	Ballast Price ($)	Fixture Price ($)
A-Type						
Incandescent Omni	46	16	2,000	0.5	-	15
Halogen Omni	29	15	2,000	1.9	-	15
CFL Omni	11	54	10,000	3.0	-	15
Directional						
Incandescent	65	10	3,000	1.3	-	23
Halogen	48	13	3,000	3.7	-	23
CFL	16	43	10,000	3.9	-	23
Linear Fixtures						
T-12 < 4ft	41	49	15,000	3.0	17	70
T-8 < 4ft	24	73	20,000	5.4	18	70
T-12 4ft	39	72	20,000	2.0	17	70
T-8 4ft	30	79	24,000	2.8	18	70
T-5 4ft	56	85	30,000	4.2	22	75
T-12 > 4ft	84	78	12,000	5.7	19	70
T-8 > 4ft	62	83	18,000	7.0	22	70
Low and High Bay						
T-12	75	72	12,000	5.7	19	70
T-8	57	79	18,000	8.4	22	70
T-5	68	85	30,000	6.2	25	75
Metal Halide	424	77	20,000	40	210	75
High-Pressure Sodium	295	106	24,000	51	260	80
Other						
CFL Pin	44	70	12,000	5.4	18	15
Metal Halide	424	77	20,000	53	200	75
High-Pressure Sodium	295	106	24,000	50	250	80

Source: U.S. DOE, 2017a

Glossary

ASDs	Adjustable speed drives
BF-MBR	Membrane biofilm reactor
BOD	Biochemical oxygen demand
Btu	British thermal unit
CAC	Compressed Air Challenge®
CADDET	Centre for the Analysis and Dissemination of Demonstrated Technologies
CDA	Copper Development Association
CEE	Consortium of Energy Efficiency
CHP	Combined Heat and Power
CFL	Compact fluorescent lamp
cfm	Cubic feet per minute
CIPEC	Canadian Industry Program for Energy Conservation
cm	Centimeter
CO	Carbon monoxide
CO_2	Carbon dioxide
COD	Chemical oxygen demand
cu ft	Cubic feet
EASA	Electric Apparatus Service Association
EIA	Energy Information Administration (U.S. Department of Energy)
EISA	Energy Independence and Security Act
EPACT	Energy Policy Act
GBtu	Giga British Thermal Unit
GHGs	Greenhouse gases
H_2O	Water
HCFCs	Hydrochlofluorocarbons
HHV	High Heating Value
HID	High Intensity-discharge
hp	Horsepower
HPD	Heat pump drying
HPS	High-Pressure Sodium
HVAC	Heating, ventilation, and air-conditioning
Hz	Hertz
IAC	Industrial Assessment Center
IEA	International Energy Agency
kBtu	Thousand British Thermal Unit
kg	Kilogram
klm	Kilo lumen
kW	Kilowatt
kWe	Kilowatt electric
kWh	Kilowatt-hour
LCC	Life Cycle Costing
LED	Light-emitting diode
lm	Lumen
Low-E	Low-emittance

LRC	Lighting Research Center
MBBR	Moving bed biofilm reactor
MBR	Membrane bioreactor
MMBtu	Million British Thermal Unit
MDM	Motor Decisions MatterSM
Mg	Milligram
MH	Metal Halide
mm	Millimeter
MW	Million Watt (megawatt)
MWh	Millionwatt-hour (megawatt-hour)
NAICS	North American Industry Classification System
NEMA	National Electrical Manufacturers Association
NEMA EE	National Electrical Manufacturers Association Energy Efficiency
NOx	Nitrogen oxides
pH	Potential of Hydrogen
PLC	Programmable Logic Controller
psi	Pound per square inch
psid	Pound per square inch (differential)
psig	Pound per square inch (gauge)
RTE	Ready-to-eat cereals
SMER	Specific moisture extraction ratio
SPC	Statistical Process Control
TBtu	Trillion British thermal unit
TLED	Tubular light-emitting diode
TSS	Total suspended solids
UK	United Kingdom
UNEP	United Nations Environment Programme
U.S. DOE	United States Department of Energy
U.S. EPA	United States Environmental Protection Agency
VFDs	Variable frequency drives
VSDs	Variable speed drives
W	Watt
WHP	Waste heat to power

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