OPPORTUNITIES FOR FURTHERING THE ELECTRIFICATION IN HEATING PROCESSES IN INDUSTRIAL FACILITIES

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Abstract- Fifty years ago, the concept that "steam was not free" became a reality in the process industry. The process industry has realized and perfected the use of electric heating as a highly efficient and in many cases a less costly energy source.

Electric process heater manufacturers provide heating solutions for temperatures under 780°C. These solutions are utilized in trace heating, space heating, heating of process fluids (gases and liquids) and conductive heating of solids.

Centralized large-scale power generation can allow improved efficiency in converting fossil fuel to electrical energy. In addition, the growing production of renewable power gives excess power to the grid. Combining this with targets for the industry on the reduction of the use of natural gas for process heating, a substantial contribution in the reduction of greenhouse gases can be achieved.

This paper will present numerous process heating application solutions where conversion to electric heating source opportunities may exist. A feasibility case study will be presented that transforms a cogeneration based steam energy supplied production unit to one that uses an electric steam boiler.

Index Terms — Trace Heating, Space Heating, Conductive Heating, Energy, Process Heating

I. INTRODUCTION

Climate experts attribute the vast build-up in the atmosphere of carbon dioxide and other greenhouse gases as a part of the reason for global warming being experienced in our world today. The carbon dioxide in the atmosphere is due in part to the growth in use of fossil fuels to generate heat and electricity for the world. There are many known ways to reduce greenhouse gas emissions in the industrial sector. For the industrial process industry, these include **improving energy efficiency, fossil fuel type switching, use of combined heat and power generating units, adding renewable energy sources to supply the electrical power grid, and the more efficient use and recycling of materials.** In the few cases where existing industrial processes have no lower-emission alternative, carbon capture and storage to reduce carbon dioxide emissions over the long term may become a required alternative.

Many of the application solutions for heating processes that exist today are evolutionary. That is, they have been the best solution based on the technology, economics, and practicality in existence at the time. Once the application solution was initially proven successful, it became the default way. With today's emphasis on renewable energy, sources used in creating electrical power and reducing carbon dioxide emission levels through more efficient conversions of fossil fuel energy to electrical power; it also seems appropriate to consider reducing in-plant usage of lower efficiency fossil fuel process heating equipment and begin utilizing direct electric process heating where possible. A number of candidate direct electric process heating application opportunities will be reviewed based on the perspective of furthering the electrification within industrial facilities. In parallel with an increased focus on a more efficient heat generation equipment selection, there is a need to reassess the heat generation and power grid sources and capacity in each industrial facility. A case study of one such infrastructure assessment of a mid-size chemical plant is given to provide a glimpse of that process.

II. Trace Heating Application Solutions Where Electrification Potential Exists

In its simplest form, trace heating may be thought of as a line source of heat that is applied parallel to a process pipe, vessel, or piece of equipment to heat its external surface. The line source of heat may be an electric trace heater or a steam/fluid trace heater. The trace heaters most basic function is to replace the heat lost from the process line, vessel, or equipment. Trace heating applications in the earliest times were often considered an incidental part of the facility processes. Today, many industrial facilities and processes find that trace heating plays a major role in its operations. For example, it is not unheard of today to find 15000 and more trace heating circuits in a petrochemical facility. In terms of energy consumption, this could represent as high as 15 megawatts of power (energy consumption is dependent in part on the process maintenance temperature, heating surface geometry, the insulation system, and ambient conditions).The following sections describe a few of the trace heating applications that may be found in an industrial facility.

A. Trace Heating of Water and Water-Base Solutions

Perhaps the largest process applications of trace heating are those where water or water solutions are involved. Along with not being processible when frozen, water and water-based solutions cannot be allowed to freeze without risk of damage to containing piping or equipment because

[1] Reproduced from https://www.nrcan.gc.ca/energy/publications/efficiency/industrial/cipec/6699

of the expansion characteristics of water when thawing. These solutions are typically maintained between 5°C and 40°C with the higher maintenance temperatures (above the traditional water maintenance temperature of 5°C) typically being for acid or caustic based water solutions. Direct electric trace heating continues to be growing in popularity for these applications. Electric trace heating is relatively easy to control process piping and equipment at these lower maintenance temperature ranges. Electric trace heating systems are more commonly configured with ambient on-off, ambient proportional controlled, or surface sensing controlled trace heaters in these applications today. Typically, a self- regulating polyolefin based core trace heater is most often prescribed. The use of ambient sensing type controls is selected to limit heater operation to only those times when the ambient drops below the desired maintenance temperature. Today, a proportional control aspect has been added to ambient sensing systems that linearly increases the heat input as the ambient drops to the minimum ambient value. In this way, the energy required is significantly reduced. The use of ambient sensing in these applications reduces the initial capital cost of the temperature controls needed especially in complex piping areas where multiple process flow paths are likely. In some longer transfer line applications, use of constant wattage series or parallel metallic element trace heaters may be appropriate. When using these types of heaters, surface sensing temperature control is generally required. Where further reduced energy consumption requirements are dictated or where tight process temperature limitations exist, pipe or equipment temperature sensing control with electric trace heating becomes the preferred trace heating control solution for all types of trace heaters. Surface sensing controls require consideration of process flow patterns when establishing the electrical circuitry.

Where low pressure steam distribution is available within the plant, steam tracing utilizing isolated tubing (for reduced heat transfer and better matched heat delivery) can be utilized in these water and water based solution heating applications. While this is not the most energy efficient application, in some cases it does provide a use for excess low pressure steam and thus helps to balance out the plant energy requirement budget.

B. Trace Heating of Crude Oil, Asphalt, and Bitumen

Another extensive application for trace heating is viscosity control. Depending on the amount of wax content in the various hydrocarbons, viscosity reduction is often required in order to maintain stagnant process lines readily pumpable. Process heating requirements range from maintaining fuel oils such as No. 6 fuel oil at 60°C or higher up to 150°C or more for asphalts and bitumens. The electric trace heating selection for these processes in complex piping areas is usually a fluoropolymer based self-regulating electric trace heater at the lower end of the maintenance temperature range and mineral insulated Alloy 825 sheathed constant wattage trace heaters at the upper end of the maintenance temperature range. Control systems used for these trace heating applications are usually of the surface sensing type, which requires consideration of process flow patterns when establishing the electrical circuitry. For long hydrocarbon transfer lines between process units, skin effect trace heating is the most prevalent trace heating system used today. Skin effect trace heating can cover a large part of this maintenance temperature range (up to at least 150°C) and generate the heat outputs typically required.

Where steam distribution lines are available and its use is justified to balance out the plant energy requirement budget, convection steam tubing tracers can be used in the lower maintenance temperature range. Conduction type steam tracers are more suitable in the upper maintenance temperature range. Steam trace heating circuits are not generally configured with temperature control devices due to the difficulty of maintaining constant temperatures along the trace heater circuit path. Acceptable temperature range control is achieved by matching the heat delivery requirement by appropriate selection of the steam tracer heat transfer characteristics.

C. Trace Heating of Sulphur

When refining crude oil (especially sour crudes), a necessary byproduct is Sulphur. The extraction and handling of Sulphur presents another significant application for trace heating. Sulphur is a rather unique process fluid to handle as it has two distinct changes in structure as it melts or solidifies. The first structural change when heating up Sulphur occurs at an approximate temperature of 100°C. The second change results in a complete Sulphur change from solid to liquid and this occurs at an approximate temperature of 120°C. As a further complication, liquid Sulphur becomes much more viscous and difficult to process when it attains temperatures in the 150 to 160°C range. These temperatures are approximate as the previous process history and the Sulphur makeup can cause these numbers to vary some. Traditionally, Sulphur is usually maintained at a temperature of 135°C for optimal control and handling.

For complex piping areas within the process unit, either steam or electric trace heating is suitable. Direct electric heating is usually achieved with Alloy 825 sheathed mineral insulated trace heaters and surface sensing temperature controllers. When using steam in this application, it is functionally best to use 3.5 to 5-bar steam in order to avoid heating the Sulphur above 150°C. Conduction type tracers or jacketed piping is usually necessary to achieve the desired 135°C to 150°C temperature range maintenance temperature when using steam. When using conduction tracers or jacketed piping, temperature control is usually achieved by selecting the proper steam pressure for this heating. Where long Sulphur transfer lines exist between process units, skin effect trace heaters with surface sensing temperature controls are usually the best choice. Providing a supply and return steam distribution system to heat long transfer lines is generally viewed as being impractical from an economic viewpoint unless the distribution headers are already in existence for other purposes.

In most of the above applications (A, B, C), electric trace heating is the most energy efficient means of delivering process heat. This is primarily due to the cost effective implementation of the electronic temperature control technologies, which are available today. These controls allow only the minimum required heat/energy to be delivered to achieve the desired maintenance temperature range. The amount of heat/energy required is also a function of the thickness and type of thermal insulation specified. There are numerous types of very efficient (low in-situ thermal conductivity) thermal insulation in use in trace heating today. For the lower temperature ranges (pipe and equipment temperatures below 100°C) water resistant closed cell insulations are generally preferred. Above this temperature range, low thermal conductivity with water resistance (to avoid in-situ thermal conductivity increases) is still important but other factors such elevated temperature exposure and dimensional stability are also important. An extensive review of the insulation selection process for trace heating may be found in the references [1]. With proper design of the electrical distribution, the energy losses in the electric distribution wiring to electric trace heating circuits can be minimized. Steam or fluid heat transfer systems should be considered in those cases where the heat delivery by the steam or heat transfer fluid tracer is inherently well matched to the heat loss requirement in the trace heating application. In general, controls for steam and heat transfer media systems are not generally as effective in maintaining a relatively constant temperature along the trace heater length. In addition, the cost of providing any such control is high compared to that cost associated with electric trace heating system controls. As well, the steam distribution system supply and return headers have a high energy/heat loss associated with them. This is due to both the heat losses through header insulation systems as well as those energy losses associated with steam trapping /condensate return systems/fluid handling systems.

III. Space and Process Heater Application Solutions Where Electrification Potential Exists

Depending on the manufacturing processes in any given industrial facility, a variety of other substantial heat generators may be found in a process unit. In each case, there is an opportunity to consider the potential of considering direct electric heating rather than using a fossil fuel based energy source such as a local steam generating unit. A variety of heat generators that have electrification conversion potential are covered in the following sections.

A. Electric Radiant Comfort Heaters

Infrared radiant heaters provide the benefit of directly transferring heat to a target location without heating the surrounding air. Heat transfer occurs without the need for an intermediary transfer material. Radiant heating solutions are therefore ideal for such applications as large open buildings in an industrial facility, where heating the entire volume would prove overly burdensome and costly.

As an example, a person doing heavy work typically requires an air temperature of 19°C to 20°C to maintain the feeling of warmth. Utilizing radiant heater technology, the same feeling can be provided at lower ambient air temperatures in the range of 13°C to 16°C.

Type of Work	Normal Air Temperature (°C)	Equivalent Temperature With Infrared Heating (°C)
Heavy Work	19 to 20	13 to 16
Light Work	21 to 22	16 to 18
Seated	23 to 24	18 to 21

Fig. 1 Comfort Heating with Infrared Equipment

The amount of heat transferred is dependent on two important factors. The first is the temperature difference between the heater (emitter) and the person or object to be heated (source). For comfort heating, the source temperature stays relatively constant (usually close to a room temperature of 20°C). Therefore, it is only necessary to consider the operating temperature of the heater. The other factor in radiant heat transfer is the ability of both the heater and the source to give off and absorb radiant heat energy. This characteristic is expressed as an object's emissivity that ranges from 0 to 1 (where an emissivity of 0 absorbs and transmits no radiant heat and an emissivity of 1 absorbs and transmits all radiant heat).

Both electric and fossil fuel powered radiant heaters utilize high temperature emitters. The temperature of the emitter is the predominant factor in dictating the amount of heat transferred through radiation. Electric heaters convert electricity to heat through high watt density resistance elements. Elements are available in a variety of constructions including metal sheathed, quartz tube, and quartz lamp. Each type of element provides a different set of performance advantages depending on both the application and user preference.

All electric resistance heaters benefit from the principle that when electricity flows through a resistive element, heat is generated at close to 100% efficiency. Although some losses can be attributed to eddy currents, these losses are so small they are widely regarded as negligible.

For radiant heaters, the overall efficiency must take into account the mode of heat transfer. For radiant applications, any heat transferred by way of convection is considered waste heat. Radiant heaters are mounted high where radiant line of sights are unobstructed and where there is sufficient clearance to keep personnel away from their hot surfaces. For this reason, any heat transferred to the air by way of convection is lost. The heated air rising from the heater offers no benefit to the target at ground level. There are a number of different variables that govern radiant heat transfer. Some of these include temperature, surface area, electromagnetic wavelength, surface finish, etc. For comfort heating, heater temperature is the predominant factor in controlling the split between radiant and convection heat transfer.

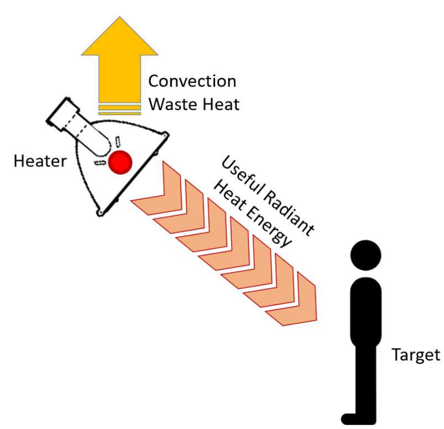

Fig. 2 Radiant Efficiency

Typical fossil fuel based combustion heaters have efficiencies that range from 80% for standard equipment to above 90% for high efficiency models. It is not as common to see efficiencies in the 90% range for radiant fossil fuel based heaters. Where possible, it is somewhat impractical for radiant heaters to achieve above 90% efficiencies as these efficiencies are usually achieved by recovering low temperature waste heat in the exhaust stream. While this is effective in maximizing overall efficiency, it has little value in transferring heat by radiation. The temperatures are simply too low to radiate heat.

The efficiency advantage of electric radiant heaters increases when varying load conditions are considered. Control of fossil fuel based radiant heaters are typically limited to one or two heat stages. The low heat stage reduces temperatures, lowering radiant heat transfer efficiency even further. At reduced load requirements (below that of any low heat setting), a fossil fuel based heater cycles on/off to regulate temperatures. Cycling of this nature is inefficient due to long heat up and cool down times outside of optimal radiant heat transfer temperatures. In addition to this, pre- and post-combustion chamber purging evacuates the heated gas to the outside and increases overall waste heat losses. For optimal efficiency and control, multiple electric radiant heaters are packaged together to heat the same target. In this configuration, heat output is varied by individually energizing and de-energizing different combinations of elements. Radiant heat transfer and overall efficiency is maximized by providing the necessary heat output at optimal heating element temperatures.

Electric radiant heaters are manufactured in a wide range of sizes and configurations. Single unit lengths can be as long as 2m or as short as 0.5m. This versatility allows for custom solutions, tailored to heat only the locations deemed necessary. Operational cost savings are realized by carefully designing a heating solution to only provide full heat where workers are commonly present. The simplicity and customizable nature of electric radiant heaters provides for precise control of temperatures. The low mass of the heating element is more conducive to on/off cycling for heat attenuation. Rapid startup and cool down times facilitate accurate temperature control while minimizing inefficient operation time at low temperatures below radiant heat transfer thresholds.

Electric radiant heaters are relatively easy to mount and install. They are simple lightweight designs. Mounting an electric radiant heater has many similarities to installing factory lighting. A qualified electrician can install both. Fossil fuel based equivalents require both a certified gas fitter and electrician to install. Typically, these heaters are larger and heavier and may necessitate moving shop floor equipment to provide proper access for installation. For interior installations, appropriate means for venting combustion exhaust must also be addressed.

B. Boilers

In the US and Europe, it is estimated that steam generation accounts for about one third of the overall industrial energy demand.[2] Fossil fuel fired boilers account for the vast majority of all boilers in industrialized countries. It is also estimated that the majority of the industrial boilers in use are more than 30 years old. [3]

Electrically powered boilers offer an interesting alternative to their fossil fueled counter parts. Efficiency numbers are higher. They provide quiet, clean, emission free operation, and their power output attenuation is more precise, providing improved temperature and steam generation control. Electric heat generation also reduces greenhouse gas emissions.

Traditionally, the practical use of low voltage electric boilers was limited to smaller applications with maximum heating requirements of 1 to 5 MW. This left industry with few options other than fossil fuel based boilers for large-scale demands. With the emergence of medium voltage heating technology in the range of 4 to 7.2kV, large electric boilers now offer a viable alternative to the fossil fuel dominated large scale boiler market. Additionally, electrode boilers are also now available which can operate at electrical supply voltages from 6 to 24 kV.

Fossil fuel burning boilers are available in a variety of different designs. Common operating fuels include natural gas, coal, oil and in some cases biomass. Thermal efficiencies for new boilers can reach 75% for natural gas, 85% for coal, 80% for oil and 70% for biomass [3]. These efficiencies can be marginally improved by adding complex and sometimes costly heat optimizing features such as exhaust heat recovery economizers, feedback loop combustion control, and variable speed combustion air drives. Poorly maintained boilers can lose up to 30% of their benchmark efficiency over 2 to 3 years [2].

Electric boilers benefit from virtually 100% efficiency in the transfer of electrical energy to heat energy. Operational waste heat is limited to pipe losses in steam/water transportation and losses at the process equipment utilizing the heat. Good insulating and sizing practices can maximize system efficiency without the need for costly and complicated waste heat recovery systems.

In larger boiler applications, electrical transmission losses become more significant as the heat load increases. Joulian (I^2R) heat losses in circuit wiring for electric loads in excess of 1MW become an obstacle for low voltage installations (480V-600V). Utilization of medium voltage heating technology can significantly improve efficiency by lowering current draw, thus lowering I^2R losses and maximizing efficiency. Through medium voltage heating technology, larger heating demands can be satisfied with high efficiency electric boilers. Medium voltage heating equipment negates the need for a medium to low voltage step down transformer. This lowers installation costs and improves overall system efficiency.

Fossil fuel boiler efficiencies are significantly impacted by varying load requirements, which are commonly experienced in industry. Turndown ratios are limited and efficiency typically drops off at lower power outputs. At heat load requirements below the minimum turndown output, fossil fuel based heaters blow off either excess steam or initiate inefficient on/off cycling.

Electric heaters naturally provide opportunity for excellent output control variation. Boiler output control is accomplished through a number of different methods depending on the size and design of the appliance. In most boiler applications, on/off switching is utilized to control heat output. Electric boilers are manufactured using many individual heating elements, bundled into multiple flange heaters dependent on the size and power output of the boiler. Through utilization of a step controller, the heat output is attenuated by switching distinct element bundles “on” and “off” to accurately match heat output to load requirements.

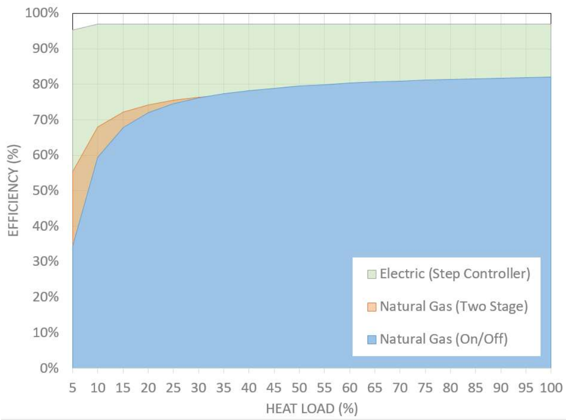

Fig. 3 Theoretical Boiler Efficiency vs. Percent Heating Load

The inherently simple design of electric boilers provide for reliable operation with low maintenance requirements. Electric boilers with vertical heating elements require less scheduled maintenance. The vertical orientation of the heating bundle creates a water to water vapour "stack" effect. This provides a cleansing action over the elements. This design has proven to minimize scale build-up on the heating element sheath that reduces the need for blowdown and increases the heater life. The vertical orientation allows for easy removal from the top when maintenance is required. Clearance to adjacent equipment is minimized enabling greater flexibility for plant layout optimization. Vertical element orientation, however, is only feasible in boilers up to a certain size. Larger boilers require elements to be installed horizontally.

C. Circulation Fluid Heating

Process fluid heating is utilized for many different applications in many different industries, including food processing, power generation, chemical manufacturing, and petroleum refining. Process heaters are used to increase the enthalpy of a fluid, sometimes to increase temperature, and other times for complete or partial vaporization. In other cases, process fluid heaters contribute to chemical processes such as cooking, fermentation, cracking, distillation, etc.

Fundamentally, heaters transfer heat to the process fluid through any combination of conduction, convection, and radiation heat transfer modes. This is accomplished directly by placing the heating device in direct contact with the fluid or indirectly by introducing an intermediary heat transfer fluid. Intermediary heat transfer fluids are more common in fossil fuel based heaters where the process temperature limitation is below that of the combustion heat temperatures. Process fluid heater designs provide great heat flux versatility. With a proper design, heating element temperatures can be reduced resulting in the elimination of the need for an intermediary fluid.

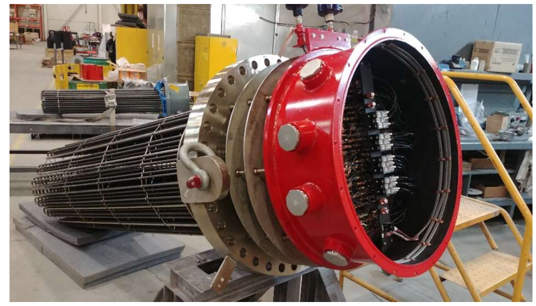

Fig. 4 Electric Process Heater

Electric process heaters are in many ways similar to tube and shell heat exchangers. The distinguishing feature is that the core heat exchanger bundle is manufactured with electric tubular heating elements. Their designs are simple and robust and provide the opportunity for high efficiency heating. The generation of heat from electricity is provided with virtually zero waste losses. Therefore, overall efficiency is governed by waste heat losses between the process and the environment. With the highest temperatures situated at the heating element core in the center of the equipment, waste heat losses are limited to the outside of the shell. These losses are easily controlled with the use of proper insulating techniques, since the temperatures are relatively low. The need for special refractory insulating material is not as common in this case.

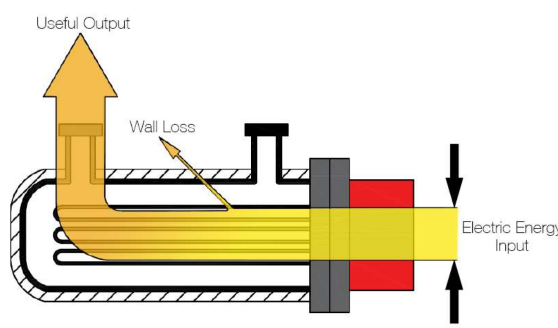

Fig. 5 Electric Process Fluid Heating Energy Losses

Fossil fuel based process fluid heaters have inherent vulnerabilities that affect their efficiency. Their fundamental designs are susceptible to varying levels of energy loss through a number of different paths. The result is overall reduced thermal efficiency. There are losses associated with incomplete or non-optimized fuel burn in the combustion process. Significant losses are linked to energy escaping as heated exhaust through the flue. Heat loss through furnace walls is also a factor.

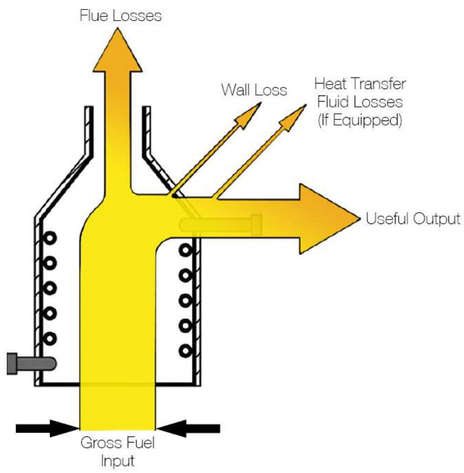

Fig. 6 Fossil Fuel Based Process Fluid Heater Losses

The total efficiency of implementing electric heaters starts to drop at load demands in excess of one to 2MW. This is a result of high current associated waste heat losses in the supply wiring and upstream electrical infrastructure. For higher heat load applications, utilization of medium voltage heating technology mitigates these losses by reducing the number of electrical circuits, lowering the overall current draw and eliminating the need for upstream transformers.

Superior turndown combined with virtually continuously variable power output control is arguably the largest functional benefit of electric powered heaters. For extremely high precision, SCRs (silicon-controlled rectifiers) are utilized for output power control. SCRs can cycle as fast as 0.008 seconds on a 50/60 Hz power line. Paired with appropriate sensors and PID control, SCR based systems provide unmatched response time and process control. The result is stable, widely adjustable process temperature control. Electric process fluid heaters also provide fast response time to changing conditions with minimal overshoot or temperature undulation.

Functionally smaller in nature, electric heaters benefit from their simple design. This characteristic not only helps with response time, but also makes for easier installation in tight plant layouts. Electric fluid heaters do not include some of the bulky components required by their fossil fuel fired counterparts. Heavy walled furnace enclosures, sophisticated controls, process fluid heat exchangers, flue gas components as well as many other add on items that are sometimes included to improve efficiency or potentially remove harmful emissions are not required with an electric heater.

Another added benefit for electric process heaters is their suitability for hazardous locations. With no open flame operating at extremely high temperatures, electric heaters can be easily constructed to comply with the various requirements for different types of explosive environments.

D. Vessel Heaters

Electric vessel heaters are used for small, medium, or large vessel heating applications. They can be either of the direct immersion type design where the heating elements are directly immersed in the fluid being heated or by indirect heating design where a heat transfer medium such as a liquid or air is used to transfer the heat to a pipe which then transfers the heat to the process fluid.

Direct immersion and indirect type vessel heaters are available for virtually any type of fluid heating application and are nearly 100% efficient since almost all of the heat generated is transferred into the process fluid. Most fossil fuel fired heating systems use steam either as a heat transfer medium, which is about 65-70% efficient, or as oils, which are about 90% efficient. Electric vessel heaters are more energy efficient, and are simpler to install, operate and maintain than fossil fuel burning equipment. Heating applications include heating or maintaining process fluid temperatures for use in their specific processes.

Other operational advantages of electric vessel heating as compared to fossil fuel burning equipment include reduced footprint (since the heater is typically contained completely inside the vessel), very precise control of process fluid temperatures, fast heat up, lower installation and maintenance service costs, easy monitoring and inspection, and fewer components.

Environmental advantages include no smoke, dust, fumes or combustion gases, no OSHA monitoring of CO emissions, compatibility where special environments such as areas with explosive dusts or gases are present, improved safety, and reduced environmental impact.

The adaptability of a closed-loop temperature control system provides additional energy efficiency, and the fast heat up time ensures that power usage is minimized. These heaters are suitable for both continuous or batch heating processes, and can accommodate multiple operating stages.

The indirect type vessel heater is suitable for use for heating viscous fluids such as heavy oils, asphalt, bitumen, lube oils and diesels. Heaters are often mounted inside of a pipe containing only air. This configuration offers the advantage of easy removal and replacement of the heater without having to stop the process or to drain the contents of the tank. Another advantage of these types of heaters is that they are designed with very low heater watt density, which is important to maintain low film temperatures as some process fluids can be damaged by over temperature exposure conditions.

Environmental advantages of the indirect type are the same as direct immersion type heaters, but also includes eliminating the possibility of costly contamination of the process fluid and reduced productivity. The indirect electric vessel heater type does not require use of oil as a heat transfer medium as used in fossil fuel burning vessel heaters.

E. Conductive Heating of Solids

Conductive heating of solids is an area where electric heating has a large presence. Many processes use exclusively electric heat since it is nearly 100% efficient, allows precise temperature control and adaptability to changing process requirements, is compact and simple to operate and maintain, and does not produce any harmful emissions.

Conductive heating applications include platen or die heating, injection-molding equipment, hopper heaters, heat transfer presses for use in plastic and laminate industries, railway track switch heaters for removal of ice and snow, and even new applications such as electric vehicle battery heating.

Conductive electric heaters are nearly 100% efficient, and are available in small and large formats for many specific applications. For many conductive heating applications of this type, fossil fuel burning equipment is typically only used where very large-scale heating is required or electricity availability is limited.

Conductive electric heaters are very easy to control, are simple to use and maintain and can be designed for very specific heating applications. They are also safe, since there is no open flame, and produce no combustion gases or harmful emissions.

IV. Increasing Electrification of The Heat Generation Infrastructure

The discussion to this point has been focused on improving the efficiency of heating processes and switching from fossil fuel based heat generators to direct electric heating within the various process units. In a new grass roots facility, these decisions will have an overall impact on the plant fossil fuel based steam and electrical power generation (including renewal energy component) requirements in the facility planning. Where enhancing electrification in an existing facility, it is important to realize that if significant changeovers to direct electric heating are achieved, the overall power and steam heat generation budget and power generation infrastructure may need changes as well. Thus, it is important when making significant changes to step back and look at the fossil fuel generated steam heat generation and electric power grid existing capability. Taking some fossil fuel based stream boiler capacity offline, converting fossil fuel based boilers to electric boilers, increasing the electrical power grid capacity, or adding renewal energy source power may be a companion requirement. Additional electrical power distribution to the various process units will also no doubt be required. Likewise, fossil fuel generated steam capacity may need to be down sized and some distributed steam generators within each process unit may need to be decommissioned. Obviously, each facility is unique in its manufacturing purpose and thus it is difficult to make general recommendations regarding this management decision-making process. However, a glimpse of this process is provided with the following case study.

Case Study of a Midsize Chemical Facility in the Netherlands

In order to reduce CO2 emissions, as required by the recent climate change agreements, a midsize chemical plant in the Netherlands needs to electrify the on-site heat generation. In the climate agreement, this is called “power to heat”. The scope for this existing plant is steam generation and oil heating. The total existing electrical plant load in this scenario is estimated to be >200 MW. In the current situation, the heat is produced with the use of two gas fired cogeneration units with islanding capacity and gas fired boilers. The plant power consumption is fed by the cogeneration units balanced by the utility grid. The current connection consists of two connections with a total capacity of approximately 90MVA and a limited back-up supply. The electrification of this site requires the modification of the grid to support the new power demand. This study identifies the necessary upgrade of the electrical grid connection, the on-site distribution system and the new electrical steam boilers, as follows:

- 10 kV steam boilers
- Redundant 150 kV grid connection
- 150kV voltage substation
- 6 pcs, 150/10 kV transformer
- 3 x 10 kV substation
- 150 kV on site cable connections

In order to identify necessary investments in the electrical grid connection and on-site distribution system, this study includes the identification of the total plant load, upgrading the power grid connection, and defining the plant distribution system.

A. Grid Configuration

Indication of plant load is as follows

Present plant load	70	MW
Other load	10	MW
Total	**80**	**MW**

The present grid configuration is based on two separate grid connections with a reduced backup power supply. Each grid has a cogeneration unit to provide steam and hot oil.

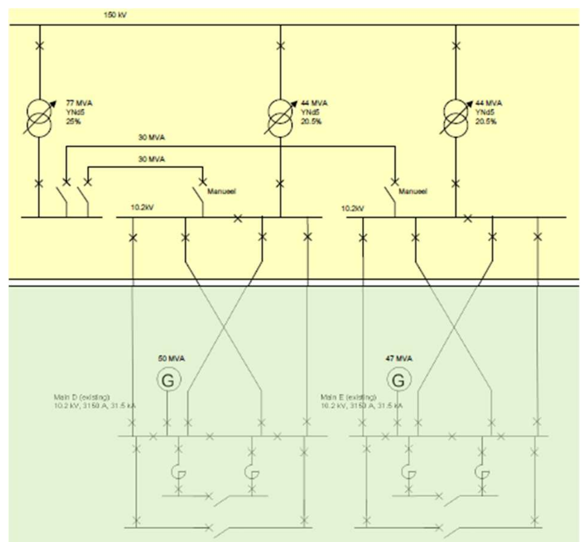

Fig. 7 Present Grid Configuration

B. Future Plant Load

The total anticipated future plant load has been defined as follows:

Present Plant load	70	MW
Other load	10	MW
Steam boilers	~70	MW
Oil heaters	~20	MW
Future expansion	XX	MW

Sub Total	>170	MW
Design Margin	>30	MW
Total	**>200**	**MW**

Taking into account a power factor of 0.8, this results in a new future apparent power of 200/0.8 = 250 MVA

C. New Grid Connection

A meeting has been held with the national grid operator. The projected plant load, as mentioned above, will result in a connection at a voltage level of 150 kV. Standard rating of one connection is 300 MVA. In order to have N-1 reliability, the grid connection shall consist of two cable connections, each with a rated continuous transport capacity of 300 MVA.

According the local grid codes, connection shall be done on the closest substation with the required voltage level. This is the 150 kV substation, which is located at about 1.5 km from the site. However, the national grid operator explained that this substation is congested. It is not to be expected that the required grid connection will be realized at this location. The national grid operator intends to build a new 380/150 kV substation. The new connection would be realized at this location.

D. Plant Distribution System

Design of the plant distribution system shall take into account following conditions:

- Plant load = approx. 250 MVA
- Grid connection = 2 x 300 MVA, 150 kV
- Voltage level for connection of medium voltage equipment = 10 kV
- N-1 reliability

Based on these conditions, one-line diagrams of four conceptual distribution systems have been developed. These conceptual distribution systems have been evaluated in coordination with the global asset technology centre, taking into account following criteria:

- Reliability
- Maintainability
- Operation ability
- Possibility to integrate/reuse existing equipment
- Possibility for future growth
- Rough cost estimate

This proposed plant distribution system consists of following main components.

- 1 x 150 kV substation
- 6 pcs, 150/10 kV transformer
- 3 x 10 kV substation
- 150 kV on site cable connection

Based on the results of this evaluation process, the selected grid configuration for the future electrification project is as shown in Fig.8

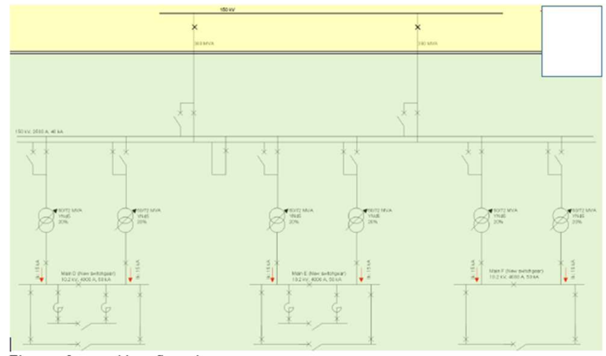

Fig.8 Future Grid Configuration

IV. CONCLUSIONS

Almost half of the world's energy use is dedicated to industrial activity [3].The drivers for optimizing process heating may be divided into **Policy**, (environmental, regulatory, and political often resulting in tax incentives which encourages lower carbon generated electricity), **Technology,** doing more with less and **Consumer Preferences** both internal and external. All the drivers influence how we use energy and each driver influences the other as they all influence **Demand.**

For the future, gaining the increased efficiencies associated with large scale centralized electrical power generation as well as adding renewable energy power to the electric grid should be a key management focus in any current or new industrial facility. In concert with that effort, every effort should be made to use direct electric process heating. As has been seen in this paper, there are multitudes of proven direct electric heating application solutions where the past practice of utilizing energy generated from smaller distributed fossil fuel based process heating units can be eliminated.

V. ACKNOWLEDGEMENTS

We acknowledge the essential contribution of SABIC in allowing information regarding the assessment process on the conversion of an existing facility in the Netherlands from a high fossil fuel energy based consumer to a more efficient electrification based facility to be used in this paper.

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VII. VITA

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