Productivity improvements through electro-technology application in industrial process heating

Baskar Vairamohan
Senior Project Engineer
EPRI
942 Corridor Park Blvd
Knoxville, TN 37932
USA
bvairamohan@epri.com

Ammi Amarnath
Senior Program Manager
EPRI
3420 Hillview Avenue
Palo Alto, CA 94304
USA
aamarnath@epri.com

Joel Watts
Alabama Power Company
Market Specialist I (Marketing)
744 Hwy 87N Bldg 7B
Calera, AL 35040
USA
jpwatts@southernco.com

Bill Howe
Program Manager
EPRI
1919 8th Street, Suite 202
Boulder, Colorado 80302-5027
USA
bhowe@epri.com

Scott Bishop
Market Specialist, Staff (Marketing)
Alabama Power Company
744 Hwy 87N Bldg 7B
Calera, AL 35040
USA
sebishop@southernco.com

Keywords
awareness, energy efficient technologies, heating, industrial energy saving, case studies, reduced pay-back time, productivity, infrared heating

Abstract
In U.S. manufacturing, process heating accounts for over one-fifth of total energy use, making it the largest end use of energy. At 12 % of all industrial net electricity consumption, process heating is also significant. Process heating therefore presents opportunities for improvements that can significantly benefit industrial customers through cost reduction and improved productivity, while reducing greenhouse gases. This technical paper uses real world examples to discuss applications of electro-technology in industrial process heating and highlights some of the emerging technologies in this field. These emerging technologies, when implemented in a plant, will provide significant energy savings as well as increase productivity. Two case studies of successful implementation of electro-technology based process heating, specifically in the area of Infrared heating, will be discussed in this paper. The case studies show how two companies with two different product lines have benefitted by the application of electric Infrared heating technology. Key performance metrics such as payback period of the installation, gains in productivity, reduction in maintenance, improvement in the work space condition, decreasing energy intensity, increased morality of the workers has been quantified (where possible) and described in detail. This research paper also shares insight into how collaboration between electric utility and the industry has helped increase the production as well as bottom line of the companies under consideration. This kind of utility-industry partnership offers a win-win situation for both the entities involved. The case studies discussed in this paper provide a channel to reach out to other industrial customers who could also benefit from the use of new and efficient process heating technologies.

Introduction
According to US Department of Energy, Energy Information Administration (EIA) data from 2006 (manufacturing energy consumption survey), process heating accounts for over one-fifth of total energy use, making it the largest end use for energy, as shown in Figure 1. As such, improvements in process heating present opportunities to significantly benefit industrial customers through cost reduction and improved productivity, while reducing their greenhouse gas emissions.

Electro-technologies in Process Heating
Process heating is dominated by natural gas, but electricity consumption used for process heating has been growing. In 1998, electricity use in process heating had a 7.8 % market share of all electricity use in industry, and in 2008 the share for electricity had grown to 12 % (see Figure 2).

Figure 3 shows electricity consumption for manufacturing process heating by sector. At over 39 billion kWh, primary metal manufacturing is the sector that consumes most electricity for process heating. Other large manufacturing sectors that are also large users of electricity for process heating include non-metallic mineral products, fabricated metal products, plastic and rubber products, and chemicals, and transportation equipment.

Electric process heating applications are concentrated in the materials production and metals fabrication industries where

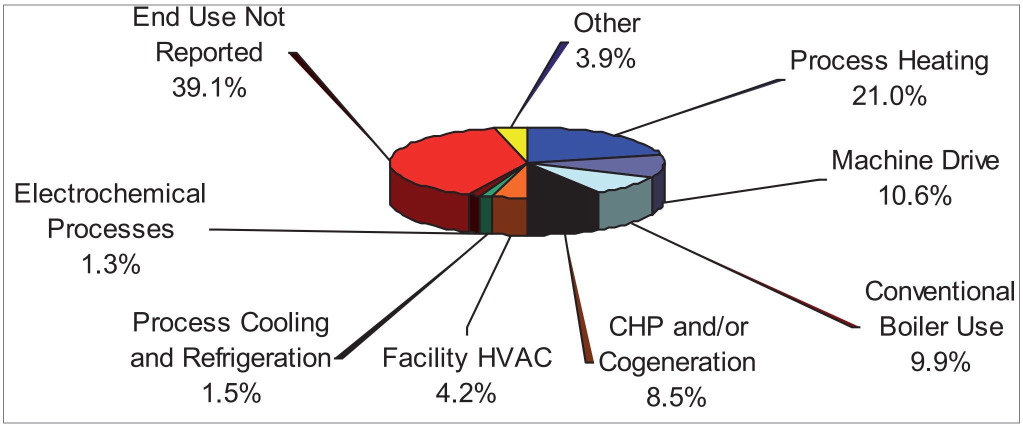

Figure 1. Industrial Energy Consumption, by End-use. (Source: Information Administration, 2006 Manufacturing Energy Consumption Survey.)

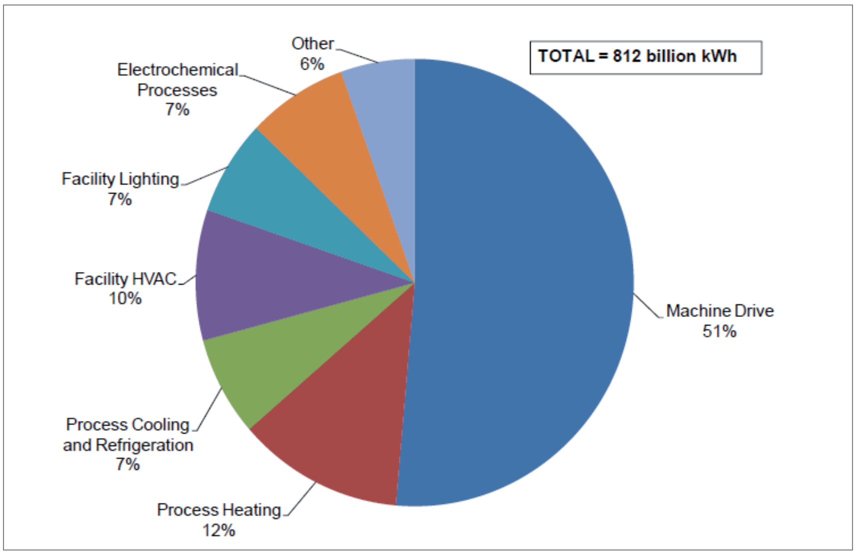

Figure 2. Manufacturing Electricity Consumption by End-use Application, 2008. (Source: Electrotechnology Reference Guide, Revision 3. EPRI, Palo Alto, CA. 2010. 1022334.)

high temperatures are required to heat, melt, dry, and cure. The materials production industries used nearly half (47.9 billion kWh) of the electric process heat in the manufacturing sector in 2008[1].

Process heating end-use applications can be sub-divided into three groups: 1) drying and curing, 2) heating, and 3) melting & holding. Each of these end-use applications is described in the following paragraphs.

DRYING AND CURING
Drying and curing applications involve the application of heat for various purposes such as removal of gases and moisture, hardening of surface coatings, or bringing about a change in the molecular structure of coatings. In 2008, drying and curing applications accounted for 8 % of process heating electricity use (see Figure 4).

HEATING
Heating processes add energy to various substances, especially liquids, to raise their temperatures, to expand them, and cause them to undergo various changes. Heating is used extensively in the rubber industry sector to heat resins. It is also used in many process and materials fabricating industries to heat liquids, such as dyes in the apparel and textile industries, and to heat synthetic fabrics. Electricity used for heating applications in 2008 accounted for 46 % of all electric process heating electricity consumption (see Figure 4).

MELTING AND HOLDING
Melting is used primarily in materials production. In these thermal processes, metals or alloys are transformed from solid into liquid. These processes consumed 46 % of the electric process heating applications in 2008 (see Figure 4).

1. Source: Electrotechnology Reference Guide, Revision 3. EPRI, Palo Alto, CA. 2010. 1022334

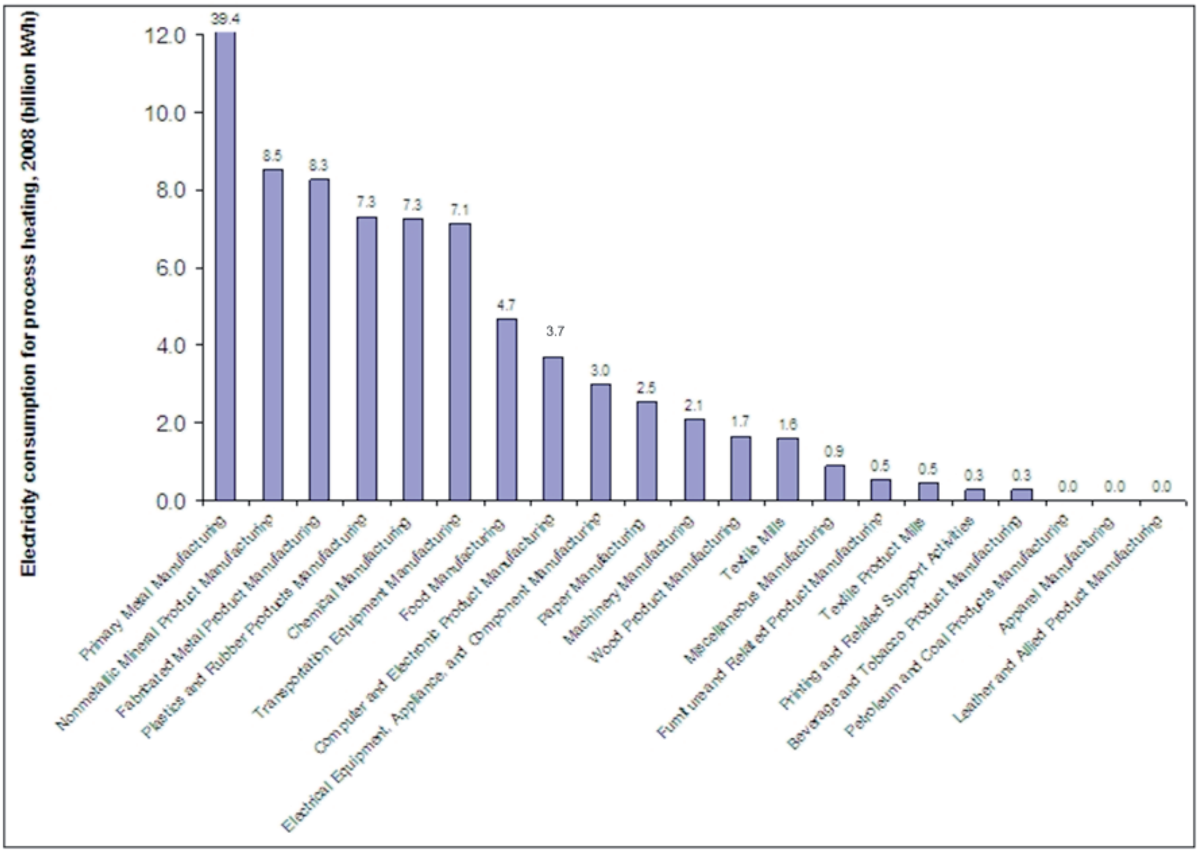

Figure 3. Manufacturing Process Heating Consumption of Electricity by Sector, 2008 (Billion kWh). (Source: Electrotechnology Reference Guide, Revision 3. EPRI, Palo Alto, CA. 2010. 1022334.)

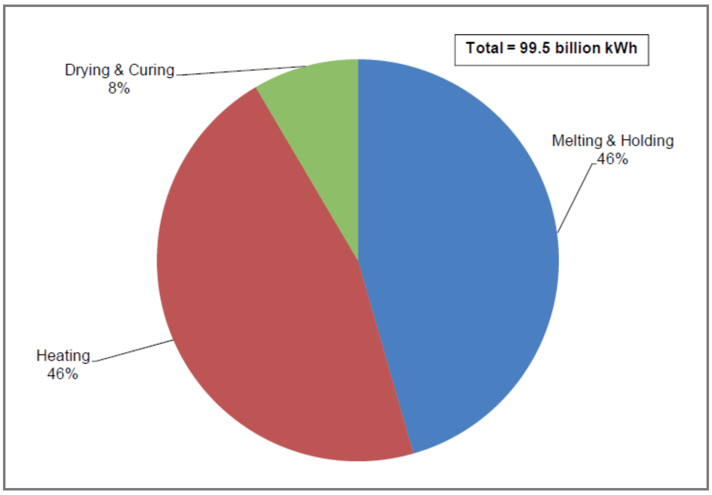

Figure 4. Process Heating Electricity Use by Manufacturing Applications, 2008. (Source: Electrotechnology Reference Guide, Revision 3. EPRI, Palo Alto, CA. 2010. 1022334.)

Infra-red Based Process Heating

This technological paper presents applications on one of the most commonly used electro-technology for process heating, the Infra-red heating also referred to as IR heating. The following sections briefly cover the operating principles of this technology and provide merits and demerits of this technology. Later, two case studies will show how this technology has been implemented in two industries that have benefitted by this technology.

OPERATING PRINCIPLES

Infrared (IR) is the range of electromagnetic energy-spectrum measured between the visible light and radio wave. Infrared radiation is typically divided into three different wavelength categories: short, medium, and long. These three different wavelengths are described below. Figure 5 shows the electromagnetic spectrum with emphasis on the infrared spectral band.

When radiant energy impinges on an object, it can either be absorbed or reflected, or transmitted by that object. This is

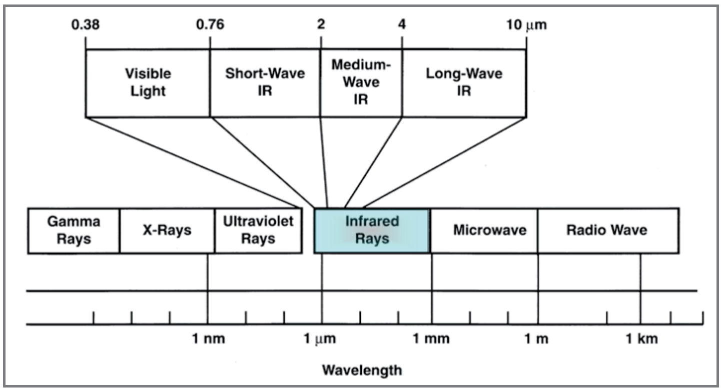

Figure 5. Electromagnetic Spectrum Showing Short-Wave IR, Medium-Wave IR and Long-Wave IR.

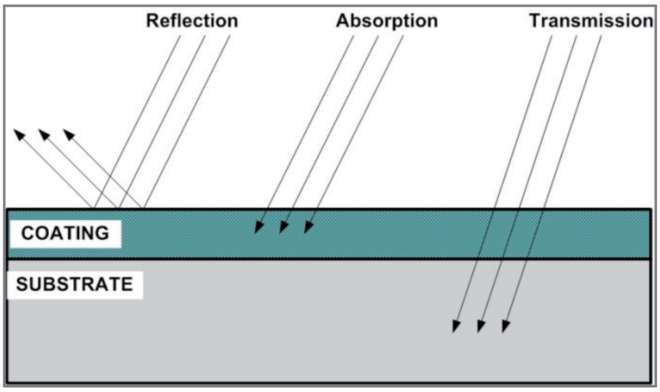

Figure 6. Visual Depictions of Reflection, Absorption and Transmission of Radiant Energy.

shown in Figure 6. The amount of absorption, reflection, or transmission is affected by the wavelength of the radiant energy and the physical and surface properties of the object. Only absorbed energy will contribute to the heating of the product. Infrared radiation can be absorbed and converted into heat energy by most materials rather than being reflected away or transmitted through the object. In addition, the amount of energy a product absorbs can be controlled by selecting the proper emission wavelength. For industrial applications, electric infrared is produced by resistance-heating the element or filament of a source or emitter. All emitters generate radiation over the wavelength spectrum in a bell-shaped distribution. The temperature of an emitter determines its peak wavelength. This means that the higher the emitter temperature, the shorter the peak wavelength and higher the intensity. As the temperature is reduced, the peak wavelength becomes longer and the intensity lower.

For traditional convection ovens the amount of heat transfer is proportional to the first power of temperature where as in case of IR the amount of power transferred is proportional to the fourth power of temperature. This is one of the reasons for higher rate of heat transfer with IR process heating technology. Infrared energy for industrial process heating is typically generated by heating metal filaments such as NiCr (nickel-chromium alloy) or tungsten filament which is contained inside a lamp. The elements can be of various shapes such as thin filaments, ribbons or bars. The temperature of these metal filaments determine the wavelength of the IR wave, so that the higher the temperature the shorter the wavelength of the IR wave.

Infrared process heating technology is a line of sight technology which implies that the object to be heated has to be in the sight of the emitter. Typically, IR sources emit IR waves in all directions. However, the IR waves can be reflected and focused using reflectors similar to the techniques used for visible light. The reflectors help focus the IR radiation to the object to be heated. For example, Figure 7 shows a parabolic reflector that redirects the IR radiation as parallel rays to heat a flat object. Similarly elliptical reflectors can be used to focus the IR radiation to point at a particular location on the heated object.

TYPES OF IR

While all emitters radiate across the three wavelengths, specific emitters may overlap (e.g., ceramic panels can emit between 3 and 5 microns) or radiate within a narrow band of a single type (e.g., quartz tubes emit between 2.3 and 2.8 microns).

The three different wavelengths into which IR is typically divided are:

Short Wave IR

Short wavelength IR is intense and has the greatest penetration depending on the material being radiated. This type of radiation is emitted over a band extending from 0.76 µm to 2.8 µm and from emitters operating at temperatures in the range of 1,830 °F to 3,990 °F (1,000–2,200 °C). Short wavelength radiation can provide fast, intense bursts of energy. It is used frequently in the printing industry to dry ink and in the rubber industry to heat extruded silicone rubber tubing where a short cycle time is required.

Medium Wave IR

Medium: Medium-wave, or medium intensity, IR comes from emitters operating at temperatures in the range of 1,290 °F to 1,830 °F (700–1,000 °C) and generally peaks in the range of 2.3 µm to 3 µm. Medium wavelength IR is readily absorbed by many plastics and glass and is less intense than short wavelength, making it useful for materials such as fabric or textiles that are heat-sensitive. It is also used for water-based inks, coatings, and adhesives.

Long Wave IR

Long wavelength IR provides the shallowest penetration of the three types and therefore tends to be more convective than others. Long-wave or low intensity infrared is emitted at temperatures from 570 °F to 1,290 °F (300–700 °C). Peak intensity occurs over a range extending from 3 µm to 5 µm. Because it is less sensitive to colour differences, multi-colored products are easier to cure and dry with long wavelength IR. Long wavelength radiation is used where slower; more even heat distribution is required, such as in the preheating of aluminium or drying paper products and films.

TYPES OF ELECTRIC IR EMITTERS

The characteristics of the four most commonly used electric IR emitters are summarized in Table 1.

MERITS AND DEMERITS

Electric infrared (IR) process heating was first developed in the 1930s for curing the paint on automobile bodies. Since that time, IR heating has been successfully applied to hundreds of different process heating applications, such as curing metal finishes and protective coatings, fusing thermoset and thermoplastic powder coatings, forming molded plastics, bonding adhesives and metals, drying papers, inks, fabrics and processing foods.

The advantages of Electric IR technologies are described briefly below:

- Faster processing – Because of the direct transfer of heat by radiation to the product and high power densities, IR systems can heat quickly and efficiently. Processing time can be reduced by as much as 50–85 % over convection ovens.
- Increased energy efficiency – Since IR components heat by radiation, the product, rather than the surrounding air, is heated. Quick start-up and shutdown eliminates costly preheating, which further increases the overall efficiency.

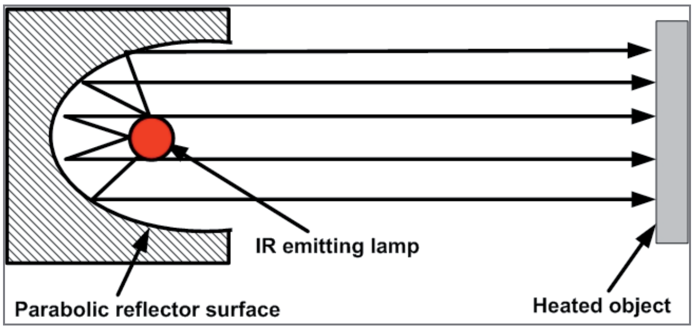

Figure 7. Parabolic IR Reflector.

- Precise process control – IR emitters are especially sensitive to changes in conditions. Accurate and consistent product temperature control within extremely close tolerances is possible, resulting in consistently high quality products with fewer rejects.
- Easy integration – The energy radiated by IR can be focused, directed, and reflected the same as light (which greatly increases its versatility and adaptability) without introducing additional heat into the work environment. The modular

Table 1. Characteristic of Electric IR Emitters.

Characteristics	Metal Sheath	Reflector Lamp	Quartz Tube	Quartz Lamp
Resistor material	Nickel-chromium alloy	Tungsten wire	Nickel-chromium alloy	Tungsten wire
Relative linear heat flux	Medium, 2.4 kW/m,13 mm diameter	High, 125 to 375 W/spot	Medium to high, 3.0 kW/m,13 mm diameter	High, 3.9 kW/m, 9.5 mm diameter
Resistor temperature	950°C (1,742 °F)	2,230 °C (4,046 °F)	930 °C (1,706 °F)	2,230 °C (4,046 °F)
Envelope temperature (in use)	840°C (1,544 °F)	275 to 300 °C (527 to 572 °F)	650 °C (1,202 °F)	590 °C (1,094 °F)
Thermal radiation-energy input ratio	0.58	0.86	0.81	0.86
Response time (heat-up)	180 seconds	A few seconds	60 seconds	A few seconds
Luminosity (visible light)	Very low (dull red)	High (8 lm/W)	Low (orange)	High (7.5 lm/W)
Thermal shock resistance	Excellent	Poor to excellent (heat-resistant glass)	Excellent	Excellent
Vibration resistance	Excellent	Medium	Medium	Medium
Impact resistance	Excellent	Medium	Poor	Poor
Wind or draft resistance	Medium	Excellent	Medium	Excellent
Mounting position	Any	Any	Horizontal	Horizontal
Envelope material	Steel alloy	Regular or heat-resistant glass	Translucent quartz	Clear, translucent, or frost quartz and integral red filter glass
Color blindness	Very good	Fair	Very good	Fair
Flexibility	Good – wide range of power density, length, and voltage practical	Limited to 125–250 and 375 W a 120 V	Excellent – wide range of power density, diameter, length, and voltage practical	Limited – 1 to 3 W for each V; 1 length for each capacity
Life expectancy	Over 5,000 hours	5,000 hours	5,000 hours	5,000 hours

Table 2. Advantages and Features of Convection Oven and Electric IR Technologies.

Advantages / Features	Convection Oven	Electric IR
Distributes heat evenly, even for products with complex shapes	✓	
Not sensitive to reflective properties of coatings	✓	
Lower-cost energy source (when compared in dollars per unit of energy consumed)	✓	
Uses less energy when only surface heating is required		✓
Provides well-controlled, low-intensity heat		✓
Provides highest-intensity heat		✓
Intensity can be easily adjusted for different products		✓

design of IR panels and ovens also makes them easy to incorporate into existing production lines. In addition, because of the increased energy efficiency and intensity, oven sizes are generally much smaller than convection ovens and require significantly less floor space.

- Clean products – Convection ovens require air handling equipment that circulates the heated air, which can contaminate the product. Since IR heats the product directly, the amount of air circulating through the oven is reduced. In certain cases some air movement may be needed to cool the emitters and reflectors, remove solvents from the oven, or to facilitate drying.
- Low maintenance – Electric IR emitters have a long life and require little routine maintenance except that emitters need to be replaced and the reflectors must be cleaned periodically.

Table 2 compares some of the features of convection oven to electric IR technologies.

Some of the drawbacks of IR are listed below:

- IR requires direct line-of-sight, hence the parts to be heated have to be placed directly in front of the IR emitters. Complex parts that are not flat may not be good candidates for IR heating
- IR is not effective where moisture is readily retained. The air surrounding the parts to be heated should be devoid of moisture
- Water vapor in IR path can absorb incident energy thus reducing the heating capacity of IR emitters.

The benefits of IR far outweighs the drawbacks however it has to be noted that IR heating may not be suited for all applications. Thorough understanding of the IR principles will help maximise the effectiveness of the application. The following case studies will help the reader understand how the IR was effectively utilized to increase the bottom line and productivity in two different industries.

Case Study 1: Electric IR Technology Increases Productivity and Reduces Maintenance Issues in a Pipe Fitting Plant

BACKGROUND

An iron melting and pipe fitting plant located in Anniston, AL is a customer of Alabama Power. One of their production lines involves dipping pipe fittings in paint and then curing them through a convection oven. The production line had some problems with maintenance issues and emissions in an existing gas-fired convection oven in the first quarter of 2011, resulting in a decrease in the production capacity. The plant maintenance manager of this company approached Alabama Power for an alternative solution to the process heating that could help them alleviate this situation.

CONVENTIONAL METHOD

In the conventional method used in industry, the parts to be painted are loaded at the loading dock on to an overhead conveyor line (see Figure 8). The parts then move along the line until they reach the dip tank which is filled with paint. The parts are dipped in the paint and then moved through an 'S'-shaped natural gas fired tunnel oven. The paint coating cures as the parts move from one end of the oven to the other end. The blower fans in the oven help in maintaining uniform temperature inside the oven. The finished parts are then unloaded outside the oven.

THE CHALLENGE

The conventional method of using natural gas burners/blowers had few problems affecting process speed. The main problem was burner maintenance – the gas filters and the gas burners required cleaning every 7 to 10 days. The production line had to be stopped while the maintenance crew fixed this problem. The ventilation system was not sufficient to remove the smoke and other gases from emissions. During the first quarter of 2011, the gas burner was not working which caused a shutdown of production line.

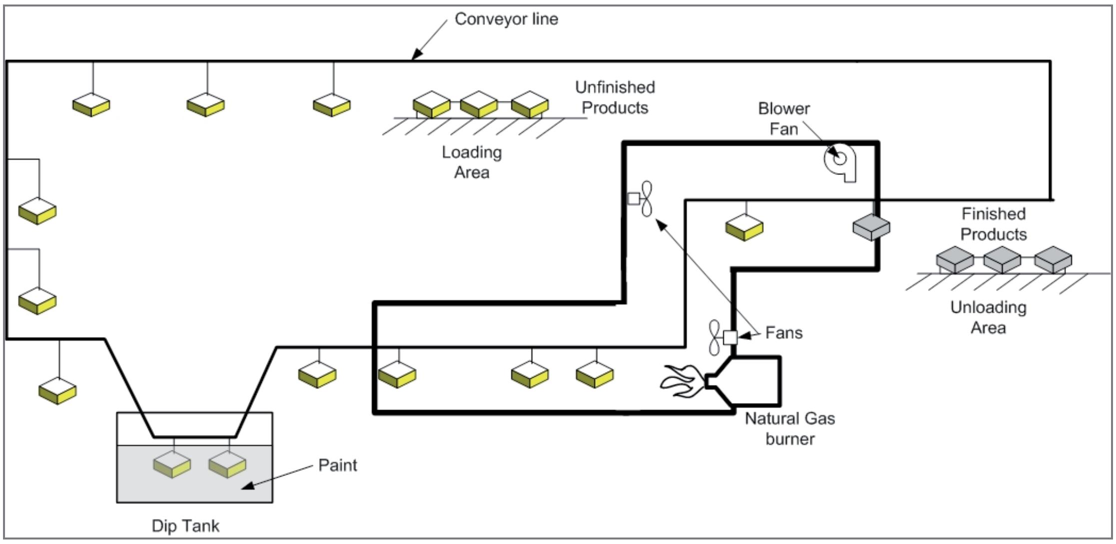

Figure 8. Conventional Method of Curing Paint in the Oven.

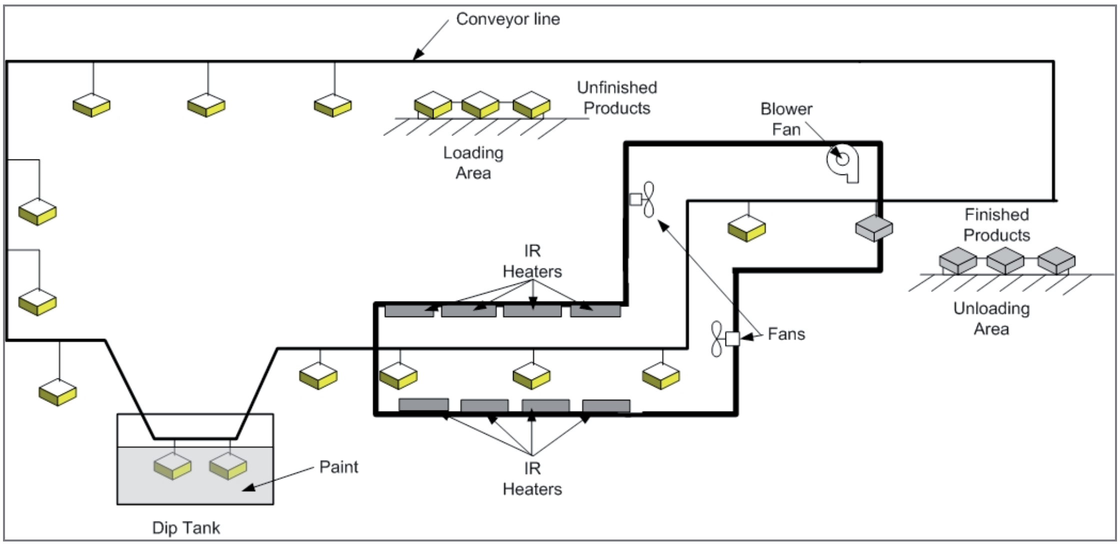

Figure 9. New Method of using IR Heaters for Curing Paints.

THE SOLUTION

The maintenance manager, David Bannister, approached Alabama Power's Technology Application Center for an interim solution to keep the production up and running. After visiting the site, Scott Bishop and Joel Watts of Alabama Power saw an opportunity to replace the gas burner with infrared heaters. They suggested putting eight electric infrared heaters on both sides of the wall (as shown in the Figure 9 and Figure 10). Each infrared heater had a medium-wave IR emitter and rated at 12.75 kW which brought the total IR capacity to 102 kW.

THE RESULTS

The modification of this oven resulted in the quick resumption of production. The cost of the IR heater was approximately $1,000 (€760) per heater. The total cost of installation was approximately $10,000 (€7,600) for 8 heaters including controls for the IR heaters. The maintenance crew soon noticed that they did not have to clean or replace gas filters or burners every week. Not having to stop regularly to clean or replace burners resulted in reduced downtime of the production line. Also, the maintenance manager noticed the absence of emissions or fumes at the oven because the oven used electric heating. With fewer components in the IR heater compared to the natural gas burners, less maintenance was required. The time taken to bring the oven to operating temperature was in the order of few minutes for infrared as compared to natural gas which took nearly 30 minutes. OSHA[2] regulations required constant monitoring of carbon monoxide (CO) levels when the natural gas burner/blower system was used because of safety concerns. The absence of combustible gases and carbon monoxide improved the safety conditions for operating personnel and reduced the environmental impact of the plant's operation. Overall, the plant was able to consistently meet the production requirements without the downtime caused by the natural gas burner/blower system.

2. Occupational Safety and Health Regulations (OSHA)

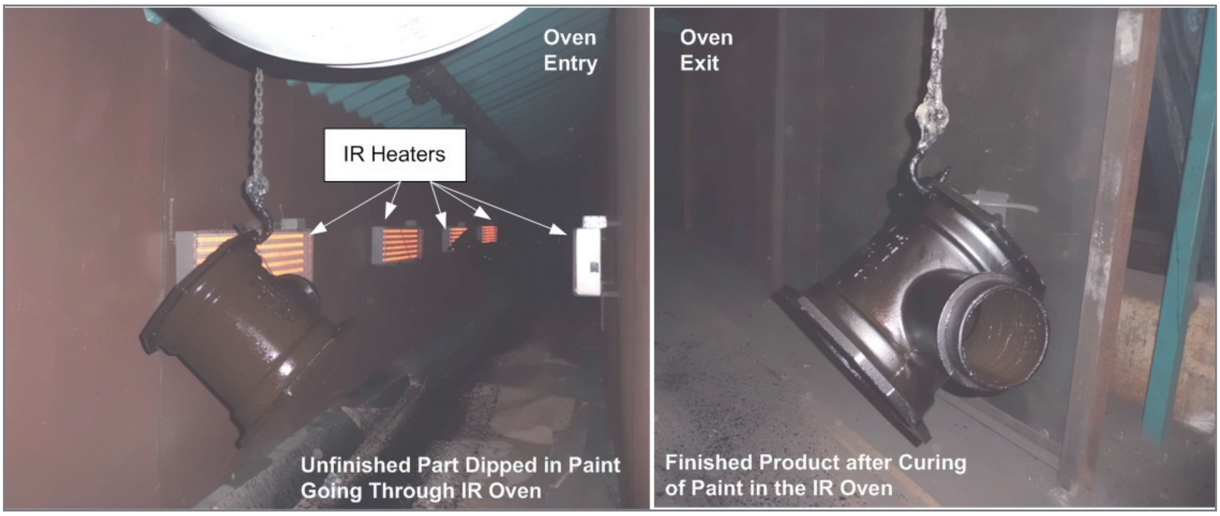

Figure 10. Actual Photos of Oven Showing IR Heaters.

Figure 11. Nameplate Information from the Fostoria IR Oven.

Case Study 2: IR Oven Saves Time, Increases Flexibility and Productivity in a Fixtures Plant

BACKGROUND

A company that specializes in providing customized shelves and cases to grocery stores and other food establishments is one of the long standing customers of Alabama Power. This company, located in Alabama, creates cases that are tailored to meet specific customer needs. They found a bottleneck in one of their heating operations and approached Alabama Power to help find a solution so that they could increase the productivity in the plant. The following section explains the challenge faced by this company and the creative solution that Alabama Power provided them.

CONVENTIONAL METHOD

The company was using a batch oven to heat metal parts of varying sizes in a 3-phase 60 kW electric convection batch oven. The typical temperature of the oven during normal operation was 375 °F and the parts were soaked in the oven for 20 minutes. The batch oven was controlled by a timer. Once the parts were placed inside the oven the timer was set for 20 minutes.

THE CHALLENGE

The challenge faced by the plant was that the small and thinner parts were soaked in the oven longer than necessary because they were placed together with larger and heavier parts that needed more time to heat. The soaking time in the oven was found to be a bottle neck and it was preventing the plant from meeting the production line demand.

THE SOLUTION

Scott Bishop and Joel Watts of Alabama Power approached this problem with a goal to solve this challenge with one simple solution. The customer was willing to separate the small/thin parts from the rest of the parts in order to speed the heating process and this helped Alabama Power to identify the solution. Alabama Power worked with Fostoria (an USA based IR heating equipment manufacturers) to come up with a 162 kW (see Figure 11), 3-phase IR oven with zone control (see Fig-

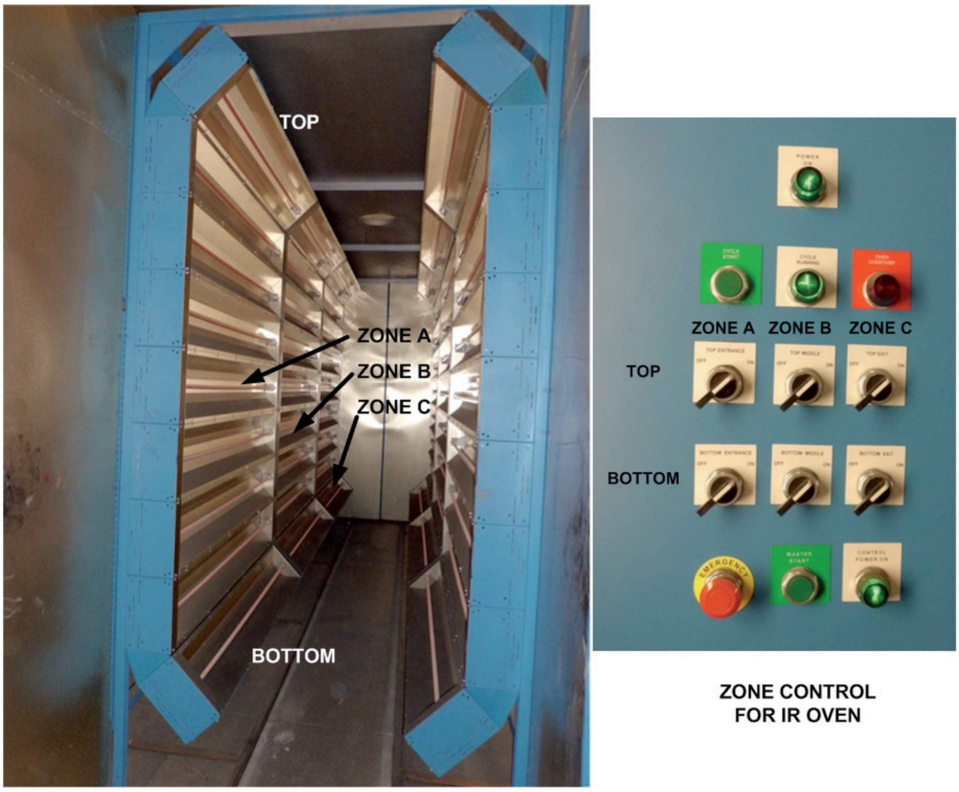

Figure 12. IR Batch Oven with Zonal Temperature Control.

ure 12). This oven could heat the small and thin parts in 5 minutes as opposed to 20 minutes for the traditional approach.

THE RESULTS

The results of installing this new IR batch over are summarized below:

1. The heat cycle time has reduced from 20 minutes to 5 minutes which is 75 % reduction in cycle time. This also has another benefit. Before the installation of IR oven, the employees have to wait for 20 minutes while the parts are heated up. During this time they did not have any other work to do since they were dedicated to this heating operation which resulted in waste of labour hour. However with the IR oven the wastage of labor hours reduced drastically. The plant manager estimates that this labor time savings was equivalent to a cost savings of nearly $50,000 (€38,000) which is a very significant savings per year.
2. The productivity has increased by four times at least for the smaller and thinner parts.
3. Zone control helped the customer by keeping the emitters ON in various zones based on the production line requirements. Since these parts are small, the entire IR oven need not be operated – only the zones where the parts are placed. In the traditional method, the oven was operated at full power regardless of the number of parts inside it. This results in significant energy savings.
4. Maintenance time decreased: should an element fail in the batch oven (without zone control), the entire oven had to be shut off for maintenance. However, with the IR oven, the operation may continue even if a problem occurs in one or two zones. Maintenance may be done at a later time when the production is low.
5. Because of the smaller footprint of the new IR oven, it may be placed adjacent to the existing convection oven. This means that the parts don't have to be transported from one section to the other inside the plant, resulting in increased productivity.
6. This new oven did not replace the traditional oven but it supplemented the production capacity of the plant. From one shift operation, the plant doubled its production line with the addition of new IR oven.
7. Due to the controllability and the flexibility of the IR oven with different zones and the ability to now run the small parts in a different oven the plant has seen a reduction in the scrap rate being produced.

The new IR oven started its operation in January 2011 at this location; hence no specific data for payback is available at the time of publication of this report. However, the customer expects the payback period to be less than a year.

Utility Industry Partnership

The case studies discussed here is a great example of how utility and industry partnership could be mutually beneficial. Alabama power has established a center called the Technology Application Center (TAC in short – shown in Figure 13) which is a concept demonstration facility established with the mission to support its customers in ways to reduce production costs, im-

Figure 13. Inside the Technology Application Center (Alabama Power).

prove energy efficiency, increase productivity, improve product quality, and address environmental concerns. It is located in the outskirts of Birmingham, AL.

The technologies primarily focused at this center are *Induction Heating*, *Infrared Heating*, and *Ultraviolet Curing*. Some of the applications demonstrated in the past are:

- Powder Painting and Powder Coating for Drying and Curing
- Comfort Heating
- Burn-off technologies, and
- Infrared Thermal Curing and Drying

The TAC staffs assist customers with problem solving and demonstrate manufacturing applications using the customer's product. They also provide technical assistance, manufacturing process evaluation and materials analysis to help improve production processes.

It should be noted that the TAC is not a design engineering firm, equipment provider, or quality assurance lab. It is a place for demonstrating the proof of concept of the new technologies. Demonstrations conducted at the TAC are for the sole benefit of Southern Company/Alabama Power's customers and therefore these customers are not charged for the use of the facility and its staff.

The TAC does not advocate the use of any particular vendors' materials or equipment (vendor neutral), nor does it sell materials, equipment or provide engineering services for production lines. However, it can assist customers, to a limited extent, with the selection of vendors for further testing and/or bidding purposes. A few days after the conclusion of each demonstration, a one- to two-page report summarizing the day's activities is sent to the account manager for distribution to the customer.

Utility-industry partnerships shown here proves to be a fruitful engagement especially in these tough economic times where the survival of the company depends upon the knowledge to identify and implement cost-effective and energy-efficient solutions that aids in the productivity and bottom line of the company.

Summary and Conclusion

Industrial and commercial enterprises are constantly striving to increase productivity and enhance their competitiveness in the global marketplace. Similarly, municipal and public institutions are facing pressure to reduce costs without compromising quality of service. In many cases, the application of a novel electro-technology as an alternative to a traditionally fossil-fueled- or non-energized- process can boost productivity and improve the quality of delivered service to the enterprise and the customers that it serves. Important general advantages of electric process heating are fundamentally supported by electricity's ability to deliver concentrated, precisely-controlled energy and information efficiently. Since no combustion occurs at the manufacturing plant, the site-specific environmental impact from process heating is minimal. In general, electric process heating possesses the advantage of a relatively small physical footprint. For example the floor space required by an IR system is 20 % to 35 % less than that of conventional gas-fired heating equipment.

The impact of the implementation of an electric process heating system upon greenhouse gas emissions (CO_2, being of particular interest) depends upon what conventional technology is being replaced. When an electric technology is being replaced, CO_2 emissions will be reduced in proportion to the reduction in electric energy and the CO_2 emissions associated with grid electricity. When an electric technology replaces a fossil fuel heating process, the CO_2 impact depends on several factors, including the efficiency of the fossil fuel system, the type of fossil fuel being replaced, the efficiency of the electric system, and the CO_2 emissions associated with grid electricity.

This paper specifically discussed one of the efficient electric end-use technologies for replacing fossil-fuelled technologies in the industrial sector. There are several other technologies such as induction heating, resistance heating etc that show considerable potential to save energy and reduce CO_2 emissions. The following figures show how the various sectors compare against each other in terms of energy consumption and CO_2 emissions.

As Figure 14 shows, the industrial sector is currently the largest energy user followed by the transportation, residential, and then commercial sectors. By 2030, the industrial sector is still forecasted to be the largest consumer (35.0 quadrillion BTUs per year), but the transportation sector is very close in second place (33.0 quadrillion BTUs per year). In addition, the residential and commercial sectors are projected to be tied for third place (25.0 quadrillion BTUs per year). Overall, total energy consumption for all sectors combined is expected to increase by 15.3 % between 2008 and 2030, an annualized growth rate of 0.65 %.

In terms of CO_2 emissions, Figure 15 shows that the transportation sector is currently the largest producer of emissions followed by the industrial, residential, and then commercial sectors. By 2030, the transportation sector is still forecasted to be the largest emitter (2,193 million metric tons per year), with the industrial sector in second place (1,733 million metric tons per year). However, the commercial sector (1,474 million metric tons per year) is expected to outpace the residential sector (1,450 million metric tons per year) by 2030. Between 2008 and 2030, energy-related CO_2 emissions for all sectors combined are expected to increase by 14.5 %, an annualized growth rate of 0.61 %.

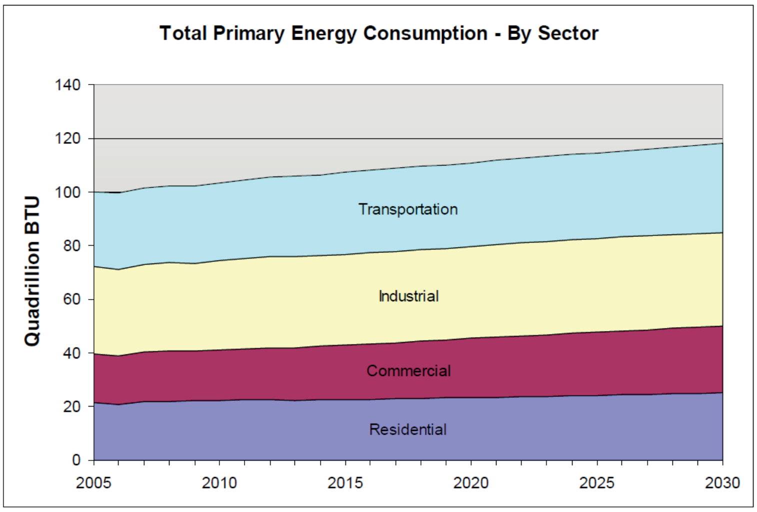

Figure 14. Forecast of Total Primary Energy Consumption by End-Use Sector from the EIA's 2008 Annual Energy Outlook (EIA AEO 2008).

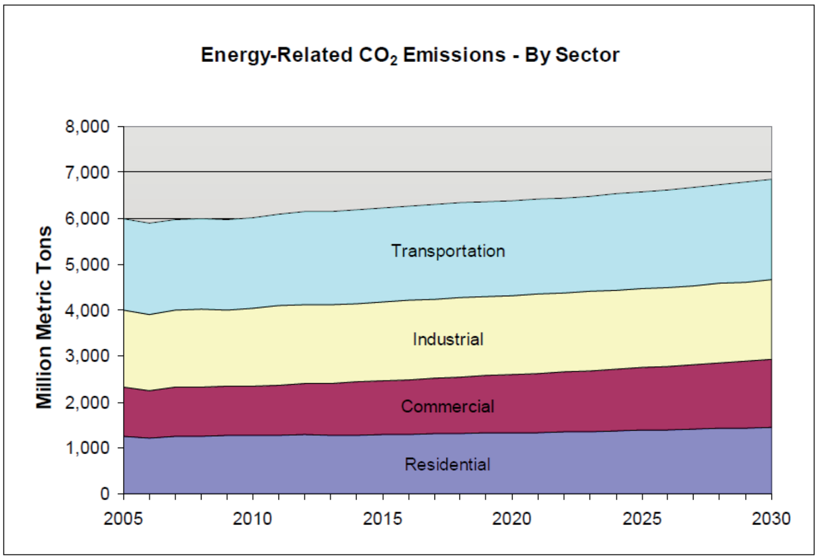

Figure 15. Forecast of Energy-Related CO2 Emissions by End-Use Sector from the EIA's 2008 Annual Energy Outlook (EIA AEO 2008).

References

Efficient Electric Technologies for Industrial Heating, Emerging Activities. EPRI, Palo Alto, CA. 2007. 1014000

Electrotechnology Reference Guide, Revision 3. EPRI, Palo Alto, CA. 2010. 1022334

The Potential to Reduce CO2 Emissions by Expanding End-Use Applications of Electricity. EPRI Palo Alto, CA. 2009. 1018871

Electric Process Heating, Orfeuil, M. Battelle Press, Columbus, OH, 1987

Improving Process Heating System Performance: A Sourcebook for Industry, Second Edition, U.S. Department of Energy, Industrial Heating Equipment Association, 2007

Industrial Process Heating: Trends in electrotechnology based process heating application. EPRI, Palo Alto, CA: 2011. 1021972

About EPRI

The Electric Power Research Institute, Inc. (EPRI) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, non-profit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries.