Energy Efficiency Projects as Short-term Solutions to Combat Greenhouse Gas Emissions Within the Metals Industry

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Abstract

Over the last several decades, data collected by scientists across the world has indicated rapid mean temperature rise across the globe. This increase in global temperatures correlates with and has been attributed to elevated greenhouse gas levels in the atmosphere due to the reliance on fossil fuels for energy since the late 16th century. Focusing in on one of the largest energy consumers and emitters of greenhouse gases within industry, the metals industry was identified as a major area for the reduction of greenhouse gas emissions. In recent years, researchers within the U.S. Department of Energy and Lawrence Berkley National Laboratory have pinpointed several avenues to eliminate the emission of greenhouse gases from processes within the metals industry. However, these projects have yet to emerge as practical, large-scale, and economically viable options for most facilities within the metals industry. Smaller energy efficiency projects offer a stop-gap solution to reduce greenhouse gas emissions until more robust avenues for sustainability become practical. In this light, recommendations for effective energy management programs are provided along with the identification of practical energy efficiency projects common within the metals industry. Additionally, a call for further research into long-term solutions to eliminate greenhouse gas emissions is put forth to encourage future work within the area.

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Severe storms, measurable sea level rise, and raging wildfires – these weather extremes bring back memories such as the costly hurricanes Katrina, Harvey, and Irma and constant drought conditions seen in the American Southwest over the past several years. In fact, Dr. John Hidore, an expert in climatology, lists 2017 as the most intense and damaging North Atlantic hurricane season since weather record keeping began [1]. Additionally, the 21st century has seen some of the most intense heavy thunderstorm and tornado activity within the record books. The increasing severity and occurrence of all these natural phenomena can be, in part, attributed to mankind's reliance on fossil fuels for energy. Since the industrial revolution of the 1700's, standard practice across the developed and developing world has revolved around the burning of hydrocarbons such as coal, oil, and natural gas to provide the energy needed to sustain and improve productivity and quality of life. Though unquestionably useful for power generation, the combustion of hydrocarbons releases significant gaseous products such as carbon dioxide, sulfur oxides, and nitrous oxide. Many of these byproducts of combustion are detrimental to the environment, and some—carbon dioxide in particular—contribute to the greenhouse effect. This process involves a molecule's ability to absorb certain wavelengths of radiation and then emit the absorbed energy at a different wavelength [2]. However, for the purpose of this discussion, a good way to think about the greenhouse effect is that, because of greenhouse gases, a substantial amount of the solar energy entering the atmosphere remains trapped near the Earth's surface. More trapped energy within the atmosphere directly correlates to an increase in mean global temperature. Applying this to the present day, data from the National Oceanic and Atmospheric Association (NOAA) indicates that the carbon dioxide levels measured in the atmosphere have exceeded four hundred parts per million, the highest levels measured in previous last 800,000 years [3]. Corresponding to this, global surface temperatures have risen nearly 1°C (1.8°F) from the 20th century average [4]. While this seems like a relatively small change in temperature, data collected from both NOAA and the National Aeronautics and Space Association (NASA) indicates that with even small rises in temperatures come both substantial rises in sea level and stronger, more powerful storm systems [5,6]. This has the potential to affect both those living in coastal regions and inland. Based on these ideas, scientists agree that the emission of greenhouse gases actively pushes climate change over a precipice, resulting in environmental, societal, and economic damages across the world.

So, the question arises, "So what do we do?" Clouded by recent political agendas and decades of cultural norms, the answer to this question does not come easily. With the complexity of this issue in mind, it is time to explore possible solution paths to combat the climate change crisis. To begin with, the answer to this question must be practical and feasible. Because of varying situations for diverse geographical and economic areas, realizing the shortcomings of a single, global solution to greenhouse gas emissions is crucial to developing a workable plan to prevent further damage to the global environment. The importance of end-use energy areas must also be evaluated to rank the importance of timely solutions. Carrying through with this mindset, industry accounts for nearly fifty percent of all energy used globally [7]. Thus, a careful focus and investigation of greenhouse gases emitted by industry is needed. Focusing down further, one of the largest energy consumers, and therefore greenhouse gas emitters, in the industrial sector is the metals industry [8]. The metals industry involves any business or facility that processes or refines metals. Well-known businesses in this category include Alcoa, Arconic, ATI Forged Products, and Honeywell. Processes common within this industry include melting, smelting, heat treating, and heating for forge applications. The majority of the energy necessary for these processes comes from the combustion of hydrocarbons, particularly natural gas. Looking at the general public, two schools of thought exist with the goal of reducing the greenhouse gas emissions from these essential processes. One focuses on decarbonization, or eliminating industrial greenhouse gas emissions through a transition to electricity created by solar, water, or wind sources. The other focuses on limiting greenhouse gas emissions by making the processes required by the industry as efficient as possible. While both groups have made great advances in long-term solutions and theoretical proposals, little has been thought about the practical short-term reduction of greenhouse gas emissions. In this area, focusing on optimizing current combustion and process heating systems rather than a transition to green energy would result in fewer greenhouse gas emissions from the metals industry in the next ten years.

Recent scientific publications and political campaigns have greatly swayed public opinion toward actively combating greenhouse gas emissions from industry and other sources. While the call for action by a large portion of the general public comes as the first step for reducing emissions, many of the loudest voices at the present time call for an immediate reduction or elimination of greenhouse gas emissions. Emerging as a major voice in the arguments against climate change in 2018, Grete Thunberg exemplifies these voices as she campaigns for the complete elimination of greenhouse gas emissions from all economic sectors. Due to negative publicity and public opinion towards industrial emissions, forward thinkers have begun to research methods to eliminate carbon dioxide and other greenhouse gas emissions from industrial processes. Projects associated with this movement fall under the broad definition of industrial decarburization projects, which focus on eliminating carbon and other harmful emissions from industrial processes and auxiliaries. Universities and national laboratories such as

Lawrence Berkley National Laboratory (associated with the University of California Berkley) and Oak Ridge National Laboratory (associated with the U.S. Department of Energy) have devoted numerous funding methods and resources to research various industrial decarburization projects. In conversations related to this research, Professor Hongyou Lu, a sustainability expert and consultant associated with the U.S. Department of Energy, offers insight into the particulars of these projects. In these conversations, Professor Lu points to microwave melting and economically viable variations of carbon capture and sequestration (CCAS) as major points of research [9]. In decarburization applications, microwave melting uses electricity produced by renewable methods to generate high energy microwave radiation to raise the temperature of metals up to and well above the melting point. Similarly, carbon capture and sequestration research focuses on efficiently and economically removing gaseous carbon compounds from industrial processes and storing or selling the captured carbon to be used in other applications. In addition to projects pursued in academic research, several small foundries, including some within the American Midwest, have become testbeds for initial project application attempts at industrial sites within the metals sector. These projects have been largely successful and include methods for producing electricity from renewable sources and biogas production to be used as a fuel for furnaces and boilers [10]. Though these projects have been successful, special circumstances have allowed economic implementation of the projects that would otherwise be prohibitively expensive. For example, the facility using renewable electricity focuses the majority of their energy load in electric equipment. Also, the facility using biogas in place of fossil fuels is located adjacent to a recently buried landfill. Prior to the implementation to this project, gas lines were installed to remove waste gas from the area. The plant was allowed to connect to the lines and use the fuel for essentially no cost, thus offsetting cost for equipment modifications. The combination of productive research and positive small-scale implementation indicates the potential for success of long-term projects to eliminate greenhouse gases from the industry.

Though industrial decarburization projects eliminate emissions of carbon dioxide and other greenhouse gases and offer the most complete long-term solution to climate change, large-scale application of these projects is costly and does not fit into the business culture of the metals industry at the present. To understand how businesses within the metals industry would respond to proposed decarburization projects, a thorough understanding of economic culture within the industry must be established. In the current economy, businesses rely on a limited amount of money to invest in improvement projects, known as capital. This capital must be split between projects aimed at reducing operating costs, normally energy, and projects aimed at increasing production levels. Because of limited capital funding and expected rate of return, businesses within the metals industry generally hone in on projects that will pay for themselves within two years [8]. Present-day industrial decarburization projects come with huge initial implementation costs, often millions of U.S. dollars. Based on the initial cost and projected energy savings of each project, industrial decarburization projects often result in subpar return on investment when compared to projects aimed at increasing productivity and production output. While this may imply that most businesses are more interested in financial gain than environmentally sustainable practices, I do not intend to enter this argument. Instead, I am arguing that we live in a world where massive changes in infrastructure cannot be implemented due to limited large-scale funding. In addition to economic impacts, industrial decarburization projects often contain new and relatively untested technology of which businesses are often wary. Because of economic and technological constraints, industrial decarburization projects are not projected to be widely adopted within the short term. If these projects will not be adopted along the short-term timeline, they will do little to combat the emissions of greenhouse gases within the next decade. Therefore, a different approach must be applied to combat the rising levels of greenhouse gas emissions.

Though industrial decarburization projects are generally accepted as the right path for long-term climate change solutions, short-term measures must also be taken to make a positive impact as quickly as possible. To be effective, short-term solutions to the greenhouse gas emission problem must be adopted by major players within the industry. Projects aimed at reducing energy consumptions on a per product basis fit within this requirement. Energy efficiency projects seek to reduce wasted energy within each facility, therefore reducing the amount of greenhouse gases emitted by the facility. For example, during work this summer as an energy consultant, poor combustion management of furnaces was identified at a forging facility in the United Kingdom. By investing in a combustion tune and eliminating the release of unburned fuel, this plant eliminated an estimated 20 billion British thermal units (BTUs) of wasted fuel energy. This combustion tune cost the facility around £15,000 (U.S. $21,400) while saving the facility roughly £80,000 (U.S. $114,000) per year. Along with the economic benefit of this project, approximately 2.3 million pounds (1,050 metric tons) per year of carbon dioxide emissions were eliminated. Because of the size and scope of projects such as this, little capital investment is required. Smaller projects may cost thousands of U.S. dollars while the cost for larger projects may cost upwards of a few hundred thousand U.S. dollars. Though this price tag may seem high to consumers, it is relatively small on the industrial scale and is dwarfed by the expected cost of decarburization and green energy projects. Because of the relatively small cost associated with energy efficiency projects, the return often fits within the acceptable payback range of two years and therefore could be considered for adoption across the industry [8]. Energy efficiency projects often offer a competitive rate of return when compared to production projects. This further strengthens their case for large-scale adoption. Energy efficiency projects also rely on well-known and proven technology, which the industry would feel safe relying on for critical production requirements. Due to matters of economics and reliability, energy efficiency projects have a definite possibility of being adopted on a large scale, thus potentially reducing the amount of greenhouse gases emitted by the metals industry. Currently, this is the best option for a short-term solution to combat climate change until further advances are made in completely removing greenhouse gases from industrial production.

If businesses are to focus resources on these energy efficiency projects on a large scale, a straightforward and effective plan must be implemented to most effectively target efficiency opportunities. In this area, engineers Ray Peterson and Cynthia Belt identify key aspects of effective energy management programs. These aspects include defining the process, measurement, benchmarking, and improvement [11]. By defining the process, Peterson and Belt refer to the multitude of vastly different processes within the metals industry. They recommend facilities look at the energy consumption of every piece of equipment within the facility. They then recommend a heavy use of measurements to determine operating characteristics of each piece of equipment. By benchmarking, these engineers suggest comparing the operating characteristics of equipment to similar pieces of equipment in other facilities across the industry. Often this comparison will indicate whether equipment is operating efficiently or poorly compared to industry averages. Finally, Peterson and Belt discuss the improvement phase of an energy management program. In this phase, steps are taken to improve the overall efficiency and decrease the specific energy consumption (energy consumed per production output) of a specific project. In essence, this final stage is the culmination of the entire program, where the solution is implemented. The intentional and well-structured implementation of an energy management program such as this is a major step toward creating a facility-wide culture mindful of energy conservation, which could easily expand to other facilities within the industry. This mindful culture would shift the emphasis within the industry from classical production methods to much more sustainable practices. In this light, energy engineer Gary Gigante redefines the term "green" to include a cultural focus on sustainable practices [12]. Gigante's new, broader definition of this term shows how conservation of energy consumption establishes itself as the first step in creating a green metals industry. While this recommended program and path toward sustainability is straightforward, one of the common hang-ups for industrial facilities is the identification of economically viable improvement projects, which is the next item that will be covered.

With the practicality and potentiality of energy efficiency projects within the metals industry outlined and good recommendations for an energy management program provided, the next step in reducing greenhouse gas emissions is identifying potential energy saving projects. Without efficiently identifying potential projects and ranking them based on importance and economic return, major players in the industry have the potential to be overwhelmed by a multitude of potential projects and may begin to shift time and monetary focus to other, more straightforward business areas. To prevent this, the standard approach in the energy efficiency arena is to first target what is known as "low hanging fruit." This term refers to projects that offer significant energy and economic savings while being relatively inexpensive and easy to implement. Some projects common to the metals industry that fit within this definition include process and equipment heat recovery, variable speed drive control, and steam system improvements.

Applications of waste heat recovery focus on recovering as much heat as possible from byproducts before they can be released into the environment. In the case of the metals industry, this heat often originates directly in process heating such as furnaces, or indirectly through boilers and air compressors. The applications of waste heat recovery in boilers and furnaces often require the same approach. For these pieces of equipment, combustion gases with significant residual heat often escape to the atmosphere. An effective way to capture this heat is to return it to incoming fluid streams. For industrial furnaces, a heat exchanger known as a combustion air preheater accomplishes this by passing hot exhaust gases (~1,800°F) over incoming combustion air. A material that offers excellent heat transfer abilities is used to separate the two streams. For industrial boilers, a similar approach is used to extract as much heat as possible from the exhaust stream. Combustion air preheaters are often implemented in boilers to increase efficiency. Additionally, the feed water stream replacing water exiting the boiler as steam serves as another avenue to recover waste heat. The equipment used to accomplish this is a heat exchanger like the combustion air preheater, known as the feedwater economizer. This device simply uses heat pulled from the boiler exhaust gases to raise the temperature of the feedwater before it enters the steam drum within the boiler.

One final often overlooked area for industrial heat recovery focuses on compressed air systems. Compressed air serves a vital purpose at the majority of industrial sites, especially within the metals industry. Because of the relationships between temperature and pressure, the compressing of air from low pressure (~0 pounds per square inch gage) to high pressure (~100 pounds per square inch gage) generates significant amounts of heat (~500°F). Most of the electrical or shaft power requirement of air compressors corresponds to this heating. In order to increase the efficiency of compressors, heat exchangers known as intercoolers (in between stages) and aftercoolers (after last stage) are installed on modern compressors. These heat exchangers often use ambient air as the working fluid, which is then released into the atmosphere. With ducts and dampers commonly used in ventilation systems, this heated air can be redirected into the industrial facility during the heating season to reduce energy consumption and overall cost of heating during the winter months. The combination of these three forms of heat recovery projects represents a majority of successful energy efficiency projects.

One of the newer technologies associated with energy efficiency projects is variable speed drive control for motors powering pumps and fans. The inner workings of this equipment require complicated electrical theory, but the goal of the device is to slow the oscillation frequency of alternating current (AC) electrical signals. Because induction motors common to industrial applications rotate at a rate directly proportional to the oscillation frequency of incoming electricity, slowing down the electrical frequency will slow down the motor. Slowing down the motor will reduce the power consumption significantly. While this explanation covers how variable speed drives reduce power consumption, it ignores the fact that real world applications for pumps and fans require a set amount of power to move enough fluid and/or add enough pressure to the fluid. This is where the idea for variable speed drive control becomes effective. Traditionally, pump and fan control for industrial applications involved setting the pump or fan to operate at a condition greater than that required by the application. Throttling valves were then used to regulate flow or pressure to the end use of the fluid. While this control method is well proven, reliable, and inexpensive, it often carries high excess energy consumption and economic costs. The excess energy added to the fluid stream to allow for this form of control is wasted at the throttling valve due to unnecessary heating of the fluid at high points of frictional pressure drop. The answer to this problem relies on using a variable speed drive to control the speed of the driving motor to impart the necessary energy to the fluid stream. Monitoring and control equipment such as pressure sensors, flow meters, and programmable logic controllers allow the variable speed drive technology to adjust electrical frequency and therefore motor speed within seconds to the levels needed by the process. This eliminates unnecessary power usage, thus reducing energy consumption and spending significantly. While often complicated and relatively expensive compared to throttling valves, the implementation of variable speed control offers both energy consumption and expenditure savings at a fraction of the cost of decarburization projects.

Though not present in all metals processing facilities, boilers and steam systems represent major pieces of equipment and consume large amounts of energy. As such, they need to be targeted for efficiency improvements as well. Two common energy efficiency projects are found from energy consumption investigations around these steam systems. These two projects center around heat recovery from blow down and dual generation of steam for both process heating and electrical power generation. In order to maintain proper water quality within the boiler, water with a high concentration of dissolved minerals must be pulled out of the boiler and replaced with feedwater with a low concentration of dissolved minerals. This highly mineralized waste water is known as blowdown. Boiling at high pressure, this blowdown contains significant amounts of thermal energy, which can be extracted to improve steam system efficiency. This can be accomplished by the installation of a flash steam tank and heat exchanger. The flash steam tank receives high pressure boiling water from the steam drum of the boiler and converts it to low pressure steam and boiling water in a process known as flash vaporization. Low pressure steam can be used to augment the deaerator, a piece of equipment that removes dissolved oxygen from makeup water destined to replace steam lost in process heating requirements or steam leaks. The boiling liquid present in the flash steam tank can be pulled off and sent to a heat exchanger to preheat makeup water like the feedwater economizer mentioned previously. The appropriate implementation of this project results in fuel energy remaining within the system rather than being wasted. The other form of energy efficiency project common to steam systems focuses mainly on large facilities within the metals industry due to their sizable process heating requirement and electrical demand. Often, facilities will need both high- and low-pressure steam to provide for differing process heating requirements. A common way to drop the pressure of steam is to pass it through a pressure reducing valve (PRV), similar to the throttle valve mentioned previously. This reduces the useful energy within the steam with no benefit. An alternative way to drop the pressure of the steam is by passing it through a steam turbine and allowing the steam to exit the turbine at the pressure needed by the process. This allows power to be extracted from the steam while the pressure drops, driving a generator to produce electricity or spinning a shaft to power crucial equipment. Though projects in this area usually result in increased requirement for steam flow, and therefore increased fuel requirement, energy and financial savings stemming from a decreased electrical demand often far outweigh the costs associated with this increase. While not applicable to all facilities within the metals industry, these projects represent large potential savings for those facilities equipped with significant steam systems.

Even when presented with economic and environmental reasons for adopting energy efficiency projects, some businesses within the metals industry may be reluctant or unwilling to adopt these measures. Given the importance of reducing greenhouse gas emissions through reduction in energy consumption, measures must be taken to ensure positive action from these business entities. Because of global nature of the metals industry, this initiative must come from an organization with a high level of power, most likely from a governing body. Incentives and regulations are two approaches that could be used to garner interest from major players within the metals industry. Incentives could take the form of subsidies or tax breaks for investments in energy efficiency projects. This represents the more subtle of the two approaches. The other approach, regulations and requirements, encroaches more on the freedom of businesses to make their own decisions, but also ensures progress on energy efficiency projects following a specific timeline. A great example of this would be the British Energy Saving Opportunity Scheme (ESOS) requirements, which calls for a thorough energy audit of industrial facilities focusing on energy saving projects every five years. Though not requiring the adoption of all identified projects, the requirement for an energy audit points out where processes could be made more efficient and puts pressure on facilities to take action. Regardless of the method used to push businesses into adopting energy efficiency projects, this represents the last step in establishing a short-term solution to limiting greenhouse gas emissions from the metals industry, and therefore improving the global outcome of climate change seen more as a crisis every day.

With the discussion of energy efficiency projects as practical short- term solutions reduce greenhouse gas emissions thoroughly covered; I would like to reiterate the point that these projects are by no means long-term solutions to solve the climate change crisis. Other, more robust solutions must be developed and adopted as soon as they become practical. Along with robust long-term solutions, measures such as incentives and emissions policies should be adopted to encourage industry to move away from stop-gap solutions toward process and practices sustainable over the long-term. As a new generation of forward-thinking leaders emerges, further emphasis and effort must be put into discovering permanent solutions to this issue. In short, much further research is required to establish a long-term plan to steer global infrastructure to a sustainable future. But in the meantime, short-term solutions such as process heat recovery, variable speed drive control, and steam system improvements should be implemented as soon as practically possible.

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