Energy Efficiency and Cost Saving Opportunities for Metal Casting

An ENERGY STAR® Guide for Energy & Plant Managers

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An ENERGY STAR® Guide for Energy and Plant Managers

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The cover photograph was provided by Grede LLC of its St. Cloud casting plant.

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Overview

This Guide provides information to identify cost-effective practices and technologies to increase energy efficiency in each of three industrial metal casting segments: iron, steel and aluminum. 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 metal casting operations. For additional information on metal casting and associated processes and their energy consumption, please consult Appendix A of this Guide.

Energy costs typically account for 5-7% of the overall operating costs in a metal casting foundry. Energy waste is found in all plants, and improving energy efficiency goes right to the bottom line. Following the procedures outlined in this guide will reduce your energy costs (and dollars spent) per ton[1] of cast metal while improving your environmental reputation as well as image in the community. This Guide is organized as follows:

- **Chapter One** - the value of energy management in a metal casting facility,
- **Chapter Two** – information on energy costs and energy efficiency opportunities in metal casting,
- **Chapters Three through Twenty-four** - step-by-step best practices to save energy and reduce costs, and,
- **Appendices** – explanation on how energy is used in the industry and in various processes and foundry types 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 metal casting plants to participate in the ENERGY STAR Focus on Energy Efficiency in Metal Casting, a group of casting companies that work together to share best energy practices and to build unique and helpful energy management tools specific to the casting 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 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.

Metal casters have additional reasons to pay attention to energy efficiency. Energy can account for up to 9 percent of operating costs. That's 5 percent higher than the typical *operating profit* for a metal casting company![3] Energy efficiency improvements also reduce the energy cost per unit of product – a practical method for growing market share.

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 reputation by

- Actively managing energy;
- Adopting a structured 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 directly;
- 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.

[3] Personal conversation with Robert Eppich, 2014.

Chapter Two: Where to Look for Energy Savings

By looking strategically at how energy is currently used throughout the metal casting industry, energy managers can better assess where energy efficiency efforts will be effective. 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 metal casting energy is consumed as well as trends in energy consumption.

U.S. metal casting facilities mainly process iron, steel and aluminum. Processing consumes a considerable amount of energy. In 2011, the U.S. metal casting industry spent $1.3 billion on energy.

DID YOU KNOW?

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

How is this money spent?

- Energy costs typically account for 5-7% of operating costs in U.S. foundries (Robison, 2010) with heat treatment accounting for 50-70% of overall energy costs.
- Metal casters spent $424 million on purchased fuels and $908 million on electricity in 2011, according to the U.S. Census Bureau (U.S. Census, 2012).
- In 2010, 47% of the energy consumed was derived from natural gas, 39% from electricity, and about 14% from coke, breeze and other fuel consumption (EIA, 2013a).
- Coke and other fuel consumption typically account for 20% of fuel-derived energy (U.S. EPA, 2007; BCS, 2005).

Energy Consumption within the Metal Casting Industry

Annual energy consumption in MBtu was estimated using energy cost data and the respective unit prices for electricity, natural gas and petroleum coke. Energy intensity is also estimated by dividing annual energy consumption by production volume. These results are shown in Figure 1 and Figure 2.

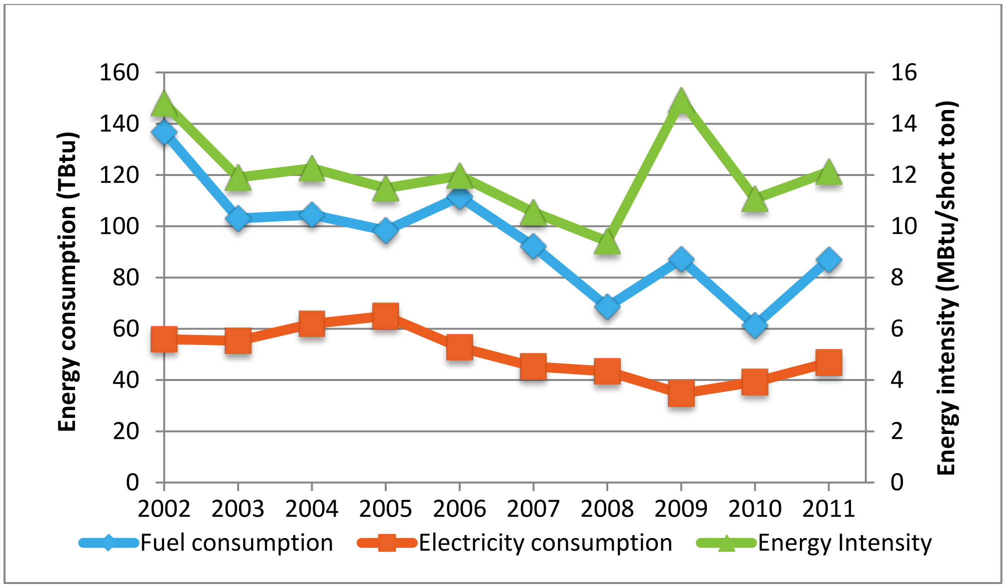

Figure 1: 2002-2009 Annual Energy Consumption in MBtu[4]
Source: U.S. Census, various years; EIA, 2012a; EIA, 2012b; EIA, 2013a; EIA, 2013b.

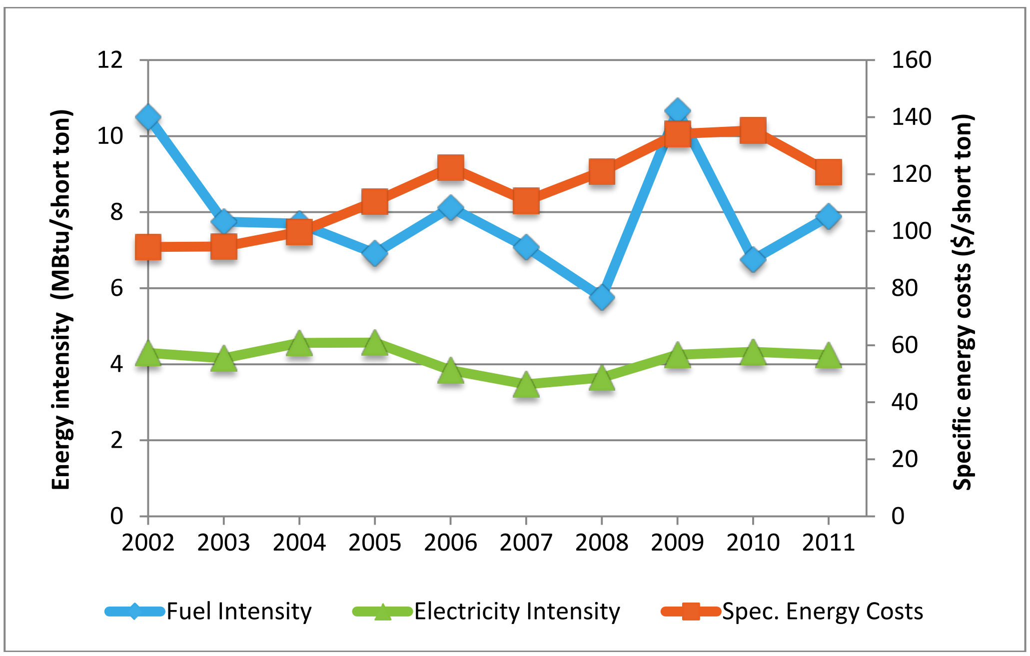

Figure 2: Estimated energy intensities and costs for the U.S. metal casting industry
Source: U.S. Census, various years; EIA, 2012a; EIA, 2012b; EIA, 2013a, EIA, 2013b.

[4] Figure 1 depicts estimated energy use in the U.S. metal casting industry. Electricity use in the period 2002-2005 is taken directly from the U.S Census Annual Survey of Manufactures. For 2010 the energy prices and fuel use breakdown is based on the latest MECS (EIA, 2013a). For all other years, fuel consumption is estimated based on the assumption that 20% of fuel-derived energy comes from coke consumption and 80% from natural gas consumption. The energy prices used are the average industrial energy prices (EIA, 2012b; EIA, 2013b). The energy content of fuels is based on high heating values (HHV).

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

Optimization of furnaces and furnace operation will yield major efficiency improvements because melting and holding account for the majority of total energy consumption. Energy can also be conserved by optimizing utilities such as air compressors, fans, motors, pumps and lights.

DID YOU KNOW?

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

Overall, these are the most effective areas for focus because energy demand in heating, ventilation and air conditioning (HVAC) strongly depends on local climate conditions. To illustrate, a foundry in the South has virtually no heating demand and may consume very little natural gas for space heating in comparison to foundries in the Midwest (Eppich, 2004).

Energy efficiency improvements in the metal casting industry are more likely to be completed when natural gas prices are high because about 50% of energy requirements are met by natural gas (BCS, 2005). Typical profit margins are below 4%, so volatile energy costs can significantly affect these margins (BCS, 2005; Monroe et al., 2008).

For information on energy use in specific types of U.S. foundries, please see Appendix B: Energy Use by Foundry Type (Iron, Steel & Aluminum).

Energy Efficiency Opportunities

Many of the energy efficiency measures discussed in this Guide require either a limited investment or none at all. Common plant systems are those that are found in most manufacturing plants regardless of the industry.

Energy efficiency measures are described below in Tables 1 and 2 by end-use category. Chapters Three through Twenty are organized according to these measures. 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 Tables 1 and 2 to be taken directly to these chapters. Refer back 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	Principles for developing energy management programs and systems
ENERGY STAR tools and resources	
Chapter 4: Motor Systems	
Create a motor management plan	Select and purchase motors strategically
Perform ongoing maintenance	Properly sized motors
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
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 casting, surface coatings or polishing	Sealings
Maintain proper seals	Reduce leakage through clearance reduction
Chapter 8: 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 tubes	Reduce lighting system voltage
Replace mercury lights with metal halide or high pressure sodium	Replace metal halide HID with high-intensity fluorescent lights
Use daylighting	Use LED lighting
Chapter 9: 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
Employ solar air heating	Modify building reflection
Install low-emittance windows	

Chapter 10: Dust Controls	
Seal areas	Employ minimum effective draft
Automate dust collectors	Install adjustable speed drives
Maintain the differential pressure for dust collector	Use a differential pressure control system
Use minimum effective pressure for cleaning	

Table 2. Summary of energy efficiency measures specific to metal casting production.

Chapter 11: Process Chain Levels	
Switch off equipment in downtime	Bring down off-spec production rate
Make use of waste heat contained in furnace off-gas	Space heating with warm cooling water
Consider different melting technology and a fuel shift	Use inorganic binder materials for core-making
Buy molten metal instead of melting on-site	Use an on-site aluminum reclaimer
Use melting process controls	
Chapter 12: Furnace Operation	
Use clean scrap, avoid slag and dross formation	Dross removal
Furnace capacity utilization	Switch to low-firing mode when furnace door is open
In-situ metal quality check	Clean the furnace daily
Chapter 13: General Furnace Measures	
Correct the air-fuel ratio	Improve insulation
Place covers to avoid heat losses	Use recuperators
Use regenerators	Preheat metal loading
Use oxygen enrichment	
Chapter 14: Cupola Furnaces	
Evaluate the operating temperature	Reduce water input into cupola
Correct furnace shaft height	Make use of waste heat
Use plasma-fired cupolas	
Chapter 15: Electric Induction Furnaces	
Upgrade metal loading, package density	Keep a liquid heel
Evaluate idling time	Maintain cooling system control
Add carburizer in the beginning of the melting cycle	Use clean scrap, avoid sand and rust
Maintain furnace linings	Upgrade low frequency systems to medium frequency
Use high nominal furnace power	Reduce peak load and phase shift
Chapter 16: Electric Arc Furnaces	
Keep liquid heel	Use clean scrap, avoid sand and rust
Avoid hot spots	Optimize electrode positioning
Use foamy slag	Preheat scrap metal
Chapter 17: Crucible Furnaces	
Close lid on crucible	Install radiant panels
Install more efficient furnace type	
Chapter 18: Reverberatory and Stack Furnaces	
Preheat hearths	Install a molten metal circulation pump
Install more efficient furnace type	Use isothermal melting
Chapter 19: Ladles	
Keep lid on ladle	Replace refractory bricks with lining
Preheat with flameless micro-porous burners	Preheat with oxy-fuel burners
Equip with cold-start systems	Use new ladle technologies
Chapter 20: Improve Casting Yield and Decrease Scrap Generation	
Optimize gating and risering systems	Use insulated exothermic feeders
Reduce casting weight	Reduce the number of trials and errors
Introduce new casting technology	

Chapter Three: Energy Management Programs and Systems

In this chapter:	
Build an energy management program	Principles for developing energy management programs and systems
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 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 utility program. 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 electric utility to see what assistance it provides. Utilities sometimes offer specific programs for improving plant systems such as lighting or motors.

DID YOU KNOW?

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

- 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.

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.

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. It requires little or no up-front capital and can result in immediate savings.

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.

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.

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.

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 sized motors
Automate motors	Motor Labeling
Correct power factor	Use adjustable speed drives
Use soft starters	Minimize voltage imbalances

Considering energy efficiency improvements to motor systems 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.

1. Locate and identify all applications of motors in a facility.
2. Document the conditions and specifications of each motor in a current systems inventory.
3. Assess the needs and the actual use of the motor systems to determine whether or not motors are properly sized and how well each meets the needs of its driven equipment.
4. 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.
5. 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.

If a motor is replaced with a more efficient one, it is possible to achieve energy savings of 5-10%.

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 changes.

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 sized motors.** Replacing oversized motors with properly sized motors saves U.S. industry, on average, 1.2% of total motor system electricity consumption.
- **Motor labeling.** Motors not in use should be 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 (ASD's).** 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^{SM} Campaign suggests the following key activities for a sound motor management plan (MDM, 2012):

1) Create a motor survey and tracking program.

2) Develop guidelines for proactive repair/replace decisions.

3) Prepare for motor failure by creating a spare motor inventory.

4) Develop of a purchasing specification.

5) Develop of a repair specification.

6) 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 more 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 and other organizations have 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.

CASE STUDY: In the SpA Torbole casting facility (Italy), 90 motors were replaced with new high efficiency motors. Electricity consumption decreased by 310 MWh/a. The total investment was about $96,000 (80,000 Euros), and the payback period was about 5 years (Caballero, 2011).

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 sized 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.

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 (24/X), 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.

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, 2008). Therefore, automatic shutdown of motors that would otherwise be left idling can reduce energy costs without requiring high investment.

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, 2008). 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.

Use adjustable speed drives (ASDs).[5]

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%.

[5] 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.

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 motor operating 8,000 hours per year, a correction of the voltage unbalance from 2.5 to 1% will result in electricity 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 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, 2012).

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, 2003b). 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

Foundries use compressed air in a variety of applications such as powering tools, filling core boxes, transporting sand, blowing of molds and core boxes and others. 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, 2003b).

Energy Savings Checklist: Compressed Air

Compressed air is often the most expensive form of energy available in a plant because of the poor efficiency. However, there are a number of 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 VFD?	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 BPUs 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.

Pressure Reductions

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

- **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.

- **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 save 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, shortening motor life and increasing 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 opened 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).

CASE STUDY: After a compressed air system evaluation project, Ohio Aluminum Industries cut annual energy costs by $73,200 while reducing their electricity consumption by 716,000 kWh. The payback period was slightly more than 1 year. The discharge header piping was corrected by replacing the 3-inch header with a 5-inch pipe and the 90° crossing header with a 30° directional entry pipe. By separating the air pressure demand of core machines from the air pressure demand of the rest of the plant, it was possible to stabilize and lower the pressure. The system improvement also included leak repair. Additionally, the performance in core machines improved due to higher air pressure stability. This has shortened the cycle time and resulted in improved product quality (U.S. DOE, 2003c).

- *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. In the period 2003-2012, 23 recommendations to limit pressurized air to the minimum required were implemented in U.S. foundries. The average payback period was 1 month (IAC, 2012).

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.

CASE STUDY: Daily energy consumption reports, prepared by an energy supplier, allowed Bradken Foundries, in Ipswich (Australia) to identify a peak in energy consumption on a day without production. Further investigation revealed the existence of several leaks in the compressed air system. Leak repair resulted in annual savings of 107 MWh (Queensland Government, unknown date).

- 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 four months (IAC, 2012).

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.

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.

Continuing Programs

Leak detection and correction programs should be ongoing efforts.

CASE STUDY: The elimination of over 100 leaks in various systems at Harrison Steel in Attica, Indiana, reduced annual energy costs by $105,600. The payback time was estimated at 18 months (FMT Staff, 2010).

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, 2012).

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 1.4 years (IAC, 2012).

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, 2012), 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. (1992), 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., 2005).

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. 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. According to Galitsky et al. (2005), gas engine-driven compressors currently account for less than 1% of the total air compressor market.

Chapter Six: Fan Systems

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

Considerable opportunities exist to upgrade the performance and improve the energy efficiency of fan systems. For fans in particular, concern about failure or underperformance have led to many fans being oversized for their particular application (U.S. DOE, 2003b). 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.

- **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, 2003b). Additionally, the U.S. DOE recommends the following important elements of an effective fan system maintenance program (U.S. DOE, 2003b):

- *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. Such build-up can create imbalance problems that can reduce performance and contribute 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, 2003b). 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, 2003b):

- 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.

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., 2005).

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, 2003b).

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 casting, surface coatings or polishing	Reduce leakage through clearance reduction
Maintain proper seals	

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.[6]

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).	

[6] The U.S. DOE's Industrial Technologies Program 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, 2006b). 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%.[7]

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 lead 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.

[7] Ibid.

- **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, 2006b; U.S. DOE, 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.

According to Caballero (2011), it is not uncommon for foundries to keep the cooling pumps active overnight even when the furnace is switched off. An iron foundry operating 2 medium frequency (350 Hz) induction furnaces with 2.4 ton capacity for 2 shifts, 5 days a week, switched off the pumping equipment when not required. Turning off the pumps (40 kW nominal power) for 8 hours a day saved about 100 MWh/year. Depending on furnace operation times, this management practice could lead to saving several thousand dollars a year with negligible investment costs.

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, 2001b).

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[8]. 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.

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[8] 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.

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, 1996a). 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, 2006b). An additional benefit of impeller trimming is a decrease in pump operating and maintenance 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 results in payback periods of only 1.8 to 2.3 years (IAC, 2012).

An energy efficiency improvement project at Harrison Steel in Attica (Indiana) include installing ASDs at its well pumps. With the use of ASDs, the pumps slowed down the pump to control the water pressure instead of using pressure-demand valves to throttle the pump. The use of ASDs decreased the annual electricity costs by $16,800. The installation cost was $25,000 (FMT Staff, 2010).

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 lead 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 measure 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, $1200, would be paid back in 5 months by energy savings of $2700 (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 sealings.

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 in. (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: 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 tubes	Reduce lighting system voltage
Replace mercury lights with metal halide or high pressure sodium	Replace metal halide HID with high-intensity fluorescent lights
Use daylighting	Use LED lighting

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. High-intensity discharge (HID) sources are used for the former, including metal halide, high-pressure sodium and mercury vapor lamps. Fluorescent, compact fluorescent (CFL) and incandescent lights are typically used for task lighting in offices.

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

Table 3. Performance comparison of lighting sources

Lamp	Efficacy (Lumen/watt)	Typical Lifetime (Hours)	Applications
Incandescent	5–20	1,000	Task
Halogen	<24	1,000	Task
CFL	20–70	8,000–15,000	Task
Fluorescent T-12	60	20,000	Any
Fluorescent T-8	80–100	20,000	Any
Fluorescent T-5	80–105	20,000	Any
Mercury Vapor	30-50	60,000	Hi-Bay
Induction	80	100,000	Exterior, Hi-Bay
High Pressure Sodium	85–150	10,000–50,000	Exterior, Hi-Bay
Metal Halide	70–115	20,000	Hi-Bay
LED	10–120	50,000	Task

Values are typical performance. Performance of individual products may vary. The performance of fluorescent lamps assumes the use of an electronic ballast. Technology development may change the future performance of these specific lighting technologies.

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 tubes.** Using T-8 lamps can save up to 30% in energy savings.
- **Reduce lighting system voltage.** Voltage controllers reduce voltage and save energy in HID or fluorescent lighting systems without losing light.
- **Replace mercury lights with metal halide or high pressure sodium lights.** Metal halide or high pressure sodium lights save up to 60% in energy.
- **Replace metal halide HID with high-intensity fluorescent lights.** High-intensity fluorescent systems yield 50% electricity savings over standard metal halide HID.
- **Use daylighting.** Increasing levels of daylight within rooms can reduce electrical lighting loads by up to 70%.
- **Use LED lighting.** LED lights use far less energy to emit the same lumens of light.

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 year (IAC, 2012).

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.

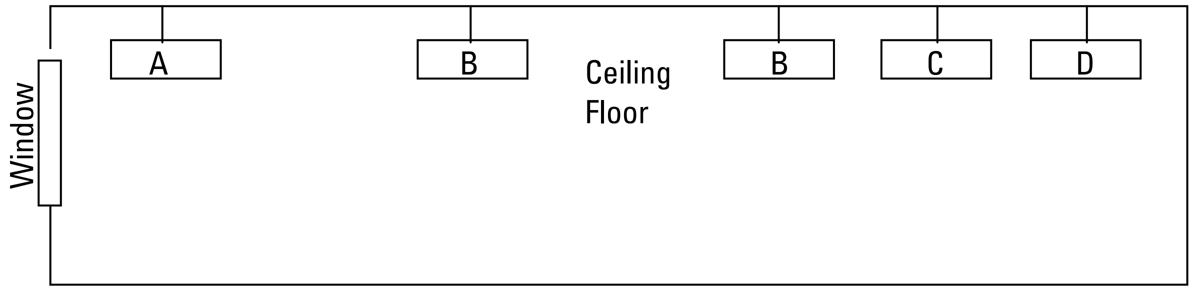

Figure 3. Lighting Placement and Controls.

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 uses about 40 W, while LED signs may use only about 4 W to 8 W, reducing electricity use by 80 to 90%. A 1998 Lighting Research Center survey found that about 80% of exit signs being sold use LEDs (LRC, 2001). The lifetime of an LED exit sign is about 10 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 starting at around $20. The U.S. EPA's ENERGY STAR program website (http://www.energystar.gov) provides a list of suppliers of LED exit signs.

Tritium 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 $150 per sign.

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., 2005). 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 tubes.

In industry, typically T-12 tubes have been used. T-12 refers to the diameter in 1/8 inch increments (T-12 means 12/8 inch or 3.8 cm diameter tubes). The initial output for these lights is high, but energy consumption is also high. They also have extremely poor efficacy, lamp life, lumen depreciation, and color rendering index. Because of this, maintenance and energy costs are high. Replacing T-12 lamps with T-8 lamps (smaller diameter) approximately doubles 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., 2005).

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., 2005). 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.

Replace mercury lights by metal halide or high pressure sodium lights.

Where color rendition is critical, metal halide lamps can replace mercury or fluorescent lamps with an energy savings of 50%. Where color rendition is not critical, high pressure sodium lamps offer energy savings of 50 to 60% compared to mercury lamps (Price and Ross, 1989). A plant wide energy assessment at the Ford Cleveland Casting Plant (CCP) in Cleveland, Ohio, identified the potential for 282,000 kWh savings in electricity consumption by replacing the 400-watt mercury lights with 360-watt metal halide lights. The payback period was estimated to be 3.7 years (U.S. DOE, 2003a).

Replace metal halide HID with high-intensity fluorescent lights.

Traditional HID lighting can be replaced with high-intensity fluorescent lighting. These new systems incorporate high-efficiency fluorescent lamps, electronic ballasts and high-efficacy fixtures that maximize output to the work plane. Advantages to the new system are many. They have lower energy consumption, lower lumen depreciation over the lifetime of the lamp, better dimming options, faster start-up and restrike capability, better color rendition, higher pupil lumens ratings and less glare (Martin et al., 2000). High-intensity fluorescent systems yield 50% electricity savings over standard metal halide HID. Dimming controls that are impractical in the metal halide HIDs can also save significant energy. Retrofitted systems cost about $185 per fixture, including installation costs (Martin, et al., 2000). In addition to energy savings and better lighting qualities, high-intensity fluorescents can help improve productivity and have reduced maintenance costs.

An energy assessment conducted in a ferrous foundry in Lufkin Industries, Texas, revealed that lighting was responsible for one third of the foundry's overall energy use. The lighting systems used consisted of high wattage, metal halide, and high pressure sodium (HPS) lamps for high bay installations and magnetic ballasts and T-12 lamps for low bay installations and office buildings. By replacing all fixtures (complete retrofit) with more efficient ones (T_5HO for high bay and T8 fixtures for low bay installations and office areas) and placing occupancy controls, the company saved 300,000 kWh of energy, about 9% of annual energy use. The decrease in electricity use would save the company $200,000 annually. The investment cost would be $800,000. Lufkin Industries qualified for a rebate of $290,000 (Modern Casting, 2011).

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, 2001; 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/).

Use LED lighting.

Light Emitting Diode (LED) lights receive attention as the next generation of energy-efficient lighting. In typical florescent lighting, electrical arcs are used to excite mercury and phosphorous compounds, which then emit light. On the other hand, 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 light fixtures (such as T-8s) are emerging on the market, and prices for LED lighting are coming down rapidly.

Chapter Nine: 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
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 replacement.** 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.

- **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 and 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, next controls, then testing, adjusting and balancing, then 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.

Adjust non-production setback temperatures.

Setting back building temperatures (that is, 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 destratify 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.

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. 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 Ten: Dust Control

In this chapter:	
Seal areas	Employ minimum effective draft
Automate dust collectors	Install adjustable speed drives
Maintain the differential pressure for dust collector	Use a differential pressure control system
Use minimum effective pressure for cleaning	

An average emission system in a foundry consumes about 20-25% of the total energy use (Gigante, 2011). Many metal casting facilities have not improved their air capture and baghouse systems since they were first installed in the 1970s. To ensure the proper operation of dust collectors, pulse air jets, mechanical shakers, bags and cartridges need to be inspected regularly, fabric bags need to be sized correctly and fitted properly, and all the worn fabrics should be replaced (MEMS, 2010).

Best Practices for Dust Control

Significant energy savings can be realized when the motors used to drive the dust collectors shut down when not needed. Energy efficiency strategies for dust collectors according to Bayne (2011) can ensure efficient operation of baghouse filters at the minimum energy consumption.

- **Seal areas.** The existence of leaks will increase draft requirements.

- **Employ minimum effective draft**. Extra draft employment will accumulate more dust on the filters resulting in increased wear of ducts and bags. Use dampers and/or variable speed fans to control the draft.

- **Automate dust collectors.** Ensure dust collectors do not operate when not needed.

- **Install adjustable speed drives.** Resizing and slowing down fans that are too big will result in energy savings. Installing a variable frequency driver (VFD) will require higher capital investment but will result in more energy savings.

- **Maintain the differential pressure for dust collector.** The differential pressure is the difference between the dirty and clean side of the bags. Maintain between 4 to 5 inches of water. For the efficient operation of dust collectors, filters should be relatively dirty or have a dust cake.

- **Use a differential pressure control system.** Differential pressure controls are helpful for cleaning systems. Differential pressure should range between 4 and 5 inches of water when a fan driven dust collector is used.

- **Use minimum effective pressure for cleaning.** When a compressed air jet pulse cleaning system is used, employ the minimum effective pressure, which usually ranges between 60 and 70 psi, and not more than the manufacturer’s recommended pressure when a pneumatic shaker is used. Employ a rather short pulse to shake the extra dust off in the case of compressed air blow down systems.

Chapter Eleven: Process Chain Level

In this chapter:	
Switch off equipment in downtime	Bring down off-spec production rate
Make use of waste heat contained in furnace off-gas	Space heating with warm cooling water
Consider different melting technology and a fuel shift	Use inorganic binder materials for core-making
Buy molten metal instead of melting on-site	Use an on-site aluminum reclaimer
Use melting process controls	

When evaluating the whole process chain in a casting facility, saving opportunities are explored to their full potential. If waste heat can be used at a different location within the facility, the combination of two devices can lead to higher savings than the individual and independent optimization of the two (Caballero, 2011). Therefore, cross-cutting equipment such as motors and pumps should also be included when exploring possible saving measures.

Best Practices for Energy-Efficient Process Chain Levels

- **Switch off equipment in downtime.** When equipment is idling, in standby or not required, a considerable amount of energy may be consumed, leading to energy savings at no extra cost.

- **Bring down off-spec production rate.** Bringing down the defect rates has beneficial effects, i.e. higher productivity, lowered labor and energy cost.

- **Make use of waste heat contained in furnace off-gas.** Waste heat can be used for preheating combustion air and scrap metal, hot water generation, steam generation or power generation.

- **Space heating with warm cooling water.** Furnaces, die casting machines, air compressors and other machines lead to the production of warm water at medium temperatures that could be used for space heating or for preheating hot tap water.

- **Consider different melting technology and a fuel shift.** Depending on the current and expected future prices for electricity and fuels, it might be worthwhile to shift from fuel-fired furnaces to electric furnaces, or vice versa.

- **Use inorganic binder materials for core-making.** Some of the benefits of replacing organic with inorganic binders are: Improved working conditions due to a cleaner process, increased casting quality, production rate (casting equipment can be cooler), and energy savings in off-gas treatment.

- **Buy molten metal instead of melting on-site.** Significant amounts of energy could be saved by integrating metal casting facilities into primary metal production plants (smelting plants).

- **Use an on-site aluminum reclaimer.** On-site dross reclaiming will avoid costs that are eventually passed to the dross producer such as container and transportation charges to and from the dross processing facility, cost for dross processing and landfill costs of salts used in the recovery process.

- **Use melting process controls.** Avoiding metal overheating due to precise temperature monitoring will result in less energy use, reduced damage of furnace lining and less quality problems as some alloys in the melt can burn out at high temperature or with time.

Switch off equipment in downtime.

Energy can be saved by simply turning off equipment while it is not needed. When equipment is idling, in standby or not required, a considerable amount of energy may be consumed. A high-pressure die casting machine, consumes about 14 kW while idling (Eppich, 2004). Other equipment has much smaller standby consumption, e.g. the cooling water pump of a shut off furnace. Nonetheless, switching off equipment in downtime leads to energy savings at no extra cost.

Bring down off-spec production rate.

The production of metal casting is a complex process involving the control and understanding of material inputs and manufacturing variables. A small amount of non-conforming castings may not be avoidable, which can lead to rework and scrapped product. The attitudes about which defect rates (scrap rates) are acceptable have proven to be very diverse. Eppich (2004) gives an extreme example of one foundry's dissatisfaction with a 0.5% rate of defective castings, while another considered its rate of 25% acceptable. This underscores the differences in comparing and benchmarking different types of operations but also the importance of individual aspiration and what the management considers acceptable and desired practice. Clearly, benchmarking and performance goal setting are critical best practices.

Scrap rates may be improved by finding and eliminating the cause of imperfections. Improvements might be reached at low cost by optimizing the pouring procedure and temperature control. Bringing down the defect rates has beneficial effects, i.e. higher productivity, lowered labor and energy cost.

CASE STUDY: At Pennex Aluminum Company in Wellsville (Pennsylvania), the utilization of waste heat gases that exited the homogenizer furnace at an average temperature of 500°F (260°C), resulted in annual energy savings of 23,994 MMBtu. With investments of $49,000, the payback period was 6 months (U.S. DOE, 2006a).

Make use of waste heat contained in furnace off-gas.

Furnaces produce considerable amounts of waste heat that may or may not be useful for other purposes in or outside the facility. For furnaces powered by fuels, i.e. cupolas, crucible and reverberatory furnaces, it is estimated that about 30% of the energy input is turned into waste heat at a temperature level above 284°F (140°C) (Pehnt et al., 2010). Waste heat can be used for several purposes; preheating combustion air and scrap metal (see Chapter 13 on 'Recuperators', 'Regenerators' and 'Preheat metal loading'), hot water generation, steam generation or power generation. Although very costly, it can even be exported to a nearby external consumer.

CASE STUDY: A German foundry (Georg Fischer Automobilguss GmbH in Singen) producing iron components for the auto industry at an annual capacity of 220,000 tons, exports high temperature waste heat to a neighboring industrial consumer (Bettinger and Kenzler, 2010). Iron scrap is melted in a cupola furnace, which produces large quantities of waste heat. This heat is transferred via circulating thermal oil at 536 °F (280 °C) to a Maggi food processing plant, owned by Nestlé. The investment costs for the metal casting and food processing facilities totaled about 7$ million and was partially subsidized by the German ministry of the environment (IfG, 2008). The benefits of this off-site waste heat use include the reduced cooling need for the foundry, the replacement of up to two-thirds of Nestlé's internal natural gas consumption (50,000 MWh/year) for steam generation, and an annual saving of about 12,000 tons CO_2. (IfG, 2008; Bettinger and Kenzler, 2010; Pehnt et al., 2010). This measure is only appealing to foundries that operate melting furnaces continuously at large scale, with continuous external demand for heat.

Space heating with warm cooling water.

Foundry equipment often needs to be cooled with water. Furnaces, die casting machines, air compressors and other machines lead to the production of warm water at medium temperatures that could be used for space heating or for preheating hot tap water. Heat will need to be transferred from a heat source that needs to be cooled during operation; therefore it has to be guaranteed that the heat sink can always absorb the heat flow.

The largest heat sources for warmed up cooling water are cupolas, followed by induction and electric arc furnaces. In case of a cupola furnace, the cooling water takes up to 10-15% of the energy input. Electric induction furnaces also generate electric losses in the coil, which may reach 20% of the input power and need to be cooled away with water (Foundrybench, 2011b). Due to the rather low temperature level of the cooling water, the waste heat is of low quality. If the outlet temperature of a cooling loop is not sufficiently high for further use, it could be increased, for example by decreasing the coolant flow rate. As equipment is often cooled more than needed, specifications should be checked and the cooling system should be adapted (IfG, 2008).

CASE STUDY: A foundry in Hundhausen, Germany, implemented a water circuit that distributes warmed up cooling water from an induction furnace to several delivery points where the heat is used for space heating. The temperature of the cooling water at the coil outlet was raised to 149°F (65°C). The water returned to the furnace at a temperature of 122°F (50°C). The installed final system saves about 70 to 80% of the former heating oil use. The investment cost was equivalent to roughly $1,700,000, and the payback period was estimated at 6 years.

Consider different melting technology and a fuel shift.

This measure primarily aims at saving money and delivered energy rather than primary energy consumption. Depending on the current and expected future prices for electricity and fuels, it might be worthwhile to shift from fuel-fired furnaces to electric furnaces, or vice versa.

Small foundries with low production can benefit from more flexible electric melting furnaces. Bundaberg Metal Industries in Queensland, Australia, replaced their cupola with an electric induction batch furnace. Before the shift, the foundry was bound to melt larger amounts every four days. The three-day break was required to produce sufficient amounts of molds, which would be filled in only one day. Switching to an electric induction furnace generates a number of benefits: a more continuous process melting 3-4 tons/day leads to an even product flow through the plant. Stockpiles of coke and lime as well as the space for storing the large number of casting molds are no longer needed. Electric furnaces cause fewer emissions and lead to better indoor air quality (Cleaner Production Manual for the Queensland Foundry Industry, 1999). Payback times for this measure strongly depend on prices for fuel and electricity and have to be evaluated individually.

Use inorganic binder materials for core-making.

Quite often chemically bonded cores are used in green sand mold making, which are typically made from organic binders. With the use of conventional organic binders, many unwanted emissions like amines, pyrolysis products and smoke, can be produced that need to be treated before released into the atmosphere (JRC/IPTS, 2005). Due to increasing emission control regulations, lower emission technologies have been developed such as new inorganic binders for core making that are basically emission-free.

The benefits of replacing organic with inorganic binders are: Improved working conditions due to a cleaner process, increased casting quality, increased production rate (casting equipment can be cooler), and energy savings in off-gas treatment.

Buy molten metal instead of melting on-site.

Significant amounts of energy can be saved by integrating metal casting facilities into primary metal production plants (smelting plants). Buying the metal in liquid form will minimize the need for extensive melting equipment. However, only a casting process with a large enough production capacity may be integrated into a smelting plant. The transportation of liquid ferrous metals is not feasible for destinations outside a production site; therefore, this measure is limited to the aluminum industry and typically only plants using secondary alloys.

Just-in-time delivery by trucks or train can replace the melting on site (Giesserei, 2010). Only holding melted metal is required, and no emissions are caused on site. The U.S. Department of Energy is testing a complete scrap-to-caster system. Aluminum scrap is melted in a central highly efficient isothermal electric resistance furnace and is then delivered to the casting facilities via trucks. The advantage is that the reverberatory furnaces that are currently in use (efficiency 20-45%) can be replaced by a central furnace with high thermal efficiency running on electricity (U.S. DOE, 2011). To transfer the aluminum to the casting facility, transportable electric ladles have to be constructed. It is expected that modern conduction-heated holding vessels at the casting facility will only consume 10 Btu per ton per hour instead of today's typical energy consumption in industrial holding vessels of about 30-40 Btu/ton/hour (U.S. DOE, 2011). The long holding times during transport weaken the beneficial effect of melting in a central highly efficient furnace.

Use an on-site aluminum reclaimer.

Aluminum foundries and aluminum melters generate rich metallic skimmings and drosses. The typical aluminum content in untreated dross averages between 85 and 90%. Fluxing can recover about half of the aluminum if done aggressively. With further dross processing at on-site metal reclaiming equipment or outside the plant at a dross processing facility, another 30-60% of the contained aluminum can be recovered (Groteke and Neff, 2008).

Reclaiming the dross aluminum values at the plant site is a great opportunity for cost reduction for any aluminum foundry. On-site dross reclaiming avoids costs associated with sending it off-site such as container and transportation charges, cost for processing, and landfill costs of salts used in the recovery process (Groteke, 2000; Groteke and Neff, 2008). In addition, when the metal reclaimed at the foundry site is returned to the furnace in a molten state, additional cost savings can be achieved due to decreased melting requirements.

Previously commercially available metal reclaiming equipment required a high capital investment and were not installed in small aluminum foundries operating crucible or reverberatory furnaces. More recent designs can recover aluminum from small quantities of skimmings and dross and minimize the amount of material for disposal. Aluminum reclaimer units can recover aluminum from dross quantities ranging from 10 lb. (10 kg) to 500 lb. (225 kg) and recover up to 80% (typical recovery rate of 60-70%) of the aluminum content (Groteke and Neff, 2008). The recovered metal can be drained into an ingot pan or transferred directly to the melting furnace to achieve considerable energy savings. About 40-45% of the energy needed to melt a cold ingot can be saved when the ingot is transferred back at a temperature of 800°F (425°C) while with molten transfers all melting energy can be saved (Groteke and Neff, 2008). About twenty aluminum reclaiming units have been installed in the U.S. (U.S. DOE, 2009).

Use melting process controls.

With the use of melting process control, the melt cycle can be managed more efficiently as the energy required to bring the bath to pouring temperature is accurately controlled. Avoiding metal overheating due to precise temperature monitoring will result in less energy use, reduced damage to the furnace lining and fewer quality problems as some alloys in the melt can burn out at high temperatures or with time. Metal overheating practices lead to higher heat losses. A 10% higher molten-metal temperature results in 33% higher radiated heat losses (Eckert, 2007).

Chapter Twelve: Furnace Operation

In this chapter:	
Use clean scrap, avoid slag and dross formation	Dross removal
Furnace capacity utilization	Switch to low-firing mode when furnace door is open
In-situ metal quality check	Clean the furnace daily

Many energy and cost saving measures apply to most furnace types. General advice on furnace management is given in this section of the Guide. Specific advice addressing individual furnaces is provided in subsequent sections.

Best Practices for Energy-Efficient Furnace Operation

- **Use clean scrap metal, avoid slag and dross formation.** The production of slag and dross is highly unfavorable and should be kept to a minimum. Bringing down metal losses by 2 percentage points makes it possible to save 2% in material costs and 2% in energy costs for melting/holding.
- **Dross removal.** Dross build-up over ½ inch acts as an insulator, forcing the furnace to work harder.
- **Furnace capacity utilization.** Overcharging the furnace results in temperature swings and increased build-up at the furnace floor with the furnace not being able to melt at its rated capacity. Operating reverberatory furnaces at the designed capacity and charging metal at a rate of ¼ of their hourly melt rate every 15 minutes will avoid overcharging.
- **Switch to low- firing mode when furnace door is open**. Operating the furnace at low firing mode when the furnace door is open can result in significant energy savings.
- **In-situ metal quality check.** Speeding up the process steps between melting and pouring can conserve energy.
- **Clean the furnace daily.** Cleaning the furnaces on a daily basis will reduce the accumulation of oxides in the furnace. Oxide is dense and absorbs heat from the metal.

Use clean scrap metal, avoid slag and dross formation.

Whenever metal is heated to high temperatures, the pure metal starts to react with oxygen resulting in the formation of slag (for ferrous metals) or dross (for aluminum). As slag and dross cannot be used in casting, all oxidized metal is lost. Slag and dross formation consumes heat in the melting process and blocks furnace capacity (BCS, 2005).

The production of slag and dross is highly unfavorable and should be kept to a minimum. By bringing down metal losses by 2 percentage points, it is possible to save 2% in material costs and 2% in energy costs for melting/holding. Metal loss can be measured by relating the amount of charged solid metal and the obtained liquid metal to the amount of slag produced.

Aluminum oxide and pure aluminum have about the same density. Therefore the two substances do not separate readily; the dross on top of aluminum melts contains about 60-65% of metallic aluminum. Dross is usually sent for aluminum recovery. Therefore, high dross generation is costly and causes additional energy consumption on several levels (Eppich, 2004).

Slag formation rates in melting ferrous metals are generally lower and may even be beneficial. Iron is melted at a much higher temperature than aluminum and therefore heat losses by radiation are much larger. A layer of slag on top of the melt brings down heat losses. Nevertheless, metal loss should also be kept low in ferrous metal casting.

The main recommendations for minimizing metal loss include these actions.

- *Keep the melting and holding period as short as possible*. The less time the metal has to react, the lower slag formation is. Stirring and pumping can increase melting rates and decrease the melt cycle.

- *Minimize turbulence*. Movement caused by the direct impingement of burner flames on the melt enhances dross formation as it breaks the oxide film formed on the melt surface and exposes new molten metal to oxidizing gases. (Groteke and Neff, 2008).

- *Avoid excessive stirring.* When metal is stirred during melting and holding to increase material and temperature homogeneity, excessive stirring should be avoided, as it will increase the slag/dross formation.

- *Use clean and dry charge.* Any sand that sticks to the scrap will turn into slag during melting. Heating sand to the melting point of iron consumes about 450 kWh/ton. This means that heating sand consumes the same amount of energy as melting iron. With a typical loading of 55 lb. (25 kg) sand per ton of iron this equates to an extra energy use of at least 11.4 kWh/ton. Sand should be cleaned from foundry returns and gating systems. Less sand contamination will result in reduced slag formation and slag minimization will reduce scrap rates. Removing 150 lb. of sand per shift will reduce annual costs by $2,500. The return on investment should be immediate (Focus on Energy, 2006).

Rust has the same negative effect as sand. Rust is oxidized metal and produces slag instead of molten metal. Furthermore, rust has very poor electrical properties, and it will reduce the coupling between coil and metal loading in electric induction furnaces (Caballero, 2011). Rust can increase the energy consumption rather dramatically. A study on an induction batch melter shows that rusty steel scrap requires over 1,090 kWh/ton, instead of 762 kWh/ton for clean scrap (capacity over 730 lb.). Exact data on rust content and other parameters remains undisclosed (ETSU, 2000).

As a rough rule of thumb, every 1% of contained contaminant (organics and moisture) will result in 2% melt loss (Groteke and Neff, 2008). Additional practices for minimizing metal loss include these actions.

- *Use charge materials with high mass-to-surface area*. Charge with high mass-to-surface area such as sows and ingot shapes are characterized by low melt losses. On the other hand, charge with low mass-to-surface area such as gates and runners will increase melt losses due to the increased surface. For example, charging turnings, borings and machining chips, charges with high surface area, will result in 10-15% dross/melt loss. (Groteke and Neff, 2008).

- *Employ as low holding temperatures as possible*. Holding temperatures significantly affect dross formation. Lowering the holding temperature by 25°C can considerably reduce dross generation. (Groteke and Neff, 2008).

- *Proper air to fuel ratio in burners.* Oxidizing conditions will increase dross formation when the oxide film on the melt surface is ruptured and new melt is exposed.

Some additional measures that should be pursued to minimize dross formation are: use of flux to cover the melt, use of covers in furnaces, proper maintenance of furnace doors, maintaining positive pressure in reverberatory furnaces, and keeping the molten transfer to a minimum to avoid additional turbulence (Groteke and Neff, 2008).

When the formed slag comes in contact with the refractory lining inside the furnace that is cooler than the slag's melting point, it cools down and sticks to the lining (build-up), increasing the wall thickness and lowering energy efficiency. According to Naro (2009), it is not uncommon for a 5 ton induction furnace to accumulate a 6 inch build-up after operating for one week. In this case, the furnace capacity is reduced to 4.5 tons.

Apart from these factors, slag formation is determined by the type of furnace and the purity of the charged metal. Reverberatory furnaces have a higher oxidization rate than electrically heated furnaces. For iron, metal loss may range from 1-2% for induction furnaces to 3-12% for cupola furnaces. Melting aluminum in reverberatory furnaces and gas-fired crucibles leads to a metal loss of 4-6%, while electric reverberatory furnaces only produce 1-2% dross (BCS, 2005). Isothermal melting produces less than 1% dross (U.S. DOE, 2009).

Dross removal.

Dross build-up over ½ inch thickness acts as an insulator, forcing the furnace to work harder. Remove the dross build-up when it is thicker than ½ inch. If a daily dross removal is not enough, the reason for increased dross generation should be investigated (White, 2004).

Furnace capacity utilization.

A furnace should be operated at its designed capacity. If a melting furnace is charged with only a small amount of metal, the relative share of energy that is spent on heating up the furnace material increases, which brings down the specific melting efficiency. Overloading will elongate the melting process, and as the process takes longer, more heat is lost to the environment. Furthermore, an increased heating rate may cause a disproportional increase in flue gas flow, which again may impair furnace efficiency.

Operating reverberatory furnaces at the designed capacity and charging metal at a rate of one quarter of the hourly melt rate every 15 minutes will avoid overcharging. Overcharging the furnace results in temperature swings and increased build-up at the furnace floor with the furnace not being able to melt at rated capacity (White, 2004).

Moreover, optimized planning of furnace and casting capacity utilization and production will allow tapping directly from the melting furnace, reduce the need for holding furnaces, and result in lower energy use and operating costs.

Switch to low- firing mode when furnace door is open.

Opening doors and/or covers should always be minimized. Operating the furnace at low firing mode when the furnace door is open can result in significant energy savings.

CASE STUDY: Pennex Aluminum foundry in Wellsville (Pennsylvania) operated the burners of the melting furnace on full firing mode when the furnace door was open. The furnace door would be open every day for 32 minutes during the charging of the metallic load, 20 minutes for the agitation process, and another 15 minutes for the skimming process. By switching the burners to low firing mode, annual energy costs were reduced by $67,000. Operating the furnace at low firing mode required only a minimal labor cost of $75 per day. The payback period was 30 days (U.S. DOE, 2006a).

In-situ metal quality check.

Speeding up the process steps between melting and pouring can conserve energy. Usually, the metal quality needs to be monitored and adjusted after melting. Regular practice involves taking a sample for testing. This procedure takes time during which the molten metal continually needs to be heated and the metal properties might even change again. Keeping one ton of liquid iron at constant temperature in a holding furnace for one hour costs €0.5 in Germany (> $0.6) (Tanneberger, 2010).

Holding times can be shortened by measuring metal properties in-situ (BCS, 2005). One way of measuring the metal quality directly in the furnace is offered by Laser Induced Breakdown Spectroscopy (LIBS). A LIBS system was installed for testing at the Commonwealth Aluminum plant in Ohio in 2003. About 30-60 minutes of holding time was saved that is usually spent waiting for probing and evaluation (de Saro at al., 2005).

An inquiry of a German manufacturer revealed that these systems have high installation costs. The equipment contains an expensive laser and optical lenses. A complete system that can measure inside a furnace from a distance of 10-26 feet (3-8 meters), costs about $100,000-$120,000. Operational and maintenance costs are about $1,200 a year (Scholz, 2012). The payback period for a facility with a 150,000 ton annual production and a 30 minutes reduction in holding times, is estimated to be less than 3 years.

Clean the furnace daily.

Cleaning the furnaces on a daily basis will reduce the accumulation of oxides in the furnace. Oxide is dense and absorbs heat from the metal. Great care is important as over-fluxing can reduce the refractory lifetime (White, 2004).

Chapter Thirteen: General Furnace Measures

In this chapter:	
Correct the air-fuel ratio	Improve insulation
Place covers to avoid heat losses	Use recuperators
Use regenerators	Preheat metal loading
Use oxygen enrichment	

Any measure that minimizes waste heat flows improves the energy efficiency of a furnace. Furthermore, energy can be conserved by making use of waste heat in preheating or by simply lowering the operating temperature.

Opportunities for Energy Efficiency

By looking at the energy flows in a furnace, potential measures for saving energy can be determined. Any heat that is transferred to the environment instead of the charge is wasted heat.

Major losses occur due to:

Start-ups, as the furnace material needs to be heated along with the metal

- Off-gassing, as heat is lost with the hot air that leaves the furnace (forced convection).
- Radiation, the hot metal and furnace surface radiate heat to the environment.
- Conduction, the furnace may need to be cooled from the outside, depending on temperature and furnace material.

Furnaces require a metering system to allow for proper measurement in order to determine the appropriate oxygen ratio.

Minor losses are due to the temporarily opening of the furnace hearth, e.g. during addition of metal or removal of slag/dross. Heat contained in slag or dross could be recovered; however, the recovery is expensive and not commonly practiced.

Best Practices for Determining Energy-Efficient Furnace Measures

- **Correct the air-fuel ratio.** It is crucial to ensure that equipment is operated with the correct mixture of fuel and air. If the fuel to air ratio is changed from optimum conditions, the furnace efficiency decreases.
- **Improve insulation.** The minimization of heat losses due to radiation and conduction will substantially reduce energy use.
- **Place covers to avoid heat losses.** The major part of the heat loss is due to radiation, which can be controlled by covering the transport channels.

- **Use recuperators.** Recuperators can preheat combustion air to about 1112°F (600°C) and recover 65% of the energy in flue gases, which leads to a 30% reduction in energy use.

- **Use regenerators.** Recovering 85% of the energy from the exhaust gases is feasible with the typical regenerator, saving around 50%.

- **Preheat metal loading.** Energy use for melting can decrease by up to 50-75 kWh/ton when scrap is preheated.

- **Use oxygen enrichment.** Oxygen may be used to temporarily increase the heating rate when there is a need to increase productivity.

Correct the air-fuel ratio.

Every furnace that is heated by combusting a fuel has a specified air-fuel ratio. If the air-fuel ratio is changed from optimum conditions, the furnace efficiency decreases. If too little air enters the burner or combustion chamber, the fuel is not combusted completely. Therefore, less chemical energy is transformed into heat energy and the temperature in the furnace drops. An excess of air causes the same effect. If only part of the air is involved in the combustion reaction, the excess air will bring down the adiabatic flame temperature as it is heated up in the reaction without contributing to the liberation of heat (BCS, 2005). It is therefore crucial to ensure that equipment is operated with the correct mixture of fuel and air. An excessive gas mixture of 5 and 20% will increase fuel costs in a melting furnace by 6 to 32% respectively, while an excessive air mixture of 5 and 20% will increase energy costs by 4 to 24%, respectively (NADCA, 2009). Control through regular or continuous analysis of actual fuel use, combustion air, and (excess) oxygen levels is essential to maintain optimal combustion conditions.

Harrison Steel castings in Attica (Indiana), operated outdated burners with a poor flame shape that used a non-optimal air to gas mixture. Annual energy costs after burner improvement decreased by $74,000 (FMT Staff, 2010). The return on investment was achieved in less than 3 months.

CASE STUDY: Adjusting the air to fuel ratio in furnaces in the Pennex Aluminum Company in Wellsville, Pennsylvania, resulted in annual energy savings of 7,506 MMBtu. The implementation cost was $9,000, and the payback period was 2 months (U.S. DOE, 2006a).

Improve insulation.

Minimization of heat losses due to radiation and conduction substantially reduces energy use. This is achieved by closing the furnace with a lid, choosing suitable modern refractories, and isolating materials. Refractories are in direct contact with the melt and have to be able to withstand the weight of the metal and the abrasive, corrosive and hot environment. Refractories must not contaminate the melt and should conserve heat.

In addition to the refractory layer, furnaces are equipped with layers of insulation material. Insulation material is not in direct contact with the melt; its purpose is to minimize heat losses. Therefore, isolating material should have a low thermal mass, i.e. low thermal conductivity, low density and low thermal storage capacity, to effectively minimize heat losses through the furnace walls. Ceramic insulation can also replace refractory bricks. This type of insulation will store and lose less heat and requires less warm-up than bricks. Insulation lowers energy use and improves control of the furnace temperature. Electricity use can decrease by 6-26%. Ceramic insulation's lifetime is about 15 years (CIPEC, 2003).

Optimized thermal insulation lowers heat losses to the environment, and more heat energy is stored in the metal load. The melting time is shortened along with the time during which heat is given off to the environment. Consequently, not only the waste heat flow per unit of time is minimized, but also the duration during which it occurs. Examples for materials of low thermal mass are ceramic fiber refractories (BEE, 2005) and micro-porous silica insulations (BCS, 2005). Super insulating materials such as micro-porous silica increases costs for furnace lining by about \$18/foot^2. The return on investment is about 6 to 12 months (White, 2011).

The benefits depend strongly on specific operating conditions, e.g. furnace capacity, melting time and temperature, but also on refractory cost and lifetime. This measure also applies to ladles and tundishes.

Place covers to avoid heat losses.

Radiant and convective heat losses lead to a rapid decline in temperature such as in the case of (holding) furnaces not equipped with covers, runners, launders and charge wells.

Runners and launders are channels for transporting liquid metal. Another possibility where metal might be transferred openly is during pouring, when liquid metal travels towards the molds in runners. Here, heat loss is due to radiation, which can be controlled by covering the transport channels. On average, and according to Caballero (2011), the temperature drops by 13°F (2°C) per foot along uncovered launders; in extreme cases the temperature may drop by 16°F/meter (3°C/meter). To bring down heat loss to about 11°F/foot (1°C/foot), the launder should be covered with concrete lining or refractory cement (Caballero, 2011). Hoel et al. (2005) state that covering an 8.2 feet long launder spout from a cupola allows the tapping temperature to be lowered by 72°F (22°C).

Covering a narrow runner can reduce heat losses to one tenth in comparison to the original situation. This corresponds to a temperature drop of only 34 instead of 57°F (1 instead of 14°C) over a distance of 10 feet (Caballero, 2011). This measure requires only a low investment and lowers energy consumption in the furnace, as less overheating is required (Caballero, 2011). The energy savings will strongly depend on the metal temperature, the mass flow and the channel geometry.

In Schwam et al. (2007), the temperature drop from three preheated ladles filled with molten aluminum that were left to sit for a period of time was lower when an insulated and covered ladle was used. For the insulated and covered ladle, the average temperature loss was 2.3°F/minute. For the insulated and uncovered ladle, it was 3.0°F/minute, while in the case of the uninsulated and uncovered ladle, the loss was 4.4°F/minute. See 'ladle insulation.'

Heat losses in uncovered charge wells are also significant; 3,412 Btu are lost per square foot of uncovered surface (NADCA, 2009). Covering liquid metal surfaces exposed to the atmosphere will limit heat losses and reduce dross formation.

Major heat losses also occur in holding furnaces as they are often left without covers or partially uncovered to facilitate ladling. It was shown by Schwam et al. (2007) that due to increased radiation and convection, the heat losses are two to three times higher for uncovered holding furnaces. For a holding temperature of 1,100°F, an uncovered electric furnace consumed 143 kWh. A covered furnace at the same temperature consumed 55 kWh while holding the same volume of metal. At a higher temperature, 1400°F, the uncovered furnace consumed 266 KWh while the covered furnace 94 kWh.

Use recuperators.

Two slightly different devices are available to recover waste heat; recuperators and regenerators. The technology applies to any equipment that is heated by the combustion of fuels, e.g. cupolas, crucible and reverberatory furnaces, ladles and tundishes.

Recuperators transfer heat from the off-gas to the incoming air by utilizing the principle of thermal conduction. The recuperator itself is an air-to-air heat exchanger with a tube or plate design. By the way that the system is set up, it can be assured that matter cannot be exchanged between incoming air and exhaust gases; reaction products do not enter the burner again. However, the heat exchanger has to be sturdy, as exhaust gases can be highly corrosive and may clog the recuperator with soot. Exhaust gases from aluminum melters can be very aggressive as chlorine gases are often used to purify the melt (BCS, 2005).

Recuperators are widely used in the industry. About 60-70% of the heat available in the off-gas can be transferred to the incoming airflow (Schifo and Radia, 2004). Recuperators can preheat combustion air to about 1,112°F (600°C) and recover 65% of the energy in flue gases, which leads to a 30% reduction in energy use (CIPEC, 2003). Even after leaving the recuperator, the exhaust gas still has a temperature in the range of 930-1,110°F (500-600°C), which means that they usually have to be cooled further before entering any emission treatment device (cupola operation) (JRC/IPTS, 2005). Therefore, recuperators (and regenerators) do not totally eliminate waste heat; there is still enough heat available that can be used for preheating other material flows or heating of premises.

CASE STUDY: A German rolling mill installed a heat exchanger with 365 m^2 in the original setup that already used a recuperator (preheating combustion air to 700-840°F (370-450°C)). The heat exchange area was increased to 560 m^2, which allows the combustion air to be heated to 900-915°F (480-490°C). In consequence, the heat transfer was increased by 400 kW. The recuperator improvement reduced energy costs and the measure had a payback period below 2 years (DEW, 2010).

This example shows that recuperating exhaust gas heat, which would otherwise be wasted, is a measure that should always be implemented unless the installation is hindered by given conditions. In 1993, the payback time for installing a recuperator system was estimated at 1.1 years (Flanagan, 1993). As fuel prices have gone up over time, installing a recuperator should be more attractive today. The use of recuperators and regenerators might increase NOx emissions. As recuperators preheat to lower temperatures than regenerators, less NOx generation is expected for recuperators.

Use regenerators.

Regenerators also preheat incoming combustion air by extracting heat from exhaust gases. However, the functional principle is slightly different. Regenerators are composed of two burners. When the one burner is turned on, the other is turned off. The hot exhaust gases that leave the furnace room pass through a storage medium that is heated up at the entrance of the shut-off burner. When the storage medium can no longer absorb any heat, the whole process needs to be inverted. Gas flows are typically reversed every 2 to 3 minutes (Flanagan, 1993). As the system needs to be monitored and switched constantly, a more complex control system is required. To overcome the issue of constantly inverting the system, different geometries are explored. One alternative setup involves a rotating wheel that is in contact with the hot and cold airflow at opposite sides. Heat is picked up and transferred by the rotation movement (BCS, 2005). However, this system is expected to be less efficient; and moving parts need to be maintained more often.

Regenerators are more efficient than recuperators. Recovering 85% of the energy from exhaust gases is feasible. The incoming airflow can be preheated to a temperature of 300°F (150°C) below the furnace operating temperature. Instead of saving 30% of fuel consumption by installing a recuperative system, typical regenerators can save 50%. Regenerators can considerably decrease the energy use in reverberatory furnaces. For more information see Chapter 18. The payback periods for regenerators and recuperators are almost equal. However, the regenerative system will save more fuel over its lifetime; therefore, it is recommended that regenerators be installed where possible (Flanagan, 1993).

A consequence of the higher combustion temperatures used in regenerative and recuperative systems is increased NOx formation. However, low NOx regenerators have been developed to minimize that pollution

Preheat metal loading.

Energy use for melting can decrease by up to 50-75 kWh/ton when scrap is preheated (BCS, 2005). The most efficient way is to use hot exhaust gases for preheating. The temperature of the flue gas decreases as metal is preheated. The measure is most suitable for continuous melting furnaces that are heated by a combustion reaction, i.e. cupola and reverberatory furnaces. It can also be beneficial for other furnace types; e.g. hot gases leaving an electric arc furnace can be used to preheat the charge for the following melt.

Setup generally requires a stack through which the metal is loaded into the furnace, more or less continuously. The surface and the mass of the scrap metal need to be large enough to ensure heat can be taken up with a high enough speed and capacity. For good heat transfer, it is important that the feedstock be compact and dense but not clogging the stack. Head space and gas channels lower the efficiency of the heat transfer. To accomplish this, the size of the charge has to fit the furnace. Individual metal pieces should not be bigger than one third of the diameter of the feeder (Caballero, 2011).

Decreased fuel consumption and increased productivity are the main reasons to preheat metal. A side benefit is the complete removal of moisture from scrap metal. This prevents the risk of explosions caused when water is added to liquid metal. Furthermore, loading dry metal inhibits slag formation, especially for aluminum that tends to absorb hydrogen (BCS, 2005).

There may be benefits in preheating the charge with natural gas burners, especially in the case of electric furnaces as gas is currently less costly than electricity.

A foundry in Ontario, R.J. Cyr Co., installed an efficient preheater to preheat iron scrap and an afterburner to decrease fugitive emissions. Although the use of the afterburner limited the energy savings to only 11%, preheating the melt reduced the melting time and increased productivity by 17%. The payback period was less than 2 years (CIPEC, 2003).

Use oxygen enrichment.

Replacing air with oxygen in combustion reactions increases the temperature of the reaction products. A higher temperature increases the heat transfer towards the furnace hearth and shortens the time required to melt. Oxygen may be used to temporarily increase the heating rate when there is a need to increase productivity. Oxygen enrichment can also be useful to increase the tapping temperature of a melting furnace. Depending on the way oxygen is introduced in the furnace, the tapping temperature can increase by 59-185°F (15-85°C) (Caballero, 2011). However, oxygen is a costly gas ($0.25/m^3) (Foundrybench, 2011b) that requires a lot of energy in its generation and is therefore generally limited in its use (BCS, 2005). In the melting of steel, oxygen may be required regularly to guarantee the purity of the melt. Oxygen is also frequently used to adjust carbon concentrations in liquid iron.

Chapter Fourteen: Cupola Furnaces

In this chapter:	
Evaluate the operating temperature	Reduce water input into cupola
Correct furnace shaft height	Make use of waste heat
Use plasma-fired cupolas	

A cupola is a vertical shaft furnace with a function similar to the blast furnace used in iron production. Metal scrap and coke are fed into the furnace from the top, which allows for metal preheating. The molten metal moves down towards the bottom of the furnace along with any slag that is produced. Cupolas are used for melting iron at high capacities, for example in foundries producing cast iron pipes or automotive parts. They are only used for melting purposes and need to run continuously until the refractory lining is worn out. Modern cupolas can be operated for 1-2 weeks, depending on the type of refractory and its cooling system. The energy efficiency of cupola melting ranges between 40 and over 70% (BCS, 2005). Cupolas are not widespread in numbers, but as their production is large, they do contribute to a large share of the total iron melted in foundries (Dahlquist, 2011; Schifo and Radia, 2004).

As solid materials charged on the top of the cupola move down the furnace and melt, abrasive conditions are created that wear down the furnace refractories. Conventional refractory-lined cupolas with no water cooling can only be operated for a short period (about a week) before the refractory lining needs to be repaired or maintained. In water-cooled cupolas, a steel internal surface with a thin or no refractory lining is used. Water-cooled cupolas have an extended continuous operation of more than two weeks however, due to water cooling they are highly energy intensive (BCS, 2005). Improved cupola designs use a small amount of water for cooling and a thin refractory lining (BCS, 2005; AFS report). To better withstand the abrasive conditions, cement castables and spray monolithic linings can be used (BCS, 2005).

Best Practices for Energy-Efficient Cupola Furnaces

- **Evaluate the operating temperature.** Lowering the temperature at the cupola may result in energy savings.

- **Reduce water input into cupola.** Water in a cupola is evaporated and heated further, which consumes energy and increases the airflow through the furnace.

- **Correct furnace shaft height.** As a general rule, a cupola should be at least five times as high as its diameter to ensure that the incoming metal is properly preheated.

- **Make use of waste heat.** A cupola produces large amounts of waste heat at relatively high temperatures. The exhaust gas may even have a sufficient heating value that makes further combustion possible for additional heat generation.

- **Use plasma-fired cupolas.** Plasma-fired cupolas can be used temporarily to increase the temperature of the hot air that is blown into the cupola and increase productivity.

Evaluate the operating temperature.

The temperature to which metal is heated has a major influence on energy use. Cupolas are used for melting, and typically the metal is then transferred to a holding furnace.

Lowering the temperature at the cupola may result in energy savings. For example, in a foundry melting liquid grey cast iron (29,000 tons per year), the metal was brought to 2,739°F (1504°C) in a cold blast cupola at a production capacity of 11 tons/hour. The metal is held in an electrical holding furnace and poured into molds at 2,552°F (1400°C). Reducing the temperature in the cupola by 68°F (20°C) brought down coke consumption by about 44 tons/year (1,140 MBtu/year), while the electricity use of the holding furnace increased by about 170 MWh (690 MBtu/year). The change in operating temperature led to decreased total purchased energy use. However, the total primary energy consumption actually increased. Whether this leads to overall cost savings, strongly depends on the prices of coke and electricity and the individual furnace efficiencies at the given temperatures. For this reason, each case must be examined carefully (Caballero, 2011).

Reduce water input into cupola.

Energy demand can be reduced by avoiding water input into cupola furnaces. Water in a cupola is evaporated and heated further, which consumes energy and increases the airflow through the furnace. Moreover, steam will further react with coke in a competing reaction, increasing the coke requirement (Schifo and Radia, 2004).

Water can enter the cupola in two ways. Some may enter with humid air. This can be prevented by dehumidification. However, dehumidification is a costly process that may not be economically feasible at the required airflow rates and the relatively low energy benefits. The other place water enters a cupola is along with the coke. Coke is usually stored outside where it is exposed to rain. Depending on weather and storage conditions, the moisture content of coke can range between 0-15% (mass basis) (Caballero, 2011). Coke is preheated when entering the cupola, but moisture is not completely removed. The addition of 2.2 lb. of water into a cupola furnace caused an additional coke use of 2.7 lb. (Schifo and Radia, 2004). One out of 4 foundries that operate cupolas in Wisconsin cover coke storage areas (Focus on Energy, 2006).

Correct furnace shaft height.

As a general rule, a cupola should be at least five times as high as its diameter (IfG, 2008). As a cupola is loaded continuously from the top, this ensures that the incoming metal is properly preheated. Very high off-gas temperatures of 1,400°F (760°C) are a sign of insufficient heat transfer between exhaust fumes and incoming charge. In such a case, the charging mechanism and packing density should be examined (Eppich, 2004).

Make use of waste heat.

A cupola produces large amounts of waste heat at relatively high temperatures. The exhaust gas may even have a sufficient heating value that makes further combustion possible for additional heat generation (IfG, 2008).

Use plasma-fired cupolas.

Plasma torches function in a similar way to oxygen enrichment. They can be used to (temporarily) increase the temperature of hot air that is blown into the cupola and increase productivity. At the same time, coke consumption may be lowered. Plasma torches generate temperatures of 6,330°F (3,500°C), and air inlet temperatures of 1,470-1,652°F (800-900°C) are feasible (IfG, 2008). The Foundrybench project mentions that plasma torches can also be used to adjust the temperature in or at the exit of a holding furnace, directly prior to pouring (Caballero, 2011).

Modern cupola installations are usually equipped with either oxygen enrichment or plasma torches. By increasing the heating rate, the cupola can be operated more flexibly, which is often necessary in casting production. General Motors' casting plant in Defiance (Ohio) used plasma torches in a cupola furnace (BCS, 2005) until the 22 year old furnace was shut down.

Chapter Fifteen: Electric Induction Furnaces

In this chapter:	
Upgrade metal loading, package density	Keep a liquid heel
Evaluate idling time	Maintain cooling system control
Add carburizer in the beginning of the melting cycle	Use clean scrap, avoid sand and rust
Maintain furnace linings	Upgrade low frequency systems to medium frequency
Use high nominal furnace power	Reduce peak load and phase shift

Electric induction furnaces are smaller in volume than cupola furnaces and can be operated far more flexibly. A large coil induces an alternating electromagnetic field that generates a current within the charged metal. Due to the electrical resistance of the metal, the induced electric current is transformed into heat. Usually, a foundry operates a number of induction furnaces simultaneously to continuously produce liquid metal at the desired volume. Large furnaces can melt up to 66 tons/hour with good control of stirring. Smaller units with power densities of 680 to 1,000 kW/short ton are able to melt a cold charge in about 30 minutes (BCS, 2005).

Generally, electric induction furnaces are energy efficient, because the electric energy heats up the metal directly; heat does not have to be conducted into the metal from the outside. Electric induction furnaces can have a very high energy efficiency of 75%. In modern induction furnaces, cast iron can be melted and heated to a temperature of 2,732°F (1,500°C) with an energy requirement of 470 kWh/ton (Foundrybench, 2011b). However, it has been found, that actual energy consumption under typical operating conditions is much higher; the Foundrybench project determined average figures of 650 kWh/ton in England and 775 kWh/ton in France (Foundrybench, 2011b).

Opportunities for Energy Efficiency

Although induction furnaces are considered to be energy-efficient, there is still a potential for energy efficiency improvement. Since induction furnaces are run on electricity, primary (or source) energy consumption is about three times larger. Any savings reached in furnace operations will lead to bigger savings along the chain of electricity generation leading back to the power plant. Furnace efficiency can be increased by a number of measures; many of them involve operational measures and do not require high capital investments.

Best Practices for Energy-Efficient Electric Induction Furnaces

- **Upgrade metal loading, package density.** High packing density ensures good electric coupling and results in a more efficient and faster melting process.

- **Keep a liquid heel.** Adding relatively little solid material to a liquid bath allows for a highly efficient melting process as isothermal conditions are approached. A rather large liquid heel of 50-70% is claimed to be most economical.

- **Evaluate idling time.** When a furnace is started up from room temperature, a lot of extra energy is used for heating the furnace instead of the charge. Therefore, keeping a liquid heel in a furnace is usually beneficial.

- **Maintain cooling system control**. Heat losses to cooling water account for about 20-25% of energy use.
- **Add carburizer in the beginning of the melting cycle.** Adding carburizers at the beginning of the melting cycle along with the metallic load will result in energy savings.
- **Use clean scrap metal, avoid sand and rust.** It is recommended to either operate the furnace in batch mode (where any humidity is removed in the start-up process) or to preheat the metal charge.
- **Maintain furnace linings.** The use of furnace lining minimizes heat conduction through the furnace walls while at the same time protecting furnace walls against corrosion and wear. There is a trade-off between minimizing heat loss and maximizing electric coupling between coil and metallic charge.
- **Upgrade low frequency systems to medium frequency**. Upgrading a low-frequency system to medium frequency leads to energy savings of 12-15% in batch mode.
- **Use high nominal furnace power.** A high power density leads to a shorter heating process and melting period. When melting is shortened, the time during which heat losses occur also decreases.
- **Reduce peak load and phase shift.** Bringing down peak electricity demand, while maintaining overall electricity use, can result in reduced electricity costs.

Upgrade metal loading, package density.

A simple measure to ensure energy efficiency is the proper arrangement of metal scrap in an induction furnace before start-up. The packing density of the furnace loading has an effect on the electromagnetic coupling. High packing density ensures good electric coupling and results in a more efficient and faster melting process (BCS, 2005). It was found that in an induction furnace filled with pig iron, cast iron scrap and recycled material, the energy consumption increased by 23 kWh/ton as the packing density was decreased from 0.08 tons/ft^3 to 0.06 tons/ft^3 (Caballero, 2011).

Some foundries also melt metal swarf in electric induction furnaces. Swarf has different properties from bulk material. Although swarf has a very high packing density, due to its small volume and oxidized surface area, electrical contact is very low. Therefore, swarf should be melted in a sump (liquid heel of 40% hearth volume). Melting swarf without a sump leads to an additional energy requirement of 45 kWh/ton and increased melting time (Caballero, 2011).

Keep a liquid heel.

When a certain volume of liquid metal remains in the furnace (a liquid heel), the amount of metal that can be obtained in one tap decreases. However, the cycle duration also decreases, preventing a decline in productivity.

As solid metal has a higher electric resistivity in comparison to the melt, it may be concluded that cold starts are more efficient (BCS, 2005). However, the electric coupling between the coil and solid metal is rather low, therefore a liquid heel is desired (BCS, 2005; Caballero, 2011). Moreover, a liquid heel allows for less fluctuation in melting operations. Adding relatively little solid material to a liquid bath allows for a highly efficient melting process as isothermal conditions are approached. A rather large liquid heel of 50-70% is claimed to be the most economical (IfG, 2008).

Evaluate idling time.

The furnace operation has to be carefully adapted to the melting schedule. When a furnace is started up from room temperature, a lot of extra energy is used for heating the furnace instead of the charge. Therefore, keeping a liquid heel in a furnace is usually beneficial. Allowing a furnace to cool down may increase energy requirements for the following melt by 30-50% (BCS, 2005).

It might be advisable to keep the furnace warm for a few hours, even if it is just idling. This strongly depends on furnace parameters, capacity, power input and waste heat flow. The amount of time that equipment should be kept in holding mode has to be determined for each furnace. Consequently, analyzing reasonable idling times might also reveal that equipment has to be turned off sooner rather than later (IfG, 2008).

A consequence of shutting down a furnace is that metal cannot be kept inside the furnace. Solidification and re-melting in the furnace is not an option as it may destroy important parts of the furnace. Thus, this energy saving measure may not be practical in some circumstances. Apart from increased refractory wear (which also occurs during elongated holding times), no additional expenditures are needed.

Maintain cooling system control.

The coil of an electric arc furnace needs to be cooled as it has a finite electric resistance. The cooling is accomplished by pumping water in a closed circuit directly through the coil. Heat losses to cooling water account for about 20-25% of energy use (CIPEC, 2003). Two ways to lower the energy use with regard to the cooling system are i) by using the waste heat that is absorbed by the cooling water i.e. for space heating and ii) by shutting off the cooling water pump when the furnace is not in use.

Add carburizer in the beginning of the melting cycle.

Energy use is influenced by the way carburizing additives are introduced into the furnace. Usually, carburizers are added once the metal has been melted into the molten bath. Based on Caballero (2011) this method results in a higher energy consumption of about 0.5-0.9 kWh/lb. (1-2 kWh/kg) of carburizer. A 2% carburizer addition results in additional energy use of about 36 kWh/ton metal.

Adding carburizers at the beginning of the melting cycle along with the metallic load will result in energy savings. It is advised that carburizing agents are adjusted based on the metallic load, as a high carbon content can lead to the erosion of the melting crucible.

Use clean scrap metal, avoid sand and rust.

Furnaces should be loaded with scrap metal that is as clean as possible. It is an absolute prerequisite that only dry material is loaded into a hot induction furnace. Adding water into a liquid bath of metal will lead to severe explosions. Therefore, it is recommended to either operate the furnace in batch mode, where any humidity is removed in the start-up process, or to preheat the metal charge.

Maintain furnace linings.

Furnace lining minimizes heat conduction through the furnace walls, while at the same time, it protects the walls from corrosion and wear. Generally, about 8% of the energy input in modern medium frequency furnaces is lost through walls (Caballero, 2011). This can be optimized by choosing a lining with higher thermal resistance or by applying thicker layers of surface linings. However, as the furnace lining is increased, the distance between the furnace coil and the metal grows, which reduces the electric coupling. There is a balance between minimizing heat loss and maximizing electric coupling between coil and metallic charge, which can be hard to achieve. Firstly, the heat loss via thermal conduction is not linearly dependent on lining thickness, as the furnace geometry is usually circular. Secondly, if the electric coupling is decreased, the energy utilization suffers from two effects: higher heat losses in the coil and lower power input to the load. Furthermore, more heat is lost in conduction, as the melting process takes longer (Caballero, 2011).

A low frequency furnace (10 ton capacity) with worn down surface lining may need an extra 45 kWh/ton on top of regular melting requirements. It is recommended that the lining type and dimensions specified by the furnace manufacturer be followed (Caballero, 2011).

Upgrade low frequency systems to medium frequency.

Low frequency furnaces (known as power-frequency furnaces) operate at the 60 Hz of the electricity grid. This type of furnace is less efficient and cannot start-up a cold charge because of insufficient electric coupling at ambient temperatures (Foundrybench, 2011b).

Low frequency furnaces are no longer the state-of-the-art and should be replaced by medium frequency furnaces that operate above 250 Hz. These have the advantage of improved electric coupling, which enables a cold start. Additionally, the power input density can be 3 times higher, which increases productivity and efficiency. Upgrading a low-frequency system to medium frequency, leads to energy savings of 12-15% in batch mode (IfG, 2008). The financial costs and benefits depend on the given conditions.

Use high nominal furnace power.

One reason that electric induction furnaces are highly efficient is the fact that they enable high power densities.[9] A high power density leads to a quicker heating process and shortens the melting period. As the time for melting is shortened, the time during which heat losses occur also decreases. These furnaces operate more efficiently at short melting times and high power input (Caballero, 2011).

Medium frequency induction systems (> 250 Hz) are most efficient as they reach the highest power densities. If there is a technically feasible option to further increase the nominal furnace power density, it should be considered for implementation.

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[9] Power density (W/t) is defined as the energy flow into the metal per amount of metal. It is a measure of how quickly heat is transferred into the metal.

Reduce peak load and phase shift.

Reducing peak load and phase shift are measures that target a decrease in energy *costs* but do not impact the amount of energy that can be *saved*. This is a contrary measure to using high nominal furnace power as it lowers peak demand and furnace power. Large industrial electricity consumers not only pay for the amount of electricity consumed but also for the level of peak demand. Peak demand may be increased dramatically when induction furnaces are synchronized in a way that they simultaneously run on peak power. Bringing down peak electricity demand, while maintaining overall electricity use, can result in reduced electricity costs.

Another issue is that transformers, which are used in operating induction furnaces, may cause a phase shift in the electricity grid when operating at high power consumption. The wave shape of the alternating current in the electricity grid is distorted, which causes energy losses. The phase shift causes reactive power losses, which means that the utility company needs to feed more electricity into the grid than the foundry actually withdraws.

This condition is addressed by new energy monitoring and control systems that have been developed in recent years. These apply to foundries operating a number of induction furnaces at the same time. By managing the operation of these furnaces in a smart way, the peak demand can be reduced, while maintaining melting capacity. Energy monitoring systems optimize the daily load duration curve in a way that the energy bill is minimized, which may lead to longer melting cycles (Caballero, 2011).

A monitoring and control system has been successfully installed in the foundry Van Voorden in the Netherlands, where marine propellers are manufactured. With the system adoption in 2009, the peak demand was reduced by 39%. The reduction led to yearly savings of $120,000 (€100,000); considering the installation costs of $102,000 (€85,000), the payback period was less than 1 year (Caballero, 2011).

Gregg Industries, in California, installed a power demand controller to optimize energy consumption in two induction furnaces. By making use of real time information, monthly peak energy use was reduced by 2,300 kW (an overall decrease of 24%). The payback period was less than 2 years (FMT Staff, 2005).

Chapter Sixteen: Electric Arc Furnaces

In this chapter:	
Keep liquid heel	Use clean scrap, avoid sand and rust
Avoid hot spots	Optimize electrode positioning
Use foamy slag	Preheat scrap metal

Electric arc furnaces use electrodes that are lowered into the furnace. The electric voltage is high enough to strike an arc that reaches from the electrode to the metal. Different setups are available, with one or more electrodes operated on direct or alternating current. The metal is heated by the thermal irradiance emitted from the arc and by the electrical resistance heating in the conducting metal. Electric arc furnaces are primarily used for melting steel, although in the past they have been used in iron casting (Eppich, 2004). Furnaces can either take in low-grade steel scrap, direct reduced iron and/or hot briquette iron, which is combined with coal and silica to melt steel or smelt iron (BCS, 2005).

Opportunities for Energy Efficiency

Electric arc furnaces are very efficient in melting scrap metal, energy efficiency ratings of up to 80% are reached for large equipment. Once the steel is molten in the arc furnace, it should be poured or transferred to a holding furnace as soon as possible because the arc furnace is inefficient in holding mode. Efficiency levels can be lowered considerably if additional treatment is required. Electric arc furnaces have a good metallurgical performance; they are often used for decarburization, and purification by slagging and de-slagging (Caballero, 2011).

Best Practices for Energy-Efficient Electric Arc Furnaces

- **Liquid heel.** Melting with a liquid heel is more efficient.
- **Use clean scrapl, avoid sand and rust.** It is recommended to either operate the furnace in batch mode, where any humidity is removed in the start-up process, or to preheat the metal charge.
- **Avoid hot spots.** Hotspots elongate the melting cycle and cause unnecessary energy use, and can be avoided by arranging oxy-fuel burners at the sides of the furnace or by injecting gas at the bottom.
- **Optimize electrode positioning.** Energy consumption can be optimized by properly controlling the level of the electrodes above the metal.
- **Use foamy slag.** Foamy slag decreases energy consumption, electrode degradation, melting cycle duration, carbon monoxide emissions and noise levels.
- **Preheat scrap metal.** Instead of using a stack design, heat losses can also be minimized by using a twin-shell furnace.

Keep liquid heel.

Melting with a liquid heel is more efficient, just as in electric induction furnaces (BCS, 2005).

Use clean scrap, avoid sand and rust.

Furnaces should be loaded with scrap metal that is as clean as possible. It is an absolute prerequisite that only dry material be loaded into a liquid metal bath. Adding water into a liquid bath of metal will lead to severe explosions. Therefore, it is recommended to either operate the furnace in batch mode, where any humidity is removed in the start-up process, or to preheat the metal charge.

Avoid hot spots.

As the heat is generated at the top rather than the bottom of the furnace, there is very little convective momentum. That is why electric arc furnaces are prone to hotspots (BCS, 2005). The presence of hotspots implies that part of the metal is overheated while some parts may still be solid. Hotspots elongate the melting cycle and cause unnecessary energy use. They can be avoided by arranging oxy-fuel burners at the sides of the furnace or by injecting gas at the bottom. Overall energy efficiency is improved as the shorter melting times result in decreased heat losses due to convection and radiation. Although oxygen is a rather expensive gas ($0.25/m^3, (Foundrybench, 2011b)), there can be financial benefits as the energy efficiency is improved.

Optimize electrode positioning.

Energy consumption can be optimized by properly controlling the level of the electrodes above the metal. By automatically managing the position of the electrodes, maximum power can be induced into the charge (Schifo and Radia, 2004). The energy saving potential of this measure could not be identified.

Use foamy slag.

Foamy slag practice is currently used in large electric arc furnaces in the primary steel industry. At the end of a melting cycle, when the charge is already molten but still needs to be purified, a thick foamy layer of slag is built up by injecting oxygen and coal dust. The coal dust consists of carbon that reacts with the oxygen to form carbon monoxide. Additional carbon monoxide is produced as the carbon reduces remaining iron oxides. Carbon monoxide bubbles facilitate a foamy slag. By inducing bubbles into the slag, density is reduced from 0.07 to 0.04 tons/ft^3 (JRC/IPTS, 2005).

A layer of foamy slag on top of the melt has several advantages. It stabilizes the arc, which allows for higher power density and longer arcs. It insulates the metal and protects refractory linings at the top of the furnace. Foamy slag decreases energy consumption, electrode degradation, melting cycle duration, carbon monoxide emissions and noise levels (IFC, 2007).

Not all foundries can make use of foamy slag. Electric arc furnaces need to be equipped with oxygen burners or oxygen injection. Also, high power transformers are needed to produce long arcs. Since installed transformers are usually designed for operation without foamy slag, they are undersized for this technology (BCS, 2005). Schifo and Radia (2004) claim that the foamy slag projects are not considered effective on smaller furnaces that are typically found in steel foundries.

According to the JRC/IPTS (2005), one foundry operating a furnace with a 66 ton capacity, was able to achieve with the adoption of foamy slag all the benefits mentioned above. Flue gas flow, electricity and coal use were reduced, while metallurgical performance improved. These benefits are strongly dependent on the specific situation and may therefore be uncertain, even for large furnaces. These potential benefits should be carefully evaluated when considering this measure.

With the foamy slag practice, a steel foundry was able to decrease electricity use by 10% (from 514 kWh/ton to 465 kWh/ton) and the heat time by 10% (Peaslee, 2008).

Preheat scrap metal.

Electric arc furnaces are equipped with a module to pre-heat the incoming scrap metal. This design is also called a shaft furnace. However, electric arc furnaces produce only medium off-gas flows. Preheating requires the extensive use of gas burners to produce sufficient off-gas; therefore this measure is not suitable for the average foundry (BCS, 2005).

Instead of a stack design, heat losses can also be minimized with a twin-shell furnace. The system consists of two furnaces and one set of electrodes. While one furnace is melting steel, the off-gas is pumped through the second furnace, which already holds the next charge. When the melting process in the one furnace is finished, the electrodes are transferred to the other furnace with the already preheated metal. As only one set of electrodes is required, this setup is less expensive than installing two independent furnaces (BCS, 2005).

As the charge is preheated, the twin shell system consumes less energy. Natural gas burners can also supplement the preheating; thus, electricity use is further decreased at the cost of additional gas use. Preheating with gas may be economically beneficial as gas is less expensive than electricity. The productivity of the twin shell setup is similar to two independent furnaces, needing to pause operation while being charged. However, the twin shell design is not suitable for retrofitting and only pays back for high load factors in furnaces with a capacity above 20 tons (BCS, 2005).

A facility operated by Nippon Steel installed a twin shell system for melting steel and reported an energy consumption of 269 kWh/ton, while preheating the charge to about 1,650°F (900°C). This equates to an energy reduction of 30% in comparison to conventional electric arc furnaces (BCS, 2005).

Chapter Seventeen: Crucible Furnaces

In this chapter:	
Close lid on crucible	Install radiant panels
Install more efficient furnace type	

Crucible furnaces are widely used in small foundries that melt a variety of alloys. Crucibles may also be used as holding furnaces at die casting stations and as metal transfer ladles (Kennedy, 2001). Due to low investment costs, these furnaces are the cheapest melting method available for small yearly capacities. This furnace type is used in large numbers, but their contribution to overall production is relatively low (BCS, 2005). The main types of crucible furnaces are gas-fired crucibles, electric resistance crucibles and induction crucibles.

Gas-fired crucibles are the most energy intensive with energy use in the range of 2,500-4,000 Btu/lb Electric resistance crucibles consume about 716-887 Btu/lb, and induction crucibles use about 785-887 Btu/lb. (Kennedy, 2001).

Aluminum melting gas-fired crucible furnaces are characterized by low energy efficiency, ranging from 7 to 19% and a melt loss of 4-6%. More than 60% of the heat loss is due to radiation (BCS, 2005). The remaining heat losses are inferred to be caused by hot exhaust gases leaving the furnace. The low energy efficiency is mainly due to the restricted combustion space and the high cost of recuperative burners (Kennedy, 2001). Other disadvantages are the rather short service lifetime, and the difficulty in temperature control during operation.

Crucible furnaces are operated in a batch-mode (they cool down between melting cycles), making improvements difficult to achieve. Waste heat from the off-gas is difficult to recover economically as the furnaces only operate with a small load factor. To improve efficiency, old gas-fired crucible furnaces could be retrofitted with newer burner technologies with multiple heat settings.

Opportunities for Energy Efficiency

Many foundries melt non-ferrous metals in uncovered crucibles with no waste heat recovery. The installation of a cover and recuperative or regenerative burner system can significantly increase the energy efficiency of crucibles (see Chapter 13 also, Section on 'Recuperators' and 'Regenerators'). At an Eck Industries aluminum foundry in Wisconsin, the installation of a sophisticated recuperative burner system to the non-covered gas-fired crucible furnace reduced the energy use per melt and three hour hold cycle by 40% (Focus on Energy, 2010). Placing a cover and adopting a recuperative system saved Eck Industries 2,160 MBtu per furnace annually and about $17,280 on energy costs. The payback period was determined to be 1.5 years. (Focus on Energy, 2010).

Best Practices for Energy-Efficient Crucible Furnaces

- **Close lid on crucible.** About 60% of the energy input in gas-fired crucible furnaces is lost due to radiation.
- **Install radiant panels.** It was predicted that radiant panels might improve furnace energy efficiency by 30%.

- **Install more efficient furnace type.** An alternative to natural gas-fired crucibles could be electric resistance crucibles. Electric resistance crucibles are less energy intensive than gas-fired ones (716-887 Btu/lb instead of 2,500-4,000 Btu/lb) and produce no stack emissions.

Close lid on crucible.

About 60% of the energy input in gas-fired crucible furnaces is lost due to radiation (BCS, 2005; Eppich and Naranjo, 2007; Schifo and Radia, 2004). In case where furnaces are unsealed, it is strongly advised to cover the furnace with a lid. This measure is relatively easy to implement and will reduce melting time and energy use significantly.

Install radiant panels.

Crucible furnaces may be equipped with radiant panels. This is under the assumption that irradiation losses cannot be controlled by sealing the crucible with a lid. Radiant panels are made from alumina and reduce the radiation that leaves the crucible. The alumina panels have a special structure with a high surface area and need to be backed-up with insulation material as alumina exhibits high thermal conductivity.

Data on the improvement of radiant panels is scarce. It was predicted that radiant panels might improve furnace energy efficiency by 30% (BCS, 2005). A study by Case Western Reserve University showed that the energy efficiency of a natural gas fired crucible was raised from 8 to 16% by installing improved gas burners and radiant panels. It was estimated that each of the two measures were equally responsible for the efficiency improvement. This means that the installation of radiant panels brought down natural gas consumption by 4-8%. The installation costs for the panels were about $4,000 per crucible. Whether this can be economically justified, needs to be evaluated on a case by case basis (U.S. DOE, 2007).

Install more efficient furnace type.

An alternative to natural gas-fired crucibles could be electric resistance crucibles. Electric resistance crucibles are less energy intensive than gas-fired ones (716-887 Btu/lb instead of 2,500-4,000 Btu/lb) (Kennedy, 2001) and produce no stack emissions. A properly designed, well insulated electric resistance furnace used for aluminum melting can have an energy efficiency of 84% (Nealon, 2011). Additionally, the melt loss is lower (1-1.5% instead of 6-7%) (Kennedy, 2001; Eppich and Naranjo, 2007).

Great care is required when making decision on an appropriate melting furnace as higher energy efficiency does not necessarily translate into lower energy costs. Nealon (2011) showed that based only on energy efficiency improvements, using a gas-fired crucible for aluminum melting with a 28% energy efficiency can be more expensive than using an electric resistance crucible with an energy efficiency of 84%. Although the energy costs for melting were similar for both furnaces, the "demand charge" commonly added in electric utility bills was substantial in the case of the electric furnace. However, when evaluating furnace replacements many parameters such as melt loss (higher in gas-fired than in electric resistance furnaces), volume requirements, etc., must be assessed to determine the actual difference in operational costs (Nealon, 2011).

Chapter Eighteen: Reverberatory and Stack Furnaces

In this chapter:	
Preheat hearths	Install a molten metal circulation pump
Install more efficient furnace type	Use isothermal melting

Reverberatory furnaces are widely used in aluminum melting facilities. In reverberatory furnaces aluminum is not heated directly. Irradiance of flames and hot furnace walls on top or sides do the heating. The main types of fuel-fired reverberatory furnaces are i) dry hearth reverberatory furnaces in which the metal is preheated prior to melting, ii) wet-bath reverberatory furnaces in which the metal is directly charged to the molten bath without preheating, and iii) side-well reverberatory furnaces which consist of a number of burners that fire inside the hearth with a charging well and pump that is usually placed outside of the furnace (NADCA, 2009). The energy efficiency of reverberatory furnaces is very low, ranging from 20 to 25% (Eppich and Naranjo, 2007). The stack furnace is a modified version of the reverberatory furnace. Stack melters are characterized by increased energy efficiency, as they utilize the heat in flue gases to preheat the charge. In the U.S., about 95% of aluminum is melted in reverberatory furnaces in contrast to Europe where stack furnaces are most commonly used (White et al., 2008).

Flue gases in reverberatory furnaces represent a major source of wasted energy. Waste heat from flue gases can be recovered to preheat air (see “Recuperators” and “Regenerators” in Chapter 13), can be used in lower temperature process heating equipment (i.e. waste heat boilers or paint-drying ovens; see “Make use of waste heat contained in furnace off-gas” in Chapter 11), and to preheat the metals charged into the furnace (see also “Preheat Metal loading” in Chapter 13).

Opportunities for Energy Efficiency

The energy efficiency of gas reverberatory furnaces can be improved by 10-15% with the use of recuperation. Further, improvements in burner technology, insulation, temperature and air-to-fuel control has reduced the energy use in reverberatory furnaces to 1,250-1,500 Btu/lb aluminum (NADCA, 2009). This section addresses a number of measures with important energy savings potentials for the reverberatory furnaces used in aluminum foundries.

Best Practices for Energy-Efficient Reverberatory and Stack Furnaces

- **Preheat hearths.** For a melter using 50% new metal and 50% scrap and returned metal which is charged in a charge well, pre-heating the metal for a half hour in the hearth, prior to charging in the molten bath, will decrease the energy use by 10-12%.

- **Install a molten metal circulation pump.** The addition of a molten metal circulation pump can considerably improve the performance of reverberatory furnaces as heat is transferred from the surface of the metal bath throughout of the bath more efficiently.

- **Install more efficient furnace type.** The most important equipment in a foundry is the melting furnace. The choice of the furnace is made based on available capital, energy and labor costs, melt demand, the type of charge materials used and the type of charge generated within the foundry.

- **Use isothermal melting.** Isothermal melting uses 70% less energy than conventional gas-fired burners.

Preheat hearths.

A preheat hearth can utilize the heat contained in flue gases to heat scrap and sow prior to charging into the melter, reducing the energy use. For a melter using 50% new metal and 50% scrap and returned metal charged in a charge well, pre-heating the metal for a half hour in the hearth prior to charging to the molten bath will decrease the energy use by 10-12% (White, 2011). For 5,200 hours of melting per year, the return on investment is less than 2 years (White, 2011).

An aluminum foundry in Australia (PBR Australia) was using low efficiency reverberatory furnaces. To preheat its metallic load, a chute was installed. When the metal reached the base of the chute, the metal was already molten. With this retrofit, 10,460 MBtu of energy were saved within a year. In addition, dross production was limited, resulting in a 4% increase in production (Sustainability Victoria, 2002).

Install a molten metal circulation pump.

The addition of a molten metal circulation pump can considerably improve the performance of reverberatory furnaces as heat is transferred from the surface of the metal bath throughout the bath more efficiently. Forcing circulation will result in lower temperature variations. It is claimed that the typical temperature variation (from top to bottom) in a 3 foot deep reverberatory furnace without molten metal circulation ranges from 50 and 85^{o}C, and it can be decreased to 3-7^{o}C with the addition of a circulation pump (Pyrotek, 2009). Since the metal is melted faster, energy can be saved or the capacity increased.

Another benefit from the use of a circulation pump is the reduced melt loss; dross formation will decrease due to the lower surface bath temperature. Metal melt loss can be decreased by 1% (White, unknown date). In addition, sludge formation also decreases due to the greater temperature homogeneity (White, 2011).

Molten metal circulation has the potential to decrease the energy use by 10-15%. The typical cost of adding a pump well to a large furnace ranges between $35,000 and $45,000 depending on the size of the furnace. The cost of the circulation pump adds another $35,000 to $43,000. The return on investment for a typical circulation pump and a well is about 24 to 28 months (White, 2011).

Energy use in a well-designed and fully utilized fuel-fired, radiant roof-fired furnace with 100% cold metal charging is about 1,500 Btu/lb (33% efficiency). Enhancing the lining, adding a sow preheat hearth and molten metal circulation can decrease the energy use to 1,225 Btu/lb (41% efficiency). In addition, adopting recuperative burners will drop the energy use at 1,095 Btu/lb (46% efficiency) while adopting regenerative burners will drop the energy use further at 940 Btu/lb (53% efficiency) (White, 2011).

In the case of an electric radiant - roof reverberatory furnace with an energy use of 750 Btu/lb, the addition of molten metal circulation will reduce energy use to about 687 Btu/lb (White, 2011).

Install more efficient furnace type.

The most important equipment in a foundry is the melting furnace. The choice of the furnace is made based on available capital, energy and labor costs, melt demand, the type of charge materials used and the type of charge generated within the foundry. Dry hearth reverberatory furnaces are chosen mainly when the charge used has minimal surface area. Wet-bath reverberatory furnaces are preferred when the charge varies in thickness, with thinner materials submerging in the molten bath limiting melt losses from surface oxidation. Stack melters are more energy-efficient than reverberatory furnaces as they preheat and dry the incoming charge prior to its entrance in the melting zone. However, stack furnaces are characterized by increased melt losses when thin charge such as thin-gage stocks and flashings are used (Groteke and Neff, 2008).

Dry hearth furnaces have high melt losses of 7-12% and an energy use of about 1,800 Btu/lb. The melt losses are lower when the volume-to-surface area increases. This type of furnace is more energy-efficient when melting large sows (1,500/lb). In wet-reverberatory furnaces all metal is melted under the bath surface resulting in low melt losses (2-5% for gas-fired and less than 1% for electric furnaces). Wet-reverberatory furnaces have an energy use of about 1,500 Btu/lb which can decrease to 1,000 Btu/lb when metal circulation, metal preheating and regenerative burners are adopted. Stack furnaces have a typical energy efficiency of 40-50%. For a 50% ingot and 50% bulky returned charge within a bath temperature of 1,330°F (720°C) the electricity use in stack furnaces is 600 kWh/ton (White et al., 2008).

The replacement of reverberatory furnaces with stack furnaces can offer substantial energy savings. Measurements under practical operation conditions revealed that aluminum melting efficiency was 25% for a reverberatory furnace and 44% for a modern stack melter, both which were operated in the same die casting process (Eppich and Naranjo, 2007). The performance of a conventional reverberatory melter and a stack melter was compared at a large Midwestern foundry. Both furnaces had the same capacity (3,000 lb/hour) and were fed with the same charge. The results showed that the melt loss was 5.5% for the reverberatory furnace and 0.9% for the stack melter. The energy use in the stack melter was also lower when compared to the reverberatory furnace; 955 Btu/lb instead of 1,975 Btu/lb (Groteke and Fieber, 1999).

Although a number of side-by-side comparisons of the melt loss in dry hearth reverberatory furnaces and stack melters have shown an advantage of stack melters over reverberatory furnaces, great care is required as the type of materials charged may have introduced some bias. For stack melters to achieve low melt losses, the proper operating conditions should be strictly followed. To avoid high melt losses in stack melters, high density charges are needed (Groteke and Neff, 2008).

It should be noted that traditional reverberatory furnaces have several advantages over stack melters. Reverberatory furnaces can be built with large capacities while stack melters have to be rather high to achieve the preheating effect; 20 feet is a common height. The refractory lining at the bottom of the stack furnaces suffers from mechanical stress which causes more frequent maintenance intervals. In addition, as the charge needs to be stacked properly, stack melters do not tolerate all shapes of aluminum scrap (Eppich and Naranjo, 2007). The increased costs of maintenance and labor negate some of the energy cost savings of stack furnaces.

Use isothermal melting.

A new energy-efficient aluminum melting technology, Isothermal Melting (ITM), utilizes immersion heaters in a closed loop multiple bay arrangement, to supply melting energy through conduction. With the use of the pumping bay, mixing is improved while there is also higher temperature uniformity. The heating bay enables electricity to be converted into heat via the immersion heaters and conducted directly to the molten metal. This type of aluminum melting reduces metal losses due to oxidation from 2-4% to less than 1% while keeping it in a molten state. Isothermal melting uses 70% less energy than conventional gas-fired burners (U.S. DOE, 2009; U.S. DOE, 2010). Energy use is about 552 Btus per pound, about half of the energy used in stack furnaces (Cochran, 2009). ITM is currently installed at one aluminum foundry in Ohio.

Chapter Nineteen: Ladles

In this chapter:	
Keep lid on ladle	Replace refractory bricks with lining
Preheat with flameless micro-porous burners	Preheat with oxy-fuel burners
Equip with cold-start systems	Use new ladle technologies

Ladles are used to transport molten metal within a facility. Although they are not actively heating their liquid content, ladles are preheated, and hence consume energy.

To be protected from the liquid metal, ladles are equipped with layers of lining usually more than 3.9 inches (10 cm). In general, these linings need to be preheated before the metal is poured into the ladle. Preheating prevents thermal shocks and removes moisture that would lead to the production of potentially harmful steam. The amount of heat that is used in ladle preheating and transporting liquid metal depends on the physical properties, i.e. thermal conductivity and heat capacity. If the temperature decrease of metal can be slowed down in ladles, less overheating is required prior to transport.

Opportunities for Energy Efficiency

It is common practice to preheat the ladles with an open flame from a natural gas burner. The efficiency of this heating process is extremely low. Excess preheating, either in temperature or time, should always be avoided. Careful management can enable this (see also below).

Best Practices for Energy-Efficient Ladles

- **Keep lid on ladle.** In practice, because lids are heavy, too hot to manage, ineffective or damaged, ladles may often be uncovered. By closing the lid on a ladle, significant energy savings can be realized.

- **Replace refractory bricks with lining.** A number of experiments assessing the role of ladle insulation in heat loss reduction have shown that insulated ladles have a substantially lower heat loss than "standard" uninsulated ladles.

- **Preheat with flameless micro-porous burners.** Combustion in pores reduces fuel consumption by 50% in comparison to conventional cold air gas burners.

- **Preheat with oxy-fuel burners.** Replacing the conventional burners with oxy-fuel burners leads to a decrease in operational costs of approximately 50% due to quicker heating (1 hour instead of 2.5 hours) and lower natural gas demand.

- **Equip with cold-start systems.** This practice requires special refractory linings that can withstand the rapid change in temperature. With the use of special refractories the temperature drop during loading the ladle is halved in comparison to the reference systems. Therefore, tapping temperatures can be lowered, saving energy in heating.

- **Use new ladle technologies.** The use of new ladle technologies can result in lower energy use and lower melt losses.

Keep lid on ladle.

In practice, because lids are heavy, too hot to manage, ineffective or damaged, ladles may often be uncovered (Foseco, 2008). By closing the lid on a ladle, significant energy savings can be realized. Ladles should be closed with a lid as quickly as possible after charging with liquid metal. An investigation was performed on a non-preheated ladle (cold start), equipped with ceramic insulation, and charged with 1 ton of steel at 3,056°F (1,680°C) (no slag cover). By using a low-density lid, the cooling rate was lowered from 16.6 to 13.5°F/foot (12.5 to 6.8°C/min). Less overheating was required, and the tapping temperature was lowered by 122°F (50°C). It is suggested that savings of about 74 kBtu/ton of tapped steel were realized. The energy savings were independent of the refractory lining used (Foseco Group, 2008). The cost of this measure was low.

Closing empty ladles should also be considered. Due to heat radiation, ladles cool down rapidly after being preheated. A ladle ready for loading, and preheated by gas burners or a previous loading, should be sealed with a lid. In this way, the temperature drop of the charged ferrous metal decreases and the tapping temperature can be lowered by about 86°F (30°C) (Hoel et al., 2005). If lids are not an option, a layer of slag on top of the metal can help reduce radiant heat losses (BCS, 2005).

Replace refractory bricks with lining.

The maintenance and relining of traditional refractory materials in ladles and lauders is a labor intensive and time consuming process, while heat requirements due to poor insulation are high. A foundry in the U.K. switched to a non-wetting lining material with by low-density and low thermal conductivity. As the lining can be installed in form-fitting shapes, less labor and time was required for its placement. In the past, the ladle needed to be preheated for 24 hours a day, while with the new lining was preheated for 2.5 hours at the beginning of each week. Additionally, the molten tapping temperature was lowered as heat losses decreased. The lifetime of the lining typically ranges between 12 and 18 months. The payback period was 9 weeks. Another foundry in Ontario eliminated the use of refractory bricks in ladles and the core furnace, also achieving a substantial decrease in energy use (CIPEC, 2003).

A number of experiments (Schwam et al. 2007) assessing the role of ladle insulation in heat loss reduction have shown that insulated ladles have a substantially lower heat loss than “standard” uninsulated ladles. In these experiments, a microporous insulation composite was used between the steel shell and the refractory in one of the furnaces. During the molten aluminum transfer from the reverberatory to the holding furnace, the insulated ladle averaged a loss of 7.3°F/minute while the uninsulated ladle lost 10.1°F/minute. Over the entire cycle, the insulated ladle lost 103°F while the uninsulated ladle lost 122°F; the uninsulated ladle was about 84% as effective as the insulated ladle. It is expected that for longer transfer cycles the efficiency gap between an insulated and an uninsulated ladle will be larger.

Preheat with flameless micro-porous burners.

It is common practice to use open flames when preheating ladles. An innovative design of a microporous burner uses a porous ceramic in which a mixture of fuel and air is burned without an open flame. This principle allows for a highly efficient combustion in pores. Three-dimensional ceramic bodies, e.g. cylinders, are formed that fit exactly into the ladle. As the geometry of the burner is adapted to the device that is heated, the heat transfer is homogenous and as direct as possible. Heat is transferred mostly by radiation. Combustion in pores reduces fuel consumption by 50% in comparison to conventional cold air gas burners. Furthermore, these innovative burners have a very high energy density, quick start-up and produce a homogeneous heat distribution. Micro-porous burners offer the opportunity to substitute electrical heaters with gas combustion without compromising quality of heat. Furthermore, microporous burners lead to a CO and NO_x emission reduction of 45% (Volkert, 2010; Caballero, 2011). The investment cost for a single station system ranges between $48,000 and $60,000 (Caballero, 2011).

Preheat with oxy-fuel burners.

Natural gas burners reach temperatures of 1,652-1,832°F (900-1000°C), while oxy-fuel burners generate heat at 2,732°F (1,500°C) (Caballero, 2011). By burning gas in a perfect mixture with oxygen, the heating process is more efficient because the burner operates at higher temperatures, leading to a quicker heating with less energy being wasted to surroundings (Caballero, 2011).

According to Caballero (2011), replacing the conventional burners with oxy-fuel burners leads to a decrease in operational costs by about 50%, due to quicker heating (1 hour instead of 2.5 hours) and lower natural gas demand. Savings increase with the number of ladles that are in use. Because ladle preheating takes a long time, ladles are frequently kept running continuously to ensure operational readiness. Oxy-fuel burners enable a quicker heating process; therefore, a continuous operation might not be required (Caballero, 2011). To justify the installation of new equipment, the described benefits in operation have to outweigh the installation costs.

Equip with cold-start systems.

Ladles equipped with cold-start systems can be loaded with liquid metal at ambient temperature; preheating is not required. This practice requires special refractory linings that can withstand the rapid change in temperature. With the use of special refractories, the temperature drop during ladle loading is halved in comparison to the reference systems (Caballero, 2011). Therefore, tapping temperatures can be lowered, saving energy in heating. Preheating with natural gas burners may cause an inhomogeneous and unspecific temperature distribution, while cold-start systems always enter the process at the same state. Therefore, pouring temperatures can be controlled more accurately (Foseco, 2008). In addition, temperature-related casting defects can be brought down.

By introducing special refractories at a U.S. steel foundry, annual savings of more than $100,000 were achieved. The tapping temperature of the electric arc furnace were lowered by 140°F (60°C), decreasing energy use and furnace lining wear. Additionally, the ladle holding time was extended by 20%, improving flexibility of the casting process (Vesuvius, 2012).

Cold-start systems must tolerate rapid changes in temperature; therefore the refractory material wears out quickly. Currently refractory must be replaced every 6 or 7 loading cycles (Caballero, 2011).

Use new ladle technologies.

The use of new ladle technologies can result in lower energy use and lower melt losses. Electrically heated transport ladles can stay hot between metal transfers. Metal temperature does not decrease when metal is tapped into the ladle. Further, plants are able to maintain the metal's temperature during degassing, fluxing and transport. Super heating the metal in the furnace is not needed. A company that adopted this type of ladle decreased furnace temperature by 50°F and reduced its energy consumption and melt loss (Cochran, 2009).

Chapter Twenty: Improve Casting Yield and Decrease Scrap Generation

In this chapter:	
Optimize gating and risering systems	Use insulated exothermic feeders
Reduce casting weight	Reduce the number of trials and errors
Introduce new casting technology	

In the production of final castings, there is a large amount of the energy used to produce the final castings is lost in re-melting. By decreasing the amount of re-melt, the yield will increase resulting in substantial energy savings. Yield is the weight of metal that remains a usable casting, divided by the weight of poured metal, including gating and risering systems (Schifo and Radia, 2004). When molten metal is poured into the mold to form a casting, more than just the weight of the casting is required. The molten metal is initially poured into a "pouring basin" in which metal accumulates and it is then fed into the gating system. The gating system, runners and risers, feeds the molten metal to the casting and continues to feed hot metal as the casting solidifies. The gating system, including the "pouring basin", consists of metal that is not a part of the casting, and, after its removal from the casting, it is re-melted and re-used.

According to Schifo and Radia (2004), in 2003, the typical casting yield in ferrous and non-ferrous foundries, ranged between 50 and 75% and the scrap rate ranged between 4 and 7%. Different metals and molding methods have inherently different casting yields. Which molding method will be adopted will depend on several parameters including casting complexity, and overall production costs, which are weighted by the yield differences. Cast iron pipe foundries use centrifugal casting machines and produce a very high yield of 90%. On the other hand, sand casting processes have for most products the lowest yields of 50-65%. In 2003, yield and scrap losses accounted for an average of 37% of the overall energy use in foundries (Schifo and Radia, 2004).

Opportunities for Energy Efficiency

With the use of computerized casting process simulation, the foundry engineer can design the gating and risering system at the physical and technological optimum prior to pouring the metal into the first casting (Sturm et al., unknown date). In this way, less material is used, and less energy is required in melting. In addition, the process and cycle times in casting production can be reduced. Casting process simulation can be used throughout the entire casting process to reduce energy use (i.e. in optimizing temperature distribution of permanent molds, reducing molding material, and improving shakeout conditions).

In addition, in die casting operations, appropriate preheating of dies, computer control of die cooling lines and an optimized start-up can decrease start-up scrap and improve yields.

A 10,000 tons (gross) casting facility with a 45% yield melts 22,222 tons of metal. By increasing the yield from 45 to 46%, 483 tons less metal is melted. Return on investment is typically less than one year. Even when the cost of computer analysis and pattern revisions is taken into consideration, the return on investment should be short (Focus on Energy, 2006).

Best Practices for Improving Casting Yield and Decreasing Scrap Generation

- **Optimize gating and risering systems.** Optimized gating and risering systems will reduce the amount of metal poured into the mold without deteriorating product quality, resulting in lower energy requirements for melting. By melting less metal, the productivity in the melting area increases.

- **Use insulated exothermic feeders.** Most metals have a lower density when in liquid state, and shrink when cooled down. Shrinkage can result in voids during solidification. Defects can be decreased with the use of feeders.

- **Reduce casting weight.** Modern simulation tools can predict with great certainty the impact that different process parameters will have on the final casting quality. A better understanding of how microstructure affects mechanical properties allows the construction of more lightweight products with fewer defects as metal will only be used where necessary.

- **Reduce the number of trials and errors.** Modern simulation tools can predict with great certainty the impact that different process parameters will have on the final casting quality. A better understanding of how microstructure affects mechanical properties allows the construction of more lightweight products with fewer defects as metal will only be used where necessary.

- **Introduce new casting technology.** Fear of potential production risks and delivery disruptions results in operating old technologies. The use of casting process simulation can assist in the adoption of more efficient processes.

Optimize gating and risering systems.

Optimized gating and risering systems reduces the amount of metal poured into the mold without deteriorating product quality, resulting in lower energy requirements for melting. By melting less metal, the productivity in the melting area increases.

Bradken Foundry, in Ipswich (Australia), examined the possibility of changing the runners' shape to limit the feeding metal requirements and improve yields. Therefore, the traditional cylinder feeder (riser) was switched to a football feeder. The outcome was 44% lower riser weight, increasing the yield by 14% and saving annually about 1,600 tons of metal. Some of the additional benefits were shorter solidification and feed times (Queensland Government, unknown date).

John Deere, in Moline (Illinois) modified the design and gating system to reduce the scrap rate of a gray iron part from 10.3 to 1.4%. This improvement yielded annual savings of $66,936. With the use of casting process simulation, the casting yield also improved from 58 to 64%, achieving another $66,600 additional cost savings. The amount of iron required decreased by 216 tons (Sturm et al., unknown date).

A steel foundry in North America, with the use of a simulation tool improved the design of the gating system and decreased scrap costs by 2.7% (Sturm et al., unknown date).

Use insulated exothermic feeders.

Most metals have a lower density when in liquid state, and shrink when cooled down. Shrinkage can result in voids during solidification. Defects can be decreased with the use of feeders. Feeders, also known as risers, are reservoirs built into the mold that provide liquid metal to the casting during its solidification. The solidification process in the feeder needs to be slower than the one in the casting cavity (for the feeders to be able to supply liquid metal to the casting), so the feeders usually have a high volume. The insulated exothermic feeder, is characterized by lower volumes than traditional feeders. Compared to traditional feeders the metal spreading is improved by savings on volume of liquid iron. For example, the use of an insulated exothermic feeder with a volume of 0.01 ft^3 (300 cm^3) instead of a typical feeder with a volume of 0.05 ft^3 (1350 cm^3) will result in a lower volume of liquid iron of about 0.04 ft^3 (1050 cm^3). That corresponds to 14.3 lb. (6.5 kg) savings in liquid iron per charge. Assuming that 620 kW are used to melt one ton of iron, about 4 kW will be saved (Caballero, 2011).

Reduce casting weight.

Modern simulation tools can predict with great certainty the impact that different process parameters will have on the final casting quality. A better understanding of how microstructure affects mechanical properties allows the construction of more lightweight products with fewer defects as metal will only be used where necessary. Computer models able to predict the microstructure of cast aluminum based on different casting parameters were linked to models that predict mechanical performance based on microstructures. In a case study, 20% lighter aluminum support arms were manufactured while the mechanical properties were also improved, making the aluminum castings cost-competitive to iron castings (U.S. DOE, 2001a).

CASE STUDY: Tyco Water in Currumbin (Australia), with the use of 3D modeling and by coating the castings with an epoxy that increased the resistance to corrosion, was able to decrease product wall thickness without compromising product properties. Tyco Water melts about 5.5 tons less metal per day, decreasing the energy requirements for melting by 11-13% (Queensland Government, unknown date).

Reduce the number of trials and errors.

When a foundry does not use casting process simulation, several trials will have to be performed before finalizing the castings. With the reduction of trials and errors, raw materials and energy are saved. An American foundry, with the use of simulation achieved $580,000 cost savings by reducing the use of prototypes, and another $208,000 cost savings by eliminating test runs that led to bad castings (Sturm et al., unknown date).

Introduce new casting technology.

Although new casting equipment can be more energy- and material-efficient, introducing a new casting technology in a foundry can be challenging. Fear of potential production risks and delivery disruptions results in continuing to operate old technologies. The use of casting process simulation can assist in the adoption of more efficient processes.

A steel casting facility, Otto Junker Edelstahlgießerei (Germany), after the verification from the simulation software switched from side risers to direct-pour top risers with filters. The required amount of liquid metal was reduced by 19%. Some of the additional benefits were the decrease in molding time, and a decreased time needed to melt the risers. Production costs for the part were reduced by 12% (Sturm et al., unknown date).

A South American iron foundry, with the use of simulation software, developed a non-traditional gating system and increased the casting yield from 62 to 67%. In addition, the scrap rate decreased from 17 to 7%. With this improvement 700,000 kWh of energy were saved, reducing annual energy costs by $500,000 (Sturm et al., unknown date).

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 through the use of energy teams dedicated to improving your energy savings.
- How to assess and fix energy waste in your plants, systems, and metal casting 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 metal casting 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 3, 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!

Acknowledgements

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Appendix A: The Metal Casting Industry

In metal casting facilities, metal is poured into molds or dies to produce a variety of simple and highly complex components of the desired size, shape and form, needed in today's manufactured products. About 90% of all manufactured products in the U.S. use cast metal components (U.S. DOE, 2005c). The major end-use markets of castings can be seen in Figure 4 below. According to the American Foundry Society (AFS) (2009), the most common metals used in casting facilities are iron, aluminum, magnesium, zinc, steel and copper-based alloys.

Some of the molding methods used for metal casting production are the green sand (horizontally or vertically parted), Nobake, pressure diecasting, gas hardened/Coldbox, shell molding, investment casting, lost foam casting, and squeeze/semi solid casting. Although most facilities use a variety of casting processes, based on a survey of 1,617 U.S. metal casting facilities, the horizontally parted green sand is the method most commonly used in the U.S. (45% of respondents) with second being the Nobake process (42% of respondents) (Dahlquist, 2011).

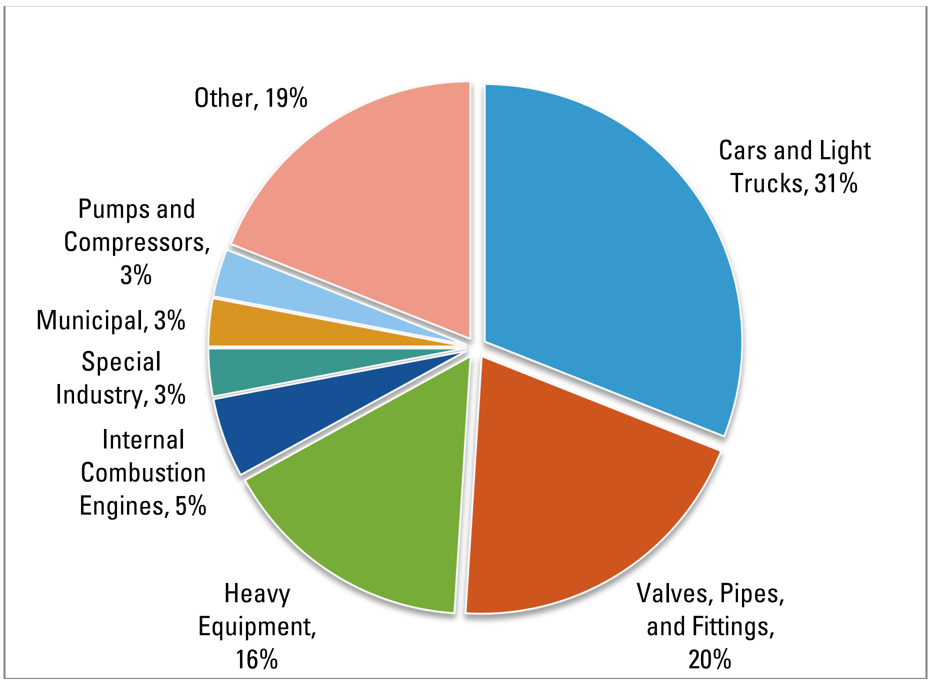


Figure 1. End-use markets for metal casting products in the U.S.
Source: American Foundry Society, 2009.

There were 2,010 metal casting facilities operating in the U.S. in 2011; 643 processing iron, 362 processing steel and 1,005 processing non-ferrous metals (World Casting Census, 2012). In 2010, there were 310 foundries processing more than one metal (Dahlquist, 2011). In 2011, the U.S. casting production reached 11 million tons; consisting of about 7.6 million tons of iron castings, 1.1 million tons of steel castings, 1.7 million tons of aluminum castings with the remaining 0.7 million tons being copper base, magnesium, zinc and other non-ferrous metal castings (see Figure 2). In this Guide weight is reported in short tons and is simply referred to as tons.[10] Although ferrous metal castings account for the highest share (weight basis) of

[10] One ton is 2,000 pounds. To convert tons to metric tonnes multiply by 0.907.

U.S. metal castings production, most of the metal casting facilities process aluminum. About 55% of American metal casters process aluminum, 31% process iron and 22% report to pour both aluminum and ferrous metals (Dahlquist, 2011).

Metal casting production decreased from 14.6 million tons in 1998 to 13.0 million tons in 2007 at an average rate of decline of 1.2% per year (see Figure 6). The low production level in 2009 was the result of the economic crisis and the drastic effect it had on the automobile industry (the main end-user of cast metal products). The production of ferrous products decreased from 12.0 million tons in 1998 to 10.0 million tons in 2007 at an average rate of 2.0%, while in the same period, the production of non-ferrous products increased from 1.8 million tons to 2.0 million tons at an average rate of 1.5% per year due to increasing demand for non-ferrous parts. In recent years, the U.S. metal casting industry has been emerging from the economic recession, increasing its productivity from 8.2 million tons in 2009 to 11 million tons in 2011, an increase of 35.1% within two years. Plant production also increased substantially in 2011, from 4,451 tons in 2010 to 5,488 tons per plant; an increase of 23.3% (World Casting Census, 2011 and 2012).

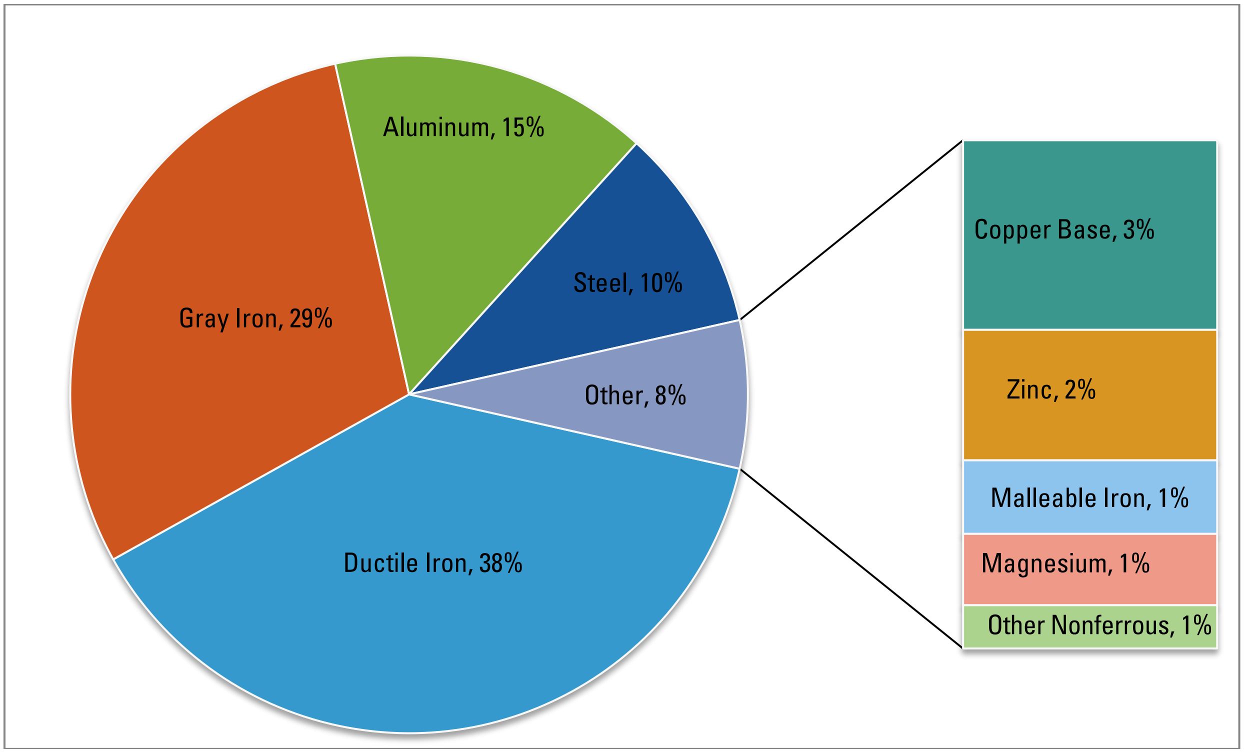


Figure 2. Share of different metal castings on the overall metal casting production (weight basis) in the U.S., in 2011. Source: World Casting Census, 2012.

In 2011, the U.S. metal casting industry was the second largest metal casting producer in the world, following China. On average, 100 people are employed per foundry; with many facilities (58%) employing less than 60 people and only 16% of all U.S. foundries having more than 250 employees (Dahlquist, 2011).

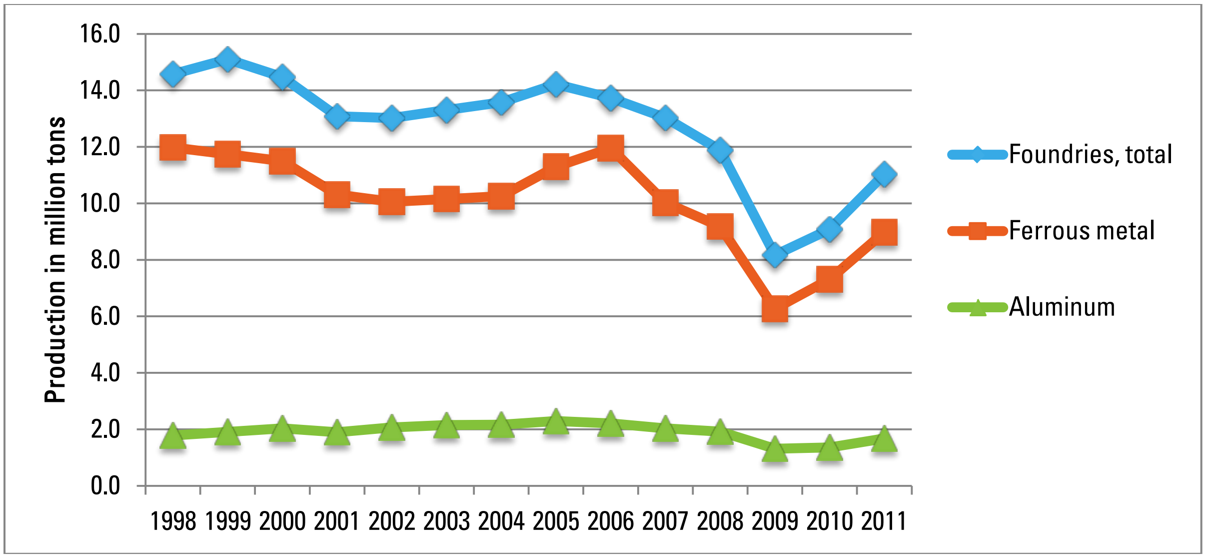


Figure 3. Production trend of U.S. metal casting industry. Ferrous metal comprises gray iron, ductile iron, malleable iron and steel. Source: World Casting Census, various years.

The definition of the metal casting industry considered in this Guide is based on the industrial sector 3315 of the 2007 North American Industry Classification System (NAICS). This sector covers all foundries that are primarily engaged in pouring molten metal into molds or dies to produce castings with the approximate dimensions of the final product. Sector 3315 is further divided into sub-categories by metals: ferrous metal casting facilities (33151) and aluminum casting facilities (331521 and 331524) (U.S. Census, 2012). Foundries that process other metals are responsible for a small share of overall production and are not discussed in this Guide. Foundries might also carry out further hardening and machining. Starting material in the metal casting industry is secondary metal bought from other facilities in the form of scrap, ingots and other semi-finished products.

Process Description

In all foundries, metal is melted and poured into the desired shape. Therefore, all foundries have a melting shop and a pouring line. Figure 7 (below) displays a typical process chain for a foundry that casts iron in sand molds.

The primary source for metal used for melting is from secondary sources, i.e. purchased recycled scrap and internal returns, and, to a smaller extent, from primary iron units like pig iron. After melting in a melting furnace, e.g. a cupola or an electric induction furnace, the liquid metal is often transported to a holding furnace where it is held at temperature. Holding the melt is required for alloying, quality checks or simply to produce enough liquid metal to start casting. The liquid metal is transported in ladles and poured into the molds. Molds are made from bounded sand and hold the liquid metal at the desired shape until it solidifies. Different molding systems are available; 'green sand' or 'Nobake' are prominent examples (Dahlquist, 2011). The green sand method uses a mixture of sand, clay and water; while Nobake molding makes use of sand and a chemical binder. At shakeout, the sand mold is destroyed to remove the casting. This sand is typically recycled within the facility, which includes cooling, transporting and processing for continued reuse or disposal. Furthermore, the contact of the hot metal and the binder may lead to production of toxic emissions that need to be controlled.

There are plants where different molding systems are used. Many large-scale aluminum casting facilities often make use of metal dies instead of sand molds. Similar to injection molding, these dies are not destroyed when removing the casting. They are made from durable steel that can withstand molten aluminum. Another example for die technology is the casting of steel railroad wheels. In 2003, semi-permanent graphite molds, able to tolerate the extreme conditions of pouring steel, were used to produce about 360,500 tons of wheels in the U.S. (Eppich, 2004).

It is important to notice that not all metal that is tapped from the furnace is transformed into a casting. The casting process requires gating systems to fill the mold and risers to feed the casting to make the desired product. The casting yield is the percentage of metal transformed into the desired product in relation to the total amount of metal melted. In addition, some castings may not meet specifications and scrap castings are produced. These rejects are recycled internally along with gates and risers. The casting yield in ferrous and non-ferrous foundries can range between 30 and 90%. Only good castings are useful output; therefore, a low casting yield leads to higher energy consumption per unit of good product. Schifo and Radia (2004) estimated that in 2003, yield and scrap losses were responsible for about 37% of the overall energy use in U.S. foundries.

Beyond the actual casting process, equipment required to operate the facility consumes additional energy. Space heating is usually done with natural gas while much of the other equipment such as lights, motors, pumps, and air compressors runs on electricity.

According to a 2010 survey (Dahlquist, 2011), among 1,617 American metal casting facilities (79% of the total in the U.S.), the types of furnaces commonly used for melting are the coreless induction furnace (38% of total number of metal casting facilities) and the crucible furnace (33% of total number of metal casting facilities). Cupola, channel induction and electric arc furnaces each have a share of roughly 10% (of the total number of metal casting facilities). Table 4 (below) displays the typical melting and casting temperatures for the three different metal types and names the most prominent furnaces and molding processes based on actual production volumes. The majority of foundries make use of furnaces with a small capacity, e.g. electric induction and crucible furnaces; while only a few foundries operate large capacity furnaces like cupolas.

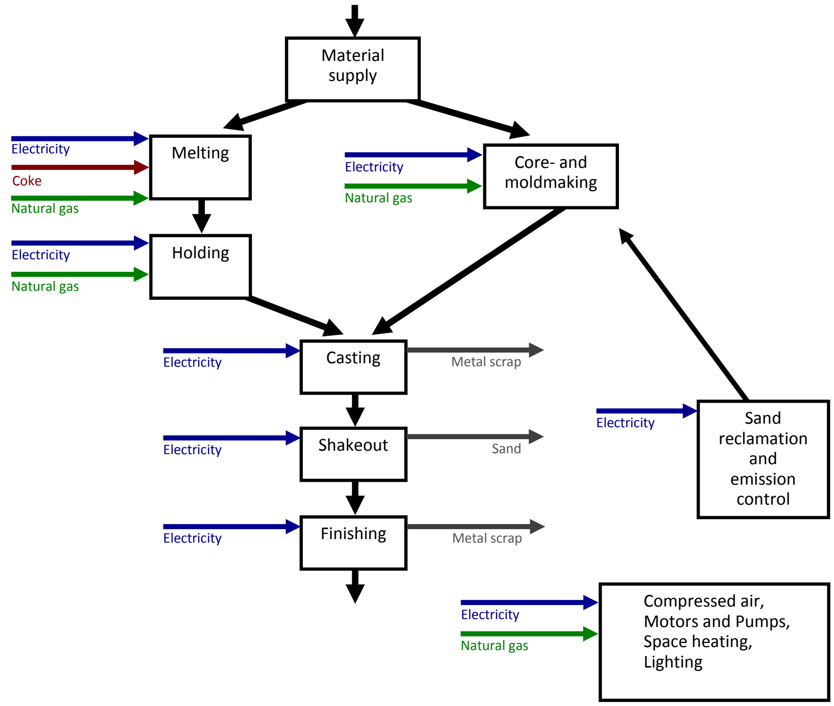


Figure 4. Metal casting process schematic.

The typical process steps in metal casting are displayed along with the corresponding main energy and material flows. The figure focuses on the production of castings. However, significant amounts of energy are also consumed in operating the facility and in recycling molding sand. *Sources: Eppich, 2004; Tapola et al., 2010.*

Table 1. Tapping temperatures, prominent melting furnaces and molding processes. Source: Eppich, 2004 and Schifo and Radia, 2004.

Metal	Melting Furnace Temperature[1]	Casting Temperature	Prominent Melting Furnaces[2]	Prominent Molding Processes[2]
Iron	< 1566°C < 2850°F	1288-1454°C 2350-2650°F	Cupola (60%) Induction (36%)	Green sand (75%) Chem. bonded sand (10%) Centrifugal casting (10%)
Steel	1621-1677°C 2950-3050°F	1566-1621°C 2850-2950°F	Electric arc (82%), Induction (17%)	Green sand (32%) Chem. bonded sand (30%) Permanent mold (32%)
Aluminum	760°C 1400°F		Reverberatory (90%) Crucible and induction (5%) Stack furnaces (5%)	High pressure die casting, Sand casting and permanent mold casting

[1]The melting furnace temperature, also know as tapping temperature, is the temperature the metal has to reach so that it will not solidify prior to being poured into the molds.
[2]The columns on prominent melting furnaces and prominent molding processes show the kind of furnaces and molding processes most commonly used; the percentages refer to the share of production and do not represent the share in the number of furnaces.

Appendix B: Energy Consumption by Foundry Type

Energy Use in U.S Iron Foundries

In 2010, the U.S. iron foundries consumed 45 TBtu of energy, of which 19 TBtu was electricity, 14 TBtu was natural gas and 12 TBtu was coke, breeze and other fuels (EIA, 2013a). In the same year, U.S. iron foundries were responsible for 46% of the energy consumption and for 100% of coke and breeze consumption.

In 2003, most of the iron in casting foundries was melted in cupola furnaces (60%), while about 36% of iron was melted in induction and 4% in arc and other furnaces (Schifo and Radia, 2004).

Table 5 shows the energy used in a number of U.S. iron foundries. Energy use in high capacity cupola furnaces ranges between 6.0 and 10.5 MBtu/ton. The ductile-pipe operation exhibits particularly low energy intensity. This is because the centrifugal casting of pipes is an exceptionally efficient process, which does not require any risers or gates. Therefore the casting yield can be as high as 97% (excluding defective castings) (Eppich, 2004). This example underlines the significance of the amount of energy that is consumed in melting.

Casting Yield Efficiency

When casting yield approaches 100% (no re-melting of metal), overall energy use decreases substantially.

Table 5. Examples of energy use in U.S. iron foundries. Source: Eppich, 2004.

#	Type of Melting	Iron type	Annual Production	Electrical	Natural Gas	Coke	Other[1]	Total Purchased	Total Primary[2]
			tons	MBtu/ton	MBtu/ton	MBtu/ton	MBtu/ton	MBtu/ton	MBtu/ton
1	Cupola	Gray	87,500	2.07	2.37	5.10	0.00	9.59	13.44
2	Cupola	Ductile	103,000	2.23	1.97	5.97	0.33	10.51	14.66
3	Cupola	Ductile-Pipe	206,000	0.46	2.65	2.79	0.00	5.98	6.84
4	Induction	Ductile	5,500	8.54	6.12	0.00	0.00	14.66	30.54
5	Induction	Gray	13,250	11.8	6.59	0.00	0.00	18.39	40.34

[1] 'Other' covers energy use in the form of oxygen equivalent, propane and fuel oil (this category contributes to less than 3% of the total energy use).

[2] 'Primary' energy also includes the energy needed to generate electricity.

Small metal casting facilities usually use induction furnaces. Regardless of tonnage, facilities using induction-melting are more energy intensive than facilities using cupola-melting as their primary source of energy is electricity. Iron metal casting facilities using coke as their main energy source have a smaller number of intermediate steps than metal casting facilities operating induction furnaces (Eppich, 2004).

Melting and holding is responsible for most of the energy use and energy expenses in a foundry (Monroe et al., 2008; IfG, 2008; Eppich and Naranjo, 2007; Caballero, 2011; Tapola et al., 2010). Table 6 shows where energy is used in a ferrous foundry. About 50-70% of the energy is used for melting and holding.

Iron Foundry Energy Use

Between 50% - 70% of energy is used for melting and heat-treating in an iron foundry.

Table 6. Energy use in a typical ferrous foundry. Source: Tapola et al., 2010.

	Consumption of Total Plant Energy Use
Melting and heat treating	50-70%
Other production accessories	10-20%
Air compressors	3-10%
Lighting	2-5%
Heating and ventilation (no pumps)	5-20%
Others	8-15%

Energy use for molding and core making will depend on the method used, and it usually accounts for up to 20% of the overall energy used in the foundry

Energy Use in U.S. Steel Foundries

In 2011, U.S. steel casting production reached 1,077,000 tons (World Casting Census, 2012). In 2003, steel foundries were responsible for about 10% of the overall energy used in U.S. foundries (Schifo and Radia, 2004). Very little data is available for steel casting facilities. The total U.S. production volume is low and the applications for steel castings are often special. Steel castings are used when iron cannot fulfill the product specifications, e.g. for strength, ductility, toughness or weldability. Steel is melted in smaller furnaces at a high temperature and requires heat treatment, which leads to high energy use in steel foundries.

Table 7 shows the typical electricity use in electric arc and induction steel foundries. Table 8 shows the electricity use breakdown in a typical induction steel foundry.

Table 7. Electricity use breakdown in a typical electric arc furnace steel foundry. Source: Monroe et al., 2008.

	Consumption of total electricity use
Arc furnaces	47%
Dust collection	14%
Air compressors	13%
Charge cranes	6%
Lighting	3%
Mullers	3%
Shot blast	2%
Cooling tower	1%
Shakeout	1%
Other	11%

Table 8. Electricity use breakdown in a typical induction steel foundry. Source: Monroe et al., 2008.

	Consumption of total electricity use
Induction furnaces	51%
Motors	14%
Compressed air	13%
Lighting	8%
Space conditioning	1%
Other equipment	13%

Steel and iron have similar physical properties with regard to heat capacity and conductivity, so the theoretical minimum energy requirement in melting should be the same for iron and steel. However, steel needs to be heated to higher temperatures and requires additional treatment. In EAF practices, liquid steel is usually injected with oxygen (another source of process energy) to adjust the carbon content. Therefore, the production of steel castings consumes significantly more energy than the production of iron castings.

As Table 9 shows, the energy intensities of steel casting production can differ substantially. Steel is melted in both electric arc furnaces (EAF) and electric induction furnaces (EIF) with most of steel being melt in EAFs (82%) (Schifo and Radia, 2004). Steel melting furnaces are very similar to iron melting induction furnaces.

Table 9. Overall energy consumption in exemplary U.S. steel foundries. Source: Schifo and Radia, 2004.

Type of Steel Foundry	MBtu/ton			
	Electricity	Natural Gas	Total	Total Primary[1]
Induction furnace, stainless, no bake molding	22.4	267.2	49.1	97.8
Arc furnace, low carbon, green sand and no bake molding	9.2	11.5	20.7	40.7
Induction furnace, low carbon, no bake molding	6.9	10.4	17.3	32.2
Average Steel Foundry (Low carbon content)	8.1	10.9	19.0	36.5

[1]"Primary" energy also includes the energy needed to generate electricity.

According to Foundrybench (2011b), the energy use in a number of small (<7,000 tons/year) European steel foundries ranged between 17 and 26 MBtu/ton. The implementation of energy saving measures identified after auditing decreased energy use by 15-20%.

The theoretical electrical energy requirements for melting steel to a temperature of 2,912°F (1,600°C) is 342 kWh/ton. However, the majority of steel foundries consume 454-726 kWh/ton in melting due to heat losses. When the energy losses are multiplied by the yield losses in casting and finishing (up to 40 percent), electrical energy used by steel foundries can be 3 to 6 times the theoretical energy requirement (U.S. DOE, 2005b).

Energy Use in U.S. Aluminum Foundries

Although aluminum castings represent only a small share of castings (by weight) produced in the U.S. (15% in 2011), aluminum foundries are big energy consumers. In 2011, U.S. aluminum casting production reached 1,679,000 tons (World Casting Census, 2012). In 2010, according to the latest Manufacturing Energy Consumption Survey (EIA, 2013a), U.S. aluminum foundries (die casting and non-die casting facilities) consumed 27 TBtu of energy, that is 28% of the overall energy consumed in U.S. foundries. Most of the energy was consumed as natural gas (19 TBtu) and electricity (7 TBtu).

Data about energy use in aluminum casting facilities is scarce. Figure 8 shows where energy is consumed in a die casting aluminum facility.

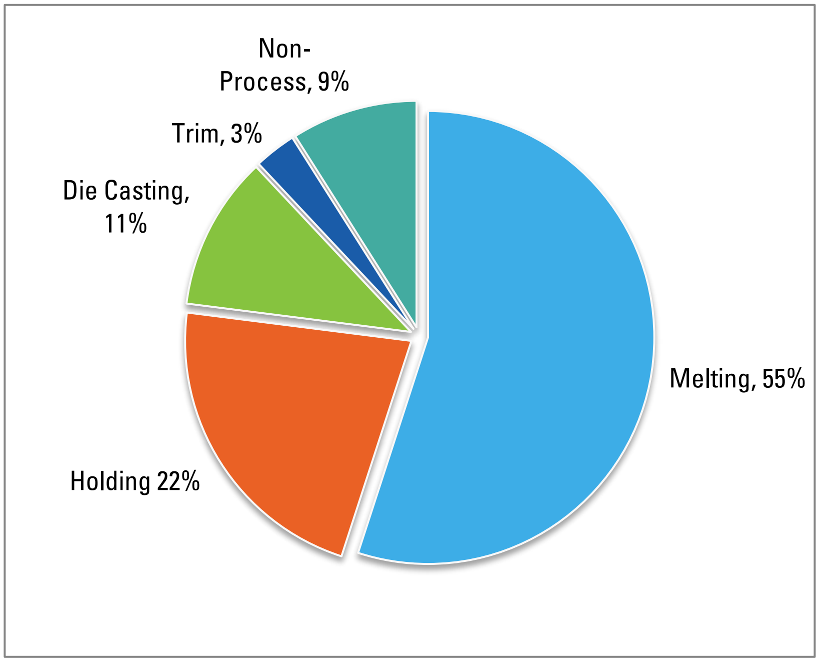


Figure 8. Energy use breakdown in an aluminum die casting foundry. Source: Schifo and Radia, 2004.

Despite the low melting temperature of aluminum, 1400°F (760°C) instead of 2732°F (1500°C) for iron, the theoretical energy required for melting is still quite high. This is due to the high specific heat capacity of aluminum (Cengel and Boles, 2010). Nonetheless, the lower processing temperature brings down radiation losses significantly. As aluminum melts at lower temperatures, which leads to an increased temperature gradient between heat source and metal, the heat transfer is more efficient. These effects bring down energy use in melting. Moreover, large production series are usually cast into dies with removable parts or cores; therefore some aluminum foundries may not make use of sand molds or cores.

Table 10 shows the energy use in a number of aluminum foundries. Facilities 1 and 2 are jobbing foundries (manufacturing small production lots on demand), and both use natural gas-fired furnaces for melting and holding. Facility 1 uses molten metal from a nearby smelter, while facility 2 needs to melt a percentage of the alloys into a molten state. The first aluminum foundry has higher electricity use than the second, most probably due to the machining performed in a big proportion of the castings (Eppich, 2004). Die casting facility 2 performs no onsite machining. The lost foam facility (Facility 4) makes use of some energy intensive processes unique to the lost foam process, operates a number of inefficient crucible furnaces, and is situated in an area with hard winters; therefore, it is characterized by high specific energy consumption.

Table 10. Examples of energy consumption in aluminum foundries. Sources: Eppich, 2004; Schifo and Radia (2004), and Foundrybench (2011a).

	Type of Facility	Tons	MBtu/ton			
		Annual Production	Electricity	Natural Gas	Total	Total Primary[1]
1	High-pressure die-casting facility, liquid delivery, melting with gas, additional intensive machining	1,712	12.2	33.6	45.8	68.6
2	High-pressure die-casting facility, solid delivery, melting with gas	1,102	6.6	25.3	31.9	44.2
3	Permanent mold with sand cores	1,392	12.1	59.8	71.9	94.5
4	Lost foam molding process	16,896	18.8	55.2	74.1	109.1
5	High pressure die casting	-	13.3	18.5	31.7	56.4
6	Lost foam	-	18.1	24.5	42.6	76.2
7	Unknown German foundry	62,265	7.6	5.8	13.4	27.6

[1]'Primary' energy also includes the energy needed to generate electricity.

Aluminum Foundry Efficiency

Inefficient melting and holding is very common in U.S. aluminum foundries (U.S. EPA, 2007).

Reverberatory furnaces, extensively used in aluminum foundries, can be highly inefficient. The typical aluminum foundry uses about 3.8 times more energy per ton of product than the typical iron foundry although the theoretical energy requirements are lower (Schifo and Radia, 2004). According to Schifo and Radia (2004), 90% of aluminum is melted in reverberatory furnaces, 5% in stack melters, and another 5% in crucible or induction furnaces. Reverberatory furnaces are characterized by low energy efficiencies ranging between 20 and 25%. As shown in following paragraphs, improvements in combustion burner systems, improved insulation, charge preheating, metal circulation and the use of recuperative or regenerative burners can considerably improve energy efficiency.

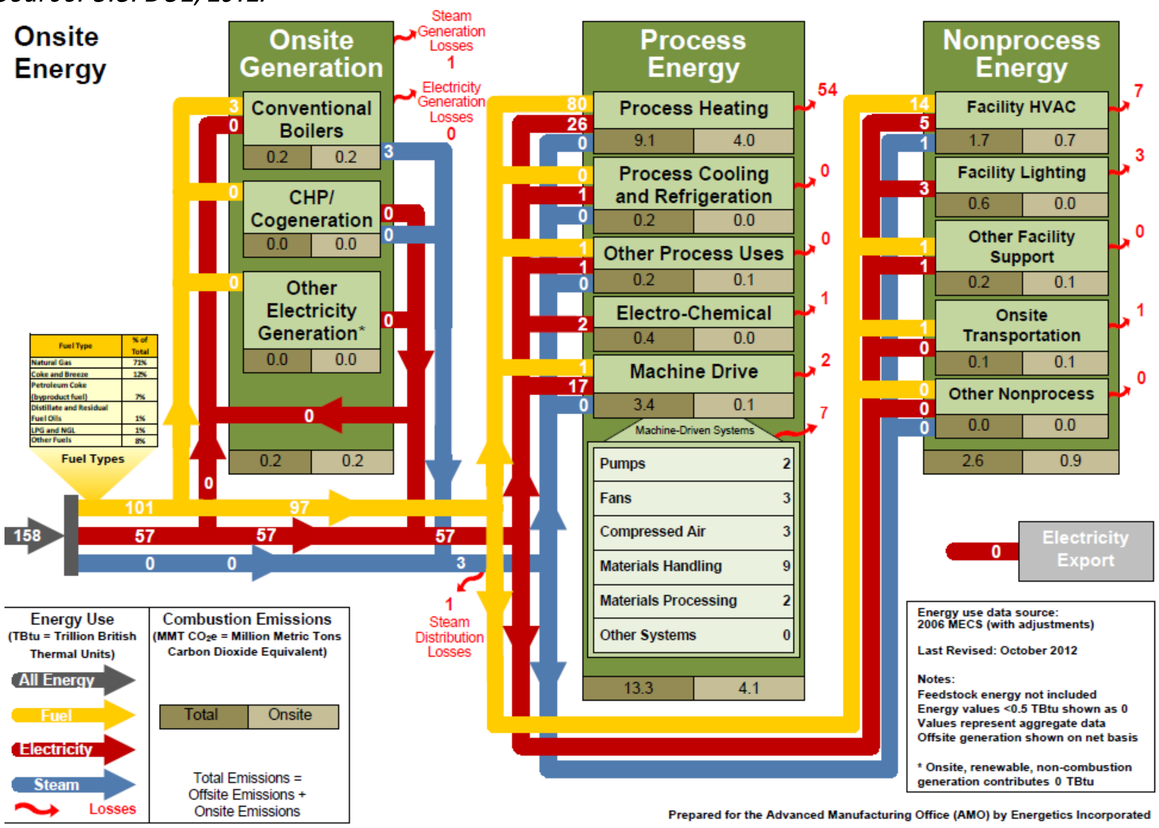
Most of the energy used in a high pressure die-casting facility is used for melting. A typical energy breakdown of such a foundry operating pressure casting equipment is as follows (Caballero, 2011): 60-85% of natural gas is consumed for melting and holding and 15-40% of natural gas is consumed by ancillary processes, such as preheating of dies before and during their use. About 30-50% of electricity is process-related energy needed in melting and the operation of the pressure casting machines, and 50-70% of electricity is used in ancillary processes such as lighting and air compressors.

The casting of aluminum is highly energy intensive. Casting machines contribute to a large share of the overall energy requirement; the electricity is mainly used in pouring if high-pressure casting machines are applied.

Aluminum casting facilities may have an energy intensity of 13, 32 or even 74 MBtu/ton. The type of casting process and the facility size are important factors. However, the lack of data does not allow for more detailed conclusions. Actual practice energy intensity is found to be 32-46 MBtu/ton for high pressure die casting foundries. Common practice in general aluminum casting energy intensity is somewhere between 30 and 70 MBtu/ton.

Appendix C: Diagram of Process and Non-Process Energy Use in U.S. Foundries in 2006

Source: U.S. DOE, 2012.



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, 2007):

- 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 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

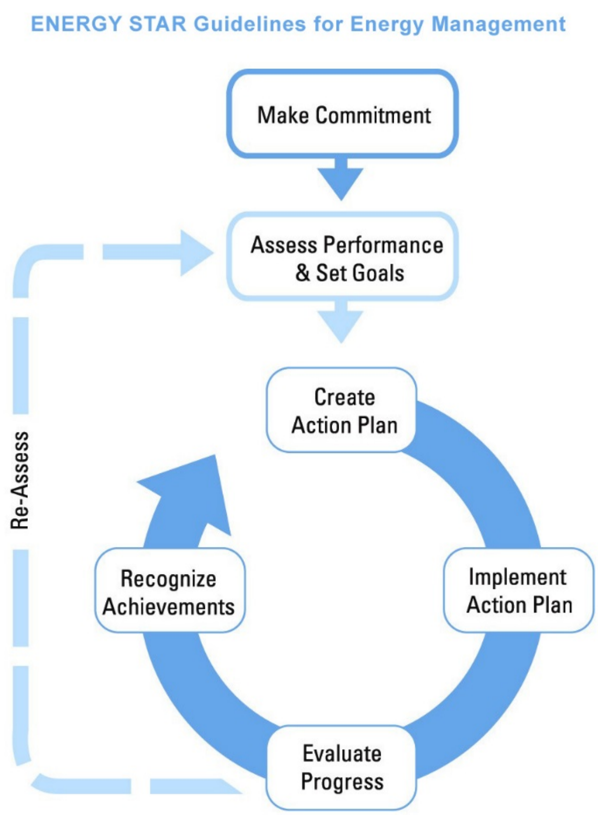
Energy Management Program Assessment Matrix

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 – http://www.energystar.gov/index.cfm?c=guidelines.guidelines_index.



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.
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	

Energy Management Program Assessment Matrix				
	Little or no evidence	Some elements	Fully implemented	Next Steps
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	
Determine roles and resources	Not addressed or done on ad hoc basis	Informal interested person competes for funding	Internal/external roles defined & funding identified	

Energy Management Program Assessment Matrix				
	Little or no evidence	Some elements	Fully implemented	Next Steps
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	

Energy Management Program Assessment Matrix D

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 three 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. Review ENERGY STAR Tools and Resources.

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

4. 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 http://www.energystar.gov/.

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 Assessment Tool
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 (13.6 MB)
Contact: U.S. Department of Energy
URL: http://energy.gov/eere/amo/software-tools.

Steam System Scoping Tool
Description: Spreadsheet tool for plant managers to identify energy efficiency opportunities in industrial steam systems.
Target Group: Any industrial steam system operator
Format: Downloadable software (Excel)
Contact: U.S. Department of Energy
URL: http://energy.gov/eere/amo/software-tools.

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 (can also be ordered on CD)
Contact: U.S. Department of Energy
URL: http://energy.gov/eere/amo/motor-systems .

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:http://www.motorsmatter.org/tools/123approach.html.

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: http://energy.gov/eere/amo/software-tools.

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: http://energy.gov/eere/amo/software-tools.

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: http://energy.gov/eere/amo/software-tools.

Plant Energy Profiler/Integrated Tool Suite
Description: The Plant Energy Profiler, or ePEP (formerly called Quick PEP), 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. ePEP is designed so that the user can complete a plant profile in about an hour. The ePEP online tutorial explains what plant information is needed to complete an ePEP case.
Target Group: Any industrial plant
Format: Online software tool
Contact: U.S. Department of Energy
URL: http://energy.gov/eere/amo/software-tools

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
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: http://www.sba.gov/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/.

Glossary

AC	Alternating Current
AFS	American Foundry Society
ASDs	Adjustable speed drives
BBBP	Better Buildings Better Plants
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
CFL	Compact fluorescent lamp
CIM	Computer Integrated Manufacturing
CIPEC	Canadian Industry Program for Energy Conservation
cm	centimeter
CO	Carbon monoxide
CO_2	Carbon dioxide
DM	Deutsche Mark (German Mark)
EAF	Electric Arc Furnace
EASA	Electric Apparatus Service Association
EIA	Energy Information Administration (U.S. Department of Energy)
EIF	Electric Induction Furnace
EPACT	Energy Policy Act
HHV	High Heating Value
HID	High Intensity-discharge
hp	horsepower
HPS	High-Pressure Sodium
HVAC	Heating, ventilation, and air-conditioning
Hz	Hertz
IAC	Industrial Assessment Center
IEA	International Energy Agency
ISO	International Organization for Standardization
ITM	Isothermal Melting
ITP	Industrial Technologies Program
KBS	Knowledge Based Systems
kBtu	Thousand British Thermal Unit
kg	kilogram
kJ	kilojoule
km	kilometer
kW	kilowatt
kWh	kilowatt-hour
lb	pound
LBNL	Lawrence Berkeley National Laboratory
LCC	Life Cycle Costing
LED	Light-emitting diode
LIBS	Laser-Induced Breakdown Spectroscopy

LRC	Lighting Research Center
MBtu	Million British Thermal Unit
MDM	Motor Decisions Matter[SM]
MECS	Manufacturing Energy Consumption Survey
mm	millimeter
MWh	Millionwatt-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
psi	pound per square inch
psid	pound per square inch (differential)
psig	pound per square inch (gauge)
TBtu	trillion British thermal unit
UK	United Kingdom
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
WBCSD	World Business Council on Sustainable Development

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