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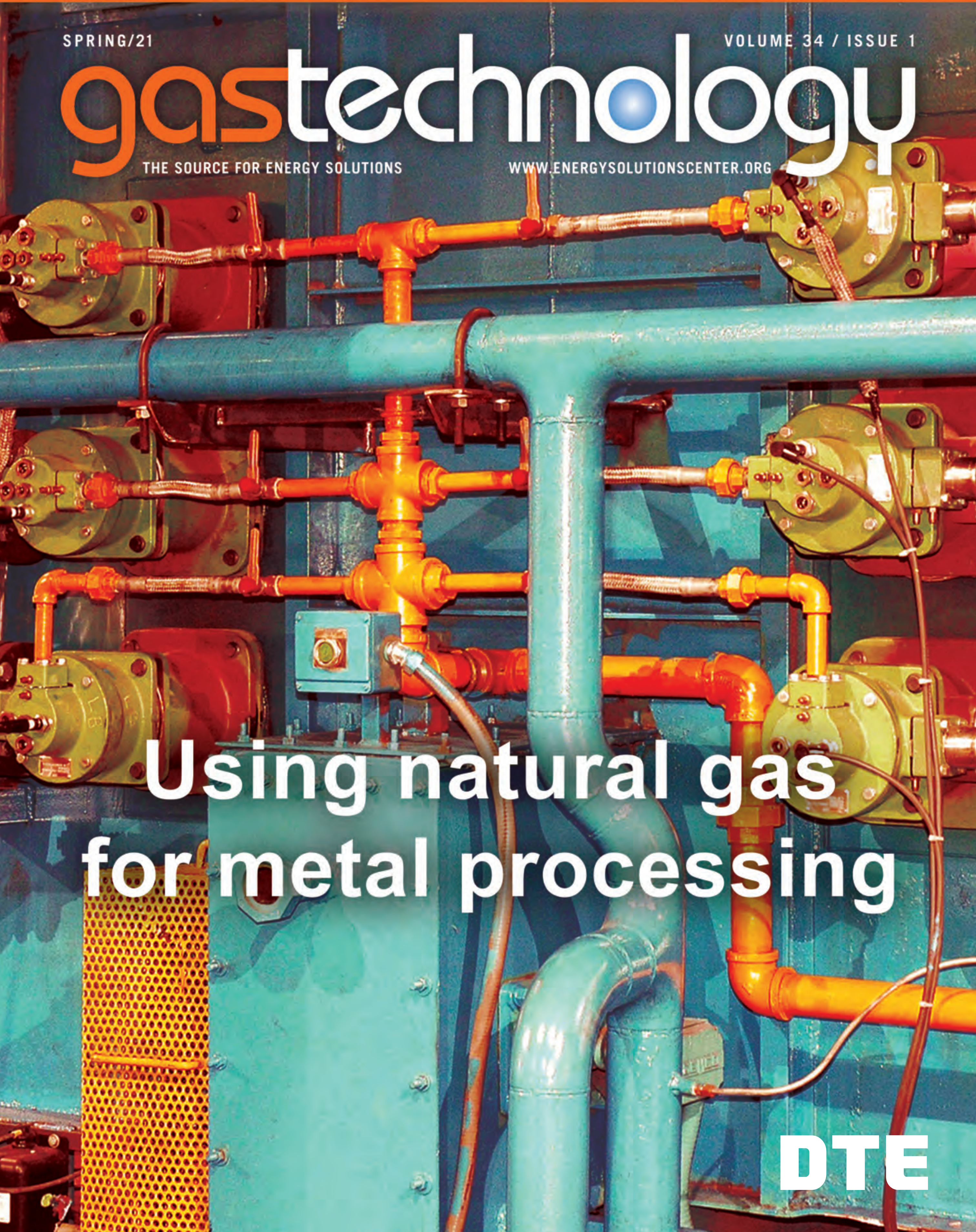

Using natural gas for metal processing

DTE

on the cover

Honeywell's Eclipse SER V5 recuperative radiant tube burner can be mounted in horizontal or vertical configurations and is suitable for continuous or batch type furnaces with a variety of atmospheres. The photo shows an external view of a batch-type heat-treating furnace. Photo courtesy: Honeywell Thermal Solutions

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Dominion Energy is developing cleaner forms of natural gas to help its customers reduce their carbon footprint. Every day, more than 3 million Americans depend on Dominion Energy to deliver natural gas to their homes and businesses. For more than 100 years, the company has focused on a core public utility mission: delivering safe, affordable and reliable energy.

USING NATURAL GAS FOR METAL PROCESSING

Metal processing involves the shaping and reshaping of metal materials to create useful objects, parts, assemblies and large-scale structures by producing metal from smelting of ore or remelting of scrap and many finished products, which may require further processing such as heat treating

THE PRIMARY METALS INDUSTRY INCLUDES FACILITIES THAT MELT AND REFINE METALS FROM ORES AND/OR SCRAP METAL. These facilities receive primary metal sources such as iron ore for steel production, bauxite for aluminum production, metal scrap or an alternate metal source to produce molten metal, which is poured into molds to produce semi-finished shapes such as pigs or ingots, or solidified into slabs, billets or other near net shape products before it is further processed to produce plate, sheet, tubing, bar, rod, wire and other items.

Commonly used gas furnaces/ovens

The metals industry uses heating equipment known as furnaces, ovens, heaters, etc. to heat and melt a variety of materials such as steel, aluminum, copper, zinc, lead, magnesium and so on. This equipment may use fuel such as natural gas or fuel oil, or electricity as a source of heat.

The terms used for heating equipment such as a furnace and an oven are used interchangeably, particularly in a temperature range of about 800 to 1,400°F. It is based on operating temperature considerations, construction based, by a particular industry or even a plant tradition. In many cases a heating equipment operating below 1,000°F is known as an oven while the equipment operating above 1,000°F is known as a furnace. Many industries use their own terminology. For example, steel tempering equipment operating at 800°F is still called tempering furnace in heat treating shop where there are many other high temperature furnaces, while homogenizing equipment in aluminum plant may still be recognized as an oven. The chemical plant and petroleum refinery has their own terminology such as heater, reactor, etc.

In a batch furnace, the material is placed in the furnace chamber and is heated by following a certain time-temperature cycle while the load is in the furnace (see Figure 1). At the end of the desired time-temperature cycle, the load is removed from the furnace and transported to another piece of equipment such as a quench or cooling chamber. In some cases, the load is heated and cooled in the same chamber by using a cooling medium at the end of a heating cycle.

Only one set of burners are used, and the burner input is controlled by a temperature control system so the time-temperature requirement is met for the process. In a batch furnace, the heat requirement may change over a large range and the burner will respond accordingly. Here, the ratio of high firing rate to low firing rate, commonly known as the burner turndown is remarkably high.

In a continuous furnace, the material is placed or loaded directly on a material handling system such as a continuous belt or conveyor and is moved through the furnace to the discharge end (see Figure 1). While the load is moving through the furnace, the temperature of the furnace is controlled to a desired value at different locations. In furnaces, the temperature is varied in a certain length of the furnace and each length or volume associated with

EDITOR'S NOTE: This article is based on a series of Energy Solution Center (ESC) seminars held from Sept. 2020 to Jan. 2021 to discuss important technical issues and marketing information on important topics related to efficient use of natural gas in industrial thermal processes used by major industries in U.S. These topics included:

- Commonly used gas furnaces/ovens
- Industrial combustion control
- Heat treating
- Aluminum melting
- Steel industry

In addition, the content of the article and the presentations are excerpted from an upcoming booklet by the author, Arvind Thekdi, PhD, president of E3M Inc.

Dr. Arvind Thekdi has more than 50 years of experience in the research and development and technical support in the areas of combustion, energy reduction and heat recovery in industrial heating systems. Dr. Thekdi started his company, E3M Inc., 20 years ago and has provided consulting services for the industries, US DOE and several utility companies including Energy Solutions Center (ESC). His focus is in improved design of process heating systems, waste energy recovery, emission control, application of combined heat and power (CHP), etc. He worked for three major furnace companies (Surface combustion, Lee-Wilson and Ipsen International) in the areas of R&D, engineering and marketing before starting E3M Inc. He has received 25 U.S. and foreign patents in subjects related to thermal systems.

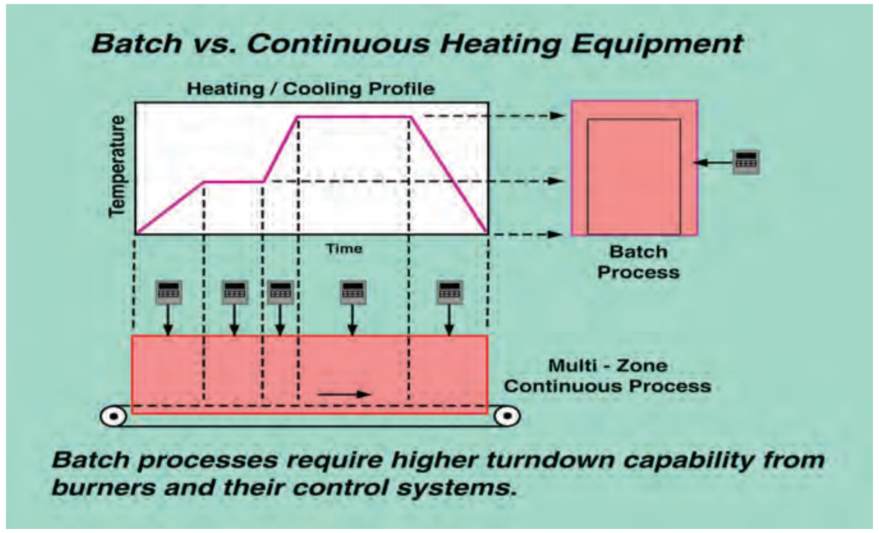


FIGURE 1: Continuous and batch furnace load positions and temperature cycles. Courtesy: Dick Bennett, used with permission

the length is known as a zone. For example, the furnace temperature may be 100°F at the entry location or zone and it is increased to a much higher value and held constant for one or two zones (soak zones). The load may be discharged from the soak zone or it may be cooled in subsequent zones of the furnace. Each zone temperature is controlled by firing one or more burners operated by a temperature control system.

Furnace functions and components. A typical furnace includes many functions and components for its construction and operation.

The heat generation system for gas fired furnaces includes the following components. For electrically heated furnaces, many of these components are not required and the system usually consists of an electrical system version of electricity supply and process-safety-specific components:

- Burners/heat sources
  - Gas fired burners
  - Radiant tubes
  - Infrared (IR) burners (Radiant, Catalytic, etc.).
- Combustion air supply
  - Air blower
  - Burner air supply control (valves, flowmeters, etc.)
  - Interlock equipment
  - Other components associated with process control.

- Natural gas (fuel) supply
  - Pressure regulators
  - Safety system such as shutoff valves, vent valves, etc.
  - Fuel flow control valves, etc.
  - Other components related to process control.

- Process and safety-specific components
  - Flame supervision system
  - Flue gas recirculating system
  - Oxygen injectors used for oxy-fuel or oxygen enriched air supply for combustion
  - Other process-specific components.

The burners are the most important part of the furnace and are selected based on process heat demand, type of operation (batch versus continuous), heat transfer requirement (convection versus radiation), combustion air temperature and required turndown (ratio of high fire and low fire condition heat input).

The two types of burners used in these furnaces are premix burners and nozzle mix burners (see Figure 2). In premix burners, gas and air are mixed before they enter the burner, and a flame retention device is used to stabilize the flame. In nozzle mix burners, air and gas enter the burner separately and are mixed within the burner before combustion of the mixture. These burners also use a flame stabilizer designed as part of the burner itself. Most modern industrial furnaces use nozzle mix burners.

Use of preheated combustion air. Use of preheated combustion air is perhaps the most used method of energy saving in industrial furnaces through heat recovery from exhaust gases. It is possible to save 5% to 30% energy in a furnace when heat from the furnace flue gases is used to preheat combustion air. Use of preheated air results in higher flame temperature, higher heat transfer and higher productivity. The general rule-of-thumb is for 100°F increase in combustion air temperature, the flame temperature increases by 40°F. It is a common belief that using preheated air results in higher amount of NO_x. The new generation of low-NO_x and ultra-low NO_x burners offer lower NO_x even with use of preheated air.

Industrial combustion control

The industry uses two definitions for defining efficiency: combustion efficiency and thermal efficiency. "Combustion efficiency," also known as available heat, is how effectively the combustion process and the heating process is carried out in a furnace. Combustion efficiency indicates how much of the energy input leaves the furnace as flue gases. The remaining heat is distributed to meet heat demand within the furnace.

Combustion Efficiency (available heat) (%) = 100 x (1 – Heat content of flue gases/ gross heat input)

"Thermal efficiency" indicates the percentage of heat input based on the gross heating value, which is approximately 1,000 Btu/standard cubic ft. (SCF) of natural gas in North America.

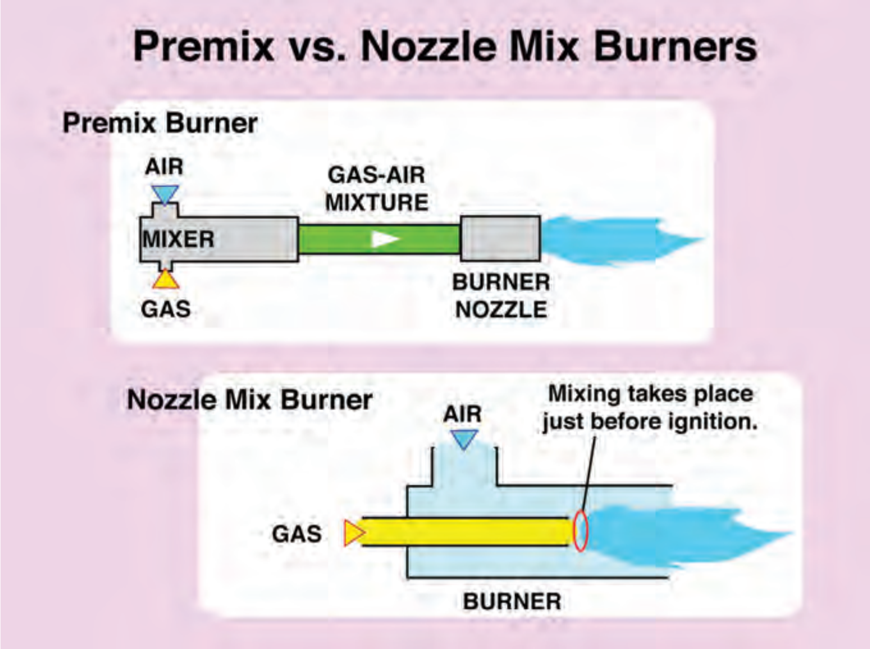
Thermal efficiency (%) = 100 x (Heat supplied to the load or charge/Gross heat input)

Thermal efficiency and combustion efficiency are interrelated. The following equation gives the relationship.

Thermal efficiency = combustion efficiency – (Heat loss from furnace/Gross heat input)

When thermal efficiency and available heat (combustion efficiency) are known, it is possible to calculate total furnace heat losses. In many cases, it is not possible to calculate total heat losses, and this is a simple method of doing so.

FIGURE 2: Premix and nozzle mix burners. Courtesy: Dick Bennett, used with permission



Furnace control systems. A furnace includes several different types of controls. Most used controls and their functions are as follows:

- A process control system supplies heat necessary to maintain the process temperature and other thermal conditions such as heat transfer to the material being processed.

- A burner fuel-air control system controls the amount of gas (fuel) and air to the burners to meet air-fuel ratio requirement and maintain required atmosphere in the furnace.

- A safety system that watches and controls all safety requirements such as flame supervision, overtemperature, etc., for safe furnace operation.

- A furnace pressure or draft control maintains the required pressure in the furnace.

- A furnace atmosphere control avoids explosive conditions and maintains process requirements in case of heat treating, curing of organic coatings and other similar special processes.

- Process specific, equipment specific or industry specific controls to meet special requirements.

These controls can be integrated in an intelligent computer or programmable logic controller (PLC)-based furnace control system.

The simplest form of process control for a gas fired furnace is temperature control of a zone for a single zone furnace or several zones in a multi zone furnace. The furnace temperature controller uses a temperature sensor such as a thermocouple connected to a temperature controller. The controller sends signal to the combustion control system to supply necessary heat or air-fuel supply to the furnace safely.

Safety is maintained by using a high temperature limit thermocouple together with appropriate components in the gas and air supply system sometime referred to as the gas and air train. The combustion control system is the heart of the thermal processing of the material being processed in the furnace.

Heat treating

The heat-treating industry includes thermal treatment (heating and cooling) of metal and nonmetal parts used in many industries such as automotive, construction machinery, general fabrication, etc. Heat treating is defined as controlled heating and cooling of materials to change their physical and sometimes chemical properties. Heat treating can be used to soften hard metal or to harden soft metal.

Heat treating is carried out for ferrous, nonferrous and nonmetals including:

- **Ferrous metals:** steel, cast iron, alloys, stainless steel, tool steel, etc.

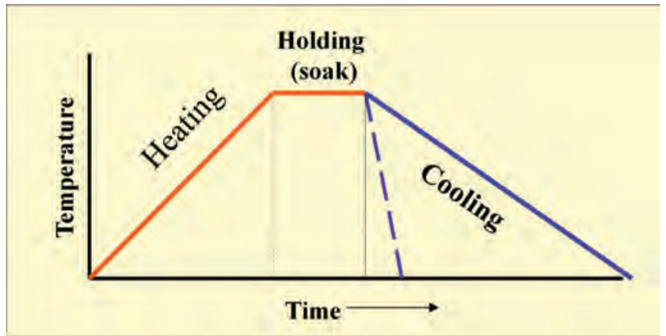
- **Non-ferrous metals:** aluminum, copper, brass, titanium, etc.

- **Nonmetals:** glass and ceramic materials.

However, steel accounts for about 80% of all the materials being heat treated.

Heat treatment process. The heat treatment process includes heating the material at a controlled temperature rise, holding the material temperature for a certain time, known as a soak period, followed by cooling at a controlled rate, which could be very quick as in a quenching operation (see Figure 3). The rate of heating or temperature rise within the part, soak time to equalize temperature within the part allowing the metallurgical transformations to

FIGURE 3: Temperature/time cycle for heat treatment of materials. Courtesy: Arvind Thekdi, PhD, E3M Inc.



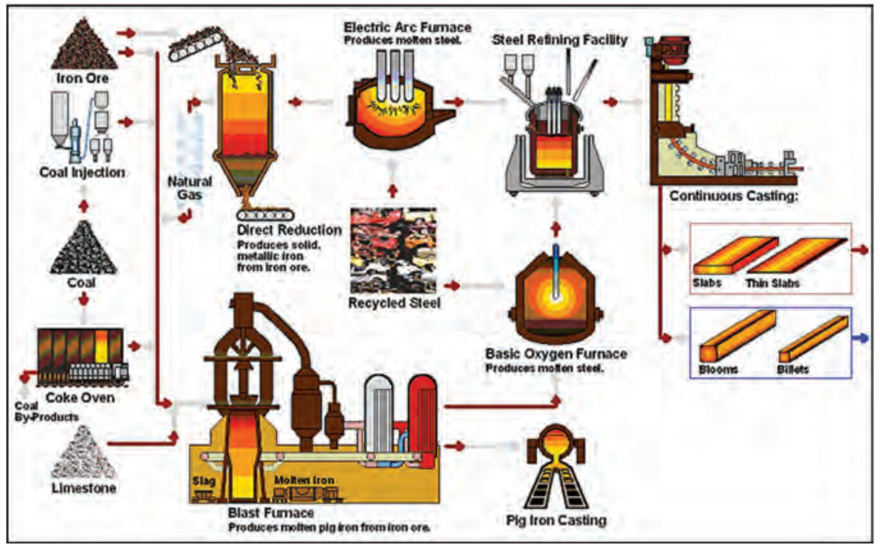


FIGURE 4: Steel making process steps. Courtesy: American Iron and Steel Institute; adapted by Arvind Thekdi, PhD, E3M Inc.

take place and cooling rates are important in delivering the desired properties (hardness or softness) to the part.

In many processes, heating is carried out in presence of a special atmosphere or mixture of inert or reactive gases. Results of the heat-treating process for steel and other materials are affected by the following parameters:

- Amount, size, shape and form of carbon present in steel primarily determine its final properties.
- The furnace atmosphere such as inert gases (N_2 and other) or reactive (CO, H_2, CH_4 and other hydrocarbons in gaseous form) affect the surface (carbon and alloying elements) in the part.
- A controlled rate of heating and cooling (heat treatment) can change the shape, size and form of carbon in steel.
- The cooling rate after heating plays an important role in properties of the heat-treated material.
- Effects of heat treatment are often reversible, and properties of steel can be engineered through heat treatment.

Results of metal heat treating with specific compositions depends on the following parameters used during heating and cooling.

- Temperature, time and transformation (3Ts)
- Steel composition (transformation)
- Cooling temperature (temperature)
- Cooling rate (time).

Heat treatment processes of iron-carbon alloys are classified in to four categories: annealing, normalizing, hardening and tempering, and case hardening. The first two (annealing and normalizing) are used to impart softness to the parts, while the last two (hardening/tempering, and case hardening) are used to impart hardness to the parts either to the entire part or to selected section of the part.

Heat treat furnaces. Gas-fired furnaces designed for heat treating can be direct fired or indirect fired. In direct fired furnaces, the burners are fired directly in a furnace and the parts are heated while in contact with combustion products. Indirectly heated furnaces use radiant tubes or a muffle to isolate combustion products from the parts being heated. In this case, the parts are heated in a selected atmosphere.

Heat treating furnace atmospheres. Heat treating processes use different gas mixtures or “atmospheres” to protect the parts from oxidation or to add certain elements such as carbon or nitrogen that react with the base metal. The atmospheres can be classified in the following categories:

- **Protective:** To protect metal parts from oxidation or loss of carbon and other elements from the metal surfaces.
- **Reactive:** To add non-metallic (i.e., carbon, oxygen, nitrogen) or metallic (i.e., chromium, boron, vanadium) elements to the base metal.
- **Purging (prevention of explosion):** To remove air or flammable gases from furnaces or vessels.

Each of these atmosphere categories includes a mixture of gases such as hydrogen, carbon monoxide, methane, nitrogen or carbon dioxide. They can be generated by endothermic or exothermic reaction of natural gas and air, steam reforming process (natural gas and steam reaction) or ammonia dissociation that gives off hydrogen and nitrogen. The atmosphere also can be prepared by mixing commercially available gases mainly nitrogen, carbon monoxide, hydrogen and nitrogen.

Aluminum melting

The aluminum industry can be broadly divided into two categories: primary sector where aluminum is extracted from bauxite and, secondary sector where aluminum is produced using scrap collected from various sources. Both primary and secondary (recycled) aluminum are important manufactured products in the U.S. Primary aluminum is produced from Bauxite. It involves several steps including electrolysis of alumina to produce aluminum metal. Secondary aluminum production uses mostly recycled aluminum and some primary aluminum.

Aluminum melting furnaces use scrap or primary material as charge material. Temperature for charge material is usually close to ambient temperature in the range of 40 to 80°F. In many cases, a scrap dryer and a preheater are used to remove moisture and organic materials before the scrap material is charged in a melting furnace. The material is heated to melting temperature, which is in the range of 1,160 to 1,210°F depending on the alloy of aluminum. The molten liquid metal is super-heated before pouring to cast it in different shapes and sizes.

Major products shipped from aluminum plants using melt shops are ingots, sows, castings, plates, sheet coils, forgings, etc. These products are often remelted or are further processed by hot and cold rolling followed by heat treatment such as homogenizing and quenching, annealing, precipitation hardening or aging.

In North America, most of the secondary aluminum plants use gas-fired furnaces. There are many types of furnaces available and used for secondary aluminum plants. Many of these furnaces, particularly large furnaces, use heat recovery devices such as recuperators or regenerative burners to improve their thermal efficiency and energy intensity (Btu per pound of molten metal). However, use of recuperators require proper monitoring and maintenance to avoid catastrophic failure and production interruption.

During the past few years, use of regenerative burners is becoming more acceptable and many new furnaces, particularly those with near constant production level, are designed with use of regenerative burners. These systems also require scheduled maintenance. However, the possibility of catastrophic failure is much less. A few new developments have been attempted to reduce energy use, increase productivity and improve the furnace performance, but the success rate has been almost non-existent.

Scrap processing. Aluminum scrap processing uses two types of fired equipment: scrap dryer and thermal oxidizer. In most cases, they are integrated as one unit. However, for some facilities, only a scrap dryer is used and the fumes from the dryer are directed to the melter.

The secondary aluminum melting furnaces use different types of scrap as primary charge material to produce molten aluminum and products. Molten aluminum or cast products, commonly known as sows and ingots, also are used as required to achieve the required production and, in some cases, to get the required chemistry or composition of the metal.

Scrap for recycling is available in many forms. Light scrap such as used beverage containers is typically baled or briquetted to reduce transportation costs. These bales and briquettes are typically crushed, shredded or sheared and ripped to controlled flowable particle sizes for ease of charging in the furnace. A conveyor system and separation system are used to segregate particle fines for further processing.

Large volumes of aluminum scrap contain paint, enamel, lacquer or porcelain coatings, which would significantly reduce metal recovery if not removed before melting. Thermal treatment is used to remove the coatings and get clean metal for charging into the melting furnace. Some clean or noncontaminated light scrap is charged directly to the furnace hearth and is covered by additional heavier charge components. In-plant production scrap is sized to handle and conveyed to the melting furnace, usually without any pretreatment.

Steel industry

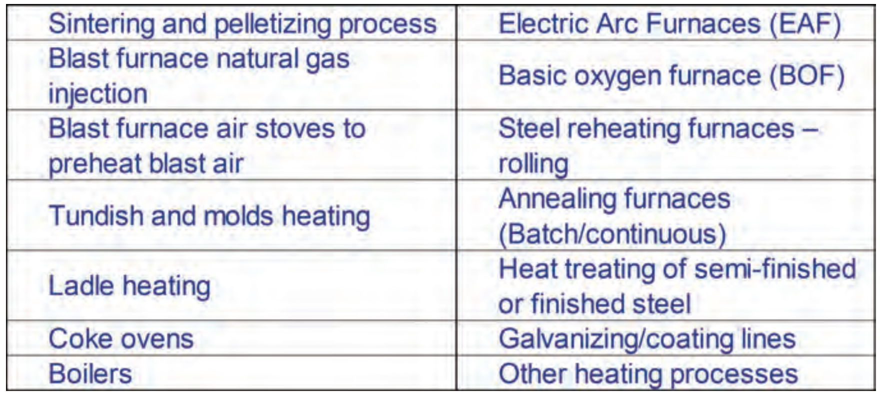
The two major routes for steel making are the use of blast furnaces to produce pig iron with the basic oxygen furnace (BOF) to produce steel in integrated mills, and the use of electric arc furnaces (EAFs) to produce steel from steel scrap and other raw materials such as direct reduced iron (DRI) or hot metal in mini mills (see Figure 4).

Approximately 38% of the energy consumed in the metals processing industry is used in blast furnace iron making, which uses coal as a major energy source, while EAF steelmaking uses 15% of the total energy, which is primarily electrical energy with small amount of natural gas or coal. Energy costs account for about 11% of the cost of producing steel for the blast furnace BOF method, while it is 8% for the EAF method.

The second largest energy user in a steel plant is reheating furnaces. This energy is supplied primarily by natural gas, and where available, coke oven and blast furnace gas. Due to increasing use of continuous casting technology, energy use in reheat furnaces is going down.

Natural gas is used in almost all stages of the steel making process. Figure 5 lists the areas where natural gas is used. The upstream processes where steel is manufactured from iron ore or scrap use a relatively small percentage of the total natural gas use. However, the downstream secondary processes (casting, rolling, reheating, annealing, coating, etc.) use most of the natural gas used in the final steel products.

It is likely the use of natural gas will increase in the steel industry due to the trend toward increased use of natural gas in EAFs to reduce use of electrical energy and higher productivity through pre-melting of scrap by using oxy-fuel (natural gas) burners. **GT**



Sintering and pelletizing process	Electric Arc Furnaces (EAF)
Blast furnace natural gas injection	Basic oxygen furnace (BOF)
Blast furnace air stoves to preheat blast air	Steel reheating furnaces – rolling
Tundish and molds heating	Annealing furnaces (Batch/continuous)
Ladle heating	Heat treating of semi-finished or finished steel
Coke ovens	Galvanizing/coating lines
Boilers	Other heating processes

FIGURE 5: Areas of natural gas use in steel making processes. Courtesy: Arvind Thekdi, PhD, E3M Inc.

Arvind Thekdi, PhD, is president of E3M Inc.

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Using hydrogen in industry

A look at hydrogen, from generation to injecting it into gas networks to the role it plays in decarbonizing the steel industry

ONE OF THE MOST SIGNIFICANT CHALLENGES FACING THE NATURAL GAS INDUSTRY IS DECARBONIZATION. The pressure on the industry to decarbonize has never been greater.

The industrial sector is one of the most difficult parts of the economy to decarbonize, and it's on track to becoming the largest source of U.S. greenhouse gas (GHG) emissions within the next 10 years, according to a Dec. 2020 report by the Rhodium Group titled "Clean Products Standard: A New Approach to Industrial Decarbonization."

Emissions from manufacturing comprise more than 60% of total industrial emissions in the U.S. Though manufacturing is a diverse subsector, a majority of emissions come from the production of a small set of GHG-intensive products, including basic chemicals, iron and steel, cement, aluminum, glass and paper. While these products/industries are significant, only steelmaking is covered in this article, which also discusses hydrogen generation and its injection into the natural gas network.

Hydrogen generation

Common hydrogen generation methods include steam methane reforming (SMR), electrolysis and biomass gasification. The most common process is steam methane reforming in which natural gas is converted to hydrogen and carbon dioxide in the presence of steam and a catalyst. More than 95% of the world's hydrogen is produced from fossil fuel, not only from the SMR process. In this reaction, natural gas is reacted with steam at an elevated temperature to produce carbon monoxide and hydrogen. A subsequent reaction — the water-gas shift reaction — then reacts additional steam with the carbon monoxide to produce additional hydrogen and carbon dioxide.

In his November 2020 presentation titled, "Hydrogen decarbonization in Steel," Roman Grosman, national business development director at Linde, describes the conventional SMR process as mature efficient and reliable. However, the process produces high carbon emissions — "100% of the CO_2 is emitted. But there is potential for carbon capture and storage (CCS), which can produce so-called Blue Hydrogen with reduced carbon intensity. Production of hydrogen in SMR using renewable gas feedstock and ultimately with an Electrolyzer powered by renewable electricity will further reduce Hydrogen carbon intensity to an ultimate net-zero or green status. The above two methods of production are commercially available and are practiced by Linde today."

Another process is gasification, which converts biomass, coal, natural gas or waxes into a synthesis gas. This gas is primarily composed of hydrogen and carbon monoxide, but also may contain smaller amounts of methane, ethane, propane, ash and tars. "In-well gasification" converts oil and gas inside a well into hydrogen and CO_2. The hydrogen floats to the top for extraction; the CO_2 stays in the well. Again, it produces zero carbon hydrogen from fossil fuel.

Green pathways. Electrolysis and gasification are the most advanced technologies, but promising research is being carried out on other pathways, according to a presentation titled "Green hydrogen: a way to decarbonize gas networks," by Nicolas Bombard, project engineer at the Natural Gas Technology Centre (NGTC) in Boucherville, Québec, Canada. This presentation was given at the Technology and Market Assessment Forum (TMAF) Webathon on Feb. 25, 2021.

Electrolysis works by connecting a dc electrical power source to two electrodes placed in an electrolyte solution. This causes hydrogen to appear at the cathode and oxygen at the anode. Electrolysis technologies include alkaline, polymer electrolyte/proton exchange membrane (PEM), anion exchange membrane and solid oxide electrolysis cells (SOEC) (see Table 1) (see Sidebar "UCI and SoCalGas to lead DOE green steel effort").

Biomass gasification. Gasification was mentioned in the previous subsection, which states the process converts biomass into a synthesis gas or syngas. Syngas is made mainly of H_2, CO and CO_2, but also some CH_4 and water vapor.

The steps in thermal conversion of biomass into syngas include drying, pyrolysis, combustion and reduction. Drying eliminates moisture in the fuel. Pyrolysis is the chemical decomposition of organic materials by heating in absence of oxygen at temperatures from 200°C to 600°C; gases and charcoal are produced. Combustion is the oxidation of the charcoal at high temperature (1,200 to 1,500°C); heat is released (used in the other steps). Reduction is where the combustion products (mainly CO_2 and water vapor) react with high temperature carbon (the charcoal) to produce CO and H_2.

Other processes are needed after these four steps because syngas is only 30 to 60% H_2; the H_2 yield depends on the biomass used. A reaction of CO with water in the presence of a catalyst increases H_2 yield. This is known as a water-gas shift reaction. Then H_2 is separated from the syngas by pressure swing absorption, amine wash, membranes or cryogenic distillation. Other post-treatments instead can be used to make synthetic biomethane (methanation) or biofuels.

Injecting hydrogen into gas networks

Blending hydrogen into the existing natural gas pipeline network has been proposed as a means of increasing the output of renewable energy systems. However, this is easier said than done.

Benefits of injecting H_2 into gas networks include:

- "Greening" the gas network
- Decarbonizing parts of the economy
- Storing electricity from intermittent renewable energy sources.

However, doing this could have consequences for the gas networks themselves, some end use cases and safety. Potential issues with H_2 injection include:

- **Material integrity:** under certain conditions, H_2 can make steel more brittle, and it can pass through plastics.
- **Leakage:** H_2 is a smaller molecule than methane and leaks easier through joints.
- **Combustion:** H_2 has lower energy content per cubic foot of gas, plus different behavior of hydrogen affects burners; more critical for industrial equipment (narrower tolerances).
- **Gas engine/turbine (powerplants/industries):** even more sensitive to H_2 than combustion equipment.
- **Flammability:** broader ignition range (4 to 75% in air versus 5 to 15% for natural gas).
- **Leak detection:** conventional leak detectors are not sensitive to hydrogen. Flame ionization detectors use a hydrogen flame and infrared (IR) laser detectors are specifically tuned to methane, so the leak will be underestimated.
- **Other issues:** Gas metering (affects billing/different energy content), compressor station, liquefied natural gas (LNG) and underground storage.

“More than 95% of the world's hydrogen is produced from fossil fuel, not only from the SMR process. In this reaction, natural gas is reacted with steam at an elevated temperature to produce carbon monoxide and hydrogen. A subsequent reaction — the water-gas shift reaction — then reacts additional steam with the carbon monoxide to produce additional hydrogen and carbon dioxide.”

Material issues notwithstanding, what would be the ideal blending rate of hydrogen in gas networks? The easy answer is "research is still ongoing and there are lots of knowledge gaps," according to Bombard. With what is known, modification to the network (pipes) or end-user equipment (burner adjustment, H_2-ready equipment) is recommended.

Due to the complexity of natural gas delivery systems, and the wide variety of the components, materials and equipment, it is not possible to specify a limiting hydrogen value that would be valid for all parts of the natural gas infrastructure. Seasonality of gas demand also will have to be considered: If H_2 injection is constant, the blending rate will increase when gas flow decreases in summer. Thus, the following things must be considered:

- How to keep the blending rate steady?
- Possible blending rates (general conclusion based on current existing research):
  - o 1 to 2% hydrogen possible as is.
  - o Up to 5% with minor modifications.
  - o Up to 20% with significant modifications.
  - o Above 20%: major modifications required(complex and costly).
- Not possible to set a universal limit.
  - o Site specific analysis might be needed.

Despite these issues, blending hydrogen into the existing natural gas pipeline network shows promise toward reducing greenhouse gas (GHG) emissions.

Decarbonization and H_2 in steelmaking

In addition to discussing H_2 generation methods, Grosman also covered hydrogen decarbonization and H_2 in steelmaking in his presentation. He said there are three major routes to reaching net-zero CO_2 emissions from steel: Decarbonization technologies, demand management and energy efficiency.

Decarbonization technologies include:

- H_2-based direct reduced iron (DRI), H_2 blast furnace (BF), electric arc furnace (EAF), H_2 reheating
- Scrap-based EAF
- Gas-based DRI (transition fuel)
- Charcoal in BF/basic oxygen furnace (BOF)

UCI and SoCalGas to lead DOE green steel effort

The U.S. Department of Energy (DOE) has awarded UC Irvine's Advanced Power and Energy Program $5.7 million to lead efforts to develop manufacturing processes for producing green steel — steel manufactured without greenhouse gas emissions. The collaboration with Italy's Politecnico di Milano and Laboratorio Energia Ambiente Piacenza (LEAP), U.S. companies FuelCell Energy and Hatch and Southern California Gas (SoCalGas) will employ solid oxide electrolysis cells (SOEC) as a way to decarbonize steel production.

The UCI team is led by Jack Brouwer, mechanical and aerospace engineering professor and APEP director; and Luca Mastropasqua, APEP senior scientist.

The project seeks to prove renewable hydrogen, produced via high-temperature electrolysis using SOEC powered by wind and solar resources, can successfully be integrated into steel manufacturing processes. Researchers will develop the technological basis, build and demonstrate a small-scale prototype unit and study the feasibility of future scale-up and commercialization.

Traditional steel manufacturing plants, known as integrated cycle steel mills, use blast furnaces that employ coke- and coal-derived gases to convert iron ore into metallic iron. Direct reduced iron (DRI) plants, which currently do not exist in the U.S., produce metallic iron from natural iron ore without melting it. The DRI process uses shaft furnaces with temperatures below 1,200°C to chemically strip oxygen from the iron ore — a more energy-efficient approach.

The newly funded three-year project seeks to integrate hydrogen produced through electrolysis — an electrochemical process that uses electricity and heat to split water into hydrogen and oxygen — into the DRI process. In this case, the electrolysis will be powered by wind and solar resources, producing renewable hydrogen. Hydrogen will be used as the reducing gas that strips oxygen from iron ore to form the metallic iron.

"The process we propose uses a high-temperature electrolysis system that can be directly coupled with the high temperatures of the shaft furnace where the iron ore conversion occurs," Mastropasqua said. Since the only byproduct of the process is water, that water can be used at high temperatures to produce more hydrogen, closing the loop and allowing it to be thermally integrated back into the DRI furnace.

Along with its partners, the UCI team will demonstrate its hydrogen production technology is more efficient and produces lower emissions than current technology. The project will prove steel can be produced with zero greenhouse gas emissions at a cost comparable to current state-of-the-art technologies. Finally, the project will verify that its new process can easily be coupled with other industrial sectors, including transportation, to further reduce greenhouse gas emissions.

FuelCell Energy, a U.S. fuel cell and electrolyzer manufacturer, will build and operate an electrolyzer prototype for the project at its manufacturing site in Danbury, Conn. The prototype is expected to produce approximately 10 kg per day of hydrogen, enough to produce one ton of steel per week.

Hatch, an engineering consulting firm with expertise in novel steel production technologies, will provide a detailed design for the large-scale plant that will use the demonstrated technology while SoCalGas will help with technology transfer.

"We will prove our process results in higher steel production energy efficiency compared to state-of-the-art technology," Brouwer said. "A blast furnace steel mill uses 11 gigajoules of fuel to produce one ton of steel. We aim to reduce that value to 8 gigajoules/ton, and those 8 gigajoules won't come from coal anymore, but from sun and wind."

TABLE 1

TECHNOLOGY	EFFICIENCY	KEY ATTRIBUTES
Alkaline	62 – 82%	Most mature Cheapest Corrosive electrolyte
Polymer Electrolyte / Proton Exchange Membrane (PEM)	67 – 87%	More flexible Smaller footprint Costly metals
Anion Exchange Membrane (AEM)	60 – 75%	Limited deployment Small scale No costly metals
Solid Oxide Electrolysis Cells (SOEC)	87 – 100%	High temperature High efficiency (waste heat) Pilot stage

Source: Natural Gas Technology Centre

- Carbon capture
- Electrolysis of iron.

DRI is the product of the direct reduction of iron ore in the solid state by carbon monoxide and hydrogen derived from natural gas or coal. The process involves the removal of oxygen from iron ore or other iron-bearing materials in the solid state, i.e., without melting, as in a blast furnace. The reducing agents are CO and H_2, coming from reformed natural gas, syngas or coal. Iron ore is used mostly in pellet and/or lumpy form.

Demand management efforts involve better scrap recycling, redesigning products for more efficiency and circularity and more intensive use of steel products. Energy efficiency involves using high-pressure leaving the furnace for power and coke dry quenching, according to Grosman.

Steel making and potential H_2 demand:

- 100 kg of H_2 is estimated to produce 1 metric ton (MT) of hot iron with DRI technology.
- 1 ton of H_2 can replace 5 tons of coke.
- If all imported steel — 35 million metric tons (MMT) of steel — is replaced with U.S. production via DRI, demand for H_2 would be 3.5 MMT.
- If all steel is produced via DRI in the U.S. in 2040 (120 MMT steel), demand for H_2 would be 12 MMT.
- In the near term, DRI in a mix of 30% H_2 by energy is feasible.

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Decarbonization paths. Grosman also pointed out the DRI-electric arc furnace route is the most commercial-ready path to full decarbonization. But, industrial-scale H_2-DRI production will not be possible before 2030. The operating expense increase would be around $75 to $100 per ton.

The blast furnace with H_2 injection route is a lower capital expenditure. However, this option is limited to a maximum of 20% decarbonization. A 5 to 10% CO_2 reduction results in a $20 per ton operating expense increase. An alternative is to substitute/augment with coke oven gas (COG), syngas or biomass.

Grosman said fuel switching and oxy-fuel combustion for reheat furnaces are incremental yet lower-cost steps to decarbonize. Fuel switching involves either blending or replacing natural gas fuel with H_2 while oxy-fuel combustion entails full or partial substitution of combustion air with oxygen. Since H_2 is around 10 times the cost of natural gas per MM BTU, combine H_2 with oxy-fuel combustion for maximum benefits. **GT**

How to improve energy efficiency in the baking industry

Energy efficiency improvement opportunities are applicable at the component, process, facility and organizational levels

MANY COMPANIES HAVE ALREADY ACCEPTED THE CHALLENGE TO IMPROVE THEIR ENERGY EFFICIENCY IN THE FACE OF HIGH ENERGY COSTS and have begun to reap the rewards of energy efficiency investments. Companies are turning to energy-efficient processes and technologies to meet corporate environmental goals.

Energy efficiency process improvements

At the component and equipment level, energy efficiency can be improved through regular preventive maintenance, proper loading and operation and replacement of older equipment or components with higher efficiency models whenever practical.

At the process level, process control and optimization can be pursued to ensure production operations are running at maximum efficiency. At the facility level, the efficiency of lighting, cooling and heating can be improved while total facility energy inputs can be minimized through process integration and combined heat and power (CHP) systems, where feasible. At the organizational level, energy management systems can be implemented to ensure a strong corporate framework exists for energy monitoring, target setting, employee involvement and continuous improvement.

Baking industry

In their simplest form, most bakery products (bread, rolls, cookies, crackers) have similar ingredients and stages of production. Common production stages include mixing, shaping, baking, cooling and packaging. Certain products require additional production steps.

Energy use is most concentrated in either the baking or freezing process. For nonfrozen products, baking is the largest energy consumer ranging between 26 and 78% of total energy, according to a report titled “Energy Efficiency Improvement and Cost Saving Opportunities for the Baking Industry,” published by Ernest Orlando Lawrence Berkeley National Laboratory (funded by the U.S. Environmental Protection Agency through the U.S. Department of Energy). Only in the case of frozen products is baking not the largest portion of energy. Baking represents 78% of the energy requirement for cookies and crackers, which are products produced with no need to wash pans or provide a fermentation and proofing period, according to the baking industry report. Bread and rolls as well as cookies and crackers, which are products that require significant baking times, require more energy per unit of production than frozen and nonfrozen cakes. In the case of frozen products, the freezing process consumes the most energy.

In addition to the baking and freezing processes, the other stages of production consume large enough amounts of energy to warrant investigating related energy efficiency measures.

Energy efficiency improvement opportunities

Ovens and dryers can consume more than 10% of a bakery’s total energy and 26 to 75% of process-specific energy, often inefficiently, according to the baking industry report. Dryers often consume two to three times as much energy as thermodynamically required to remove a pound of water from product. Ovens are less energy efficient, consuming at least five times as much energy as thermodynamically required to heat product. Most of this extra energy is lost as heat to the outdoor environment through the oven or dryer stack.

The type of heating element selected for use in an oven or dryer affects the thermal efficiency of the system. Gas burners are 85 to 95% efficient while steam heat systems are 70 to 80% efficient, according to the report. Due to losses at the power plant and transmission lines, delivered electricity is only about 30% efficient. Advanced baking technologies such as radio frequency assisted ovens provide an energy efficient way for goods to be baked that requires low final water content.

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

Proper burner maintenance will help bakeries that operate with air quality permit to ensure their stack emissions are within permitted levels and avoid fines. Damaged or obsolete burners should be replaced with more efficient ones.

Burner optimization can be determined by analyzing the combustion stack gasses. As a part of commissioning, a stack sample should be taken for reference. Periodic stack sampling can be performed and differences in stack exhaust levels will indicate problems with one or more of the burners. An oxygen or combustion analyzer along with stack temperature measurement can be used to determine a host of potential energy inefficiencies. If the combustion efficiency is lower than when the oven was commissioned appropriate strategies should be developed to improve this efficiency. The combustion air/fuel ratio will often need to be adjusted or in some instances a burner will be damaged and needs to be repaired or replaced.

> **“Baking represents 78% of the energy requirement for cookies and crackers, which are products produced with no need to wash pans or provide a fermentation and proofing period, according to the baking industry report.”**

Creating a temperature profile of the oven will indicate temperature imbalances across the width of the oven. Temperature imbalances should be investigated and corrected. This might require adjustment or replacement of burner elements or repairs to insulation. An oven temperature profile will also indicate stages of the oven that are too hot or cool, which may impact product quality.

Control measures can save energy by interfacing with just the oven or by integrating oven control with the bakery system as a whole. Oven exhaust ducting can be controlled to minimize the energy required to ensure combustion exhaust is safely expelled from the bakery and ambient air is not able to enter the bakery through the exhaust system. Exhaust control uses external pressure, wind and temperature data to control variable speed motors. These types of systems can result in 5 to 20% energy savings. Exhaust control systems can be coupled with heat recovery devices to produce hot water.

In addition to these opportunities, there are also emerging technologies that hold promise for improving energy efficiency in the baking industry. Improved baking technologies are being developed and continuously evaluated, many of which can provide increased energy savings, product consistency and quality and improved productivity.

One such technology is reflective coatings. Advanced coatings can be applied to pans along with interior walls and burners of installed or new ovens. They contain high-emissivity ceramic materials that increase oven energy efficiency by absorbing heat and radiating it back to the product in the form of infrared energy waves. This allows a greater portion of the original energy contained in the burned fuel to be applied to the product, reducing the amount of fuel required by up to 20%.

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Final thoughts

Establish a focused and strategic energy management program that helps to identify and implement energy efficiency measures and practices across the organization and ensure continuous improvement. Then assess the company’s energy-using systems and identify areas for improvement.

Keep in mind that while expected savings associated with some of the individual measures may be relatively small, their cumulative effect across an entire facility may be quite large. Many measures have relatively short payback periods and are therefore attractive economic investments on their own.

The degree to which these measures are implemented will vary among plants and end uses, but continuous evaluation of a facility’s energy profile will help to identify further cost savings over time. **GT**

LDC Focus

Spotlight on Dominion Energy

Dominion Energy is developing cleaner forms of natural gas to help its customers reduce their carbon footprint

EVERY DAY, MORE THAN 3 MILLION AMERICANS DEPEND ON DOMINION ENERGY TO DELIVER NATURAL GAS TO THEIR HOMES AND BUSINESSES. For more than 100 years, the company has focused on a core public utility mission: delivering safe, affordable and reliable energy.

As governments and corporations across the globe confront climate change, Dominion Energy is determined to serve a broader mission. The company is pioneering clean energy technologies to reduce its emissions and provide cleaner forms of natural gas.

In early 2020, Dominion Energy announced an ambitious plan to achieve net zero greenhouse gas emissions across all its operations by 2050. Technological innovation is playing a critical role — not only in achieving the company's climate goals, but also helping customers reduce their footprint.

FIGURE 1: Dominion Energy and Smithfield Foods are developing RNG from 26 hog farms in Milford, Utah. Courtesy: Align RNG

Reducing methane emissions

Over the last decade, Dominion Energy has reduced emissions from its gas distribution system by 25%. The company says it's just getting started. Over the next two decades, they will reduce emissions by 80% by deploying new technologies like Zero Emissions Vacuum and Compression (ZEVAC), which eliminates gas venting into the atmosphere during maintenance, replacing higher-emitting infrastructure and expanding the use of infrared technology to detect the hardest-to-find leaks.

Renewable natural gas

One of the most exciting aspects of the company's strategy is its pioneering work with renewable natural gas (RNG). Dominion Energy is partnering with leading ag producers like Smithfield Foods and Vanguard Renewables to capture methane and convert it into a cleaner form of natural gas (see Figure 1). The company says RNG is an effective way for climate-conscious customers to reduce their carbon footprint.

A large natural gas user, for example, can achieve carbon neutrality by sourcing just 11% or 12% of its gas supply from RNG. That's because more emissions are captured from the farms than are released when customers use the gas, giving RNG the lowest carbon-intensity score of any energy source. The company says this value proposition has been very appealing for natural gas users across sectors — from transportation and heavy industry to colleges and hospitals.

Hydrogen

In addition to RNG, the company is exploring the use of zero-carbon hydrogen. Hydrogen can do everything natural gas can do — only with fewer or even zero emissions. It can generate electricity, heat homes and buildings, serve as a heat source and feedstock for heavy industry and fuel transportation. The company will use a process known as electrolysis, which results in zero emissions. The company will begin blending hydrogen into a test system in Utah this year with the goal of blending hydrogen into the distribution system that serves its gas utility customers in the years to come.

As Dominion Energy explores these and other next-generation clean energy technologies, the company says it is focusing on the principle of shared value. What is good for the company's customers, shareholders and employees is also good for the climate. Technological innovation is making it all possible. **GT**