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Mitigating Global Temperature Change Through Industrial Sector Improvements: A Case Study In Automotive Manufacturing

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MITIGATING GLOBAL TEMPERATURE CHANGE THROUGH INDUSTRIAL SECTOR IMPROVEMENTS: A CASE STUDY IN AUTOMOTIVE MANUFACTURING

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May 6, 2023

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DEDICATION

To my parents, Bill and Vicki Ernst, who have selflessly taught me that I can accomplish anything through hard work and determination. To my wife, Emily, I sincerely appreciate your love, support, and the strength our family has found through sacrifice. To my two beautiful sons, Max and Memphis, you are the motivation that has bound me to capstone my education. I will pass you the foundation of wisdom and love my parents instilled in me. My underlying inspiration and determination can be summarized by a quote that has always lifted me in courage:

> *"A soft, easy life is not worth living, if it impairs the fibre of brain and heart and muscle. We must dare to be great; and we must realize that greatness is the fruit of toil and sacrifice and high courage... For us is the life of action, of strenuous performance of duty; let us live in the harness, striving mightily; let us rather run the risk of wearing out than rusting out."*
>
> \- *Theodore Roosevelt*

ABSTRACT

Manufacturing is an integral part of our country's flow of products and people and a top contributor to carbon emissions, promoting global temperature rise. During processing, toxic substances are emitted across the value chain. These emissions account for nearly 25% of all greenhouse gas emissions in the United States and the World. Until 2023, an accessible pathway for manufacturing companies to transition to net-zero emissions hasn't been made readily available. The current research was conducted to determine if reducing carbon emissions in manufacturing facilities through efficiency improvements, process optimization, and technology advancements can mitigate global temperature change.

This quantitative, mixed-method approach was conducted by investigating major constraints and evaluating the current state of energy security in manufacturing. A feasibility study was conducted on deploying biomass-to-energy as the primary energy source for the facility and the state of Missouri. A case study was conducted at an automotive manufacturing facility to measure efficiency improvements in a real-life context. The research shows that emissions reductions from manufacturing favor the ability to impact global temperature change. Education was found to be the top constraint by cost and impact. Energy security within the sector and the United States is favorable at an index value lower than 70. Improvements in energy efficiency and new processing methods showed favorable business savings (+$125k) and emissions reductions (-200k tons) in less than a year. The feasibility of biomass-to-energy showed being able to become a primary supplier of energy to the plant and Missouri. Findings indicated that it is necessary to promote and mesh education, technology growth, and energy-saving efforts to have a favorable impact on global temperature change.

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GLOSSARY OF TERMS

1. *Acreage:* An area, measured in acres that is subject to ownership or control by those holding total or fractional shares of working interests. Acreage is considered developed when development has been completed. A distinction may be made between "gross" acreage and "net" acreage: (EIA,2023)
2. *Biomass waste:* Organic non-fossil material of biological origin that is a byproduct or a discarded product. Biomass waste includes municipal solid waste from biogenic sources, landfill gas, sludge waste, agricultural crop byproducts, straw, and other biomass solids, liquids, and gases; but excludes wood and wood-derived fuels (including black liquor), biofuels feedstock, biodiesel, and fuel ethanol. **Note:** EIA biomass waste data also include energy crops grown

specifically for energy production, which would not normally constitute waste. (EIA, 2023)

3. *Carbon dioxide (CO_2):* A colorless, odorless, non-poisonous gas that is a normal part of Earth's atmosphere. Carbon dioxide is a product of fossil-fuel combustion as well as other processes. It is considered a greenhouse gas as it traps heat (infrared energy) radiated by the Earth into the atmosphere and thereby contributes to the potential for global warming. The global warming potential (GWP) of other greenhouse gases is measured in relation to that of carbon dioxide, which by international scientific convention is assigned a value of one (1). Also see Global warming potential (GWP) and Greenhouse gases.
4. *Cord of wood:* A cord of wood measures 4 feet by 4feet by 8 feet, or 128 cubic feet. (EIA, 2023)
5. *Cost-Benefit-Analysis* determines whether a project is feasible or not by quantifying its costs and benefits (Turner, 2006).
6. *Energy Audit* is an inspection, survey and analysis of energy flows in a building, process, or system with the objective of understanding the energy dynamics of the system under study (Capehart et al. 2006).
7. *Energy Audit:* An “energy assessment” or “energy study” to determine where, when, why, and how energy is used in a home, and to identify opportunities to improve efficiency. It includes an evaluation of a home based on data from inspections, diagnostics, data collection, analyses, and reporting, which identifies opportunities for the homeowner to improve energy efficiency. See also "home performance assessment.” (energystar.gov,2023)

8. *Energy Efficiency* is simply the process of doing more with less. The goal is to accomplish the same tasks and functions as before while using less energy.
9. *Energy Efficiency:* The concept of using less energy to provide the same service. (energystar.gov,2023)
10. *Greenhouse Gas:* A gas that traps the sun's heat in the atmosphere. When these gases are trapped in the atmosphere (and not reflected back into space), the planet becomes warmer than it would be otherwise. This process is commonly referred to as the greenhouse effect. Greenhouse gases include water vapor, carbon dioxide, methane, ozone, chlorofluorocarbons, and nitrogen oxides; gases which are produced and sometimes released to the atmosphere when generating energy to power our homes. (energystar.gov,2023)
11. *Kaizen* is a Japanese philosophy that focuses on continuous improvement throughout all aspects of life.
12. *Landfill gas:* Gas that is generated by decomposition of organic material at landfill disposal sites. The average composition of landfill gas is approximately 50 percent methane and 50 percent carbon dioxide and water vapor by volume. The methane percentage, however, can vary from 40 to 60 percent, depending on several factors including waste composition (e.g. carbohydrate and cellulose content). The methane in landfill gas may be vented, flared, combusted to generate electricity or useful thermal energy on-site, or injected into a pipeline for combustion off-site. (EIA, 2023)
13. *Lean Manufacturing* is a business philosophy and strategy that focuses on eliminating waste, which includes all steps or processes that do not add value to

the final product or service. It is usually employed along with the concept of kaizen, or continuous improvement (OHNO, 1988).

14. *Rate of Return* is the gain or loss generated from an investment over a specified period of time.
15. *Renewable energy resources:* Energy resources that are naturally replenishing but flow-limited. They are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. Renewable energy resources include biomass, hydro, geothermal, solar, wind, ocean thermal, wave action, and tidal action.
16. *Renewable Energy Technologies:* Technologies that produce sustainable, clean energy from sources such as the sun, the wind, plants, and water. These include biomass, geothermal, hydrogen, hydropower, ocean, solar energy, and wind. (energystar.gov,2023)
17. *Right-Sized-Equipment* is a design that can be fitted directly into a production cell and permit the flow of products so the products do not need to be transported to a monument and wait in queue. (Womack, 2003)
18. *Standard Work* is a description of each work activity, specifying cycle time, takt time, sequence, inventory and standard. They are tasks that are sequenced, organized and repeatedly followed.
19. *Wood energ*y: Wood and wood products used as fuel, including round wood (cord wood), limb wood, wood chips, bark, saw dust, forest residues, charcoal, pulp waste, and spent pulping liquor.

CHAPTER ONE

1.0 INTRODUCTION

1.1 The War on Climate Change: A Critical Mission

Climate change is said to be the greatest threat to the natural environment and modern societies that the world has ever faced. According to (Chapman & Ahmed, 2021), it threatens the web of life on this planet. It continues to affect the environment and human life negatively. Our basic needs of sufficient food, safe drinking water, and secure shelter are in constant jeopardy (Sly, 2011). According to the World Health Organization (WHO), between the years 2030 and 2050, climate change and the effects on our necessities will be the cause of more than 250,000 deaths per year (WHO, 2021) Health-related costs as a result of climate change, are expected to exceed 2 Billion USD per year, by 2030 (Chapman et al., 2019). So, what is climate change?

Climate change is the change in temperature and weather patterns that the world experiences over a long period of time (Ebi et al., 2021) (UN, 2022). The impacts of these changes include rising sea levels, extreme weather events, and hotter temperatures (Mimura, 2013) (Church & White, 2011). It may be hard to see as those changes happen over extended periods, many times greater than the average human life. When adverse effects occur, however, they are hard to deny. We must understand if we are in control of this change and if we can positively affect climate change. To correctly answer, one must address the issues surrounding climate change. We must step back and understand what causes climate change, identify the major contributors, and drill down to the root cause. As a society, we must first educate ourselves and realize that there is a problem. Jerry M.

Melillo et al. (2014) stated, “Climate change, once considered an issue for a distant future, has moved firmly into the present.”

The world is moving so fast that even science and technology are almost immediately obsolete, sometimes even during deployment (Fenwick et al., 2017). As shown in *Figure 1.1*, the world’s population continues to grow, around 8 Billion at the time of this writing, and is projected to grow to 10.4 Billion by the year 2100 (Roser, 2022).

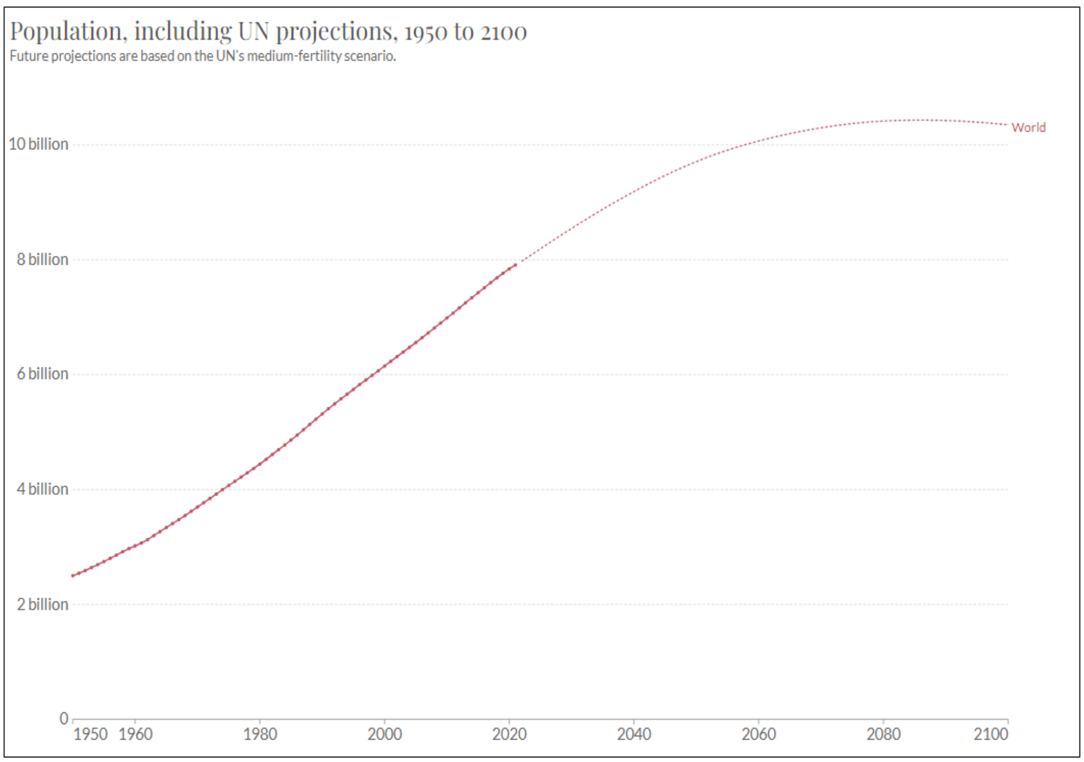


Figure 1.1: World Population Projection (1950-2100) (Roser, 2022)

10.4 Billion is a significant increase from today’s population, around 35 %. Now step back, and think about the basic needs of each human. Food, water, and shelter are critical to our being. Each of these necessities requires energy to deliver to the consumer. Furthermore, each of these is in continuous jeopardy with our current population, not only from climate change but also due to outside influences such as the war in Ukraine and pandemics such as Covid-19. These influences drive our human rights even further in a negative direction. Can the human race thrive and survive with an increase of 35%? With this, the consumption of goods is increasing at excessive rates, depleting our natural resources and further harming the natural defenses against climate change. Around the world, many, but not all, have realized that we need to address climate change (Grossman, 2018) for today's purposes and how we will leave the planet for future generations. This shift will not happen in one day or year; it will take time to correct, just as it has taken time to shift in a negative direction.

In March 1995, a Conference of the Parties (COP) was formed and held jointly in Berlin, Germany, to address climate change (UNCC, 2022). The COP has been held every year since, and participating countries have met to evaluate progress on previous climate activities, the results, and the plan for the future. On December 12, 2015, at COP21 held in Paris, a legally binding international treaty on climate change was formed by 196 parties. The treaty aims to limit global warming to below 2 °C and, ideally, 1.5 °C compared to pre-industrial levels (UN, 2022).

In order to achieve this goal, each country is to reach its greenhouse gas emissions as soon as possible, as it is considered the number one contributor to climate change. Requirements of the treaty called for social and economic transformation and 5-year cycles of climate action improvements carried out by each country. By 2020, each country was to submit plans or nationally determined contributions (NDCs) for reduction measures. All 193 parties to the Agreement issued at least a first NDC (UN, 2022). Other plan outlines include developed countries supporting one another in finance, technology, and capacity building. Progress will be tracked through an enhanced transparency framework (ETF) by 2024 to allow for a review of progress and further accountability. Overall this treaty allows for a uniform approach that can drive success toward the goal.

In May 2021, 130 countries submitted plans to reach net-zero emissions (Climate Action Tracker, 2023). As of November 2022, 140 countries had committed plans to reach net-zero emissions or an increase of 7.6 % from the previous year. As of this writing, in the fourth quarter of 2022, almost all countries are off track to meeting the Paris Climate Goal of 1.5 °C, as shown in Figure 4.

Figure 1.2: Climate Action Tracker 2022 (Climate Action Tracker, 2022)

The scorecard from *Figure 1.2* portrays that more needs to be done faster to meet the goals outlined in the Paris Agreement. Even more alarming, the top 2 countries, China, and the United States of America, making up almost 50% of the world's emissions, are not on target (Mulvaney, 2021).

COP 27 was held in Sharm El-Sheikh, Egypt, from November 6th through November 18th, 2022. 190 countries were represented through an estimated 35,000 representatives (Friedman, 2022). The top greenhouse gas-emitting country's leaders were not in attendance for various political reasons. These countries included China, the USA, India, and Russia. China's leader abruptly dropped out. The leaders from the USA and India prioritized campaigning conflicts. Russia's leader is at wartime with Ukraine, and many of its activists did not attend as well as they are filing exile paperwork and protesting the war. The perception is that if the countries with the most power and influence cannot agree on climate change, how will we be able to stop the shift in temperature?

Many crucial points from COP27 are considered critical to addressing issues caused by climate change. These key takeaways are listed in *Table 1.1*. The most notable is creating the "loss and damage" fund (Blaine, 2022).

Table 1.1: Takeaways from COP27 Climate Conference (UNFCCC, 2022)

Takeaway	**Description**
Maintaining a clear intention to keep goals within reach	Off course to hit 1.5 °C
Established Loss and Damage Fund	For vulnerable countries hit hard by climate change effects.
Increasing financial support for developing countries	Pathway to align broader finance flows towards low emissions.
Pivoting towards implementation	Business that provide services Research
Holding businesses and institutions accountable.	New focus on accountability in all sectors.

Table 1.1 shows that although we are not on track globally, we must work together and hold ourselves accountable to minimize climate change. If the world continues on the pathway that it is on, destruction beyond measure will ensure to the point that we may forever change the landscape of our Earth as we know it. We must turn the knob to change the direction of the Earth's temperature (Davis, 2017). Understanding the causes of the temperature change will be vital to developing active countermeasures.

The leading cause of change in the Earth's temperature is not as simple as it may seem. There are both natural and human factors working independently and together that move the needle on Earth's temperature gauge. The simple answer is to continue moving forward as expected and improving the processes that we have control over along the way.

Improvements in consumption and production and technological advancements will support this initiative over time, but more is likely needed to offset the climate shift. Analysis shows that the adverse effects of doing nothing to reduce emissions will far exceed the cost of reduction activities today (Ashraf & Bocca, 2022). According to the U.S. EIA, global primary energy consumption will grow by nearly 50% between the years 2018 to 2050, as shown in *Figure 1.3*.

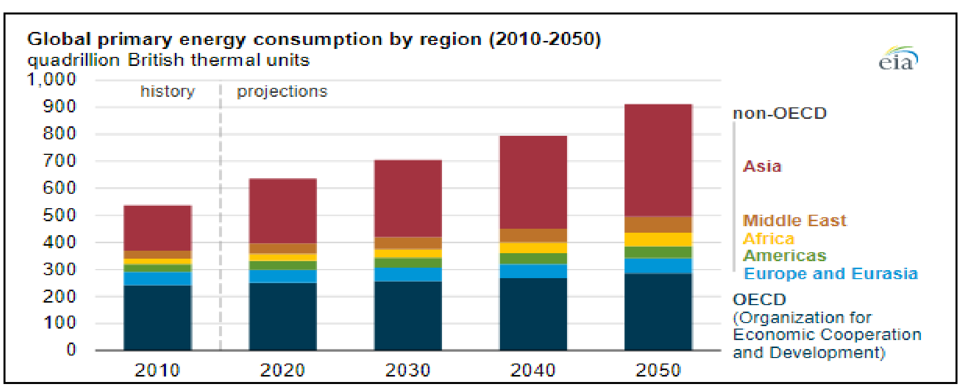


Figure 1.3: Global Primary Energy Consumption by region (Kahan, 2019)

The industrial sector accounts for the largest share at greater than 50% of the end-use energy consumption throughout the projection period, as shown in *Figure 1.4*. This is primarily due to population increases and, thus an increase in the demand for goods.

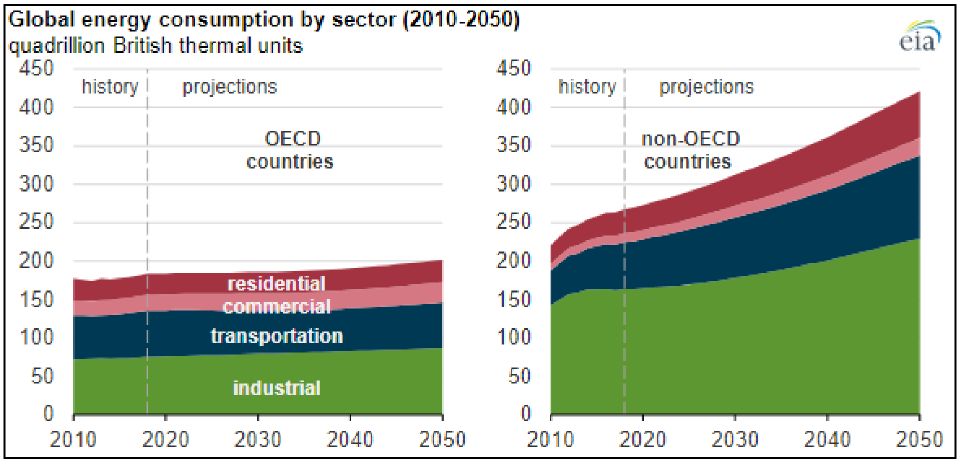


Figure 1.4: Global Energy Consumption by Sector (2010-2050) (Kahan, 2019)

The industrial sector is divided into four main areas as shown in *Table 1.2*.

Table 1.2: Industrial Sector

Sector	**Description**
Primary	Extracting natural resources
Secondary	Manufacturing of goods
Tertiary	Business that provide services
Quaternary	Research

In the United States, goods manufacturing accounts for the largest annual industrial energy consumption share within these four main areas. In 2020, manufacturing accounted for 77% of the industrial energy consumption, followed by mining at 12%, 7% in construction, and 5% in agriculture (US EIA, 2019). The global scorecard ranks the United States second for manufacturing goods globally (Global Upside, 2022).

Manufacturing is a discipline considered a key player in transitioning and adopting a transition into a carbon-neutral future. Not only does the manufacturing sector employ millions of people, but it also produces the technologies and products that make a lower-carbon future possible. Examples of products manufactured that will support this transition are electric vehicles (EVs), solar panels, turbines, and other vital components. These companies may appear resilient to carbon output and energy efficiency as they produce products that support the transition (Stern et al., 2021); however, it is critical that they also take the necessary measures to consume and produce products with clean energy and a carbon-neutral manner. With the industrial sector as this study's main focus of this study, it is crucial to understand each layer of the process and identify the root cause. The research will focus on fully understanding the part that industrial manufacturing plays in meeting the energy transition through de-carbonization and use the results to deploy and benchmark a working road map to move this aging sector in a positive direction.

1.2 The Problem: History of Climate Change, Causes and the Impact to Our Planet

The History of Earth's Temperature

The fast pace of our world, the patterns that lie within our daily lives, and the advancement of technology leave a particular little time to step back and understand how each of us contributes to the health of our natural environment. The effects of climate change and its catastrophic impacts have already been seen in various countries worldwide (Davis, 2017). *Figure 1.5* represents the global temperature over time utilizing a baseline temperature of 13.7 °C, established during the pre-industrial period between

1850-1900 (Schlanger, 2017) (Haywood, 2019).

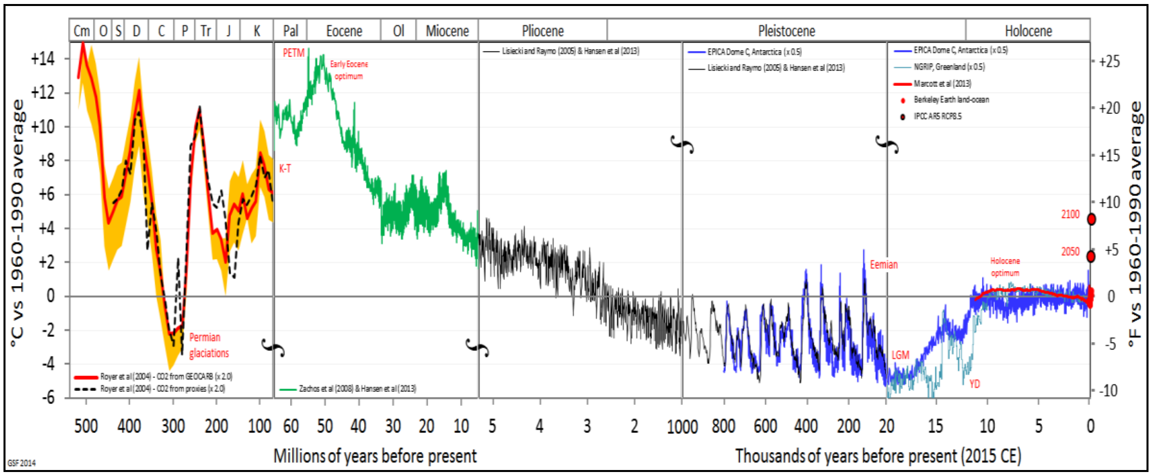


Figure 1.5: Global Annual Mean Temperature Variation of the Earth Through Time (Royer, 2014).

As shown in *Figure 1.5*, humans have inhabited the earth at a maximum of 3 °C from the baseline temperature. In 2022, the global temperature reached 14.6 °C, or 0.85 °C greater than the baseline (NASA, 2022). Projections show that by the year 2100, global temperature could reach more significant than 4 °C above pre-industrial baseline levels. This temperature runaway will have consequences for our current way of life.

<u>The Business as Usual Effect</u>

Scientists have projected pathways through model scenarios showing how a business-as-usual approach will affect the Earth’s temperature over time, as displayed in *Figure 1.6*. Variables include population increase and current climate change targets, legislation, and policies.

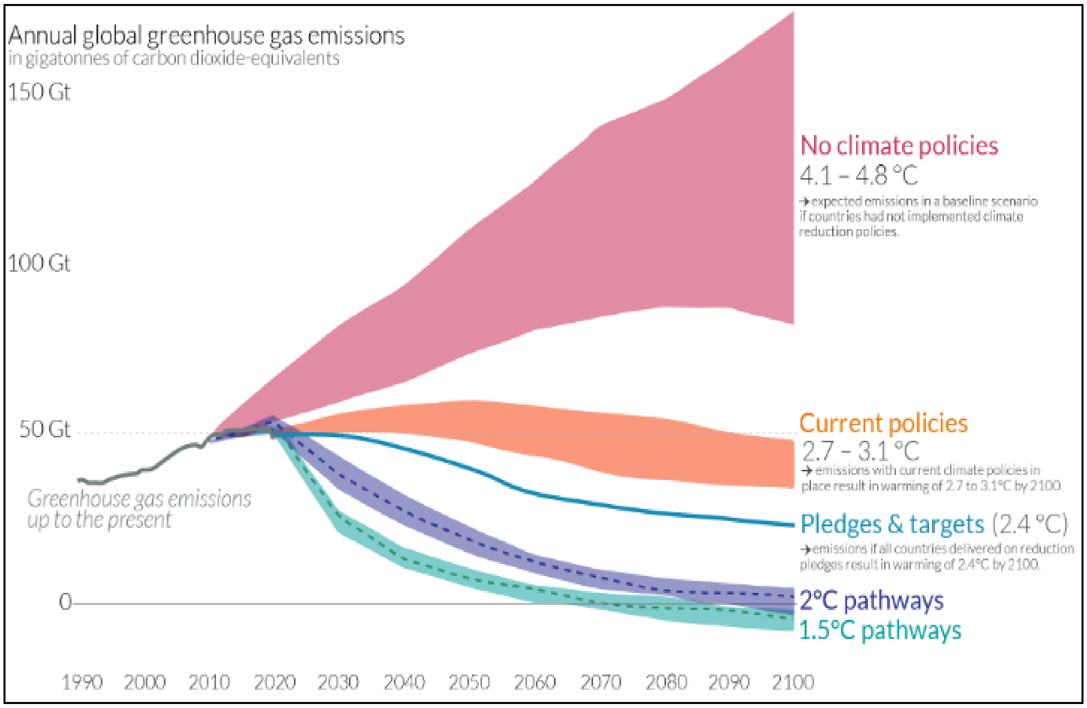


Figure 1.6: Annual Emissions and Climate Change Projection (Climate Action Tracker, 2021)

Our current pledges, targets, policies, and overall pathway shows that greenhouse gases will continue to soar, and negative impacts of climate change can reach levels higher than man has inhabited (Kemp et al., 2022). Both severe climate and health impacts are happening across various countries worldwide. These impacts cost the world trillions of dollars, as shown in *Figure 1.7*.

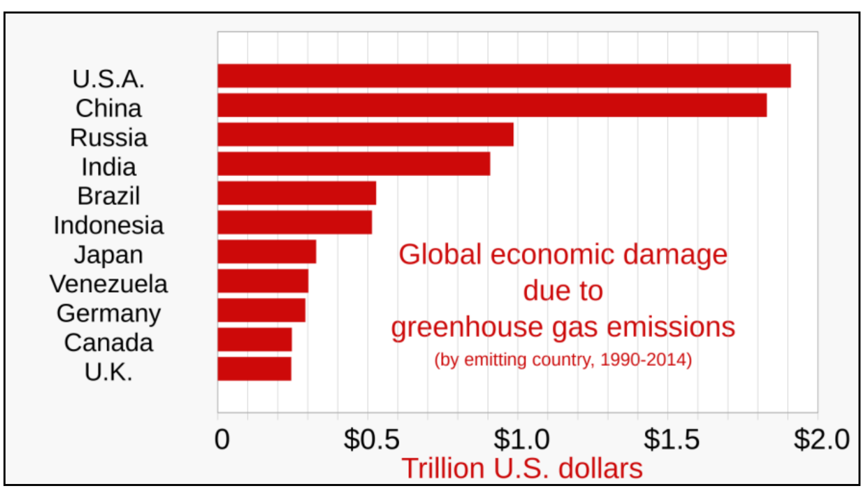


Figure 1.7: Global Economic Damage Due to Greenhouse Gas Emissions (Milman, 2022)

Far worse than the cost of the economy and each country's impact on their gross domestic product (GDP) score, these impacts are costing millions of lives, as shown in *Figure 1.8*. One study conducted over the course of two decades shows that 5 million deaths per year resulted from abnormal hot and cold temperature-related events. (Zhao et al. 2021).

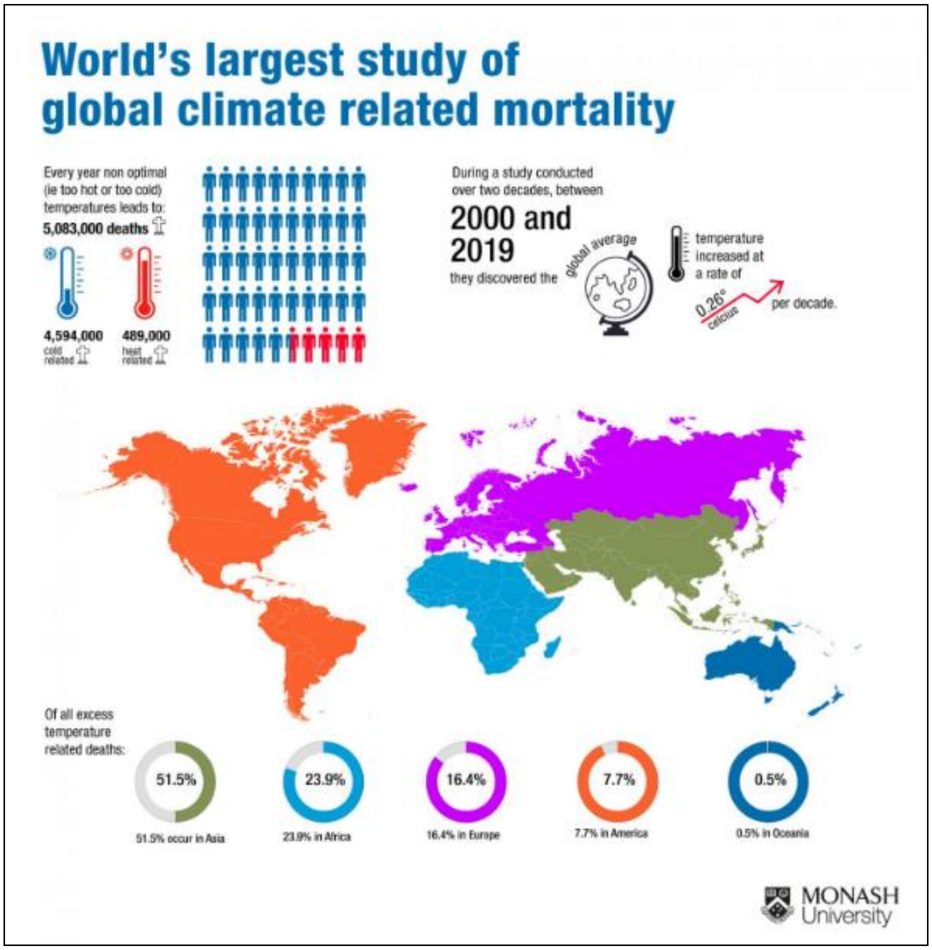


Figure 1.8: World's Largest Study of Global Climate Related Mortality (Zhao et al. 2021)

As shown in *Figures 1.7 and 1.8*, negative impacts happen worldwide daily. The cost of doing nothing will continue to have unfavorable effects. In order to mitigate these effects, we must dissect the problem and understand climate change, and its causes, to determine what course of action is suitable.

The History of Climate Change

Climate change is essential to our success as humans and the world we live in. Throughout the history of Earth, periods of both sweltering and freezing temperatures have radically driven life changes and thus shaped Earth into what it is today (Voosen, 2019). The mean temperature across the last 500 million years has been over 20 ° C (Engber, 2012). As technology has evolved and record keeping improved, scientists have been able to develop models to understand when the Earth's temperature has changed across millions of years. Adding plant and animal life and human evolution to this timeline gives a glimpse into the world's future, as shown in *Figure 1.5* (Haywood, 2019).

For millennia human populations have only resided in a narrow part of this mean temperature span, from around 11 ° C to 15 ° C (Xu, 2015). Understanding the shift in Earth's climate, its cause, and its impact on our way of life will guide what course of action should be taken as Earth's temperature navigates outside of the bounds it has historically operated within.

Earth's climate is on a continuous shift, where it is constantly changing. Without outside influence, planet Earth naturally cycles its climate. In just the past 1 million years, Earth has experienced both cold periods (glacial) and warm periods (interglacial) (Herring, 2020). Typically, these cycles last around 100,000 years, and the last glacial period peaked around 20,000 years ago (Buis, 2020). These climate changes revolve around a series of cycles. Over a century ago, in 1920, Serbian scientist Milutin Milankovitch hypothesized that Earth's orbital movements were affected by the solar radiation reaching the Earth's atmosphere through three types of orbital cycles (Kerr, 1978). The three cycles of climate change include obliquity, eccentricity, and precession, as displayed in *Figure 1.9* (Ness-Cohn, 2019).

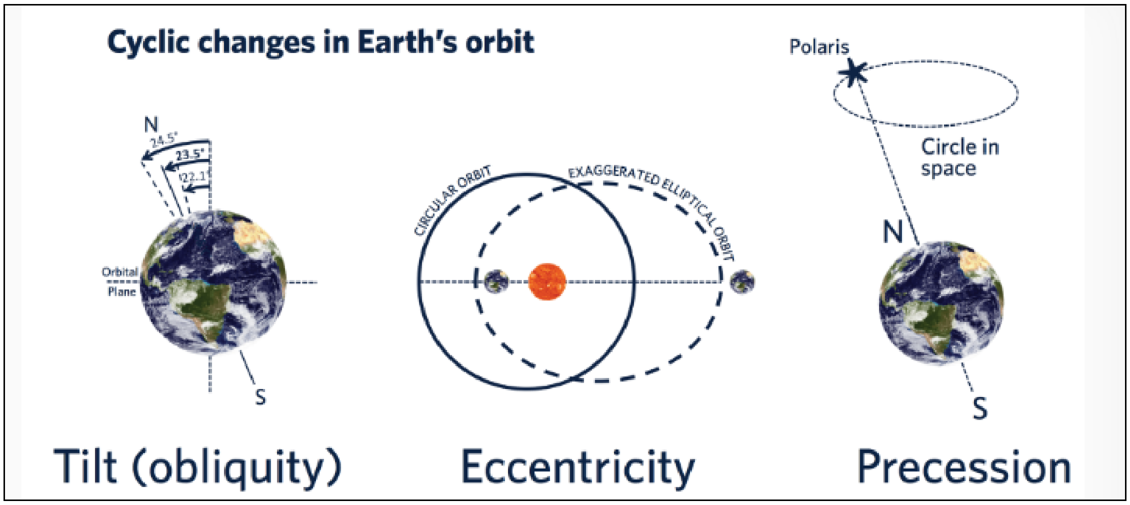


Figure 1.9: Cyclic changes in Earth's Orbit (Ness-Cohn, 2019)

The first periodic motion, obliquity, is the tilt of the Earth's axis (Laskar, 2011). Every 41,000 years, the Earth's axis tilts between 22.1 ° and 24.5 ° (Buis, 2020). The current tilt of Earth's axis is 23.44 °, which places it between the lower and upper extremes. The last time the Earth reached its maximum was in the year 8,700 BC. An increased tilt of the Earth towards the sun increases the amplitude of the seasonal cycle, allowing for more solar radiation in the summer and less in the winter. This increased tilt also promotes the melting and retreat of glaciers (Buis, 2020). The tilt is on the downward cycle, and projections place the minimum to be reached at year 11,800. This decreasing trend will promote warmer winters and colder summers, thus allowing for an overall cooler trend.

The second-period motion, eccentricity, is the orbital shape of the Earth around the sun. *Figure 1.9* shows this orbital change moves from circular to more elongated in periods close to 100,000 years. In 2023, the eccentricity of the Earth will be around .0167 and decreasing (Lourens, 2021). The equation for calculating eccentricity is as follows.

Equation 1.1

$$E = c/a$$

E is eccentricity, c is the distance from the center of an ellipse to the focus, and a is the axis length (Haywood, 2011). *Figure 1.10* provides a visual depiction of the eccentricity equation.

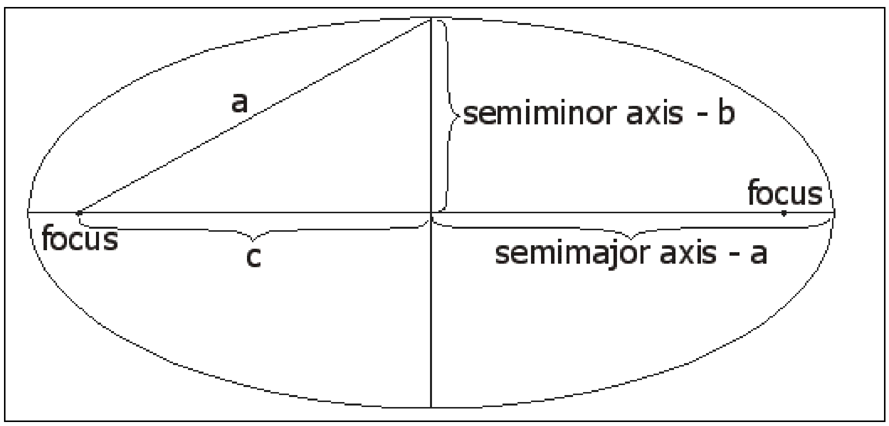


Figure 1.10: Geometry of an Ellipse (Harwood, 2011)

The maximum eccentricity for the Earth is considered to be 0.057 and the minimum 0.005. Within the last 250 million years, the highest eccentricity was .0679 and considered mildly elliptical (Laskar, 2011). As the Earth's orbit becomes more eccentric, the seasonal changes magnify as the Earth becomes closer to the sun (Berger, 2006). The length of each season, spring, summary, fall, and winter, changes with eccentricity.

The third-period motion, precession, is the wobble or change in the direction of the Earth's rotational axis, as displayed in *Figure 1.9*. This resembles how a top wobbles during rotation (Szabo, 2016). The cycle of axial precession spans 25,771.5 years (Buis, 2020). Axial procession causes extreme seasonal shifts in one hemisphere and less in the opposite hemisphere based on position (Zharkova et al., 2020). In 2023, the Earth's axial precession is causing the Southern Hemisphere to be hotter while regulating Northern Hemisphere seasonal variations. These conditions will flip roughly 13,000 years from now.

These three cycles work independently and together to shift Earth's climate change over long spans. Milankovitch used each cycle to create a more significant model capable of running backward and forward to predict future climate conditions. His studies show that Ice Ages occurred at 41,000-year intervals up to 3 million years ago (Buis, 2020). Around 800,000 years ago, however, the length of the Ice Ages moved towards 100,000-year intervals, matching the eccentricity cycle (Sullivan, 2016). Scientists still do not have a clear answer on why this transition occurred. Although validating these long-term changes in Earth's climate can help explain changes throughout history, they cannot fully correlate to Earth's current warming rate. Since the pre-Industrial period, around 1850 to 1900, Milankovitch cycles have shown that solar radiation should be decreased (Buis, 2020).

These cycles are just one factor that may contribute to climate change. One example is the number of ice sheets, which affects how much of the sun's energy is reflected in space, thus changing Earth's temperature. Earth is currently in an interglacial period. Without outside influences on climate change, Milankovitch cycles would predict that our planet should be cooling and not warming, based on a cycle that started 6,000 years ago. Scientists have also analyzed tree rings, glacier lengths, pollen remains, ocean sediments, and many other indirect measures to correlate how climate changes over long periods (Wuebbles, 2017). However, the variation we have seen in the past 70 years is not explained by these methods. Some other outside influence is at work.

Causes of Climate Change: Natural & Human

Daniel Fahrenheit invented the modern thermometer in the early 1700s (Grigull, 1966). From 1880 forward, global record keeping has allowed us to measure more precisely without great uncertainty. This certainty of measurement has scientists scrambling to understand the true causes of the impact of climate change from trusted models. Many factors can change the course of Earth's temperature, but they can all be grouped into two main categories, natural causes and human causes, as displayed in *Table 1.3*.

Table 1.3: Causes of Climate Change (Kobiruzzaman, 2021)

Natural Causes	Human Causes
Axial Tilt	Burning Fossil Fuels (Carbon Dioxide)
Eccentricity	Deforestation
Solar Variation	Livestock Production
Volcanic Eruptions	Chemical Fertilizers
Continental Drift	Fluorinated Gases
Ocean Current	Industrial Gases
Natural Forest Fire	Food Waste
Greenhouse Gases	Transport Vehicles
Meteorite Impacts	

As displayed in *Table 1.3*, there are many causes of climate change. Each can work independently and become amplified through a feedback loop from the effects of one or more additional causes.

Natural Causes

Natural causes of climate change include those from the Milankovitch cycle. These are the Earth's tilt, eccentricity, and solar variation. Almost all the energy affecting

Earth's climate originates from the Sun (BGS, 2023). As the energy from the sun passes through space and towards Earth, some of it is lost or intercepted at the top atmosphere. Some of the energy is reflected in space, and some of the energy is absorbed.

The natural insulators of the Earth's temperature include greenhouse gases in the atmosphere. The most prominent greenhouse gas emitters include methane (CH4), nitrous oxide (N2O), carbon dioxide (CO2), ozone, and water vapor. This multi-step process is displayed in *Figure 1.11* and varies over time (NPS, 2023).

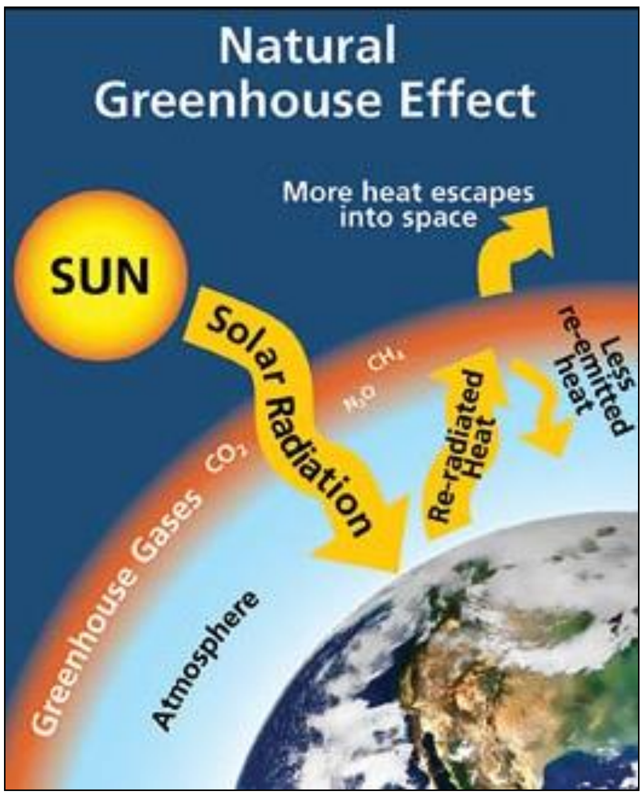


Figure 1.11: Natural Greenhouse Effect (NPS, 2023)

This variation over time has a direct impact on the Earth's climate. Another natural cause of climate change is volcanic eruptions through changes in plate tectonic processes (USGS, 2023). The movement in these tectonic plates causes continents to move to different positions on Earth. Their movement also causes volcanoes and mountains to form. Large mountain chains can change air circulation around the globe, such as warm air being deflected to cooler mountain regions. During significant volcanic eruptions, vast amounts of volcanic gas and ash are injected into the stratosphere. As sulfur dioxide is emitted and converted to sulfuric acid, condensation quickly forms in the stratosphere (Laaksonen et al., 2000). These fine particles increase the reflection of radiation from the Sun back into space, causing Earth's lower atmosphere to cool (Groisman, 1985).

The majority of radiation from the Sun is absorbed by the ocean, thus causing the ocean to act like a massive solar panel (OE, 2023). The ocean's currents and drifts are another natural cause of climate change. The ocean's massive role in climate change does not come as a surprise, as it covers more than 70 % of the Earth's surface (USGS, 2019). These currents move heat around the Earth. These ocean currents act like a conveyor, as shown in *Figure 1.12*.

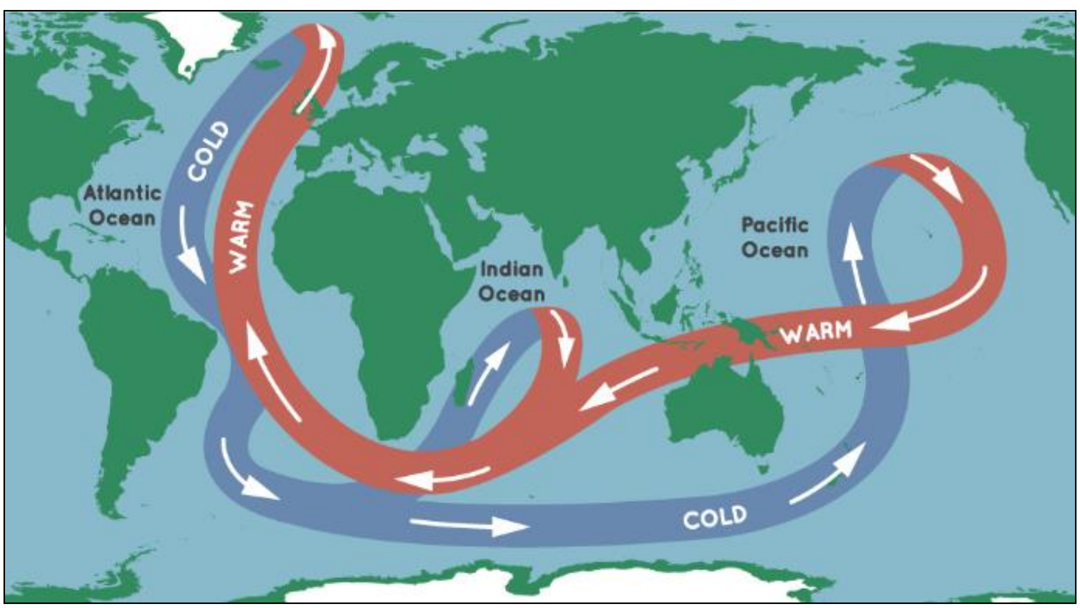


Figure 1.12: Depiction of Ocean Currents in 2023. (NASA, 2023)

The ocean currents move warm water from the equator to the poles and cool water from the poles back to the equator, thus helping to counter the uneven distribution of solar radiation from the Sun (OE, 2023). Ultimately, if the ocean sat idle, temperatures in each region would be much more extreme. The ocean absorbs carbon dioxide from Earth's atmosphere, but it can also increase the amount of greenhouse gases in the atmosphere. The warmer the ocean is, the less it can absorb carbon dioxide from the atmosphere.

Meteorite impacts can affect climate change. Although very little material is added to the Earth by cosmic dust or meteorites, there have been times when meteorites changed the Earth's climate. The Chicxulub crater buried beneath the Yucatan Peninsula in Mexico is said to have smashed into Earth around 65 million years ago (Hampson, 2018). Scientists project that the impact is thought to have created a temperature change on the Earth's surface by up to 5 °C while also causing devastation, including a mass extinction of animals (Pultarova, 2018). This temperature change is projected to have lasted 100,000 years (Weinreb, 2002). This is an example of what can happen during an event that causes extreme environmental changes.

Human Causes

Human causes of climate change are not a discovery. In fact, since the 1800s, experiments have been conducted suggesting that human-produced emissions could collect in the atmosphere and insulate Earth (Weart, 2008). Initially, scientists were more curious than concerned about these emissions as data collection methods and modeling were limited (Anderson, 2021).

As of 2023, human causes of climate change are recognized as a climate change contributor based on years of research and a consensus among scientists and proven models. One human activity that can cause climate change is deforestation. Deforestation is cutting down forests or trees to utilize the land or those trees for another purpose (Bologna, 2020). Trees draw out carbon from the atmosphere through a process known as photosynthesis. Photosynthesis is when the parts of a tree pull in carbon dioxide and water and use the sun's energy to synthesize foods such as sugars. A single mature tree can absorb more than 48 pounds of carbon dioxide from the atmosphere annually (Stancil, 2019). This process is lost when cutting down trees, and carbon stays in the atmosphere.

Although a part of the human food chain, livestock production is a human contributor to climate change. The animals emit large amounts of nitrous oxide, carbon dioxide, and methane. The land used for livestock is also a contributor as it contributes to deforestation, water pollution loss, and biodiversity (Karlie, 2022).

Chemical fertilizers are a human-induced cause of climate change. One of the primary chemicals in fertilizers includes ammonia, which allows plants to absorb from the soil. Ammonia has to be made at high pressure under high temperatures and takes much energy to manufacture. Around 50 % of the world's food production depends on mineral fertilizer application (INRAE, 2023). The energy to produce the fertilizer is commonly generated through burning coal and methane gas which causes pollution to the air and climate change (Skorupka, 2021). These human-made fertilizers have positive effects, such as boosting crop production and letting farmers grow more food on smaller plots of land (Manthiram, 2021). The invention of these fertilizers has doubled the number of people that one acre of land can feed (Erisman, 2008).

Fluorinated gases such as sulfur hexafluoride are emitted from household, commercial, and industrial processes (Ferreira, 2019). Food waste from humans emits significant greenhouse gases into the atmosphere. Production, transportation, and handling generate significant carbon emissions. When food waste sits in landfills, it generates methane (Buzby, 2022). One of the most significant human-generated causes of climate change is the burning of fossil fuels. When burned, most commonly to create energy and electricity, the emissions release large amounts of carbon dioxide into the air.

The greenhouse gases trap heat in the atmosphere, causing global warming. The most significant contributors are coal, oil, and gas, which are present in almost every sector and every industry (Zhang, 2020). Across the globe, humans are burning 4,000 times the amount of fossil fuels they were in the late 1700s (UGC Berkeley, 2023). *Figure 1.13* shows how different sources have contributed to carbon dioxide emissions since the 1700s.

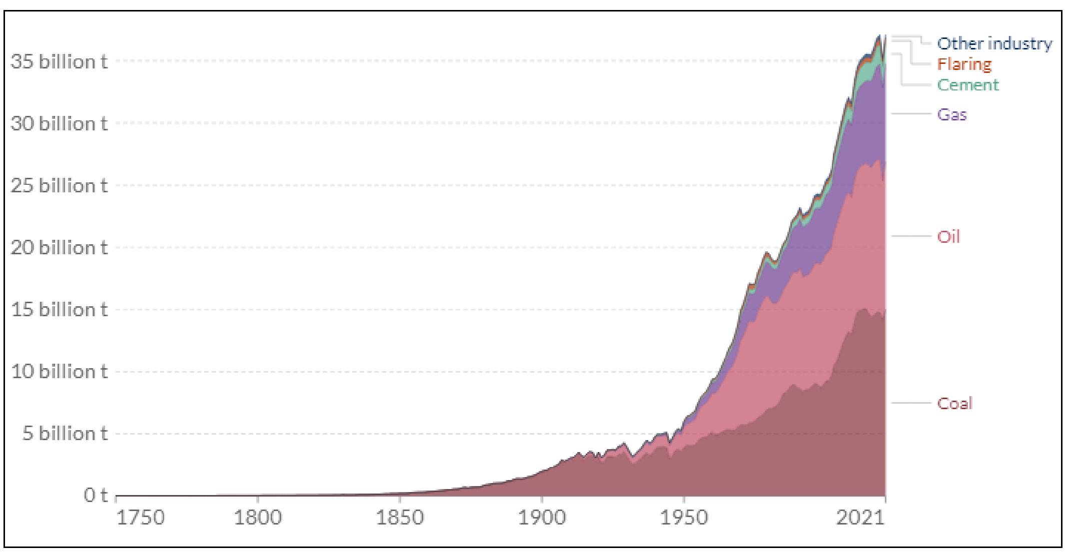


Figure 1.13: CO_2 Emmissions by Fuel or Industry Type, World. (Ritchie, 2022)

The Greatest Impact

It is obvious that natural and anthropogenic changes, known as human causes, can significantly affect climate change, as shown in *Figure 1.14*.

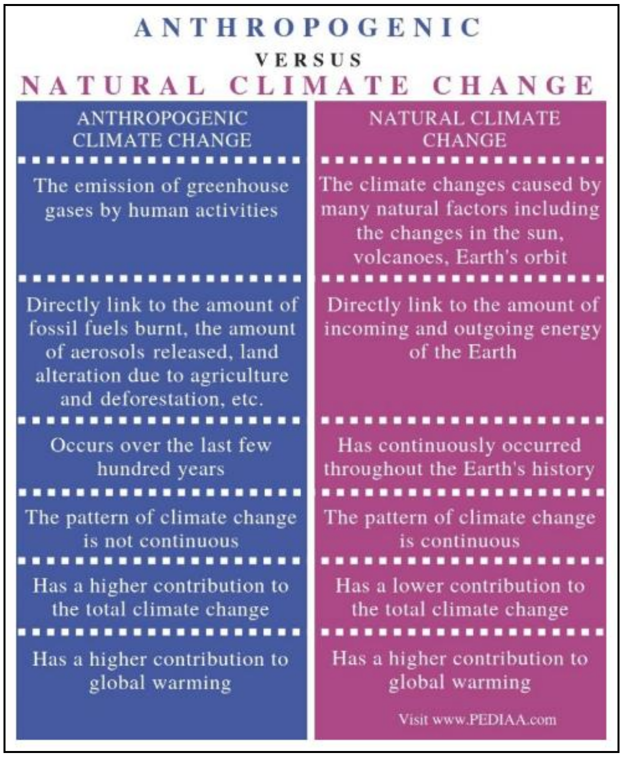


Figure 1.14: Anthropogenic Versus Natural Climate Change (Lakna, 2019)

A side-by-side comparison of human-induced warming versus natural warming shows that our human activities have a significant effect on global warming and can be traced to the changes in climate that we are currently facing (Lakna, 2019). Understanding which has the more significant impact could be a key to the door that generates a solution.

The University of Oxford Environmental Change Institute and the University of Leeds Priestley International Centre for Climate conducted an observational assessment and modeling study. It highlights the effects of climate change in a natural and human-induced setting, displaying long-term trends observed over the past century. This study is detailed in *Figure 1.15*

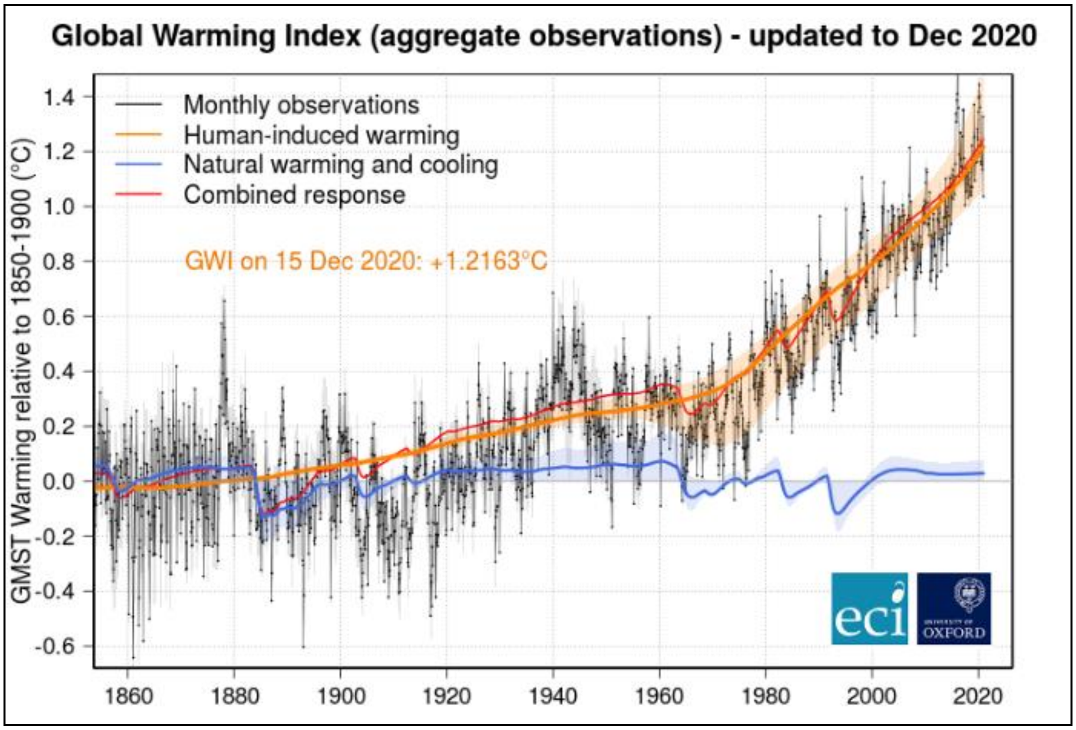


Figure 1.15: Global Warming Index (Haustein et al. 2017)

The equation behind the model and its future projections is shown below.

Equation 1.2

$$\Delta T = \kappa \cdot (E + \Delta F / \alpha)$$

The equation is simple, the delta temperature change (ΔT) is a result of the change in human influences on climate (ΔF) divided by the normalized absolute global warming potential of CO2 (α), about 1.0 W/m2 per trillion tonnes of CO2, plus the time interval (E) times the transient climate response to emissions (κ). Results show that global temperatures have risen over the past 160 years, and this study correlates with the long-term temperature change of the world in Figure 5. The black line within the graph shows real-world observations of global mean temperature. Since the year 1960, the global temperature has been steadily increasing.

Both past and current studies show that not only are human-induced factors a contributor to climate change, but they are also the number one contributor to climate change in today's world. Since many human factors contribute to climate change, it is vital to understand which one has the most significant effect.

The answer may lie in research up to a century old. In 1930, research by a British steam engineer, Guy Steward Callendar, theorized that carbon dioxide concentrations in the atmosphere were linked to global temperature changes (Hawkins, 2013). Although met with skepticism, his research estimates have convinced scientists that CO2 concentrations in the atmosphere may be the primary driver (Flemin, 1998). His studies have shown to be incredibly accurate to this day (Hawkins, 2013).

1.3 Carbon: The Leading Cause of Greenhouse Gas Emissions

As previous and current studies have shown, greenhouse gas emissions can change Earth's temperature. There are many greenhouse gas emissions generated by the human sector that take part in this; however, there is one that is the most significant contributor. As shown in *Figure 1.16*, these greenhouse gases occur more prominently with increased effort through human influence than naturally, as shown in *Figure 1.16*.

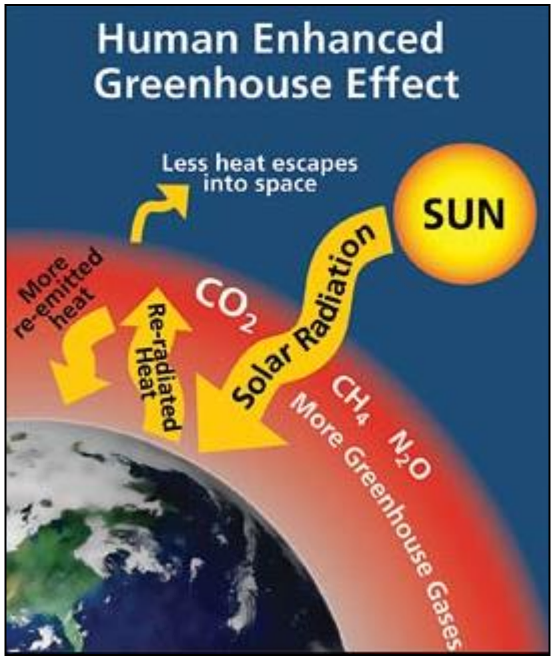


Figure 1.16: Human Enhanced Greenhouse Effect (NPS, 2023)

The leading greenhouse gases are listed in *Table 1.4*, along with the percentage of each accounted for in the atmosphere today.

Table 1.4: Human-Caused Greenhouse Gas Contributors by Gas type (Margarida et al. 2022)

Greenhouse Gases	Prominent Causes	Percentage in Atmosphere
Carbon Dioxide	Burning fossil fuels Industrial processes Forestry Land Use	74.4 %
Methane	Agriculture Fossil fuel Operations Waste	17.3 %
Nitrous Oxide	Fossil fuel combustions Industrial processes Biomass burning Human Sewage Agricultural activities	6.2 %
Fluorinated Gases		2.1 %

Carbon dioxide is the number one contributor to human-caused greenhouse gas emissions and accounts for nearly 75 % of total emissions (Friedrich & Vigna, 2020). Not all carbon dioxide is generated from human activities, as carbon dioxide is naturally present in the air, at about 0.04% (Monnin et al., 2001). This is displayed in *Figure 1.17*.

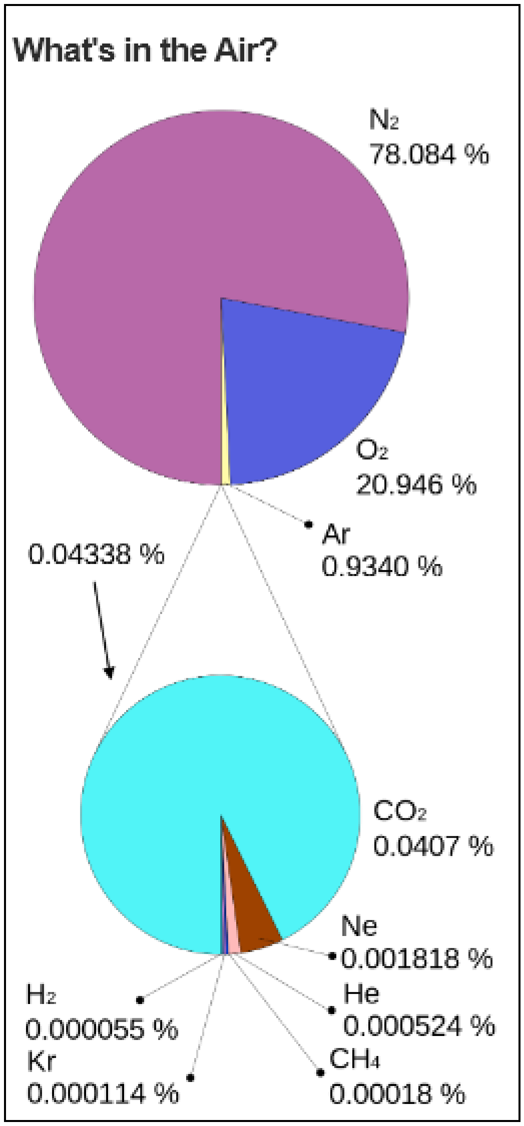


Figure 1.17: What is in the Air? (Buis, 2019)

Carbon dioxide is commonly abbreviated as CO_2. It is clear gas composed of one carbon atom and two oxygen atoms (NETL, 2022). This chemical structure is displayed further in *Figure 1.18*.

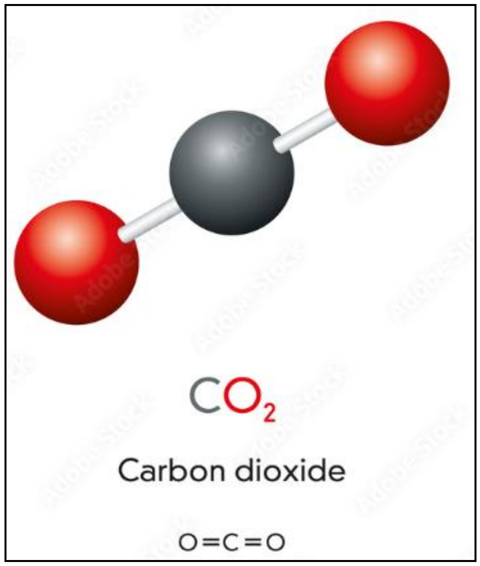


Figure 1.18: A Simple Carbon Dioxide Molecule (Furian, 2018)

Humans both breathe in carbon and exhale it. Plants also need carbon to thrive. It is an essential part of the global carbon cycle. It moves between plants, animals, microbes, and minerals in the earth and the atmosphere. *Figure 1.19* shows an Earth system carbon cycle model.

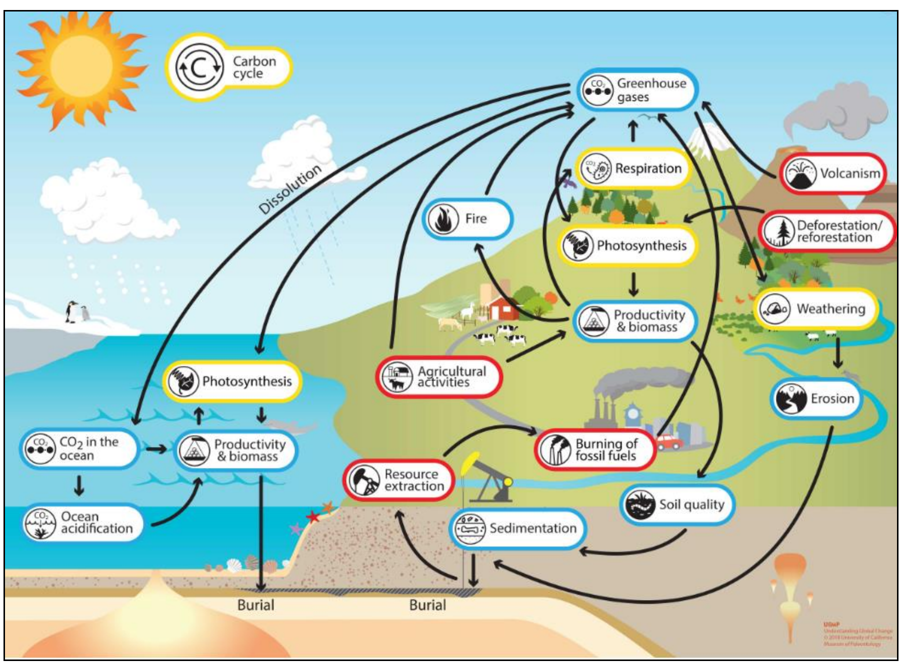


Figure 1.19: Earth System Carbon Cycle (UGC Berkeley, 2023)

Carbon dioxide is the primary control knob for the Earth's temperature (NASA, 2010). This was further illustrated in research conducted by (Gavin Schmidt et al., 2010), showing that carbon dioxide accounts for about 20 % of the greenhouse effects, water vapor and clouds account for 75 %, and aerosols and minor gases account for around 5 %. Carbon is transferred over time scales of hours to millions of years. Understanding how human activities have altered the carbon cycle can help shed light on the rapid rate of change the Earth's temperature is experiencing. On long timescales, from thousands to millions of years, weathering of rocks removes carbon dioxide from the atmosphere (Archer et al., 2000). Over millions of years, these rocks are exposed to heat and pressure, causing them to release carbon back into the atmosphere, typically through volcanic activity. Carbon is also transferred to rocks from the biosphere through the formation of fossil fuels, which form over millions of years. The carbon is removed from the cycle for millions of years when buried.

Human activities highlighted in red, as shown in *Figure 1.19*, have dramatically increased carbon exchange from the ground back into the atmosphere and oceans. This has caused upset to concentrations, as displayed in *Figure 1.20*.

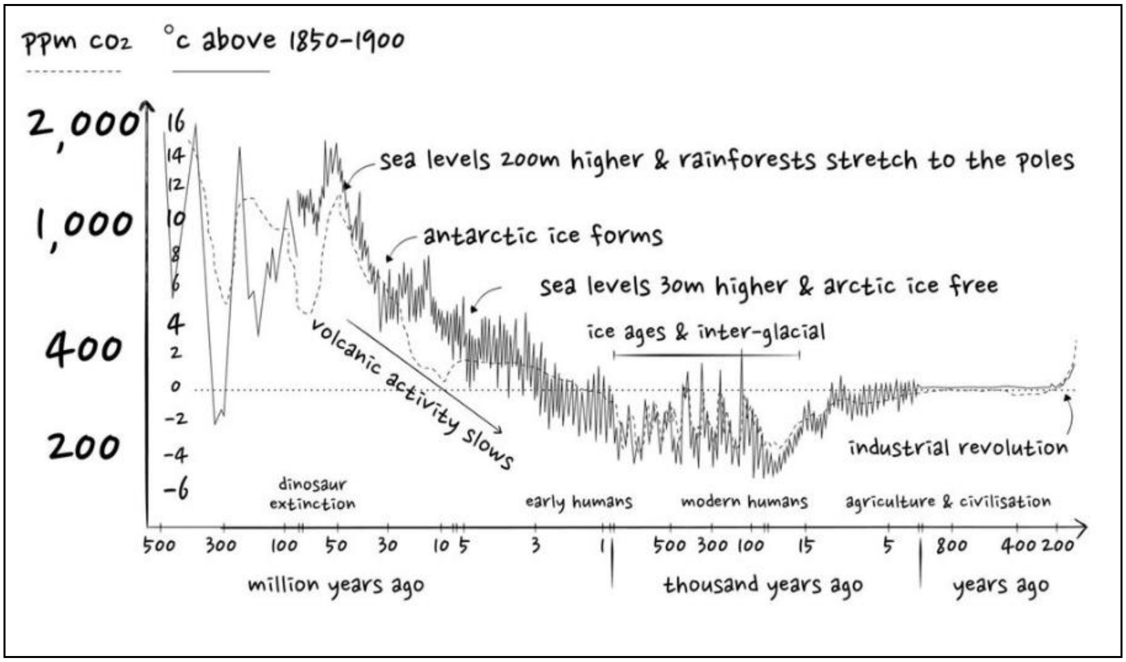


Figure 1.20: Atmospheric Carbon Concentration Changes Over Time (Schlanger, 2017)

The concentration levels shown in *Figure 1.20* directly correlate with the global temperature changes in *Figure 1.5*. History shows that significant CO_2 levels and global surface temperate directly affect the habitable earth. Focusing on what human activities cause fluctuations in CO_2 levels and which countries are the most significant contributor is necessary to drive change.

<u>The Industrialization Effect</u>

The Industrial Revolution had a significant impact on the way businesses operated, and people lived. The first Industrial Revolution started in 1750 and ran through 1840 (IHEC, 2021). It marked a significant turning point in history. Standards of living increased, a capitalist economy, rapid urbanization to city life, and changes in manufacturing were all highlights of this era. Wages were improved, lower prices, more goods, and increased production and efficiency resulted. The global population growth rate increased from 0.04 % prior to 1700 and continued to increase to greater than 1.0 % through the year 2020, as displayed in *Figure 1.21* (Census, 2022).

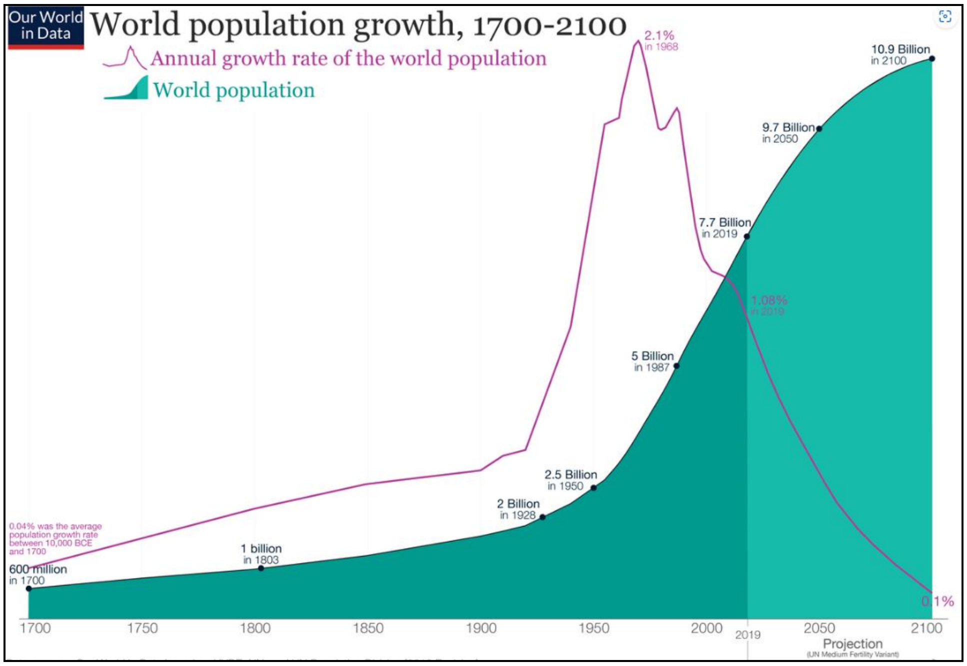


Figure 1.21: World Population Growth (1700-2100) (Maddison, 2001)

The positive effects of the Industrial Revolution on the world are highlighted in five critical areas shown in *Table 1.5*.

Table 1.5: Benefits of the Industrial Revolution (UKEssays, 2018)

Key Area	**Positive Impacts**
Economy	Increased Trade Distribution of Wealth Lower prices Expanded markets Growth of cities Business trade and commerce Improved Housing Clothing and consumer goods Population increase Labor savings

Manufacturing	Mass production of goods Iron production Textile production New energy sources such as coal and steam Iron process innovations Large-scale chemical production Concrete production Glass making Mining Development of factory system
Agriculture	Industrialized to produce greater crop yields. Advanced crop breeding methods Applying fossil fuel energy.
Transportation	Improved communication River and canal transport to move raw materials Railway development Roadway improvements
Healthcare	Scientific discoveries and improvements Germ theory of disease Advancements in medicine that improved life expectancy Surgery standardization

Many benefits and positive impacts came out of the First Industrial Revolution. These were improved upon during the subsequent Industrial Revolutions. In the second Industrial Revolution, from 1870-1914, the world saw new technology deployments in steam energy, steel, chemicals, gas, and electricity. (Muntone, 2013). In the third Industrial Revolution, from 1950-1990, the use of electricity, nuclear, combustion engines, and digital electronics had significant impacts (Rifkin and Easley. 2017). These new ideas increased efficiency, economic growth, scientific advancement, improved socioeconomics and geopolitics, and the connection between world countries through trade markets (Dubai Sensor, 2022). Death rates decreased, birth rates increased, and literacy levels improved. It was undoubtedly one of the fastest periods of change in human history. Although there were many benefits from the Industrialization Revolution, there have also been negative impacts. These negative impacts are highlighted in *Table 1.6*.

Table 1.6: Negative Impacts of the Industrial Revolution (Rafferty, 2023)

Key Area	Negative Impacts
Hygiene	Poor nutrition Stressful life Lower prices Overcrowding Overwhelmed sewage and sanitation systems Passive entertainment causing sedentary lifestyles
Disease Transmission	Poverty Poor living conditions
Pollution	Garbage increase Human waste increase Air pollution from factories, burning coal Increase in atmospheric carbon dioxide
Resource Exploiting	Low wages Child labor Financial disadvantages Depletion of resources (water, rocks, soil, trees)
Safety	Discrimination Child labor Regulations not fully in place for equipment

As displayed in *Table 1.6,* the negative impacts of the Industrial Revolution continue today as we are nearing the fifth Industrial Revolution. One key point is that atmospheric carbon dioxide, which is a primary driver of climate change and global warming, shows significant expansion during the period of Industrialization of the world.

Concentrations prior to 1750, shown in *Figure 1.20*, are around 275 parts per million (ppm) and increased to around 400 ppm today (Carbon Brief, 2021). With the Earth's population increasing tenfold throughout this period, consumption, production, emissions by person, and waste generation have all increased. Today we are in the fourth Industrialization Period that started in 2011 (Bai et al., 2020).

Rapid changes are occurring in technology, industry, renewable energy sources, and societal patterns due to intelligent automation and increased interconnectivity (Marr, 2023). Although there are many benefits to the fourth Industrial Revolutions advancements throughout the world, many aged processes need to be renewed to turn the direction of carbon pollution. We now understand that carbon through human activities is one of the main drivers of climate change, causing significant risks. We must next understand which countries have the highest emission rates and which industries are most responsible.

1.4 Emissions: Around the World

<u>Emissions by Region</u>

Emissions worldwide are not uniform, and the effects are not either. Emissions data collected through 2021, displayed in *Figure 1.22*, highlights which countries have the most significant annual emissions.

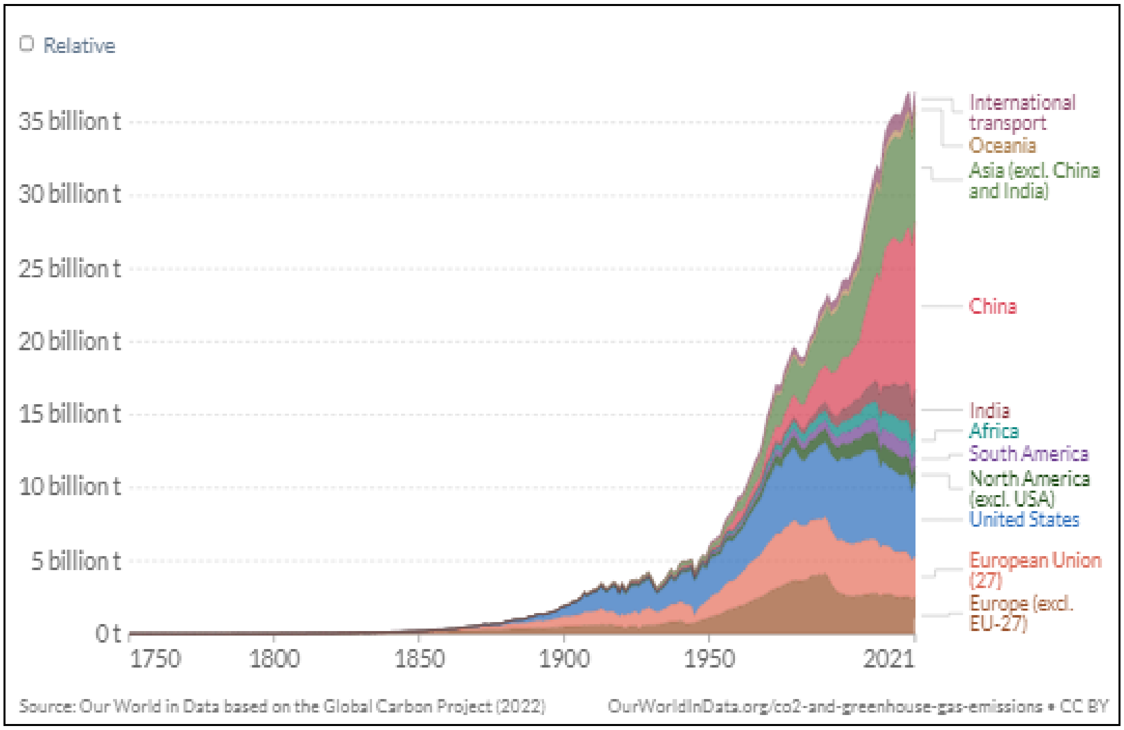


Figure 1.22: Annual CO_2 by World Region (Ritchie et al. 2020)

The chart shows the countries that emit the most outstanding share of 37 billion tons of carbon emissions per year. The top 5 are listed in *Table 1.7*.

Table 1.7: List of Top Carbon Emitting Countries 2021 (Ritchie et al. 2020)

Country	Emissions (billion tons)
China	11.47
Asia (excludes China and India)	7.5
United States	5.01
European Union	2.79
India	2.71

The top countries, interestingly enough, are those that have seen periods of increased industrialization. This is highlighted in *Figure 1.23*.

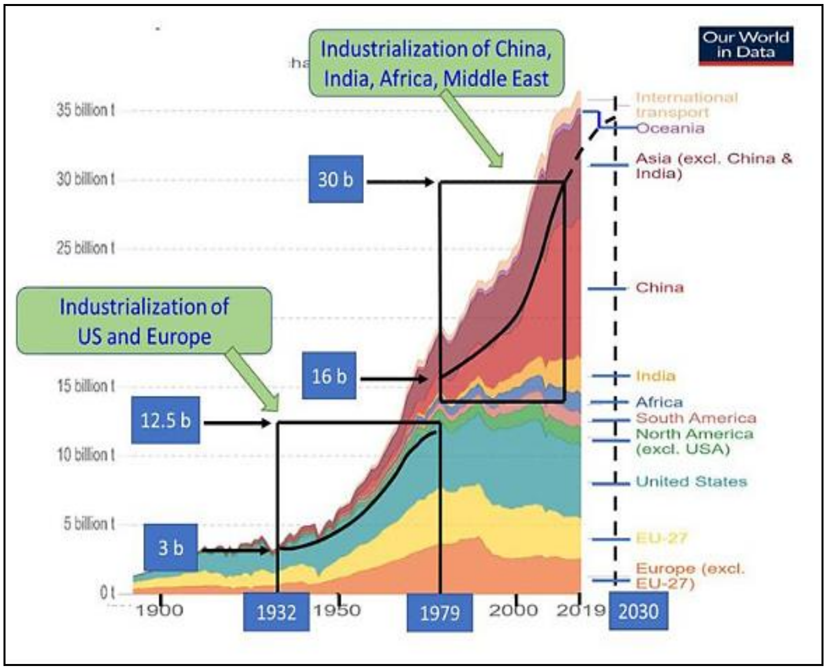


Figure 1.23: Annual CO_2 by World Region (Ritchie et al. 2020)

China and the United States, together account for almost 50 % of the world's annual emissions (Bearak and Popovich, 2022). We must focus not just on the United States or China for emissions reductions, we must focus our efforts throughout the world and find out what sectors are the greatest contributors.

<u>Global Emissions by Sector</u>

Emissions come from many sectors. Overall each sector's contribution, whether small or large, contributes significantly to pollution and climate change. *Figure 1.24* displays each sector, and its respective output, based on a 2020 study.

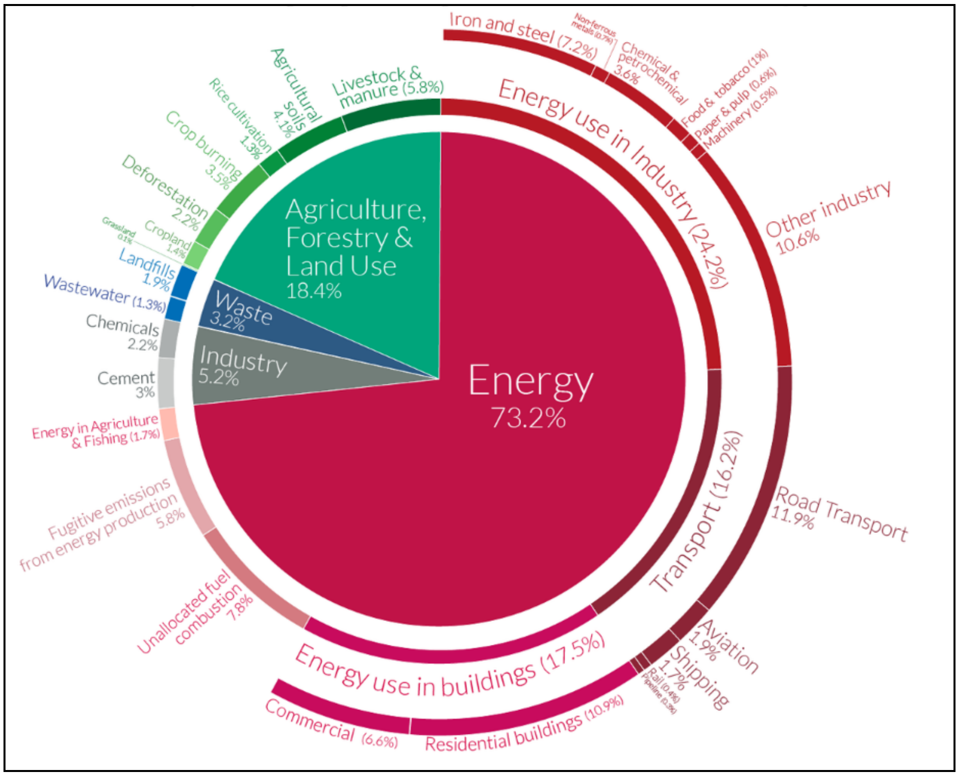


Figure 1.24: Breakdown of Greenhouse Gas Emissions by Sector (Ritchie et al. 2020).

The first layer sectors included in the analysis are waste, agriculture, industry, and energy use. Energy use shows the highest global greenhouse gas emissions at around 73 % (OWID, 2021). Unfortunately, there is not a simple fix to the energy sector, even though it accounts for almost three-quarters of the output. Even if we could fully de-carbonize energy, we would have to electrify many areas, such as heating and transport (Ritchie et al., 2020). In the second layer, energy use and thus emissions are most significant in transportation at 16.2 %, building use at 17.5 %, and industry at 24.2 %. This is visualized further in *Table 1.8*.

Table 1.8: Emissions by Sector Breakdown (Ritchie et al. 2020)

Sub-Sector	GHG Emissions Share	Further Breakdown
Transport	16.2 %	• Road 11.9 % • Aviation 1.9 % • Rail 0.4 % • Pipeline 0.3 % • Ship 1.7 %
Buildings	17.5 %	• Residential 10.9 % • Commercial 6.6 %
Industry energy	24.2 %	• Iron & Steel 7.2 % • Non-ferrous metals 0.7 % • Machinery 0.5 % • Food and tobacco 1.0 % • Paper, pulp & printing 0.6 % • Chemical & petrochemical (energy) 3.6 % • Other industry 10.6 %
Agriculture & Fishing energy	1.7 %	-
Unallocated fuel combustion	7.8 %	-
Fugitive emissions from energy production	5.8 %	• Coal 1.9% • Oil & Natural Gas 3.9%
Total	73.2 %	

Industrial manufacturing is one key driver that consumes a significant amount of energy. Global energy consumption from this sector alone consumes around 54 % of the total energy produced (EIA, 2021). Total world energy produced as of 2019 was more significant than 600 oxy joules (EJ) (IEA, 2022). On the pollution side, this sector is responsible for roughly 33 % of global emissions or 15 billion tons of GHGs. (WEF, 2022).

<u>United States Emissions by Sector</u>

The United States' annual energy-related emissions as of 2021 were around 5 billion tons (Sands, 2022). *Figure 1.25* shows the breakdown by sector of contribution to the total output. The emissions output from the United States is in line with the percentage by sector of global emissions.

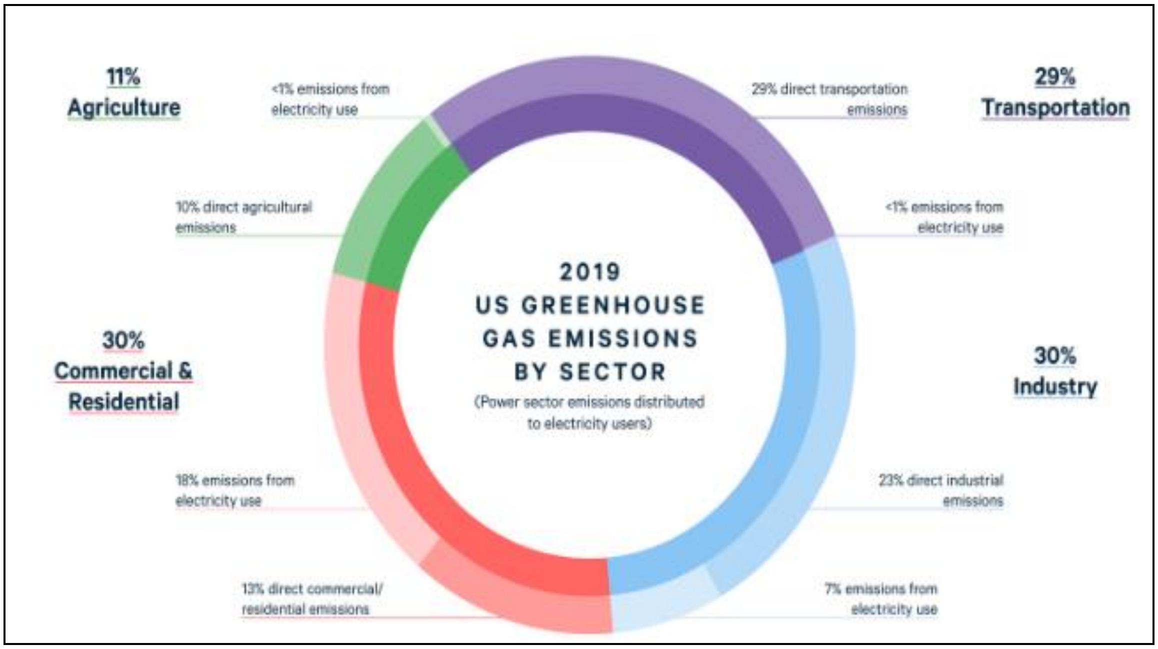


Figure 1.25: US Greenhouse Gas Emissions by Sector (Boyd and Wear, 2021).

The industrial sector within the United States emits more than 1.4 billion tons of carbon. In manufacturing, more than 1.1 billion tons (EPA, 2022). U.S. manufacturing also has the most significant industrial sector energy consumption share (Ritchie et al., 2020). The top contributor is energy-related emissions through the combustion of fuels, primarily coal, and gas. On-site combustion accounts for 23 %, while 7 % is contributed to off-site generation, as shown in *Figure 1.26* (U.S. EIA, 2022).

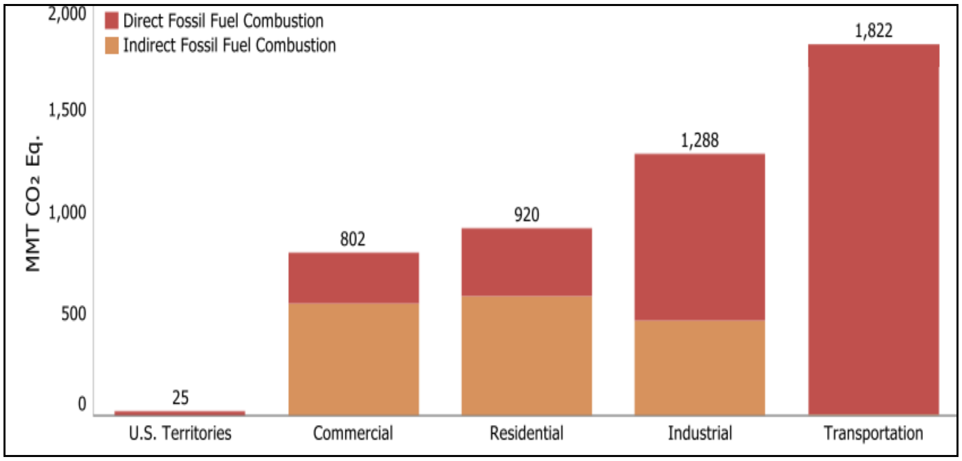


Figure 1.26: Direct vs In-direct Fossil Fuel Combustion (U.S. EIA, 2022).

It is now apparent that carbon-related emissions, primarily from human factors, can disrupt the Earth's temperature to levels above what humans have inhabited in the past. Above this, industrial manufacturing, both today and tomorrow, will have a significant positive or negative impact as it is a major contributor. De-carbonizing the manufacturing industry will play a critical role in the net-zero transition.

1.5 Industrial Manufacturing: An Important Contributor with Challenges

The Importance of Manufacturing

Manufacturing is an essential contributor to the United States and the world. It is said that every $1.00 spent on manufacturing has a total impact of $2.60 on the overall economy (Nam, 2022). This vital sector takes raw materials and creates finished goods for sale worldwide. Traditional manufacturing has allowed the world to operate more efficiently while reducing safety risks to hand assembling. Modern manufacturing has evolved. With the practicality of electricity in the late 1800s, many factories yielded productivity gains of well over 30% (NRTC, 2021). Throughout the last 100 years, manufacturing has been the beating heart of the United States economy. Manufacturing adds jobs, creates critical products such as healthcare equipment, enhances productivity growth and GDP, and circulates the economy. The industrial manufacturing industry is comprised of many sub-sectors operating within it. Based on the types of goods produced, manufacturing is categorized according to *Figure 1.27*.

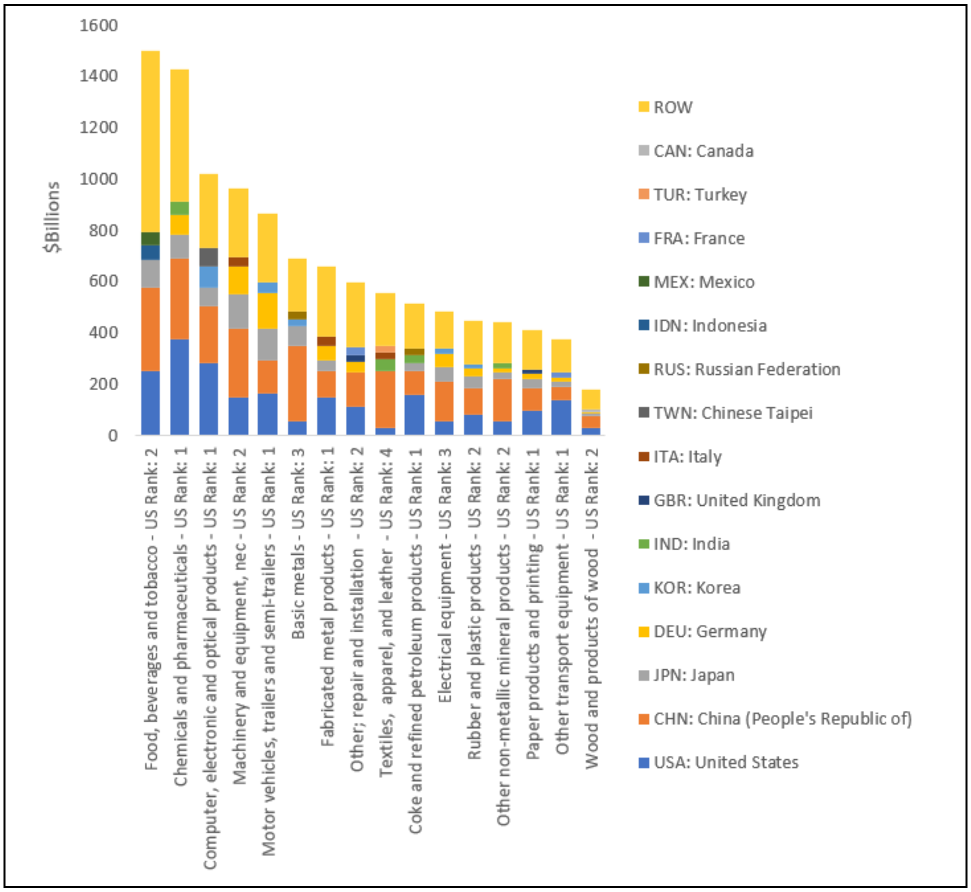


Figure 1.27: Manufacturing Industry Sub-Sector by Size (Thomas, 2023)

Many sub-sectors are producing many goods that we rely on daily. Countries such as Poland, Germany, and Italy have the highest percentage of their workforce employed in manufacturing (Bizvibe, 2020). In the U.S., it is estimated that for every manufacturing job, another three jobs are created as wages are spent in multiple parts of the economy (Bivens, 2019). This employment multiplier reaches much further than the manufactured product to include direct, induced, supplier, and other indirect jobs. These include suppliers, managers, shippers, utility workers, professional services, IT technicians, and engineers. Through manufacturing, the United States and many other countries have grown economically to where they stand today. *Figure 1.28* highlights the global manufacturing output by country as of 2020.

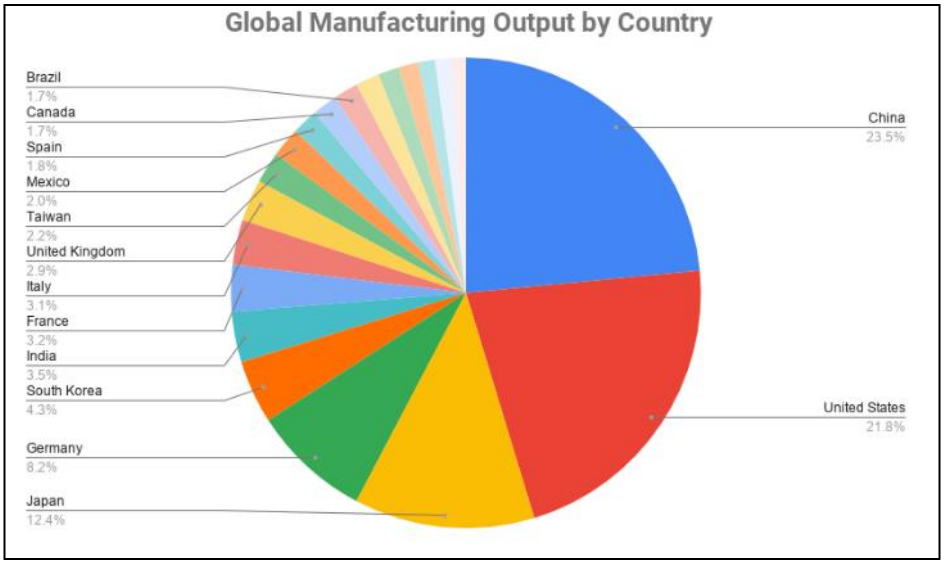


Figure 1.28: Global Manufacturing Output by Country (Bizvibe, 2020)

The United States and China command a significant portion of the manufacturing output in the World. With this comes benefits and a duty to responsibly produce the World's needs without sacrificing our way of life.

There are many critical social and economic points as to why manufacturing is vital to the growth of the United States and the World's economy.

These key points are listed below in *Table 1.9*.

Table 1.9: Key Metrics of U.S. Manufacturing (Nam, 2022) (TE, 2023) (USCB, 2022)

Positive Contributor	**Description**
GDP	2,256 billion (10.7 % of total)
Jobs	12.5 million (8.4 % of direct employment) 1 job creates 3 more jobs
Trade	Greater than 80 % of interregional
Capital Investment	$250 billion (20 % of total)
Productivity Growth	35 % of total
Research & Development	70 % of total
Exports	60 % of total
National Power	Military supplies and equipment Technology Advancement
Economy	Accounts for 12 % of the U.S. economy 5th largest employer

These key points are critical to protecting this vital sector that provides food, transportation, jobs, and wealth worldwide. Each of these benefits provided by the manufacturing industry results from an array of sectors within the industry. *Figure 1.29* shows the top 10 sectors in the manufacturing industry in the United States responsible for the countries manufacturing output. Each of these sectors is part of the intricate fabric that sustains our way of life and economy.

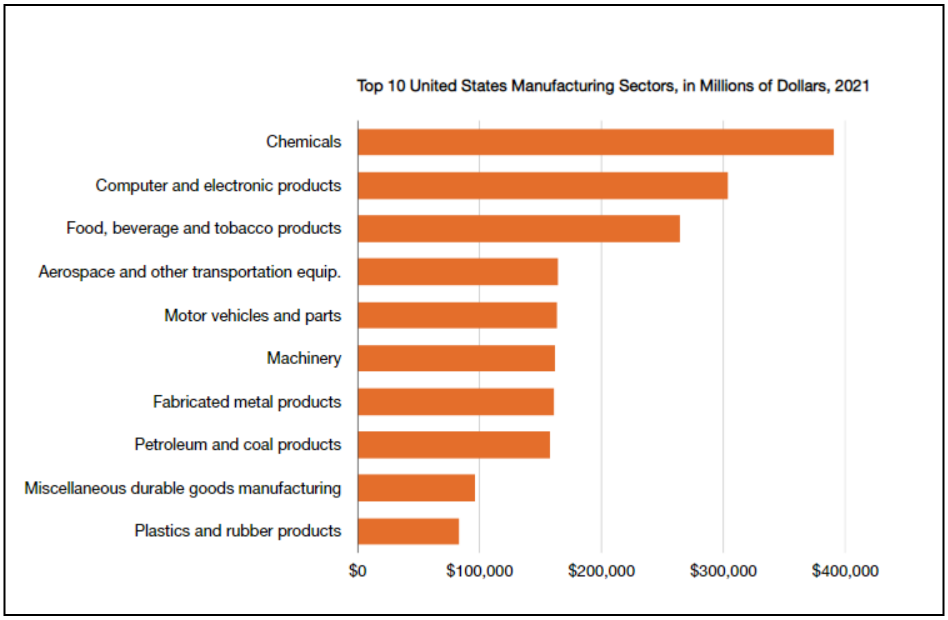


Figure 1.29: Manufacturing Sectors Share in the U.S. (Nam, 2022)

Table 1.10 lists the World's top 10 manufacturing companies by revenue. The United States headquarters are 30 % of the top 10 companies, while China houses 20 %.

Table 1.10: List of Largest Manufacturing Companies by Revenue (CNN, 2022)

No.	**Company**	**Industry**	**Revenue (by US$ billion)**	**Headquarters**
1	Apple	Electronics, telecommunications equipment	274.515	United States
2	Toyota Group	Engineering, various	256.721	Japan
3	Volkswagen Group	Automotive	253.965	Germany
4	Samsung Electronics	Electronics, various	200.734	South Korea

5	Foxconn	Electronics	181.945	Taiwan
6	Mercedes-Benz Group	Automotive	175.827	Germany
7	Cardinal Health	Pharmaceuticals	152.922	United States
8	China Railway and Engineering Group	Engineering	141.383	China
9	Huawei	Telecommunications equipment, Electronics	129.183	China
10	Ford	Automotive	127.144	United States

Throughout the past decades, a manufacturing decline has occurred as the labor market has polarized itself into high-paying and low-paying jobs. With the onset of Covid-19, this reality became hastened even further. Manufacturing jobs have been pushed to low-labor markets, and jobs in service industries have replaced them. *Figure 1.30* shows the current state of manufacturing jobs across the globe.

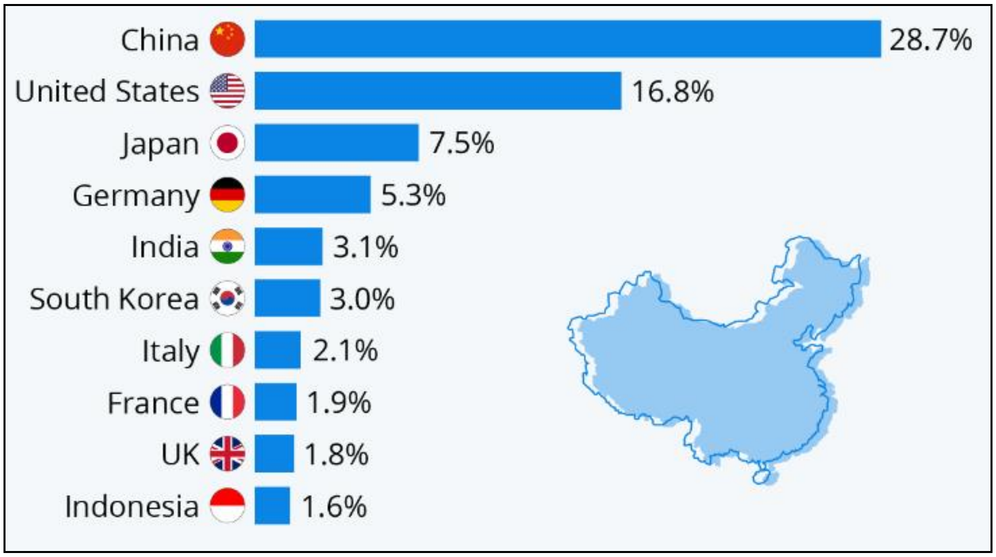


Figure 1.30: Global Manufacturing Share (Richter, 2021)

Understanding the importance of global and U.S. manufacturing is imperative for economic prosperity and for maintaining and enhancing the country's standard of living. Manufacturing is a large consumer of energy and requires factories and the use of machinery. The adverse effects are that it produces waste materials and waste heat that can pollute the environment.

In order to sustain this standard of living, care must be taken in this critical sector to reduce pollution output and achieve net-zero carbon emissions. As regulations, labor, and legislation tighten, this industry's reaction to change will determine the standard of living set forth for the United States and the quality of life and equity across the world. Understanding the United States' position, increasing the manufacturing footprint, baselining industry energy metrics, and available sources in the United States,s along with net consumption today and into the future, will help to drive activity.

Manufacturing Footprint

The number of manufacturing plants in the world is a number that constantly changes. As of this writing, the estimated number of factories worldwide is around 10 million (Loisy, 2019). As of the first quarter of 2023, there are 591,720 facilities in operation within the borders of the United States (IBIS, 2023).

Sources of Energy – Role of Fossil Fuels

In order to power our highly industrialized world, it takes a significant amount of energy. In the United States and many other countries, both non-renewable and renewable energy sources provide energy to the industry. These sources are listed in *Table 1.11*.

Table 1.11: Sources of Energy in the United States (EIA, 2022)

Non-renewable Source	**Renewable Source**
Petroleum	Solar
Hydrocarbon gas liquids	Geothermal
Natural gas	Wind
Coal	Biomass
Nuclear Energy	Hydropower

Each of these is consumed at a different rate in the U.S., and the mix has changed over time, as displayed in *Figure 1.31*. Overall, manufacturing in the U.S. consumes 81 % of industrial energy (EIA, 2022). In general, there are both fuel and non-fuel types of energy consumption. Fuel consumption considers combustible energy sources to generate electricity or produce heat. Non-fuel sources are raw materials used to make products. Overall first energy use is around 68 % for fuel and 32 % for non-fuel sources (EIA, 2022).

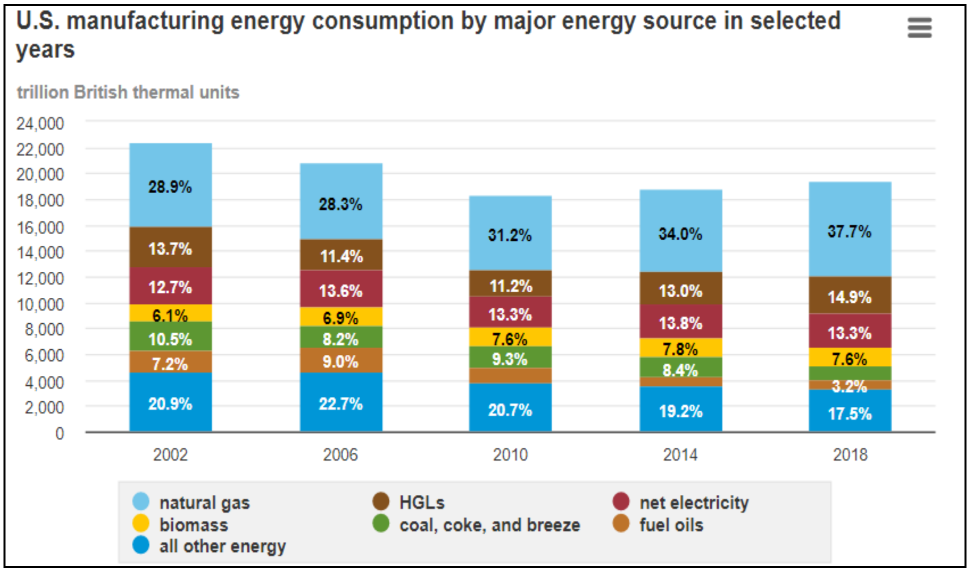


Figure 1.31: U.S. Manufacturing Energy Consumption by Major Source (EIA, 2022)

Non-renewable sources continue to dominate the industry as infrastructure, including technology, transportation, and optimization in consumption methods, have been molded around the industry. They are at the market, attainable, and provided at scale. Most industries purchase their power from electric utilities or power producers. Others generate electricity through residue or scrap from their industrial processes.

Current Manufacturing Energy Profile

As of 2023, the Industrial sector continues to dominate energy consumption within the United States. Most of that energy is produced through fossil fuels, as shown in *Figures 1.32 and 1.33*.

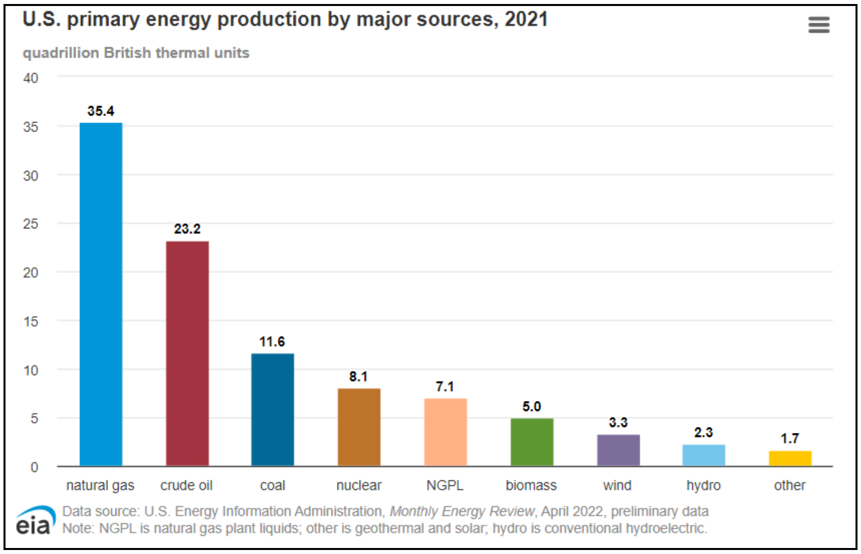


Figure 1.32: Primary Energy Production by Major Sources (EIA, 2022)

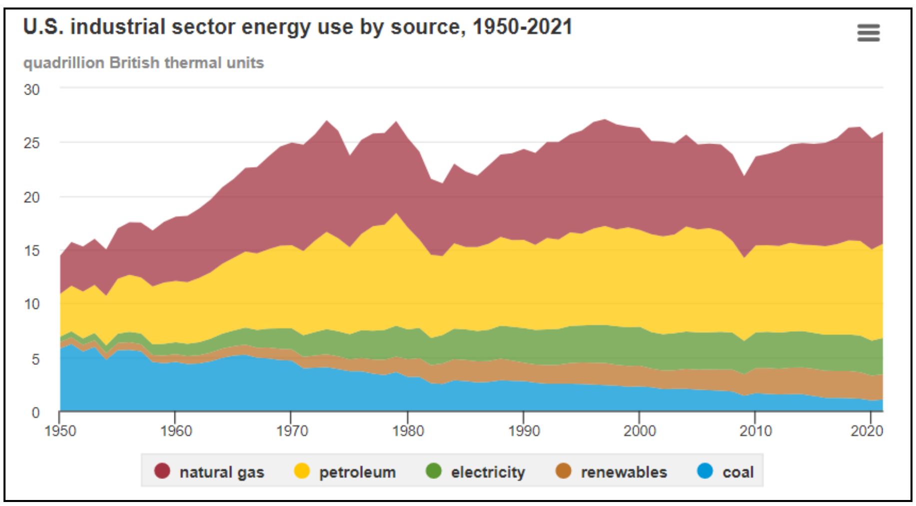


Figure 1.33: U.S. Industrial Sector Energy Use by Source (1950-2021) (EIA, 2022)

Six sectors within the manufacturing industry are responsible for nearly 90 % of all end-use consumption. These include chemicals, petroleum, and coal products, paper, primary metals, food, non-metallic mineral products, and all other manufacturing. *Figure 1.34* shows that 25.9 % of 73. 5 quadrillions BTU are consumed through the industrial sector.

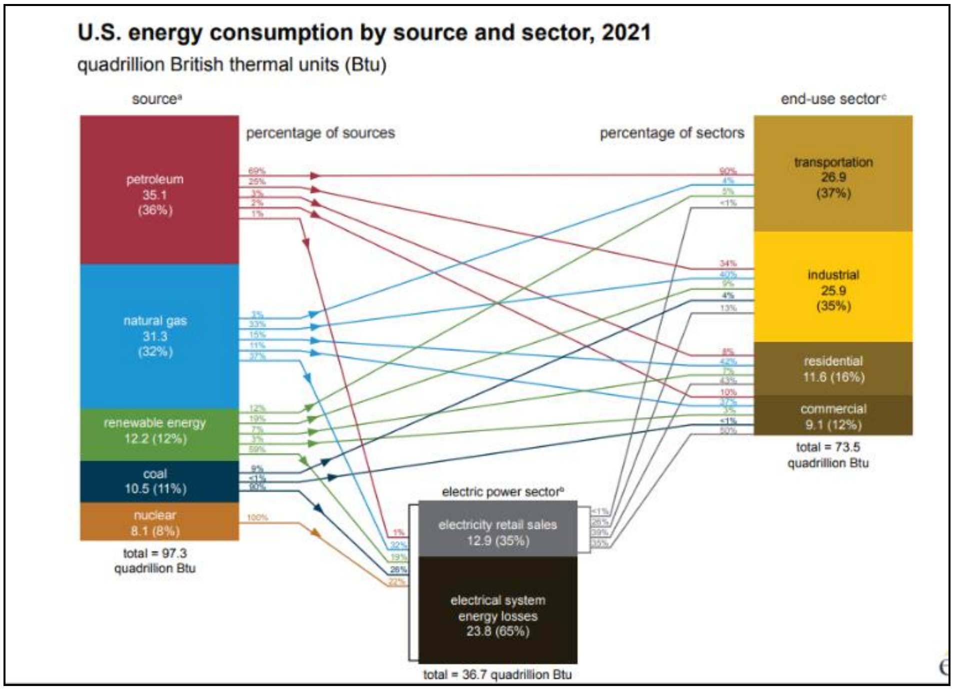


Figure 1.34: U.S. Energy Consumption by Source and Sector 2021. (EIA, 2022)

As technology and cost-effectiveness continue to become favorable to renewables, the manufacturing industry will have to adapt its core processes to adopt alternative energy sources.

<u>Energy Consumption Today and Projected</u>

The manufacturing industry has slightly declined over the past five years, around 0.4 % year over year (IBIS, 2023). However, projections show that energy consumption and subsequent emissions will rise through 2050, as shown in *Figure 1.35*.

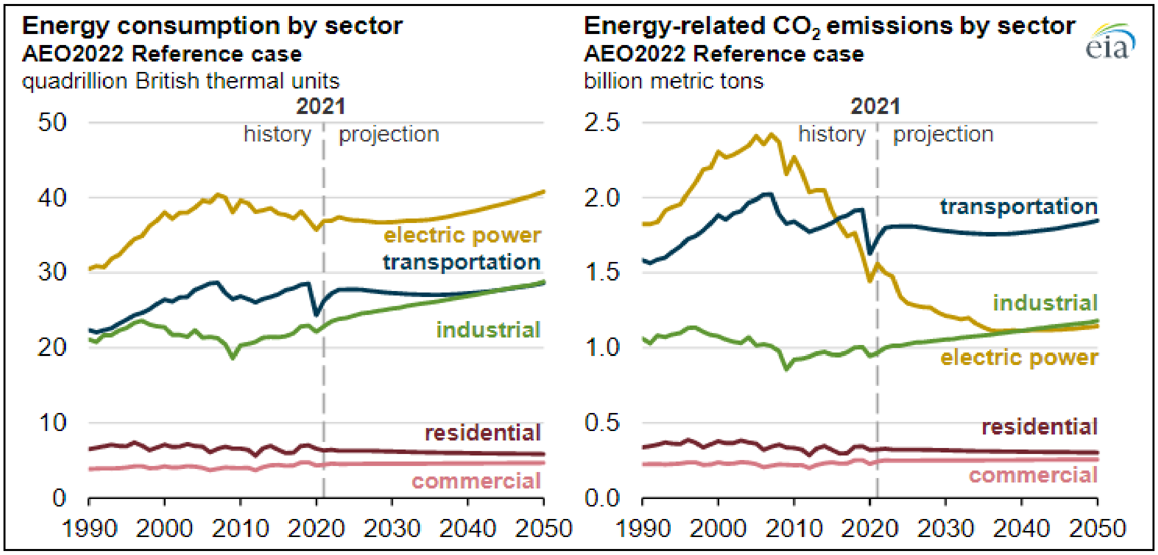


Figure 1.35: Annual Energy Outlook 2022 (EIA, 2022)

Projections show that the mix of energy sources favors renewable energy gaining a more significant portion of overall energy production and consumption in both OECD and non-OECD countries due to technology cost improvements and favorable government policies. The detail is displayed in *Figure 1.36.*

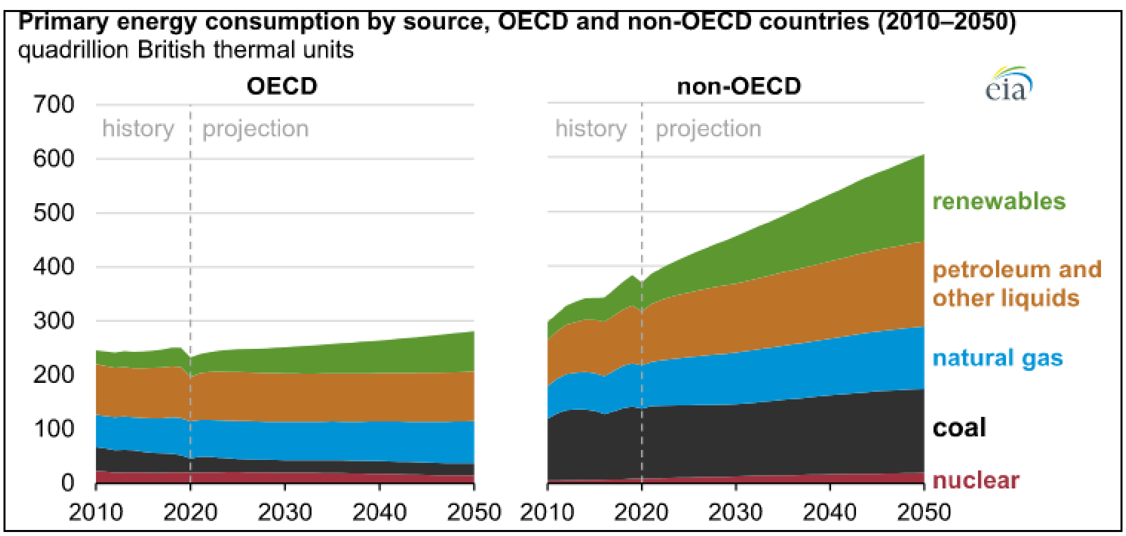


Figure 1.36: Global Primary Energy Consumption by Source - 2010-2050 (EIA, 2021)

The contribution to climate change from the industrial sector is significant. To this point, our findings can be summarized in 5 key points.

1. Climate change is a real problem that we are facing.
2. Human factors are the top contributor.
3. Carbon is the leading cause of climate change.
4. The United States is a leader in emissions.
5. Manufacturing in the United States and the World is a top contributor and an important sector to focus on.

An initial analysis into understanding and measuring the effects and potential impact of minimizing emissions within the industry is imperative to continue efforts. This will give justification to exert resources and continue fighting the war against climate change.

1.6 Impact to Climate: Can the Manufacturing Sector Positively Contribute?

It is crucial to fully understand what effect the manufacturing industry can have in minimizing unfavorable temperature changes based on de-carbonizing the sector. In order to do this, baseline data is used from the previous sections to analyze the impact of carbon emissions on temperature from the manufacturing sector both within the United States and globally. Two critical systems will be analyzed as justification to further the research. If accepted, they will continue to be used as guidelines through the research set forth to strengthen the integrity of the literature reviews, case studies, and current state of the art. This will allow for quantitative analysis to be conducted and measured to give a realistic depiction of activity impact.

The first system is a series of equations, utilizing data consolidated from critical points throughout the first chapter to put the potential temperature effect from manufacturing in perspective. The second, EN-Roads policy simulation software, will be used to test against scenarios applicable to the capability of the manufacturing industry both with intervention and without intervention.

<u>Equation Scenario</u>

This simple analysis does not consider equilibriums, oceans, or biomass as carbon collectors. A standard conversion factor converted parts per million CO2 to GtC of carbon. An equation for human-induced global warming by the Environmental Change Institute Group was utilized. (GWI, 2023)

Equation 1.3

$$\Delta T = k * (E + \Delta F / \alpha)$$

In the equation, K is the transient climate response to emissions at 0.4 °C per trillion tonnes of CO2 (NASA, 2022). *E* total cumulative carbon dioxide emission over a time interval is represented. ΔF is the impact of any change in global energy imbalance due to other human influences. α is the "Normalized Absolute Global Warming Potential" of CO2 (about 1.0 Watts/m2 per trillion tonnes of CO2 (Schlanger, 2017).

Table 1.12: Simple Analysis of Carbon (Brulle et al. 2012) (Hafner et al. 2022)

Description	United States	Global
Manufacturing Companies	0.59 Million	10 Million
Annual Carbon Emissions (GtC)	1.1 GtC	15.0 GtC
Carbon (2.13GtC to 1PPM)	2.1	2.1
PPM by Year (Ann. Carbon Emissions/Carbon)	0.5	7.0
PPM to Temp. change	450	450
°C (2°C /450PPM) 1PPM = .004 °C	0.004	0.004
Temperature effect from Manufacturing (Annual) * (PPM/YR * °C)	0.002 °C	0.031 °C

Temperature effect from Manufacturing (0 change to 2050)	0.1 °C	0.9 °C
Temperature effect from Manufacturing (0 change to 2100)	0.2 °C	2.4 °C

As displayed in *Table 1.12*, a high-level, simple analysis shows that based on the current output of carbon emissions across domestic and global manufacturing companies, an annual temperature effect of 0.002 °C in the USA and 0.031 °C globally is happening. When projected across 2050, greater than 0.1 °C in the United States and 0.9 °C globally. When projected across 2100, greater than 0.2 °C in the United States and 0.9 °C globally. Equations are written in full below to support *Table 1.12* understanding.

Annual Carbon Emissions (GtC) = 1.1

Carbon to PPM Ratio (2.13 GtC to 1PPM) = 2.13

PPM to Temperature change (450PPM = 2 °C) *See below IPCC equation (Ramaswamy et al., 2018)*

Equation 1.4

$$\Delta F = 5.35 \ln (C/C0)$$

This model aims to give an image of the impact of global temperature change contributed by the industrial sector based on metrics chosen as inputs from current data. This model image shows us that the manufacturing sector, along with the industrial sector as a whole, impacts temperature change.

PPM to temperature change for this model is considered at 450PPM to equal 2 °C. If concentrations exceed this, for example, to 550PPM, and considerations of sinks are not considered, the result would move towards a 3 °C state. Improvements to this *model could include actual PPM measurements taken across time to project temperature change more precisely going forward. Other additional variables could include a carbon sink or offset factor based on reliable data sets to strengthen the use case of the model.*

U.S. Manufacturing Impact

PPM by Year = 1.1 / 2.13 = .52 PPM

Temp effect from US manufacturing annual = 2 / 450PPM * .52 = 0.002 °C

Temp effect from US manufacturing 2022-2050 = 2050-2022 = 28 * 0.002 = .06 °C

Temp effect from US manufacturing 2022-2100 = 2100-2022 = 78 * 0.002 = .18 °C

Global Manufacturing Impact

PPM by Year = 15 / 2.13 = 7.0 PPM

Temp effect from Global manufacturing annual = 2 / 450PPM * 7 = 0.031 °C

Temp effect from Global manufacturing 2022-2050 = 2050-2022 = 28 * 0.031 = .88 °C

Temp effect from Global manufacturing 2022-2100 = 2100-2022 = 78 * 0.031 = 2.44 °C

EN-Roads Simulator Software

EN-Roads aims to simulate the impact of over 30 policies. Climate Interactive, MIT Sloan Sustainability Initiative, and Ventana Systems developed the software. Its backbone is a systems dynamics model related to what we built in our dynamics courses at UND. It is a free software tool available to individuals and businesses to help connect what they care about and how to promote a resilient future free of pollution.

The main goal is to teach and equip business leaders, officials, and leaders with knowledge so that rationale-guided choices can be made that have a positive impact. This software will mesh well with the equation model in the previous section and subsequent research that needs validation to further a positive impact.

Three scenarios, displayed in *Figures 1.37, 1.39, and 1.41*, will be chosen for the justification section of this study. The first scenario is a business-as-usual approach or current scenario. If we do nothing today, what will the outcome be? Key inputs were not adjusted from the current pace. The results are shown in *Figure 1.39*.

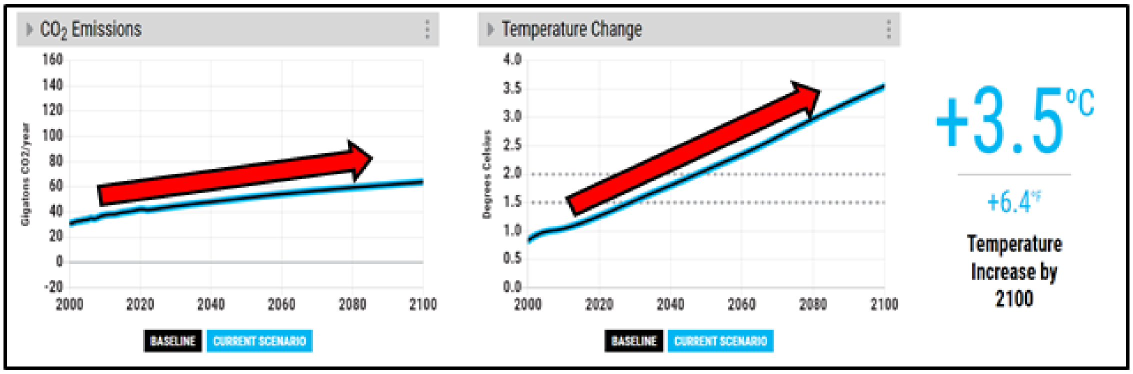


Figure 1.37: Scenario 1 – EN Roads Simulation (Climate Interactive, 2022)

This output aligns with *Figure 1.6*, showing little to no activity, incentive, legislation, or policy improvements. The resultant effect is that there will be a significant amount of additional deaths incurred in the future as a result of extreme heat, as shown in *Figure 1.38*.

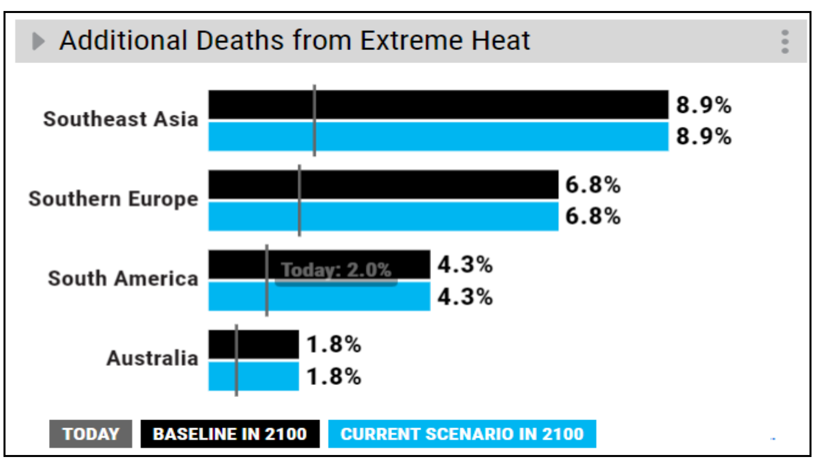


Figure 1.38: Resulant Deaths from Scenario 1 (Climate Interactive, 2022)

In scenario 2, I chose to adjust variables that would apply to the manufacturing industry based on research. The variables I increased included energy efficiency by incentivizing and electrification of buildings and industry. The results are shown in *Figures 1.39 and 1.40*.

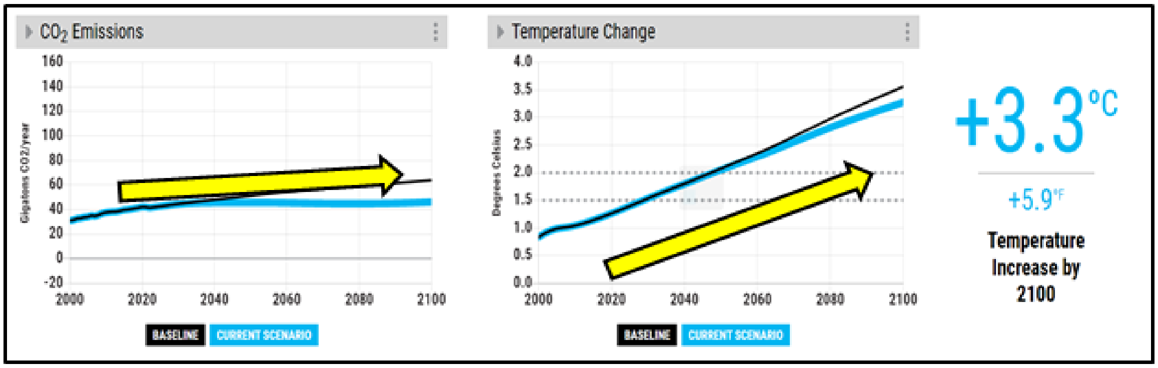


Figure 1.39: Scenario 2 – EN Roads Simulation (Climate Interactive, 2022)

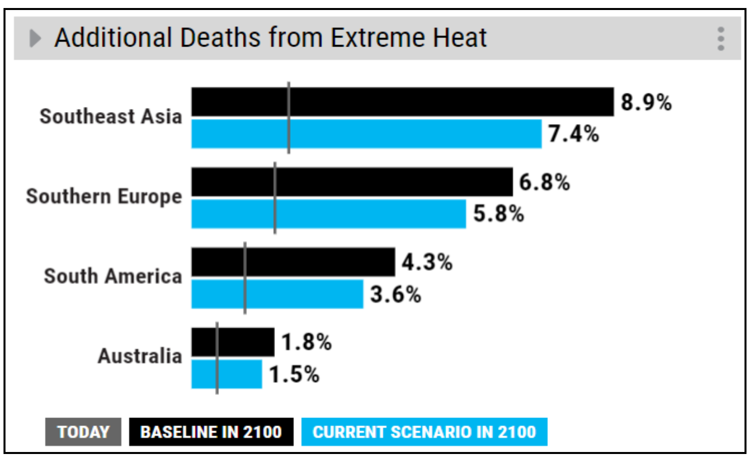


Figure 1.40: Resulant Deaths from Scenario 2 (Climate Interactive, 2022)

This is an improvement from scenario 1, as increases in energy efficiency and electrification positively affected climate change. The resultant deaths shown in *Figure 1.40* are still considered unfavorable, and more needs to be done.

Scenario 3 improves upon scenario 2 by fully incentivizing energy efficiency and electrification. Highly taxing coal while subsidizing renewables as an energy source was also adjusted in the energy supply category. *Figures 1.41 and 1.42* show the resultant outputs from the scenario.

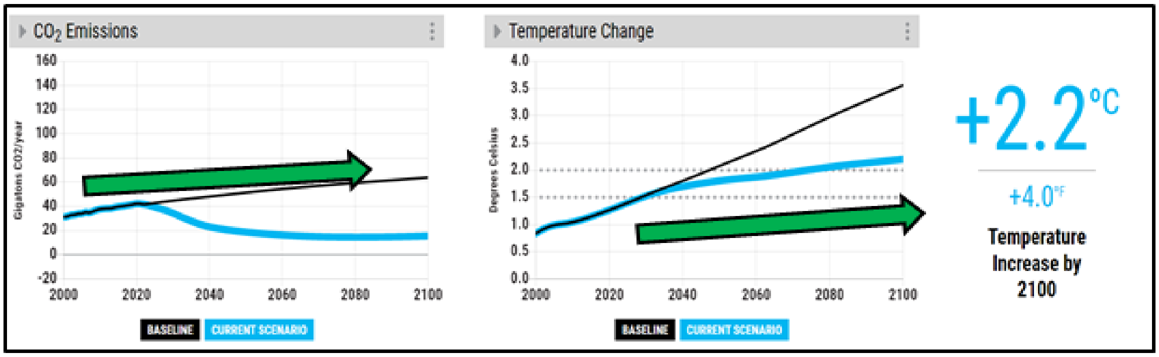


Figure 1.41: Scenario 3 – EN Roads Simulation (Climate Interactive, 2022)

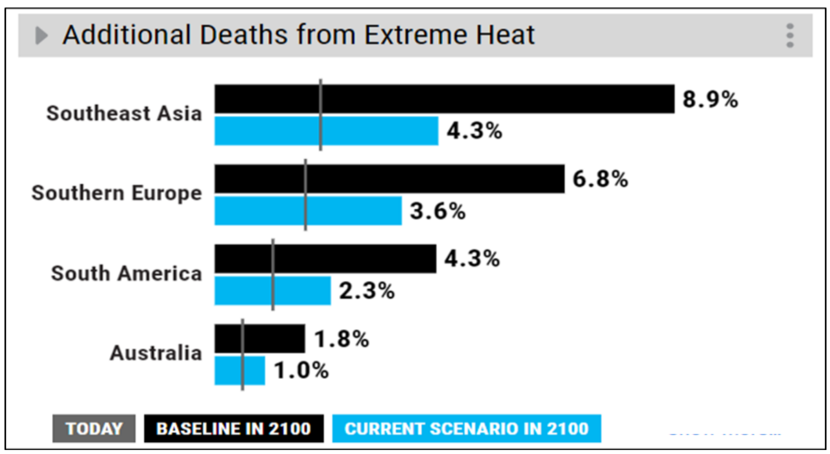


Figure 1.42: Resulant Deaths from Scenario 3 (Climate Interactive, 2022)

A high-level analysis of the EN-Roads simulation software shows that the current pathway to climate change correlates with *Figure 1.6*, showing which pathways are possible. In order to digress from the current path that climate change is on, we should maximize our efforts to incentivize favorable policy that does not harm others, and we should immediately start to act with an energy-efficient mindset in all sectors.

<u>Covid-19 – A Glimpse of Hope</u>

Covid-19 wreaked havoc on the world we once knew. Mobility, travel, and being social all abruptly stopped, threatening our way of life. The economy essentially stood at a standstill. The fear is instilled in the minds of many based on the unknown roads ahead. There was a silver lining. However, the limitations on travel and within the industrial and economic sectors showed a drastic reduction in air pollution and greenhouse gases (Rasmussen, 2021). It is essential to understand that circulating the economy through shutting it down is not feasible. The goal is to understand the effect on the environment of emissions reductions during this time and capitalize on it during stable periods of a heightened economy. *Figure 1.43* shows the effects that COVID-19, the lockdowns, and halting the churn of the industrial sector had on global emissions.

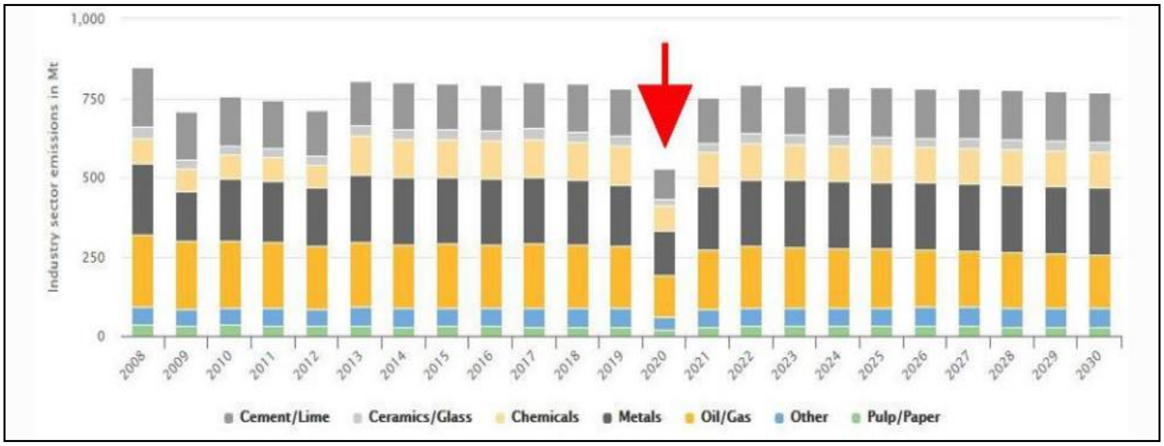


Figure 1.43: Industry Sector Emissions during COVID-19 (Fedinand, 2020)

Reductions show a potential decrease of around 30 % from simply shutting down. This is a rapid response to greenhouse gas emissions concentration levels. This change shows that it is possible to make changes that have immediate effects.

This further confirms the data models shown through EN-Roads simulation software and the equation models in previous sections.

1.7 Hypothesis & Theoretical Framework

The findings and background information to the problem presented in the research above aligns with the model and equation scenarios to justify generating a hypothesis.

This hypothesis denotes that carbon emissions in manufacturing facilities can mitigate global temperature change through efficiency improvements, process optimization, and technology advancements.

This is the basis of this research. A plan governed by a series of research questions aims to evaluate the hypothesis. This will allow for a holistic approach to testing the hypothesis. These research questions are presented as follows.

1.8.1 Research Questions & Objectives

1.8.1.1 Research Question #1

What are the major constraints in manufacturing that act as barriers to emissions?

Objectives

i. To *investigate the top constraints in manufacturing* that act as road blocks to emissions reductions.

ii. To evaluate *which variables have the greatest effect* on emissions reductions.

1.8.1.2 Research Question #2

Will deploying an increase in energy efficiency and new manufacturing techniques have an effect on emissions and business KPI?

Objectives

i. To *evaluate impact on emissions reductions* by collect data utilizing measurement tools through qualitative and quantitative measures.
ii. To *conduct improvements in energy efficiency* aimed at carbon emissions reductions.
iii. To *compare effects of improvements on KPI metrics* such as defect rate, short time stoppage, and equipment downtime.

1.8.1.3 Research Question #3

Do energy security and regulations in policy correlate to a positive or negative effect on emissions in manufacturing?

i. To *investigate policy* in accordance with energy security and sustainability.
ii. To *evaluate the current state and future projection of energy security* within the United States.

1.8.1.4 Research Question #4

Can deploying renewable energy have an effect on emissions and energy security?

i. To *explore current state renewable energy opportunities* within the state of Missouri.
ii. To investigate the *feasibility of deploying renewable energy* technology in the state of Missouri.
iii. *Evaluate improvements* and the *effect on business and emissions reductions*. Utilizing an adjacent business case study to authenticate the study.

In order to provide authenticity and justification to the research questions discussed above, an on-site project case study will be used to provide necessary data to align with theoretical concepts. In this study, a tier one automotive manufacturing plant in Missouri is developing a plan to transition into clean energy while transitioning into a net-zero carbon footprint.

The timeline, cascading down from global, country and state targets is to reduce emissions to 50% by the year 2030 while increasing renewables to 20% or greater, and to reduce emissions by 100% by the year 2050. These targets run alongside current profit targets and other industry constraints. Payback on many renewable technologies is not deemed to be advantageous in the interim as they can be costly and exceed return on investment guidelines developed by the corporation.

In an approach to balance and check the true potential of the EN-Roads software, each key area that is within the scope and control of the automotive industry is highlighted in each of these research questions. Ultimately, each area will aim to be tested and authenticate the hypothesis by providing in-depth analysis and output to each specific area.

1.8 Research Aim & Structure

The current pathway that the world is on results in climate change effects unfavorable to the Paris Agreement of 1.5 ℃. A review of current activities, case studies, and historical data sets shows that the manufacturing industry is a top contributor and emitter of GHGs, with carbon being the primary driver. This study aims at determining if the manufacturing industry can positively contribute to climate change through emissions reductions. In order to fully validate the capability, the research will be structured to give the reader a background of the problem and highlight the critical industrial manufacturing industry as a top contributor with the capability of making a change. Quantifying the sector’s emissions and temperature change by year with projections through 2100 is the next step, highlighted above. Exploration and scoring this opportunity will be done through 4 key pillars.

The first pillar aims to challenge and support this opportunity by identifying barriers to adopting a net-zero transition. Categorizing each into a matrix that tests the capability of each barrier against adoption will help to stratify the activity into focus areas of future improvement. This will be explored from the manufacturing perspective while focusing on adverse impact effects through energy security. The second pillar is to explore, experiment and deploy energy-efficient measures, utilizing principles in manufacturing favorable to reductions, such as lean manufacturing.

New manufacturing approaches will be tested and analyzed to improve energy and emissions reductions while remaining cognizant of materials and business limitations and opportunities. The third pillar will analyze, matrix, and test current policies and proposed policies stemming from pillars 1 and 2. The fourth pillar tests the feasibility of renewable energy integration as a primary energy source for the state of Missouri and the case study site. Ultimately, these four pillars will round out to test the feasibility of the manufacturing sector transitioning from its current pathway to a net-zero pathway.

This research is presented in nine chapters.

Chapter One contains a detailed overview of the current problem. The historical global temperature change across time was presented. An analysis of findings was discussed to show that in critical non-cycle points in recent history, the introduction of the industrialization period throughout the world significantly impacted both CO2 concentrations in the air and temperature changes.

This data cascaded into identifying the root cause between anthropogenic and human factors. Analysis showed that human factors were the greatest factor during this period forward. From this point, an analysis of the critical sectors showed that world emissions from industry accounted for 15 billion tons of 37 billion tons annually. In the U.S., manufacturing has a significant footprint, to the effect of 1.1 billion tons of emissions, equating to 3 % of the total world emissions. It was noted that this sector could move the earth’s temperature significantly, as displayed in Table 11. This leads to the hypothesis presented in the previous section, which indicates that reducing carbon emissions in the manufacturing sector, energy efficiency improvements, process optimization, and technology advancement can mitigate global temperature change.

Chapter Two contains a detailed overview and literature assessment of the current problem. Reviews of scholarly journals, books, and other relevant sources are presented to highlight the current state of art in research. Clarity and focus are brought to the research problems and identifying the gaps in knowledge that the research set forth will address. From this point, a reasonable and appropriate methodology will be set forth.

Chapter Three presents the research methodology, aim of the research, contribution to the sector, and structure of the subsequent chapters. Research questions are also presented in this chapter, aiming to challenge and test the overarching hypothesis to understand the potential to change and the feasibility therein.

Chapter Four takes a deep dive into the theoretical and qualitative framework by exploiting the barriers presented in the industry. Understanding the proper factors affecting the industry is critical for current and future activity generation. Focus points include influencers such as workforce and automation, cost, materials sourcing, and types. A matrix highlighting which barriers have the most effect against transitioning is then utilized to support the objective and give an accurate analysis. This paves the way for the need for a pilot study that will be the focus of Chapter 4.

Chapter Five is the heart of this study, providing experimental and conceptual data to fully understand the potential for a net-zero transition today, deploying activities at a manufacturing facility in a case study format to test the ability to transition. Industry-available tools and analysis metrics are used to test energy efficiency activities and their impacts. Management and control software utilization is introduced from a sustainability aspect to curb regression of positive impacts through activities. Experiments are conducted to test material types following clean and green technologies against current materials choices. Feasibility analysis studies are then utilized to test for cost, quality, and market readiness.

Chapter Six aims to heighten awareness of the current state of energy security by exploring gaps to a net-zero transition through a glimpse into the current state of energy security. The United States is the primary subject of the evaluation and how it affects the critical manufacturing industry. Exploration of the effects of business KPIs on emissions effects stemming from activities generated is also considered. Internal, state, and government policies today and into the future are explored to give a reasonable understanding of how areas in taxation, regulation of emissions, and technology adoption will have at the local, country, and potential world levels. In support, Chapter 4 shows the need for energy security through renewable energy and to remain competitive in the market.

Chapter Seven explores the use of renewable energy technology as a primary means of energy consumption. A feasibility case study conducted by the author at the state level, and is translated to the plant level. Solar panel technology is also explored as a pilot project for future-scale deployment.

Chapter Eight summarizes the findings and results from **Chapters 4, 5, 6, and 7.** An exploratory and conceptual approach is used to identify critical variables and favorable policies for the sector to approach net-zero emissions further. The testing method includes using EN-Roads, and researcher-generated equations and simulations.

Chapter Nine provides an overarching conclusion to the previous chapters' work, summarizing opportunities and shortfalls of the industry to provide a reasonable assessment and contribution to the overall hypothesis. An exploratory and conceptual approach is used to identify key variables and favorable policies for the sector to approach net-zero emissions further. The testing method includes using EN-Roads, and researcher-generated equations and simulations. Limitations from each core component of the research and opportunities for future research are discussed. General application to industry and the probability of global adoption will be assessed and analyzed across the entire sector to round out the results and conclusion of the research.

1.9 Research Significance

There has yet to be a collective strategy for achieving net-zero emissions that can be applied to the whole automotive manufacturing industry and cascaded into a unique strategy for every facility. The optimum renewable energy source or transition strategy has yet to be identified in any particular way. Grid connections, stability, and storage options all need to be analyzed.

Research is broad and not specific to manufacturing companies only. My proposed research will examine reduction, transition, optimal methods, and timing to meet industry and company goals. The goal is to create an industry vessel that can be used efficiently and effectively to allow for a transition to net-zero emissions. The outcome will be to research, analyze, improve, and control key metrics for a sustainable transition into net-zero emissions while meeting company milestones and maintaining regulatory compliance. Ultimately, understanding the role that the industrial manufacturing sector plays in the impact of climate change will be presented and challenged through approaches listed in the methodology listed above.

The faculty I chose to guide me along the way holds extensive knowledge within the energy and industrial sectors. Through their leadership, I can contribute to the sector I work in while offering the industry a strategic and methodical approach, visible to all through the lens of theoretical and experimental research.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

The manufacturing sector contributes to greenhouse gas emissions, the leading cause of global temperature change. In a simple sense, we know the problem but need help understanding it, as there is a gap. Companies, and the world for that matter, still need to prioritize emissions reductions. Some are waiting for regulations and subsidized assistance in order to progress forward. This presents three critical points.

The first is that there is no complete trust in the effects of temperature change. Studies are vague, there is no uniform consensus, and actors advocate for both sides. The second is that some companies may believe that by improving their emissions, an impact could even be made on global temperature. Data collections are limited. The third is that the pathway needs to be clarified, policy is not in place, business practices do not lend to emissions or energy efficiency being a top priority, and technology is not at market and reliable.

The cost and infrastructure of putting emissions reductions as a top priority is out of reach. This is the basis of this research. In order to understand if emissions reductions can have an impact favorable to companies and the environment, it is vital to investigate critical areas that are within the scope of manufacturing companies.

2.2 Review of Literature

What has been done?

Many nations are indeed experiencing catastrophic flooding, heat waves, wildfires, and droughts above the normal, creating severe damage (Pascaline et al., 2018). It is easy to see this effect by remaining in tune with the world. As of this writing, it is estimated that nearly 25 % of Fortune Global 500 companies have committed to reducing their net greenhouse gas emissions to zero by 2030 (FormaSpace, 2020). This commitment is the first step.

A preliminary literature review shows that past studies primarily focus on energy management reductions. Toolkits are available for facilities to use as guidelines. In this literature review, the following areas will be examined and summarized.

1. Public opinions about energy transition
2. Energy efficiency in manufacturing
3. Financial feasibility of reductions in emissions
4. Impact of policy and legislation on industry transitioning
5. Clean energy in industrial manufacturing & the ability to meet demand
6. Available transition tools and pathways

This is a significant step in moving towards net-zero emissions, understanding what has been done, the gaps, and how to improve to meet targets collectively.

Review of Public Opinions on Energy Transition

Based on studies from research (Brulle et al., 2012) and (Thomas et al., 2022), public perception is that there is a pessimistic evaluation of the future of the oil and gas industry. This is not limited to only the U.S. According to (Corner et al., 2011), public attitudes have been deeply divided. A high worry about climate change and energy security has become important (N.F. Pidgeon et al., 2008). Determinants of this opinion are based on age, gender, and education level Brulle et al. (2012). One such finding by Van der Ree (2019) shows that there is support for low-carbon forms of energy when the public believes the greener industry creates jobs or revitalizes the economy.

Future customer expectations are likely to require clean energy. Findings from research by Fischetti (2013) show that the public opinion is that transition poses a substantial cost, potential job loss, and education changes. A hybrid transition may be beneficial. (Thomas and McGrath, 2016) found that pre-existing values and beliefs about the economy will shape the landscape of the future of clean energy.

Improvements to the economy from the energy transition will be hard to impress those with hope for fossil fuels (Tvinnereim et al., 2016). A 2005 National Association of Manufacturers poll revealed that 93% of directors from small and medium-sized manufacturing companies believe that higher energy prices harm their bottom line (Brahim, 2009). Arshed et al. (2022) found that it is true that societies legitimize their beliefs or embedded values and actions based on their consumption patterns or lifestyle.

Energy Efficiency in Manufacturing

According to (Konstantinos & Ball, 2013), energy efficiency has grown in the manufacturing field. It is considered a prime decision-making factor along with productivity and cost (Menghi et al., 2019). Interest in energy management has grown considerably (Zhu et al., 2017), and several case studies are available highlighting this achievement. A systematic approach was proposed by (Shi & Meir, 2012) to assess carbon emissions and identify production planning and operation procedures.

An example of success in lean and energy comes out of Wisconsin. Eck Industries, Inc., established in 1948, is a family-owned business operating in the aluminum foundry, making aircraft cylinder heads, military equipment, and other specialty parts. The company employs 250 people and operates in a 200,000-square-foot facility. Throughout the years, the company has established itself as a “world-class producer of castings.” Lighting improvements were not always on the radar for Eck Industries. As they evolved through the years, technology in lighting did as well. Some years were strewn with insufficient working capital to cover the initial investment, the payback was not quick enough, and the technical resources to install were unavailable.

To overcome these hardships, they worked with their state organization to collect data through light meters, analyze the findings, and determine appropriate solutions. They went from 360 high-pressure sodium fixtures to the same amount of fluorescent lights, with motion sensors for low-traffic areas. Results from the improvements included $70,000 spent on the upgrades with a state rebate of $33,000. Lighting levels were improved to appropriate quality levels, and electricity consumption levels were reduced by 675,000-kilowatt hours per year. Bonus savings included reducing carbon dioxide emissions by 443 tons per year. It was estimated that $55,000 was saved annually on the upgrades with an ROI of 8 months. *Figure 2.1* shows an example of “energy savings based on an individual fixture” that can be useful when calculating a project for return on investment.

Return on investment	Fixture cost difference	Energy Difference	Annual Energy Savings	Payback (Years)
Upgrading from Incandescent to LED	$120.00	80	$41.93	2.86
Upgrading from Halogen to LED	$85.00	55	$28.83	2.95
Upgrading from CFL to LED	$30.00	22	$11.53	2.60
Upgrading from MH to LED	$0.00	19	$9.96	0

Figure 2.1: Lighting types and respective ROI (USAI, 2015)

Each case study highlights that a tremendous lean program can translate and mesh perfectly with energy management. The toolkit between each is very similar, and with a sound system in place, some opportunities will improve profit levels and help the environment simultaneously.

<u>Review of Financial Feasibility of Reductions in Emissions</u>

Roadblocks include long-life capital projects for existing plants, showing that transitioning fully may not be financially feasible. New plants show the need for further technological development to ensure, for example, the chemical industry (Samji et al., 2022).

Manufacturing processes such as die casting are old and energy intensive. Reform is needed in the manufacturing process sector, and Ma et al. (2020) stated that energy demand response is a crucial factor for cleaner production. Investors and stakeholders can show that clean technology will have increasing returns. Policy and legislation are imperative to prevent carbon lock-in to current dominant technologies and pave the way for renewable energy commercialization (Unruh, 2000). Previous studies from (Stavropoulos et al., 2022) highlight that applying digitalization and energy efficiency is the answer to a company’s need to become more attractive. The study also notes that training the workforce and aligning the framework with trends shows positive results.

Review of Policy, Legislation & Energy Security on Industry Transitioning

Scientists agree that climate change is occurring (Klare, 2020), and the role of what drives it is understood. On the global stage, economic recovery, energy affordability, and energy security are issues many governments face today (Basseches et al., 2022). Government incentives, however, have recently been shifted toward relief from the pandemic (Birol, 2020)

In the U.S., new and amended policies show significant investment in clean energy, with greater than $140B allocated from public spending (EPT, 2021). One monumental initiative is the Inflation Reduction Act which adds $369 billion over ten years (EPA, 2022). This aims to reduce emissions through domestic manufacturing, expand tax credits, and create jobs. Over 936k jobs over ten years, as well as securing domestic supply chains (EPA, 2022). Expand clean vehicle manufacturing and attach domestic production incentives to clean energy and vehicle tax credits. The critical points of this initiative are listed below.

- DOE $58M to 30 projects aimed at de-carbonizing the industrial sector.
- $1B for a Clean Hydrogen Electrolysis Program
- Trade policy to reward clean manufacturing – Steel & Aluminum industry

Energy security is essential as the nation's energy system is constantly threatened by cyber and physical attacks. State legislatures and lawmakers will lead the way in years ahead (NCSL, 2022)

The issue of energy security within the United States has been addressed extensively throughout the last decade. In the 1980s, the Energy Security Act was signed by President Jimmy Carter (Public Law, 1980). This consisted of renewable, synthetic fuels, solar, geothermal, and ocean energy conversion acts. Throughout the years, the U.S. Department of Energy has reported the valuation of energy security to Congress.

They focus on policy within each sector, followed by considerations, objectives, and integration to and from competitive markets. The EPA has assisted throughout the years in environmental regulations (EPA, 2022) (Kepner, 2016). Emissions, pollutants, and contaminant levels have each been considered and regulated, which have promoted positive adjustments in energy security.

In the private sector, the Research and Development Corporation, RAND, has explored options to improve energy security due to smaller nations' economic, social, and geopolitical concerns (Schill, 2022). These concerns stem from the fact that the world's oil and gas resources are confined to smaller nations. Options are being explored to improve security in energy through alternative and renewable energy sources. Anu Narayanan, an engineer at RAND, is researching critical infrastructure and national security. Her work includes helping the military assess and build resilience to various risks to missions and installations. A recent work of hers includes investigating the potential threat of a cyber-attacker taking down the power grid and the implications and issues that would follow (RAND, 2021).

Shoki Kosai and Hironobu Unesaki wrote a study on energy security within the United States. This study aimed to evaluate the security of the nuclear energy supply in the United States. Highlights within the study include the security of the nuclear energy supply within the U.S. Findings showed that the nuclear energy supply security in the U.S. seemed to improve, and the methodology for evaluating security in the U.S. nuclear energy was developed (Kosai & Unesaki, 2020).

According to (Hoang et al., 2022), there are many individuals at both the national and private levels researching the latest trends and developments in energy security. This is due to tremendous pressure from the pandemic. For our nation to become bullet-proof in energy security, we must keep the topic at the top of our nation's priority list regardless of who is in office and the overall political agenda.

We are still amid the effects of a global pandemic that has changed the way we interact with each other and has ultimately limited our mobility. The effect on energy use and energy production is rapidly changing. Travel has slowed in air, sea, and land. The ripple effect has had tremendous impacts. This way of life could end up being our new normal. The goal of energy security in the United States does not consist of energy created within its borders without trade. It consists of being flexible, diverse, competitive, and redundant.

Clean Energy in Industrial Manufacturing

Resources are available, but each is at a different level of maturity and is continuously being revised for technology and feasibility at scale updates (Hafner, 2020). Energy storage can help to level those gaps. Geographical contexts will impact the choice of technology during the decision-making process. A systems management approach to manage technological limitations can have positive effects in one area but adverse effects in others (Van der Ree, 2019).

Nuclear energy has high capability, but has social perception issues that need resolution. Past incidents such as Three Mile Island have scarred the public's perception. Renewable energy sources have high capability, but resolve is needed for around-the-clock reliability. In manufacturing, high-heat processes and chemical reactions make it challenging to electrify fully (CAP, 2021).

In order to energize the manufacturing sector and the entire supply chain, reliable resources are necessary. Renewable energy technology is available, but only in some places. Smart grids can help to bridge the gap. However, microseconds of outage can cause wasted product, equipment damage, and downtime. This costs companies a large amount of money. Shifts among multiple power generation and end uses are one way to alleviate the risk (Geneau, 2021).

From a cost standpoint, reform in infrastructure is slated to add $2 million in upgrades to the U.S. infrastructure by 2030 to maintain utility grid reliability (CAP, 2021).

Demand is high, and a reasonable economic strategy in critical areas of supply chain management, diversification of resources, material efficiency, grid resiliency, and on-site microgrids will help to meet targets.

A 2019 study on the modern state of wood biomass showed that a multi-stage thermal chemical biomass conversion is the most promising gasification technology (Kozlov et al., 2019). There are roughly 160 projects currently within the Organization of Economic Cooperation and Development (OECD) countries, utilizing fluidized bed reactors, and layer gasification, used in 38 projects. Thermal and electrical energies are driving factors for biomass gasification technology. Economic efficiency is shown through the levelized cost of energy. Results show that wood fuel's electricity cost is 2.5-3 times less than a diesel power plant (Kozlov et al., 2019).

The Environmental and Energy Study Institute held conferences on high energy costs, struggling rural communities, low investment in resilience, and the solutions created at the community level. As many smaller farms struggle to remain financially viable against manufacturing or super farms, the overall bio-economy is at risk. Farm income is down by almost

50% from 2013 (Arthur, 2020). Job retention and attraction have been difficult. Trade disputes, flooding, and grant waivers to small refineries have been somewhat crippling in the Midwest. Biofuels can play an essential role in reversing harmful pollutants from emissions through renewable fuel standards, blending ethanol into gasoline, low-carbon fuel programs, land restoration projects, and utilization of renewable energy sources (Arthur, 2020).

The three major types of pollution that cause harm to our environment are air, water, and land pollution. Examples of water and land pollution include commercial or industrial wastes, such as medical waste or construction materials (Danish and Ahmad, 2018). An example of air pollution would be exhaust from a vehicle or greenhouse gasses emitting sulfur or carbon dioxide. Data suggest that more than 2 million people are killed yearly by air pollution alone (Bradford, 2018). Exposure to pollution also causes lasting effects on our health, such as aging of the lungs, and environmental effects, such as temperature increase resulting in global warming.

Energy initiatives are only sometimes at the top of the list regarding business cases for lean improvement activities. Most of the time, however, an improvement in lean inadvertently becomes an improvement in energy. In 2006, Boise Inc., a paper mill company in Idaho, utilized "assessment tools on steam systems to identify energy savings opportunities." Through value stream mapping the overall process and analyzing potential improvements, they were able to maximize efficiency within their facility. Benefits included achieving annual energy cost savings of more than $1 million, annual fuel savings of 150,000 MMBtus, and an ROI of less than one month. This list of improvements gave Boise Inc., and other paper mills, a new perspective and a catalyst to reduce and target energy waste in future projects.

Available Transition Tools and Common Pathways

The Department of Energy lists a de-carbonization roadmap that displays four key pillars to reduce emissions. The lean and energy toolkit provides Strategies and guidelines for merging lean and energy (EPA, 2022). Checklists, tools, and audits all help identify and improve greenhouse gas reduction activities. This shows that the EPA is invested in helping new and current industries promote energy conservation and efficiency.

They also provide greenhouse gas management tools and resources so companies can measure and improve (EPA, 2022). Green manufacturing has a carbon emissions reduction plan for carbon-intensive sectors, which includes manufacturing. Key drivers include electrification and the falling cost of renewable energy sources. Increased efficiency is the main driver in reducing emissions (CICC, 2022). According to the book "Energy Efficiency," improving the flow of product and input to the process can significantly reduce the amount of energy required to support a production process (Zambini, 2006)

Textbooks, Case Studies and Journal Reviews

The first book I looked at, available to the industry, is A Guide to Energy Management (Capehart et al., 2020), which focuses on guidelines to maximize energy efficiency. The following key points were takeaways from the reading.

- Guidelines for energy management that can be utilized in any industries
- Energy managers will never be short on work due to a continuous improvement approach.
- How to maximize profits and minimize costs, continuous improvement.

I then reviewed journal articles to understand the current state of the art better. Li et al. (2020) research reveals that the world will be challenged in reducing greenhouse gases and improving energy efficiency. The authors show rising energy consumption worldwide and compare country to country. International experience will help to expedite the world's efficiency and reduction rate. Learning from others' mistakes and victories will guide improvements. Restructure through policy and demand flexibility will allow for further advancements in renewable energy technology.

In another study by Hulshof and Mulder (2020), it was noted that there was no impact from renewable energy use on profit, tested at over 920 firms. However, data analysis shows that the correlation appears weak over four years. Objectives need to be validated to understand the true impact of environmental contributions versus financial objectives.

In a study by Martinez-Hernandez et al. (2020), the author showed how renewable energy can reduce greenhouse gases along with life cycle analysis costs applied and sustainable methods for renewable energy. This is rounded out by showing renewable energy as a viable source.

Case Studies included three studies highlighting improvements in energy efficiency measures and their impacts.

Case Study One - Energy Audit

Performed by the Sustainable Engineering Solutions at Tower One East. The retirement Facility is 20 stories, 268k square feet, constructed in 1969, and runs a 24-hour operation (SES, 2020).

The energy audit showed great potential; a summarized list of the findings is below.

- Dated facilities have great opportunities at all levels.
- Utilizing the DMAIC methodical approach allows for efficiency in findings, and short paybacks, controls, and equipment replacement are highlights.

Case Study Two – Natural Gas Reduction

In the second case study, an energy system upgrade allowed for natural gas to be reduced significantly. Highlights of the study are listed below (MMB, 2014).

- Large complex, high usage of natural gas.
- Equipment and operational improvements led to 140k savings in year one and a 25 % reduction in the overall use of natural gas.
- Part of the federal green challenge is to reduce the environmental impact. Minor improvements yield significant results.

Case Study Three – Natural Gas Reduction

In the third case study, energy conservation was highlighted through efficiency measures that resulted in savings of over $1 million dollars (OTA, 2020). Highlights of the study are listed below

- Less toxic alternatives and production process mods. This allowed for the reduction of 1.25 million pounds of trichloroethylene.
- Water consumption is down 70 %, equivalent to $242k in annual savings.
- The project included leak repairs, receivers/dryers, and a compressed air and lighting monitoring system.

2.3 Synthesizing Prior Research

We have discovered a problem with the earth's temperature change, mainly due to human activities. The manufacturing sector is a significant contributor but can also make changes. Through literature review, case studies, and research conducted, a summary of findings is essential to drive further research activity.

1. Economic feasibility and technology are the primary drivers. Constraints include buy-in at all levels from both the producer and consumer.

- Government and state legislation reform, incentives, and collaboration between key actors to drive positive change.

- Different transition pathways are possible without the need to "pay" for carbon credits

With the state of previous research, we should be able to capitalize on the primary drivers or constraints preventing emissions reduction in manufacturing today. However, there is an underlying issue causing the transformation not to occur. This will be explored in full in Chapter 4.

2. Energy efficiency and investment in new technology are critical. Local, state, and government support will be critical.

- Utilization of resources available today with the flexibility to adapt. High capital investment projects will need grant support to transition early.
- Primary power sources must reliably feed the energy needs of the most intensive industry.
- Financial feasibility of transitioning must focus on legislation, technology, and policy reform. Investors are uncertain without protection, including patent laws.

There are years of previous research and projects supporting positive improvements through energy efficiency and the deployment of new technology. The author agrees with this; however, there needs to be more in reading about the success of other companies and deploying a successful program at each facility. Energy still needs to be considered a main cost by many companies. This is the basis of research in Chapter 5.

3. Policy preferences and commitment must align with corporate strategies and deployment.

- Market design will become crucial to the energy transition's success in manufacturing.
- Investment in new technology must have the protection of interests.

Policy is critical in promoting a clean transition, according to the literature review presented above. It will help to align the pathway to the energy transition. However, consideration must be taken to determine if policy within the United States and *the manufacturing industry is favorable to emissions reductions resulting in an impact on temperature change. This is the basis of research in Chapter 6.*

4. Reliable and stable energy. Manufacturing is a primary consumer and an important economic driver.

- Focus areas on storage, grid reliability, recycling materials, waste and reduction methods, and new manufacturing techniques.

Renewable energy technology can provide a cleaner and greener future by utilizing resources that can be replenished. Infrastructure still promotes the use of fossil fuels. Studies are needed to further the advancement of renewable energy applications and the feasibility of deploying them. This is the basis of research in Chapter 7.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Introduction

The research aims to create a vessel for the manufacturing sector's clean energy transition through feasibility analysis. Assuming a positive result, energy reduction, renewable energy creation, and the development of systems guidelines will collaborate to create a transition portfolio applicable to the automotive manufacturing sector. The primary data source for this study will be an automotive plan in Missouri. The shop floor will provide actual data that will be used to test the hypothesis by way of three research questions. Potential impacts on temperature based on each key area will be explored. Each chapter will contribute to testing the overall hypothesis.

Table 3.1 shows the breakdown by chapter of the total impact from areas within the control of the manufacturing sector.

Table 3.1: Potential Impacts to Temperature (Contributed by Author: Ernst, Alec)

Chapter Addressing Research Area	**Impact Areas**	**Potential Max Impact of Global Effort at Year 2100** ***(EN-Roads)***
Chapter Four	Population growth Economic growth Other constraints	+ 0.3 °C
Chapter Five	Energy efficiency Improved processing methods	- 0.6 °C

	Fuel switch	
Chapter Six	Policies	- 0.7 °C
	Carbon price	
Chapter Seven	Renewables	- 1.1 °C
	Coal & other fossil fuel reduced	
	Afforestation	

Applying a carbon footprint to manufacturing

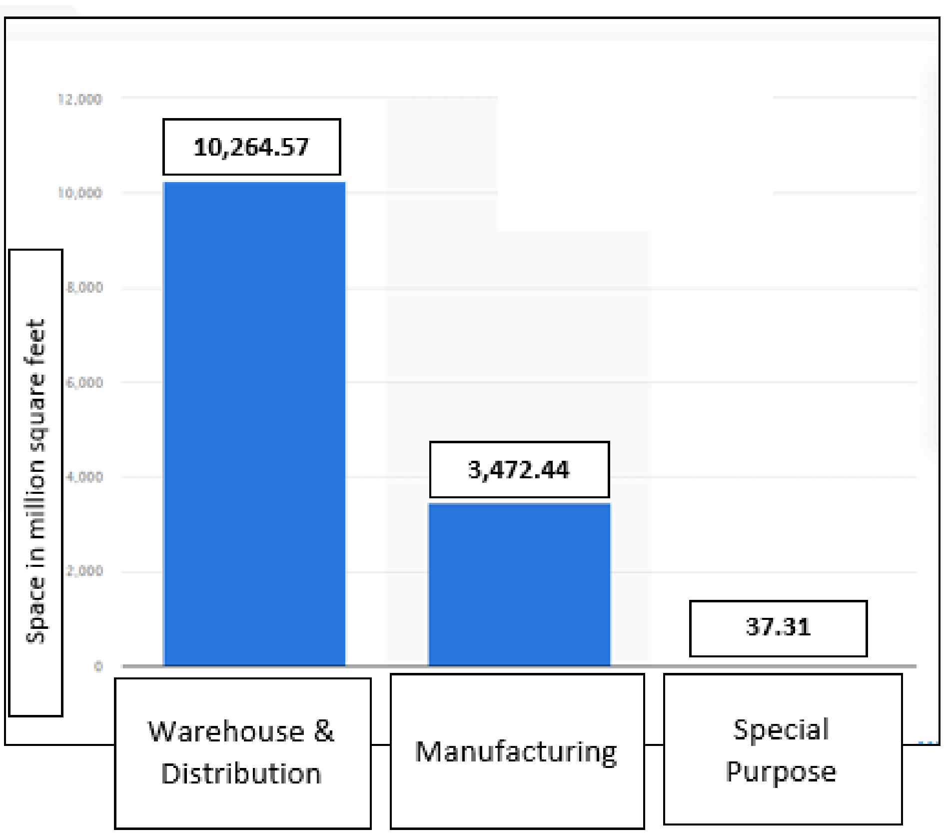


Figure 3.1: Total Square Feet of Manufacturing Space in the U.S. 2021 (Placek, 2021)

Total industrial space in the US = 4,536.32 million sq feet *(10 % warehouse and distribution) (This percentage was chosen based on the assumption that warehouse* *square footage is primarily for storage, with light industrial applications such as forklifts in use.)*

Total industrial emissions in the US = 1100 million tons of CO_2

Industrial emissions per square foot in the US = 0.242 tons of CO_2 / sq ft

Temperature Effect from Manufacturing Annual *(Table 1.12)* = 0.002 °C

Temperature change potential annual per square foot in the US = (0.002 °C)/(4,536.32 million sq feet)/1,000,000 = **4.41 X 10-13 °C/ sq ft**

The purpose of the simple model displayed in Figure 3.1 is to be used as a simple metric to understand the average potential impact that the manufacturing industry produces on global temperature annually. This model could be enhanced for accuracy to the industrial sector and individual facilities by adding variables such as industry type and total energy consumed by the facility.

3.3 Research Design & Procedure

The study focuses on optimizing transition methods to net-zero carbon emissions in manufacturing. The goal is to develop a streamlined playbook that allows for a stress-free, efficient transition across an automotive plant while maintaining shareholder commitment and profit structure. The methodology deployed within this study directly aligns with the research questions presented. Understanding and counter-measuring constraints and developing sustainable solutions during company, state, and world policy changes will remove barriers to emission reductions. Current industry practices, technological advancements, and reactions to this while remaining profitable are primary needs and keys to success. The research outline will be considered as follows.

Historical methods of solving the problem

Current studies are vague and are based loosely on facilities management and energy efficiency, which are very important when reducing consumption. The problem is that no foolproof method allows a company to change to net zero quickly. Data collection methods are limited to a broad understanding that deploying renewable energies will allow a company to turn green.

Most companies have relied on the Department of Energy or Environmental Protection Agency to determine what issues are relevant to them. As profits and businesses expand, emissions risk will ultimately increase based on current technology. Most companies wait to be told what to do through government or state policy. However, this has a crippling effect as most renewable technologies have been considered past the typical return on investment structure used by corporations. Developing a strict baseline data of consumption or

Research Philosophy

The research paradigm employed within this study is primarily from a positivist standpoint utilizing real-world data collected on-site in the year 2022 at a manufacturing facility and other manufacturing facilities within regions across the United States. This experimental, quantitative approach will utilize testing and experiments as primary collection methods. Examination of grounded theories will govern feasibility when outreaching capability or scope.

Research type

The research type is that of an inductive nature. Baseline data will be collected, and the approach will be exploratory regarding solutions. Theory and measurements will mix in to determine what is capable, what makes the most sense, or what is confirmed. The quantitative mixed method approach will allow for alignment to future policy and business optimization that will allow for strict key process indicators to judge the effectiveness.

Research strategy

The research strategy is primarily to utilize an experimental approach. This approach will collect baseline data and develop consumption and production of emissions metrics. From this point, an analysis of the impact of each and how they affect both the environment and the company's bottom line. Current renewable and mitigation techniques will be explored through case studies and feasibility studies previously explored by the author. These technologies will be analyzed and deployed to model cost and reduction scenarios across growth and time. This will ultimately give a vessel or scenario guideline.

Time horizon

The data for this study will be longitudinal, as it will be collected over a period of time, data will be extracted from the years 2015 through 2021, and real-time data will be collected in the year 2022.

Sampling strategy

Practicalities and resource constraints will be considered. Non-probability will ultimately be considered the ideal approach to sampling strategy as the data will be collected on-site. Consideration will be given when developing a model usable to all manufacturing plants.

Proof of Concept

In order to authenticate the research and to reasonably answer the hypothesis, a proof of concept is used through EN-Roads and Table 1.12. These will act as the governing methods to quantify the results of the research questions presented in the subsequent chapters. The framework for this methodology is shown in *Figure 3.2.*

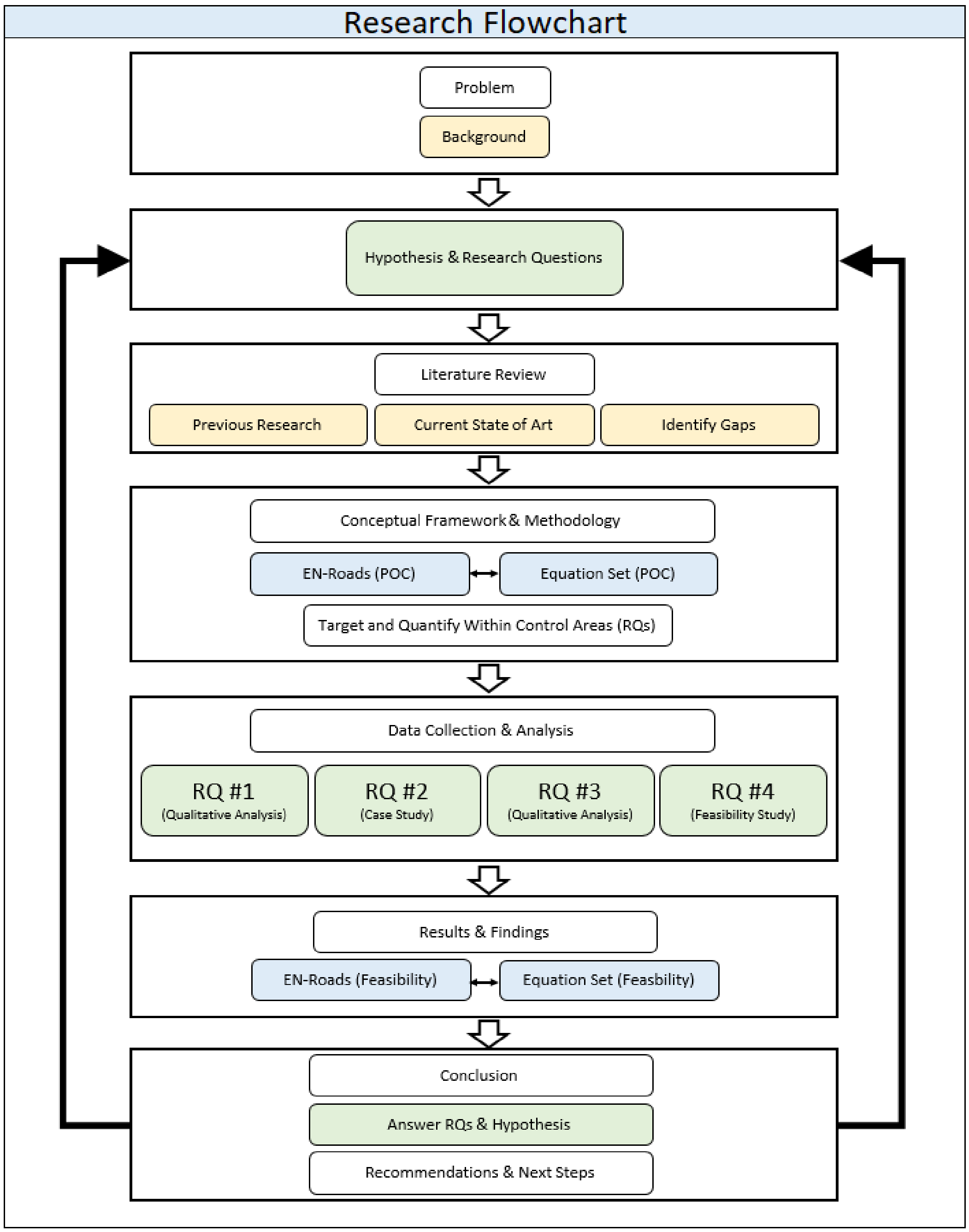


Figure 3.2: Research Flow Chart (Contributed by Author: Alec Ernst)

3.4 Data Collection & Analysis

Data collection method

Quantitative collection methods will be limited to available tools on location at the site. Calibration will be documented and deployed by certified individuals as possible.

Data Analysis Method / Techniques

In this quantitative approach, the data will be analyzed using a developed model to project the impact and the overall impact on the bottom line of emissions reduction and plant profit.

Limitations

The limitations of the study are as follows. The first limitation is where the data is being collected and where the work is being performed. This can create a sense of skewness based on industry, product type, and geographical location. Data may also show skewness based on statistical model constraints, time of year, plant health, and other underlying factors. Other limitations include sample and selection bias, time, and budget.

Assumptions

It is assumed that all responses, interpretations, and subjective thoughts, when expressed, are of the author's opinion and are considered truthful and honest. When possible, these opinions have been quantified through data collection.

Concluding summary

Figures of work, model development, deployment, and scenario to adjacent plant. This will show cost and impact and act as a streamlined vessel to realize net-zero emissions without paying for carbon credits or transferring work to another facility.

CHAPTER FOUR

4.0 Barriers: Constraints in Emissions Reductions

4.1 Introduction

To efficiently conduct the remainder of this study, the researcher aims to investigate the top constraints in manufacturing that act as roadblocks to emissions reductions. From this point, the *top variables with the greatest effect on emissions reductions will be isolated and discussed. This will allow for a pathway through the rest of the research.*

With the many advantages of reductions in emissions, some impacts could be considered unfavorable to a company's business model. Considerations should be made to understand the benefits and concerns and to analyze the challenges appropriately to implement countermeasures to reduce risk and negative impacts. This will affect both companies, technology, and the current and future state of emissions reductions. Within the following section, the researcher takes a deep dive into the constraints in the manufacturing sector that act as barriers to emissions reductions.

Focus points in the manufacturing industry include influencers such as workforce and automation, cost, materials sourcing, and types. To explore gaps in a net-zero transition, a thorough review of the current state of manufacturing constraints was considered.

Experiments are conducted to test material types per clean and green technologies against current materials choices. Feasibility analysis studies are then utilized to test for cost, quality, and market readiness. A matrix highlighting which barriers have the most effect against transitioning is then utilized to support the objective and give an accurate analysis.

4.2 Current State of Art

Although there are many barriers to emissions reductions in manufacturing, only five key areas will be considered in this study. These five significant areas are focused on the overarching aim of this study in order to generate results that tie into each research question and thus give a calibrated view of the hypothesis as a result. These five areas include the following.

1. Lack of awareness and education
2. Cultural resistance
3. Political and regulatory barriers
4. Economic and business considerations
5. Technological limitations

Each of these key areas extends past the reach of the manufacturing industry. However, this sector must analyze and contribute to each area's study as it is a significant contributor to energy consumption and resulting emissions globally. The following three questions will guide the systematic review this chapter presents to understand better the current state of art of barriers in emission reduction.

1. What is the current and possible perception of each barrier in relation to reduction emissions?
2. What are the factors that can influence change within the industry in order to positively impact emissions output?
3. Is it possible to categorize which area is the most important to focus on?

The first area under review details a need for more awareness. As both sides of the political spectrum drive media, it is imperative that a general understanding of the current situation is brought to light responsibly and truthfully.

In manufacturing, standardization is crucial to a quality, consistent product delivered in a mass production setting (Anatoly et al., 2021). This concept has been proven by many years of research and development and six sigma techniques in repeatability and reproducibility to meet customer expectations. When designing products, engineers are bound to cost planning which may promote a “lock-in” effect to current materials and technologies. Most commonly, these materials are chosen as they are readily available in the market at or below a desired cost. Drawing requirements can also dictate them, leaving the manufacturing plant bound to a material that may be energy-intensive to produce. Alternative materials are important to consider (Sizirici et al., 2021).

Other areas highlighting the need for awareness include energy efficiency, supply chain, employee perception, and regulations. *Energy efficiency* is an area that is very important to the manufacturing industry as it is a very intensive user. However, it is most often hidden within the bounds of overhead, labor, machine capital, and other top contributors to a company’s profit and loss statement. The perception can be attributed to the cultural norm of just being part of doing business. Another barrier that stems from a lack of awareness is the overall impact of the supply chain. Transportation costs, the surrounding footprint of emissions generated by suppliers, and moving materials within or from plant to plant all generate waste and, thus, emissions (Jiang et al., 2022).

Within the plant business level, it is also essential to consider that an underlying perception is that emissions reductions cost money. Business leaders may opt to wait until complete regulations are in place or subsidization is in place so that they can continue to meet shareholder and business key process indicator (KPI) targets. Employee engagement is another area that needs to be considered when identifying the need for more awareness and education. Determinants of perception have been studied extensively, with age, gender, and education being primary drivers (Brule et al., 2012). Perception may

This can be a significant barrier in the sector as each employee may lack the skillset or knowledge needed to understand which areas they control and the positive and negative effects that can ensue. Awareness and education in regulations and upcoming regulations are also important. Manufacturers may resist change without a full understanding of existing and new regulations. *Table 4.1* highlights barriers to awareness.

Table 4.1: Awareness and Educational Barriers. (Cordero et al. 2020) (Kannan et al. 2022) (Olatunji et al. 2019) (Damart and Baumgartner 2018)(Dasaklis and Pappis, 2013) (IEA, 2022)

Barrier	**Possible Perception / Issue**
Energy Efficiency	Awareness is low
	Hidden costs
	Not a top priority
Materials	Lock-in to current market
	Pricing to high
	Understanding of emission impact low
Technology	High cost of new technology
	Replacement technology not feasible
	Cost not feasible

Supply Chain	Not aware
	Contracts locking in for many years
	Transportation limitations
Regulations	Utilize the economy to drive success.
	No clear understanding of what is required
	Plant side, local, state and government differ
Employee Programs	Not available
	Not top priority
	Do not fully understand strategy

The second significant factor that will be reviewed is cultural resistance. Cultural resistance is a primary barrier to emissions reductions. In order to adequately address emission issues resulting in climate change at the manufacturing level, key areas of cultural resistance need to be reviewed. *Table 4.2* gives insight into the key areas of cultural resistance. These areas include awareness of the environment, general attitudes towards emissions reductions, gaining a sense of responsibility, the business culture, available incentives, and education and awareness.

Table 4.2: Cultural Barriers. (Song et al. 2020) (Sovacool, 2019) (Narayanamurti et al. 2011)

Barrier	Possible Perception / Issue
Education and Awareness	It may not be financially feasible
	Dependent on prioritization of the company
	Dependent on publicity and company beliefs
Attitude towards regulations	Economic growth may be prioritized over it
	Shaped by personal values and political

	ideologies
	Scientific understanding
	Limited resources
Environmental Awareness	Technology availability limited
	Money or program not in place
	Education system not in place
	Regulations limited
Business Culture	Not budgeted
	Not worth the time or investment, just a fad.
	Not required by the customer
Incentives	Not fully in place, understanding is limited.
	Hidden within other business costs
Technology Availability	Not stable
	Not cost feasible
	Upon transition, technology is outdated.

Cultural barriers are a barrier that must be carefully analyzed. Based on education, societal norms, value, and beliefs, differences in opinion will ensue. For example, carbon pricing may be considered over-investment in renewable energy sources as those technologies have yet to be fully adopted at market.

The third area that will be reviewed is political and regulatory barriers. Based on previous research, many companies within the United States have committed to becoming carbon neutral at different levels. The timeline and pathway to complete this need to be fully aligned. However, each company is completing this based on their feeling or understanding of what they should do to satisfy their shareholders and customers and stay within the bounds of state and government regulations. *Table 4.3* reviews the political and regulatory barriers seen within the manufacturing industry.

Table 4.3: Political and Regulatory Barriers. (Sarkodie, 2021) (Rosa and Dietz 2012) (Bolin and Kheshgi, 2001)

Barrier	**Possible Perception / Issue**
Lobbyists	Fossil fuels are still the most widely used and available
	Renewable energy is not sustainable
Inconsistency	Changes based off of political position
	Compliance within multiple regions hard to navigate
Funding limitations	Costs too much
	Assistance is needed to do enough, fast enough
	Resources are limited
Competition	Regulations are more relaxed in other regions
	If cost is high, it will be hard to stay competitive
Political	Regulations are not clear and uniform
	Resources and availability are not in place
	Policies not fully in place to support

Political and regulatory barriers have a significant impact on emissions reductions both today and into the future. As the U.S. is trying to remain competitive within the global market and the manufacturing industry employs many of the country's citizens, it is important to balance the scales between environmental responsibilities and economic growth.

The fourth area will be reviewed from an economic and business consideration standpoint. Many manufacturing plants focus on areas in quality, delivery, and productivity. These core areas are essential to maintaining a stable and viable plant that consistently delivers on-time products at the highest quality. Some adopt emission reporting as committed companies navigate toward emission reductions (Sureeyatanapas et al., 2021). This reporting has allowed them to further look into the current state footprint of each company to understand how they connect to the overall impact and goal of the transition. This also opens the gate to allow them to place a metric on the cost of carbon to their respective company, thus allowing analyzing improvements in a return on investment format. *Table 4.4* highlights economic and business barriers to emissions reductions within the industrial manufacturing industry.

Table 4.4: Economic and Business Barriers. (Brown et al. 2022) (Smoot 2023) (Liu et al. 2022) (Allayannis and Weston 2001)

Barrier	Possible Perception / Issue
Cost	Paying for offsets not sustainable but easy
	Counting manipulation, misrepresenting
	ROI is not feasible
Materials	Materials are deeply rooted from the petroleum industry
	Low-carbon materials aren't available or cost a lot.
	Recycling infrastructure isn't in place
	Performance characteristics aren't proven
Financing	Inflation has caused business models to change
	High upfront costs not attractive
	Lenders may be hesitant for long ROIs

	Grants and subsidies are limited
Creating more problems	Reduction in one area may create problems in another area. (example is energy equity) Models may not be accurate Measurement systems are not regulated causing money to be better utilized elsewhere
Carbon off-sets	Paying for offsets is not sustainable Does not work at the core issues Not fully regulated

The fifth area of review is technological limitations in manufacturing. Since the rise of the industrial revolution, four critical milestones have been discussed in previous chapters. Technology has adapted, and the world is moving towards a new automation standard, artificial intelligence. Although it is promising and can offer many incredible benefits to both emissions reductions in manufacturing and the world as we know it, areas of concern must still be addressed to bridge the gap from the ideal state to the current state. *Table 4.5* considers technological barriers from within the manufacturing sector.

Table 4.5: Technological Limitations in Manufacturing. (Ekholm and Rockstrom, 2019) (Brown et al. 2008) (Ahmed et al. 2020)

Barrier	**Possible Perception / Issue**
Infrastructure	Aging companies and buildings are outdated Power grids limited on-site and regionally Equipment costs are high for intensive capital (i.e. Die Cast machine, injection molding machine)
Cost	Regulatory uncertainty

	ROI is unfavorable to switch (i.e. hydraulic → electric)
	Renewables have a high investment cost
Compatibility and Connectivity	High temperature processes
	Chemical requirements can be out of bounds
	Circular framework not in place to connect
	AI, IoT and other exponential technologies
Monitoring	Measurement system reliability
	High cost to implement
	Handcuffed to reporting and costs

4.3 Research Design & Methodology

The chosen approach is to review the qualitative data collected from the literature review and consolidate it into an organized decision matrix to drive a data analysis approach. This descriptive research will then be utilized to correlate the influencers that match against each of the five barriers. Ultimately education and awareness showed up the most throughout each of the barriers.

Through reviewing each of the five key barriers in the attempt to minimize or reduce emissions in the manufacturing sector, it is possible to highlight the barriers and issues into those that are seen the most and, thus, the most important to focus on. To analyze the data and narrow the focus, *Table 4.6* was created to prioritize which barriers are the most important to focus on.

Table 4.6: Consolidation and Priority Rating of Barriers in Emissions Reductions (Contributed by author: Alec Ernst)

Primary Barrier	**Influence (High, Mid, Low)**	**Control by the Facility**	**Long-term or Short-Term**	**Cost Incurred ($ low, $$$ high)**	**Priority Rating**
Lack of awareness and education	H	Y	S	$	1
Cultural resistance	H	Y	S	$	3
Political & regulation	H	N	L	$$$	4
Economic and business considerations	H	Y	S	$$	2
Technological limitations	H	N	L	$$$	5

4.4 Data Analysis

Table 4.6 displays the barriers that have the most influence, are within the control of the manufacturing facility, and are long-term or short-term countermeasures, as well as the cost to implement. This decision matrix then generated priority ratings to highlight the focus areas that should be considered today. *Figure 4.1* displays this information.

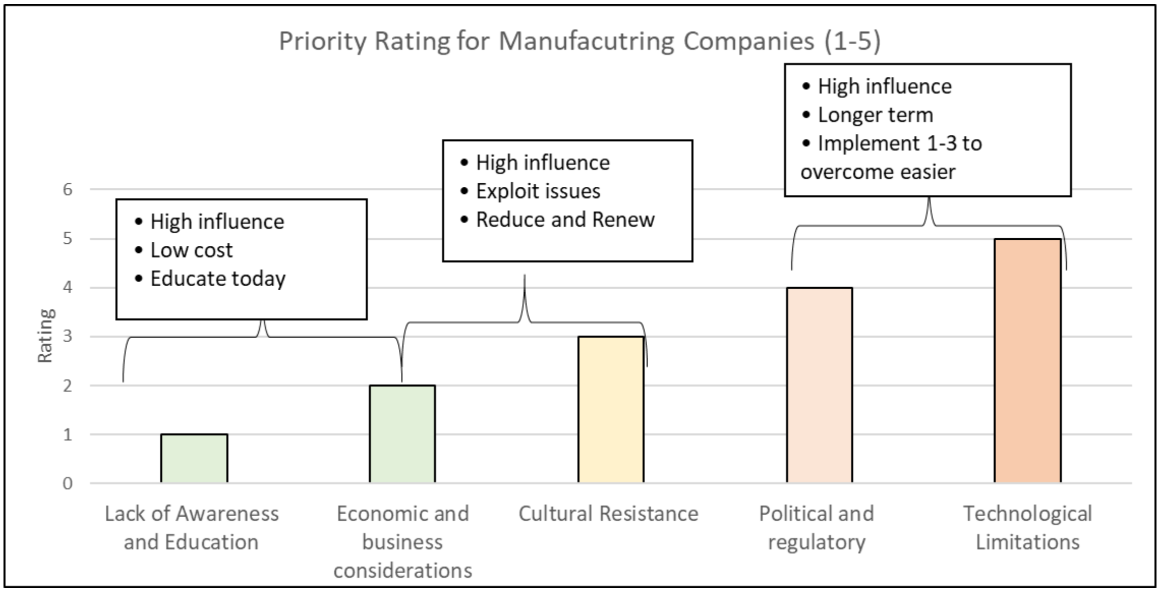


Figure 4.1: Priority Rating for Manufacturing Companies (Contributed by Author: Alec Ernst)

4.7 Summary

There are a significant amount of barriers that the manufacturing sector will encounter when attempting to reduce emissions within a facility. Several influencers show up throughout each of the barriers.

The primary is education and awareness and exposing the economic and business advantages that can be harnessed by the company if approached correctly. Education and awareness are the first areas of focus that show the most significant potential in the shortest time. The second area of focus is on economics and business analysis. Cultural resistance follows this and will have a more significant influence over time as it becomes more critical to each individual. Political and regulatory compliance is a barrier that will take time to shift.

Technological limitations are also essential but outside the complete control of each manufacturing facility. They can, however, work with designers, colleges, and industry leaders to work towards more sustainable technology, materials, and practices. Outside of each of these barriers lies increases in population and economic advancement. As developing nations build their economies, energy usage and consumption will continue to increase. This is above population increases, which also significantly affect energy usage.

4.9 General Discussion & Summary

Although many constraints will act as barriers to a company's emissions reductions, a few key variables should be considered above all, as shown in the review of this chapter. Continuous improvement in education and awareness of the employee is vital and considered the number one variable presenting with the highest constraint or effect on reductions, as displayed in Figure 4.1.

This is the focus of the next chapter, utilizing a company in Missouri as the primary case study. Deployment of a pilot program will help a company further understand the gaps and constraints not only significant to the industry or their geographical location but also to their facility and what methods can be utilized to drive change. As previously displayed in Chapter 4, the barriers and constraints of emissions reductions within the manufacturing sector can reduce the probability of offsetting the potential impacts of temperature change. This will be further highlighted in the results section.

CHAPTER FIVE

5.0 Preparation: Lean Manufacturing, Energy Efficiency & Improved Processing Methods

5.1 Introduction

The researcher chose a case study as the primary method to evaluate a manufacturing company's feasibility in reducing emissions. This chapter aims to evaluate the impact of emissions reductions, conduct improvements in energy efficiency, and compare the effects on KPI metrics.

As mentioned in the previous chapter, we should dive deeper into the capability of manufacturing companies to reduce emissions and thus affect carbon concentrations within the atmosphere that cause temperature change. In order to appropriately prove or disprove this capability, a case study was chosen to pilot. The start of this chapter briefly introduces lean manufacturing and the core concept behind eliminating waste. Energy efficiency is then brought in to show the relationship and merger with lean manufacturing. This concept is carried forward throughout the remainder of the chapter as a case study is deployed at a manufacturing plant in Missouri to benchmark and identify key areas of emissions reductions.

An introduction of available equipment to reduce emissions and monitoring and control equipment will be brought into the study. Ultimately the results of this study will be translated into the core research hypothesis that this study aims to answer. This chapter may be the most important chapter within this study as it takes actual data from a real company and exploits it to expose capability today.

5.2 Energy Efficiency in a Lean Manufacturing Environment

Manufacturing has been a primary economic driver for the United States. It contributes to “12.5%” of the gross domestic product and supports millions of jobs at or above the average compensation level (Nnyanzi et al., 2022). As technology expands and the entire world is at our fingertips, competition within the arena becomes much fiercer. Now you are competing not only with companies within your respective city, state, or country but across the world. In order to remain relevant in today’s market, manufacturing companies must learn to adapt, become flexible in their strategies, and eliminate waste at every corner.

The industrial sector is one of the top energy consumers in the manufacturing arena (Edelenbosch et al., 2017). Toyota developed the core standard of lean manufacturing through waste elimination. Essentially, they aim to create the highest quality product while expending the fewest possible resources. Many companies have shifted their culture to this thinking way and have developed many new standards requiring continuous training and tools. The companies will yield great results from an appropriate lean transformation if appropriately harnessed.

Most manufacturing companies run two and sometimes three shifts, potentially six or seven days a week. Depending on what product they are making, equipment may be required to stay on around the clock. The cost of energy to keep these companies running has a substantial financial impact on the bottom line. Many tools and techniques are available to the industry; however, energy consumption is not always at the top of a company’s radar.

Integrating energy management principles into the everyday function of a manufacturing facility has the potential for great results. There will be struggles along the way and consistent challenges. It is hard to change the mindset and culture of an organization’s people. Benchmarking best practices through past project successes and providing incentives and rewards to employees will all help to ease the transition.

5.2.1 The Roots of Lean Manufacturing

The history of lean manufacturing dates back to the 1450s in Venice, Italy, through standardizing the galley shipbuilding processes. By creating a standard way of building, shipbuilders could move entire ships through their production processes within 1 hour (Jeong et al., 2020). Building on the foundation of this thinking way in the 1800s, Eli Whitney was credited with the concept of interchangeable parts on the cotton gin. Modern-day lean manufacturing began with Ford optimizing assembly line production with “a bomber an hour,” as shown in *Figure 5.1*.

Figure 5.1:1944 – Willow Run Assembly Plant “A Bomber an Hour” (Trainer, 2019)

Key figures at Toyota took this a step further by taking all of these improvements and creating a system of management, production, and logistics standards, the Toyota Production System.

All of the improvements throughout the centuries have one thing in common, the elimination of waste and a focus on the efficiency of production and resources. The Toyota Production System categorized these wastes into eight categories (De Bucourt et al., 2011).

- Transportation – moving parts and logistics
- Inventory - excess inventory past what will be used within a short period
- Motion – any movement that is not value-added
- Waiting - idle machines and people
- Over-processing - do more than what is required or necessary
- Overproduction – building or creating more than what is required
- Defects – materials that do not satisfy customer requirements and are scrap
- Non-utilized talents - limiting people and their capabilities

Most modern-day companies are familiar with lean manufacturing and have a program at some level within their organization (De Bucourt et al., 2011). As an organization’s lean efforts take hold, other financial waste areas start to surface. One of these areas is energy consumption.

5.2.2 Energy Management

The business world constantly consumes energy (Nguyn et al., 2021). Energy is consumed from the time you walk through the door at work. Electricity is used to illuminate the entranceway to provide safe movement, natural gas fuels the furnace to keep you warm, and compressed air is used in automation to power hand tools to perform work. *Energy management* is a philosophy and approach that helps businesses to cut energy costs where capable.

An example of energy management can be seen in lighting. Led lights, for instance, draw less energy than metal halide lights inside a warehouse; this saves on the cost of lighting the area by pulling fewer kilowatts per hour. Those kilowatts have a service price from the supplier based on off-peak or on-peak hours. Tuomela et al. (2021) found that structuring shifts at work to light those areas during off-peak hours would be an example of energy management. Another example would be only to turn the lights on when needed. Instead of leaving them on for an eight-hour shift, an operator may only be in the area for 25% of that time. Therefore, light is only needed for two hours.

In order to effectively manage the consumption of energy, a systematic approach must be taken. This approach is very similar in structure to any other improvement project.

- Site analysis – mapping how and where energy is being used
- Measurement of consumption – consumption of energy by type and location
- Analysis and solution – determine the best countermeasure and reduction strategies
- Implementation and improvement – conduct activities
- Control and sustainability – develop control system and audits for long-term results

Energy Management is essential not only at the company level but also at the global level. Consumption levels affect pricing, emissions, and finite resource consumption. Integrating energy management into lean manufacturing could be very beneficial to a company already realizing lean improvements.

5.2.3 Merging Energy and Lean

A report by the American Council for an Energy-Efficient Economy says "economic indicators suggest that the industrial sector is poised for a new period of major capacity investments because existing capacity is approaching full utilization." Market trends are beginning to favor a shift to domestic production for domestic consumption.

The U.S. manufacturing sector spent $5.9 billion on capital expenditures and $20.7 billion on pollution prevention and treatment operating costs in 2005 (EPA, 2005).

If anyone thinks lean manufacturing is just a management fad that will be here today and gone tomorrow, they must look at its impact on the U.S. automobile market. In 1950 there were not any Japanese cars in the United States. In 2004, Asian manufacturers, principally Japanese companies, benefited from 37.4% of the U.S. market (The Detroit News, 2005). According to the EPA, there are three main reasons for implementing lean and energy efficiency efforts. These reasons are promoting cost savings, addressing climate change and environmental risk, and lowering operating costs to sustain a competitive advantage.

The relationship between lean and energy management is a very close one. Both focus on driving out waste to improve processes. Lean focuses on process waste, while energy management focuses on wastes in energy (Serdar et al., 2019). Some companies may already have both programs but need to mesh better. The environmental health and safety, or facilities management group, may focus on energy waste.

Conversely, process engineers are mainly focused on manufacturing wastes. This approach is correct. However, many improvements may be lost due to the defined roles that do not allow for overlap. Developing systems that allow employee engagement and incentives to improve will allow every employee to make his or her voice heard. It allows them to earn extra money while also recognizing their efforts, ultimately increasing employee morale.

Energy value mapping is an example of a blend between lean and energy. In lean manufacturing, the entire process or supply chain is laid out on paper; from this, the ability to visualize gaps and wastes becomes apparent (Nwanya & Oko, 2019). This same technique can be used for the energy that supplies that process. The easiest way to provide the employee or shop floor with what they need to become effective is to create a standard set of tools or a kit.

5.2.4 Measurement and Analysis Tools

Many tools are available to start your lean and energy-integrated journey. Each adventure needs to start with a plan and commitment from the entire organization top-down so that it has the best chance of remaining sustainable. In 2007 the EPA developed a lean and energy toolkit capable of being used across almost all industries. The kit was created "to offer implementers practical strategies and techniques for enhancing lean results in waste elimination." Below is a short list of lean and energy tools considered the most effective.

- Kaizen event – workshop event used to achieve waste reduction or process improvement
- Energy audit – assessing current energy consumption
- Value stream mapping – process step analysis highlighting value versus non-value
- Light meters – a tool used to measure the amount of light within a specific area

- Ultrasonic acoustic detector – used to measure air leaks
- Right-sized equipment – validation that equipment is not undersized or oversized
- Six Sigma methodology – a systematic approach to problem-solving
- Total productive maintenance – approach to machinery running at 100% efficiency
- Standardized work – systematic standard work of elements and processes
- Energy treasure hunts – employees compete to find savings opportunities, morale builder
- Visual Controls – promotes standardization and repeatability.

Each one of these tools has gained success through different projects at many different organizations and levels. What works for one company may not work for another, and the successes of one company may be easily integrated into another. A company's culture must first shift to understanding that energy is being used twenty-four hours a day, seven days a week, and affects operating costs. This will help executives, managers, and floor-level employees make energy-conscious decisions. Teaching awareness will help to launch a successful program

5.2.5 Sustainability and Challenges

Lean manufacturing has changed how many companies approach improvements, as seen in the two case studies above. Every industry has something to gain, whether its operation is in industry, manufacturing, healthcare, or other services. Incorporating lean and energy management will yield tremendous benefits by increasing overall profit levels and employee morale, environmental quality, meeting customer expectations, and reducing operating and maintenance costs. The goal is to do more with less. Start by gaining commitment to the cause. Develop a baseline and build the company or organization’s knowledge, understanding, and rewards system.

Challenges and barriers to improvements are that energy costs are often not readily available at the floor level (Papadis & Tsatsaronis, 2020). They are often hidden from the view of the masses in accounting or overhead accounts. Ways to countermeasure this would be to display them in each department or during quarterly meetings. Other obstacles include resistance to change, insufficient support staff to complete projects, not understanding the short- and long-term benefits, and “reverting to the old way of working.” Developing standards, past project successes, and having a playbook will assist in streamlining improvements. In closing arguments, take the step to merge energy management and lean into your organization. The adventure will sometimes be challenging but will make your business more profitable and environmentally friendlier.

5.3 Introduction to Case Study

5.3.1 Site Location and Plant Specifics

The setting for the case study is a tier-one automotive parts manufacturing plant in Missouri. The global company established its business in the United States in 1986 and started operations in 1987. It has grown year over year and vertically integrated to house over seven buildings totaling over 1 million square feet on over 200 acres. Key Missouri plant metrics are listed below.

<u>Key Missouri Plant Metrics</u>

- The customer base in North America is greater than 30 companies.
- Major OEMs include Toyota, Ford, Honda, Mazda, Subaru, GM, and Daimler.

- Manufacturing floor space = 1,445,346 square feet
- Acreage = 246 acres
- Employee count = 1,620
- Major Equipment
    - Injection Machines 25T – 2400T = 206
    - Reaction Injection Molding – 51
    - Paint Booths – 13
    - Chrome Plating Lines – 1
    - Die Cast Machines (Al & Mg) – 11
    - Assembly lines – 27
    - Stamping Machines – 7
    - Spot and Projection Welding – 64
    - Active Robots - >500

Affiliated North American Plant Metrics

- Total companies under the umbrella= 6
- Total square feet across 6 plants = 2,193,133
- Total employees across 6 plants = 6,371

5.3.2 Strategy

The strategy or aim of this study is to utilize actual shop floor data coupled with improvements in energy efficiency, monitoring, and control equipment and to model a scenario across time that is favorable to the business. A systematic approach will be utilized to achieve this. The first step will be to collect baseline data and develop key consumption and production of emissions metrics.

From this point, an analysis of the impact of each and the methods that are available to promote energy efficiency will be deployed along with new techniques. Improvement methods will promote the merger of new technology, energy management techniques, and future improvements to promote a pathway to meet net-zero emissions. The study will ultimately be conducted in multiple phases through the project's life, ending in the year 2050 and transferring to a stabilization and compliance approach. This study regarding project requirements, will be conducted between December 2021 and December 2022.

The quantitative mixed method approach will allow for alignment to future policy and business optimization that will allow for strict key process indicators to judge effectiveness.

5.3.3 Stratification of Scope

For this study, data will be collected and analyzed from the plant in Missouri and applied across the North American plants as possible. The roadmap presented forward is in line with company executive expectations. A budget has been set year over year to assist in the net-zero transition and is in agreement and accordance with parent company targets. Stakeholder expectations and the understanding that customers would require specific metrics to meet targets were considered. This includes a percentage of energy coming from a renewable source.

5.3.4 Measureable KPI

These quantifiable measurements will be used throughout the life of the project. They will help identify gaps, fulfill customer and key shareholder expectations, and drive growth. Each of these KPIs is critical to a manufacturing plant's success and will be measured for impact throughout the project's life. These include the following but are not limited to those shown in *Table 5.1*.

Table 5.1: Plant KPI and Units of Measure (Contributed by Author: Alec Ernst)

KPI	Unit of Measure
Equipment Availability	Downtime
Cycle Time	Second
Defect Rate	Percentage
Productivity	Pieces / Hour
Safety	Number of Incidents
Costs	Dollars $

In addition, energy level metrics will be used to identify improvements and impacts per the targeted improvements to guide activities. These include the following but are not limited to those shown in *Table 5.2*.

Table 5.2: Energy Metrics and Unit of Measure (Contributed by Author: Alec Ernst)

KPI	Unit of Measure
Electric	kilowatt hours (kWh), megawatt hours (MWh)
Natural gas	Cubic meters (m^3)
Liquefied petroleum gas (LPG), Landfill Gas	pounds (lb)
Water	Cubic meters (m^3)
Landfill & Waste	Metric tons (MT)
Carbon output	tonnes (T)
Compressed air	Pounds per square inch (PSI), Cubic feet per minute (CFM)
Lighting	Lumens (lm)

5.4 Setting the Target

The researcher worked with the team at the facility to generate a timeline for reduction that would remain in step with the global target.

All vested parties and stakeholders within the company agreed upon these targets. This also allowed the targets to align with the utility company's net-zero carbon emissions target by the year 2050. It was agreed upon that the emissions responsible to the plant would be categorized into three scopes. These are shown in detail in *Figure 5.2*.

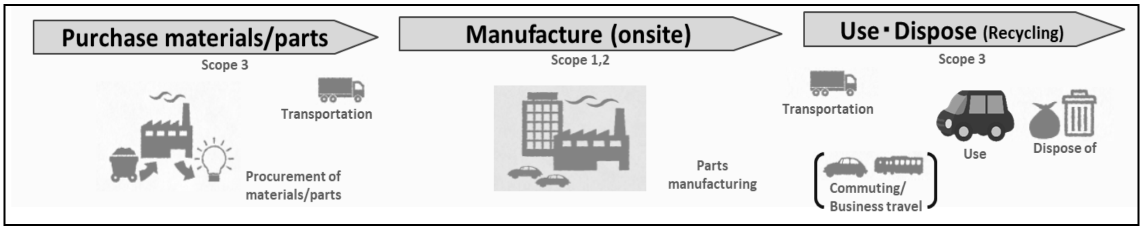


Figure 5.2 Separating the Project into Scopes (Contributed by Author: Alec Ernst)

The scope that is the focus of this study is the on-site manufacturing section. Along with carbon reductions, water renewable energy usage, landfill waste, and water consumption are also being targeted for improvements, as shown in *Figure 5.3*.

2. Targets:				
Compared with 2015 Baseline	2025	2030	2035	2050
Carbon: CO2 Reduction	-25%	-50%	-75%	-100%
Carbon: Renewable Energy Usage	+20%	+50%	+75%	+100%
Landfill Waste	-50%	-80%	-100%	
Water Consumption	-15%	-22%	-35% ***Not fully defined	
***Targets subject to change based on policy / regulations				

Figure 5.3: Target setting at facility for Environment and Carbon reduction Activities (Contributed by Author: Alec Ernst)

In order to carry the project into the future, production and consumption sources are being considered. Due to the project's timeline regarding this study, most areas of improvement are focused on consumption-based emission versus production based. *Figure 5.4* describes how the author decided to measure the targeted areas.

-		Source of Emissions	Unit of Measure	How to Measure
Carbon	1	Electricity	Mega-watt hours(MWh)	Consumption / Purchase
	2	LPG	gallons (gal)	Consumption / Purchase
	3	Natural Gas	Cubic Feet (ft³)	Consumption / Purchase
	4	SF6 Gas	Cubic Feet (ft³)	Consumption / Purchase
Landfill	1	Landfill	metric tonne	Production
	2	Treating/Incinerate	metric tonne	Production
	3	Off-site recycle	metric tonne	Production
	4	On-site	metric tonne	Production
Water	1	Wastewater - Copper	pounds (lbs)	Consumption / Purchase
	2	Wastewater - Hexavalent Chrome	pounds (lbs)	Consumption / Purchase
	3			
	4			

Figure 5.4: Target setting at facility for Environment and Carbon reduction Activities (Contributed by Author: Alec Ernst)

5.5 Baseline Data Collection

The researcher collected the study's data from historical documents and ongoing research, processed it, and then analyzed the results using Microsoft Excel. The data gathering started in 2022 and, for this research report, concluded in December 2022. The research is ongoing, however, and the researcher will continue to collect and analyze data in the future.

5.5.1 Historical Energy Consumption

The first data the researcher collected included the history of electric usage, LPG, and natural gas from 2015 until now. This gave a feel for the baseline consumption that the plant consumed over time. *Figure 5.5* displays electricity consumption over time in MWh. This is displayed in *Figures 5.6* displays facility gas. *Figure 5.7* displays LPG over time. .

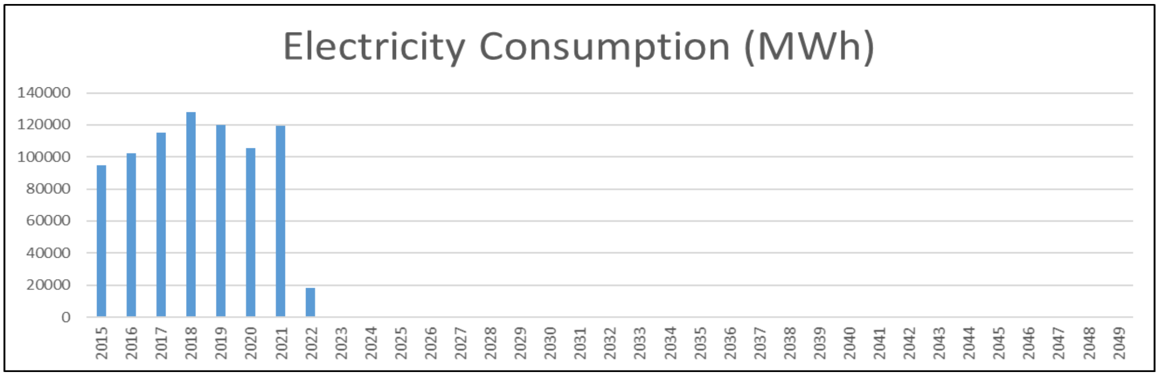


Figure 5.5: Electricity Consumption Historical 2015-2021 (Contributed by Author: Alec Ernst)

The researcher found that the average annual electricity consumption from the year 2015 to the year 2022 was around 100,000 MWh.

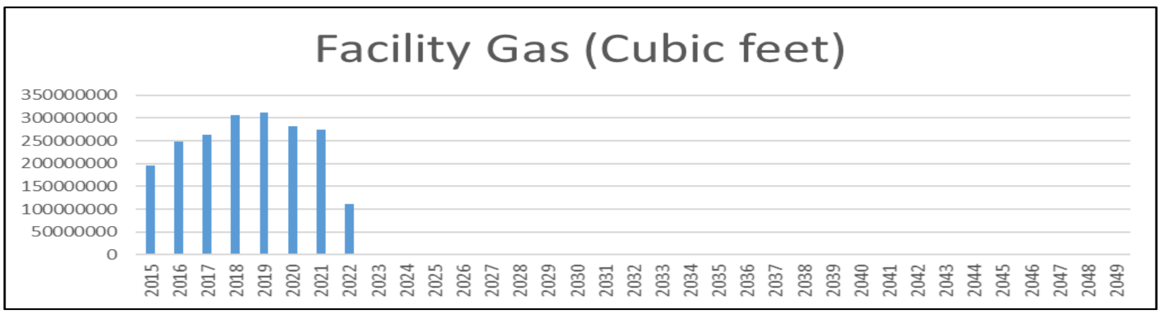


Figure 5.6: Natural Gas Consumption Historical 2015-2021 (Contributed by Author: Alec Ernst)

The researcher found that the average annual natural gas consumption from the year 2015 to the year 2022 was around 249,000,000 m^3.

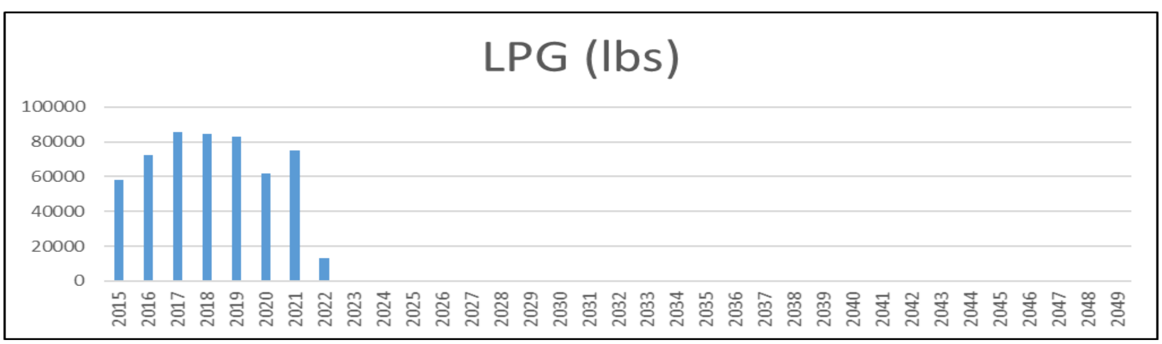


Figure 5.7: LPG Gas Consumption Historical 2015-2021 (Contributed by Author: Alec Ernst)

The researcher found that the average annual LPG consumption from the year 2015 to the year 2022 was around 66,000 pounds.

The researcher compared this to the company's sales to see if a correlation existed between an increase or decrease in sales and energy consumption over time. It was discovered that there was not a clear correlation between sales increases and the amount of energy used. This could be due to capacity capability and not shutting down equipment when sales are low versus high.

The researcher next sought to understand which energy source was the greatest by consumption percentage. This is shown in *Figure 5.8* below.

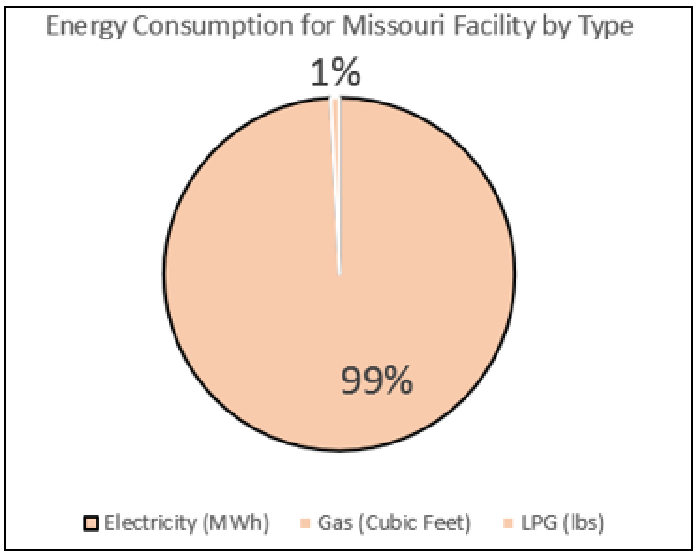


Figure 5.8: Energy Consumption by Source at Facility (Contributed by Author: Ernst, Alec)

The greatest use of consumption-based power at the facility was shown to be electric. As this would become the primary focus of the consumption-based emissions of the study, the researcher then moved toward determining where the incoming power came from.

5.5.2 Electric Energy Provider

A local electric corporation provides the electricity to the plant and ultimately receives its power from a greater power alliance that serves 23 different co-op members.

This particular co-op serves both commercial and residential members. The current makeup of end users is around 7% commercial and industrial and 93% residential (WVPA, 2023). This information is displayed in *Figure 5.9* below.

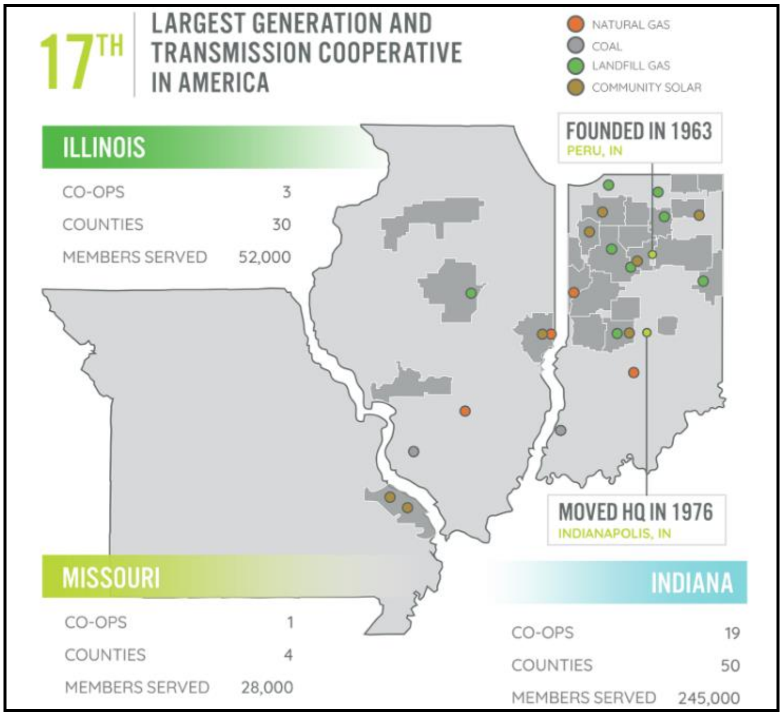


Figure 5.9: WVPA Power Supply & Breakdown (WVPA, 2023)

It is America's 17th largest generation and transmission cooperative, serving Missouri, Illinois, and Indiana. The generated fuel mix comprises coal, nuclear, natural gas, market purchases, renewables, and fixed-price contracts. This breakdown is shown in *Figure 5.10* below.

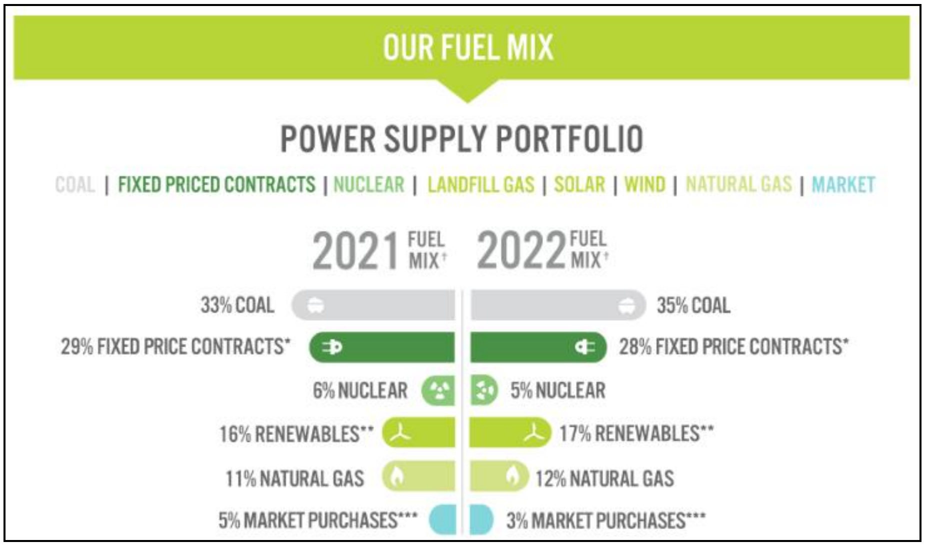


Figure 5.10: Power Supply Portfolio (WVPA, 2023)

From this point, the researcher discussed the reduction strategy with the parent power supply company and how it planned to reduce carbon. The carbon reduction target is shown below in *Figure 5.11*.

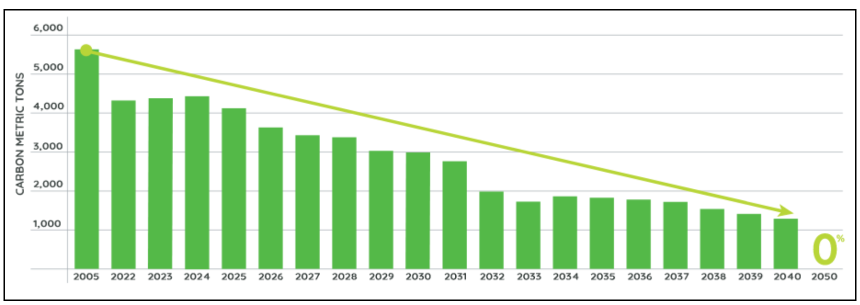


Figure 5.11: Owned Generation & Energy Purchased - Carbon Reduction Target (WVPA, 2023)

Based on the energy mix at the company's current state and its pathway into the future, a conversion factor of MWh to carbon emissions was ratio was generated. This is shown in *Equation 5.1* below.

Equation 5.1

884.2 lbs CO_2/MWh × 1 metric ton/2,204.6 lbs × 1 / (1-0.073) MWh delivered/MWh generated × 1 MWh/1,000 kWh × = 4.33×10^{-4} metric tons CO_2/kWh

The overall ratio by year is shown in *Figure 5.12*.

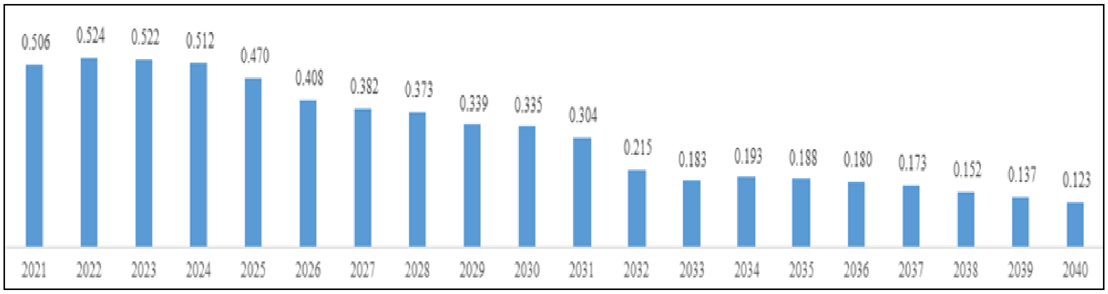


Figure 5.12: Carbon emissions ratio (WVPA, 2023)

Other ratios are shown in the Appendix, which will be utilized across all plants utilized in adjacent studies.

5.5.3 Converting to Carbon Emissions

The ratios were then used to calculate the emissions produced at the plant due to energy consumption. The other ratios chosen were generated based on industry standards available on the EPA website. The ratio for LPG was chosen to be 0.005681 tonnes of carbon per lb. The ratio for facility gas was chosen to be .0000526 tonnes of carbon per cubic foot.

Below is the conversion of each type of energy used to the output of carbon emissions. This is displayed in *Figures 5.13, 5.14, and 5.15*.

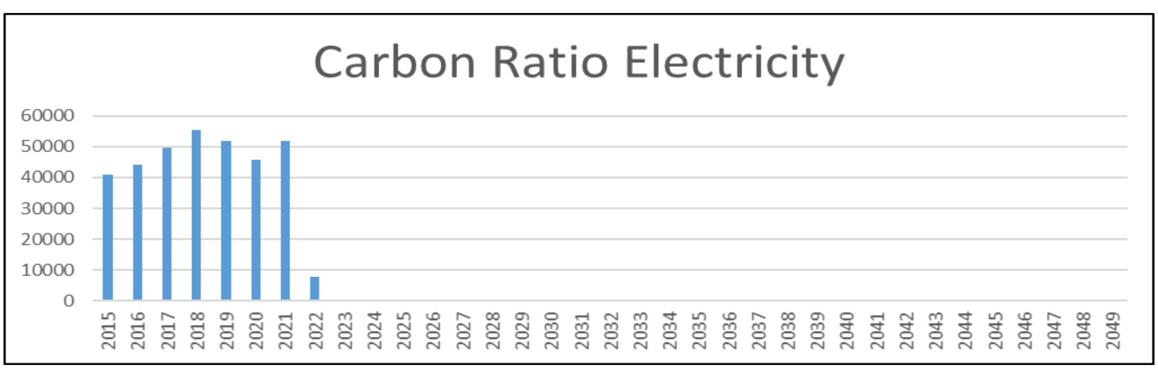


Figure 5.13: *Carbon emissions output for electricity at facility (Contributed by Author: Alec Ernst)*

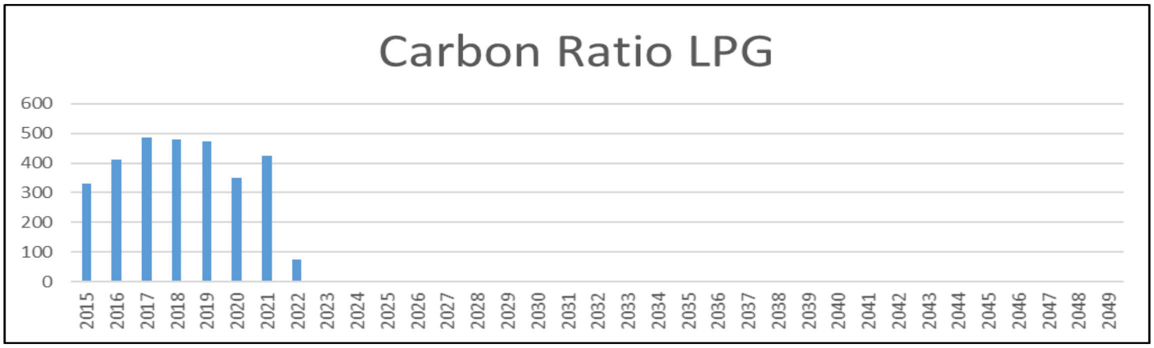


Figure 5.14: *Carbon emissions output LPG at facility (Contributed by Author: Alec Ernst)*

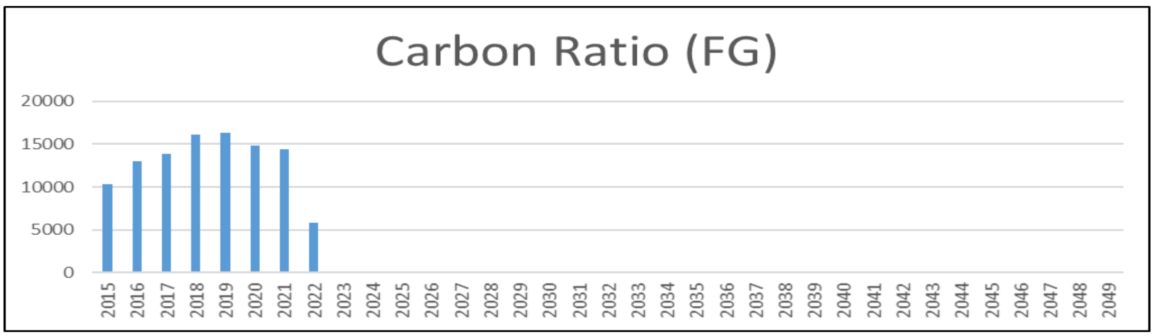


Figure 5.15: Carbon emissions output for FG at facility (Contributed by Author: Alec Ernst)

5.5.4 Facility Equipment Mapping

Upon compiling the information from the energy sources, the researcher attempted to map the energy use throughout the facility. After the transformer, electricity is distributed to a series of main switchboards (MSB) at the facility, then to the facility equipment, and directly to the processes. This is shown in a high-level schematic in *Figure 5.16.*

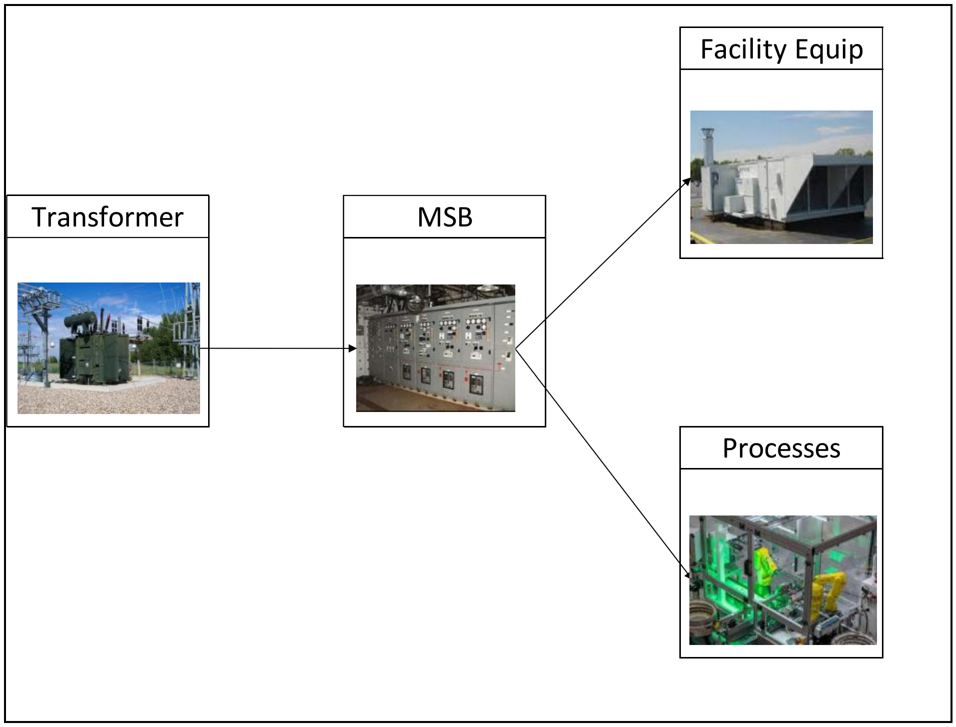


Figure 5.16: Schematic of Electric Distribution through Manufacturing Plant (Contributed by Author: Alec Ernst)

Mapping allowed the researcher to gain an understanding of equipment layout and proximity. This was deemed very useful for future energy treasure hunts, maintenance deployment, and asset distribution and placement.

5.5.5 Equipment List

The next step was to generate a list of equipment and determine the assumed energy usage based on the nameplate and years in service to understand each piece's efficiency better. This allowed the researcher to understand the most significant energy consumers within the plant. An example list is displayed below in *Figure 5.17*.

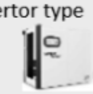
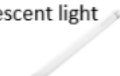
Items	Type	Number of machine	Power consumption (Kwh)
Air compressor	Conventional type 	1	79.18
	Invertor type 	1	57.88
Injection molding machine	Hydraulic type 	2200t : 4	136
		1300t : 1	69.6
	Electrical type 	2200t : 4	50
		1300t :1	22.7
Light (New building)	Fluorescent light 	96	0.035
	LED light 	96	0.019

Figure 5.17: Schematic Equipment and Power Consumption at Facility (Contributed by Author: Alec Ernst)

Many different pieces of equipment were considered throughout the facility, including air compressors, air makeup units, lighting, injection machines, and die-casting machines. Equation 5.1 was used to determine the energy consumption usage per day. This considers E in kWh per day to be equal to the power P in watts (W) times the number of usage hours per day t divided by 1000 watts per kilowatt (rapidtables.com, 2023)

Equation 5.2

$$E_{(\text{kWh/day})} = P_{(\text{W})} \times t_{(\text{h/day})} / 1000_{(\text{W/kW})}$$

Equation 5.2 was used to calculate voltage.

Equation 5.3

$$V_{(\text{V})} = I_{(\text{A})} \times R_{(\Omega)}$$

Data was then compounded into the most significant energy consumers so that an action plan could be made. Ultimately, the researcher wanted to account for every kWh of electric usage *(Figure 5.4)* that was being billed by the provider and also to categorize what activities would benefit the company most.

5.6 Applying a Road Map

In order to approach the targets from a realistic point of view and stay on course and in alignment through the project's duration, a roadmap was set forth as a guideline to serve the facility. This was done to remain visible, have metrics to grade against, and steer the project, as it is always possible that critical team members today might be different from team members tomorrow. The researcher utilized a three-phase approach, displayed in *Figure 5.18*.

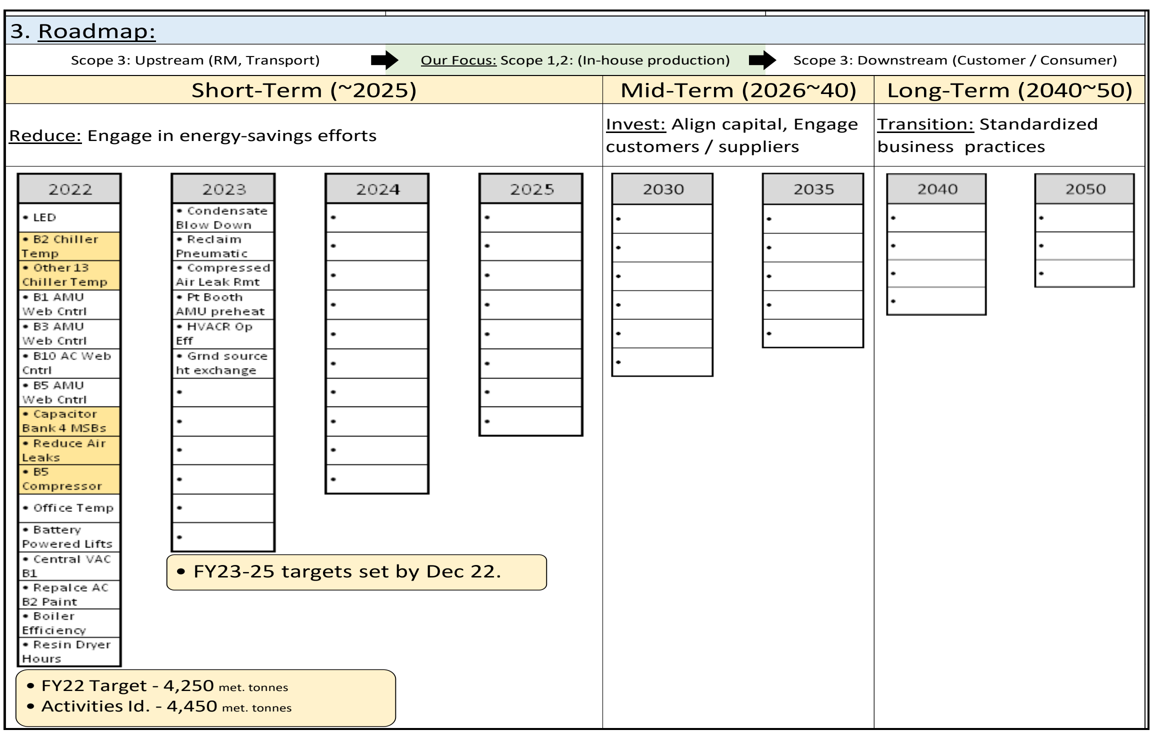


Figure 5.18: Roadmap for facility Net-zero emission transition (Contributed by Author: Alec Ernst)

The focus of phase one is to engage in energy – savings efforts. These are the quick win improvements that can be done now, and some with little to no investment with high rates of return that could be favorable to the facility. Phase one is planned to run through 2025. Phase two aimed at aligning capital and engaging customers and suppliers. Although renewable energy technology is being piloted within a sister company, as discussed further in *Chapter 6*. As the company remains competitive in the industry, its business model may shift to customers requiring a percentage of its energy consumption used for production to be clean. A list of projects was generated to align with the carbon emissions reduction plan. These projects will be highlighted in the following sections.

5.7 Dashboard for Management

This dashboard allows for visibility to high-level management and the company, displaying plan versus actual for each key area. Projects are tracked monthly and communicated to management in a meeting. The dashboard that is being utilized is shown in *Figure 5.19*.

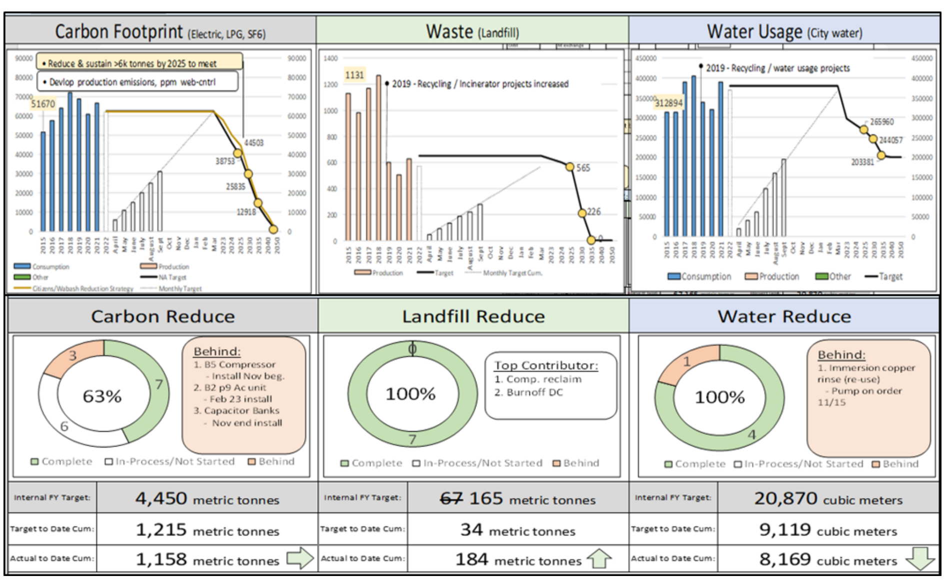


Figure 5.19: Roadmap for facility Net-zero emission transition (Contributed by Author: Alec Ernst)

5.8 Project Categories

For fiscal year 2022, each CO2 project was analyzed and then put into buckets to understand which projects would have the greatest effect. These are shown in *Figure 5.20.*

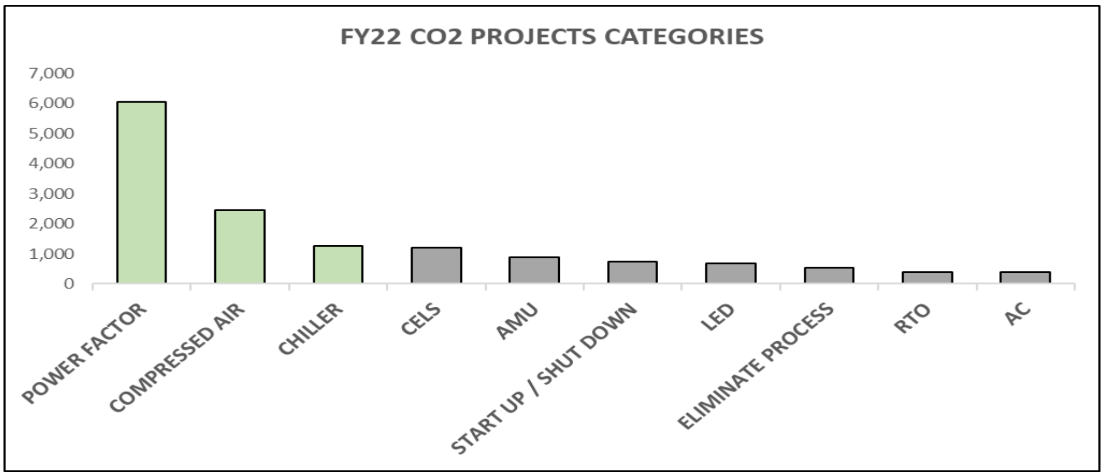


Figure 5.20: Roadmap for facility Net-zero emission transition (Contributed by Author: Alec Ernst)

5.9 Activities, Analysis & Savings

To highlight the energy savings, associated cost savings, and carbon reduction, the researcher will highlight three key areas of improvement. This first area or project spotlight includes power factor improvements. The second includes compressed air and variable frequency drive improvements. The third area considers cooling tower temperature change. These projects are being utilized to show that improvement can be done with little to no investment cost and high rates of return. Most facilities may have the equipment available and need a push to realize the potential improvements through this study.

5.9.1 Energy Efficiency & Carbon Reduction Improvements

Power Factor Efficiency Improvements

To judge the power factor, or energy efficiency within the plant, the researcher worked with electricians to understand the difference between wasted power and usable power. The equipment used to determine the power factor was a power quality analyzer similar to the one shown in *Figure 5.21*.

Figure 5.21: Power Quality Analyzer & Motor Analyzer Fluke 438-II (Fluke.com, 2023)

After a series of measurements were taken across four main switchboards (MSBs), *Figure 5.22*, it was determined that the power factor was around 75 %. This was also calculated through *Equation 5.4*. The power factor is the ratio of working power to apparent power.

Equation 5.4

$$PF = kW / kVA$$

It was found that each of the four capacitor banks was running around 75 %. Capacitor banks were investigated and proven beneficial to correcting the power factor at each location. *Figure 5.22* shows a capacitor bank install within an MSB.

Figure 5.22: Image of capacitor bank install (AWE, 2021)

The power factor is shown below to improve from around .93 to .97, as shown in *Table 5.3*.

Table 5.3: MSB with Capacitor Bank Install Improvements (Contributed by Author: Alec Ernst)

	MSB & Capacitor Bank Improvement					
	PF	Capacitor Install Cost $	PF New	Savings Per Month kWh	Savings Per Month $	Carbon emissions Savings / Month
MSB 1	78%	35,000	97%	147,840	11,827	64
MSB 2	87%	25,000	95%	26,018	2,081	11
MSB 3	80%	15,000	96%	384,480	30,758	167
MSB 4	94%	45,000	97%	28,800	2304	12

After reviewing the improvements made during the project and reflecting on the results, the researcher and group discussed different ways to control and sustain the newly realized state. A monitoring and control system was deemed the best choice and will be discussed further in this chapter.

Compressed Air Leak Improvements

Compressed air leaks can impact a company negatively in the following ways.

- Financially

- Production downtime
- Shorten equipment life

Compressed air leaks were measured in the production area using a FLIR Si124 industrial acoustic imaging air leak detection tool *(Figure 5.23)* supplied by the facility. This tool allowed the user to take pictures to log the data and allow for repairs during scheduled downtime. The acoustical imaging detector can also calculate the air leak cost and measure up to 430 ft. away. This is very convenient and safe for the user and the company. The instrument was calibrated in a certified lab at the facility following manufacturing specifications.

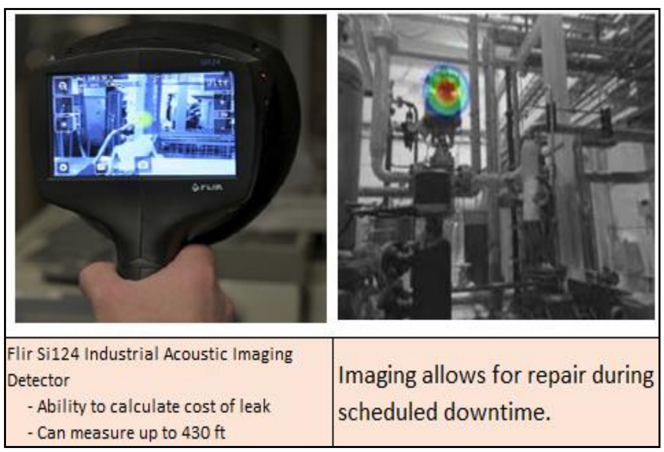


Figure 5.23: FLIR imaging tool (Contributed by Author: Alec Ernst)

After the problem and tools were put into place, the researcher ensured proper prioritization and planning were implemented. Utilizing maintenance connection software to plan a work order was able to be submitted and then scheduled by area and person and given a date to complete. This method made sure that all identified leaks were fixed on a timeline. If past due, they would continuously ping the user to say they still needed to be completed. PM frequency checks were put into place and monitored for out-of-control compressor load. *Figure 5.24* shows this method.

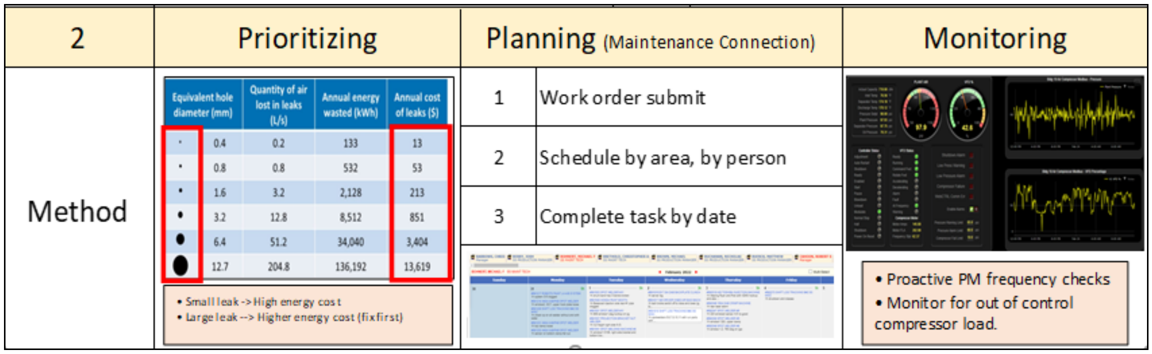


Figure 5.24: Method to Improve Compressed Air Leaks (Contributed by Author: Alec Ernst)

The researcher discussed the method and the procedure further with the team and implemented a preventative maintenance schedule to target the number of leaks fixed per month. This is shown further in *Figure 5.25.*

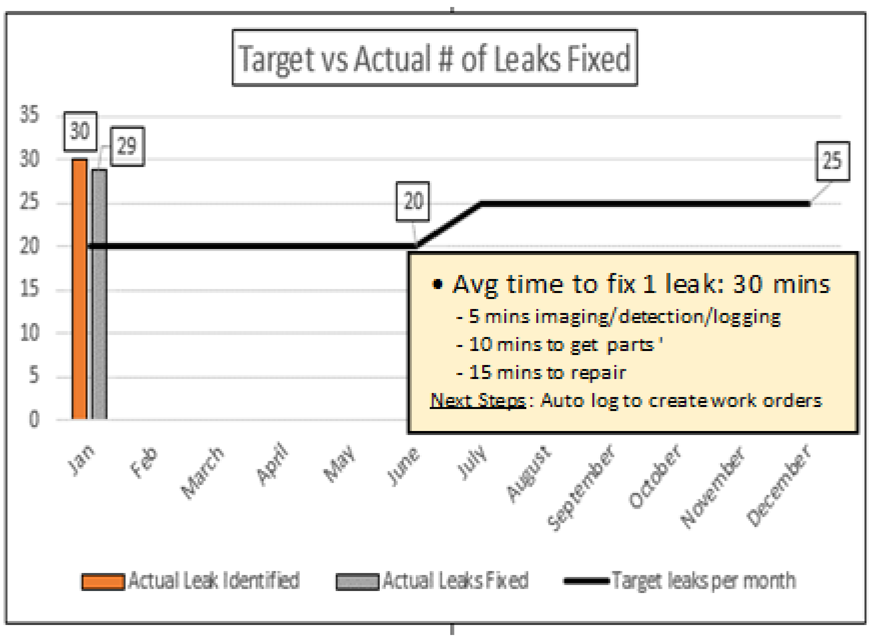


Figure 5.25: Target number of leaks fixed per month (Contributed by Author: Alec Ernst)

In order to determine if the leaks were worth fixing, a series of equations were used to calculate the value of fixing the leak. (titusco.com) *Equation 5.4* provides a formula for calculating leakage. P1 is operating pressure, P2 is half of the operating pressure in PSIG, T is time in minutes, and V is the total system volume.

Equation 5.4

$$[V * (P1 - P2) / (T * 14.7)] * 1.25$$

The average time to fix a leak was calculated, considering repair, parts retrieval, and imaging detection and logging time. The total time estimated to fix one leak was calculated at 30 mins. A future *improvement point: Auto-log to create work orders.* The impact of fixing leaks was then calculated to translate into monthly savings based on fixing 30 leaks per month at the average size displayed in *Figure 5.26.* This data is shown in *Figure 5.26.*

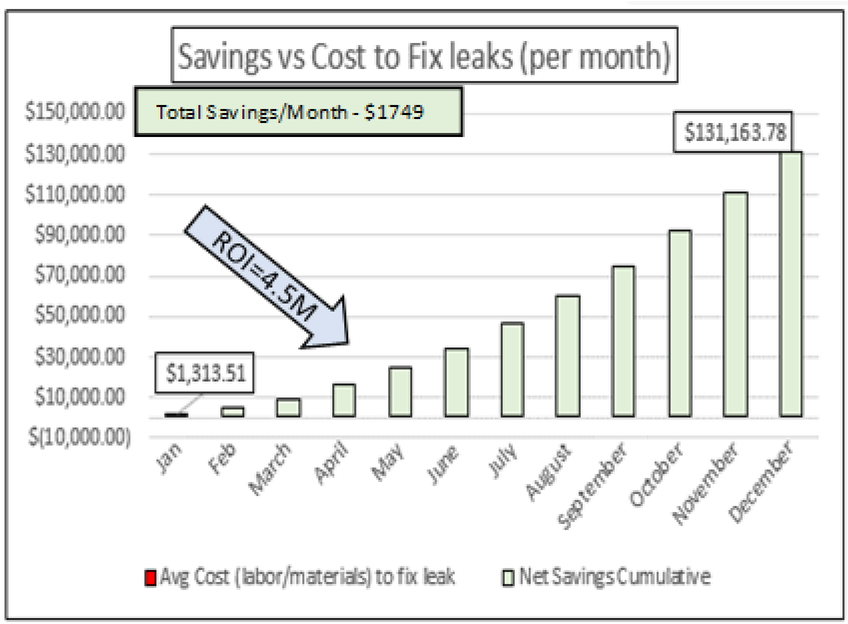


Figure 5.26: Savings vs Cost to Fix Leaks per month. (Contributed by Author: Alec Ernst)

A return on investment (ROI) was considered for the project to present a realistic value that aligned with the need to improve for the company and its executives. This ROI is shown in *Figure 5.27.* The calculation used to calculate ROI is shown in *Equation 5.5.*

Equation 5.5

$$ROI = \text{Savings per month} / \text{Investment} * 100$$

Cost	One-time cost equipment	$	20,000.00
	Total Cost per month (ex: MO 30 leaks)	$	435.00
savings	-		-
	Savings per month (29 leaks fixed / month)	$	1,748.51
Return on investment (months) (Assumed at 29 leaks fixed / month)			4.5

Figure 5.27: ROI for equipment (Contributed by Author: Alec Ernst)

Suppose the company continues to repeatedly fix 29 leaks per month at a savings of $1,748.51 savings month over month. The equipment will pay for itself in 4.5 months. The researcher then translated this into an energy and carbon emissions reduction annually. The results of this are displayed in *Figure 5.28.*

- Average kWh cost at:
  - $0.085/kWh
- Carbon offset (Annually):
  - .00043 t-Co2/kWH *8512 (avg annual wasted kWh/leak) *29 (leaks/month) *12(months

  - **Carbon reduced: 650 t-Co2**
  - **Annaul kWh saved: 1.5M (348 leaks fixed, staggard)**

Carbon offset (t-Co2)	650
Annual kWh saved ($s)	$131K

Figure 5.28: Carbon Savings and kWh savings (Contributed by Author: Alec Ernst)

A reflection meeting was held upon project completion, and future improvements were considered to eliminate the risk of recurring leaks. The first point of improvement was to replace fittings with ferrule-type fittings, as shown in *Figure 5.29.*

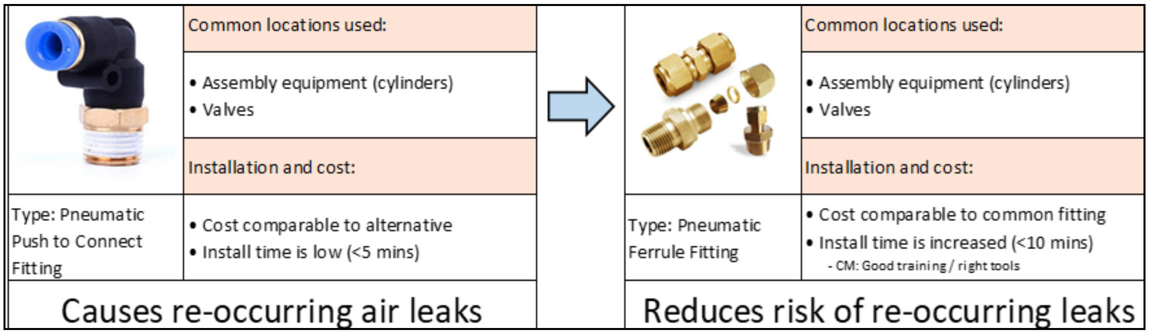


Figure 5.29: Air leak improvement method (Contributed by Author: Alec Ernst

Cooling Tower Temperature Improvements

The third highlighted improvement includes moving the temperature set-point on the buildings' central chillers or cooling towers. These chillers cool water to the desired temperature to feed equipment. The method utilized in this study was to study the manufacturer's specifications for the temperature set point. Past this, we chose to raise the temperature on each chiller until parts and production equipment started showing quality issues. Although this was not ideal, it was the easiest way to start and dial back. Based on the initial calculations, it was concluded that for every degree the set point is increased, an estimated savings of 2% energy and, thus, emissions reductions would occur.

Procedure

We recorded amp draw and refrigeration discharge PSI of running compressors at average production before the change to have a baseline. We noted which process machine currently had the lowest chilled water set point. We also recorded the number of compressors running at standard production before the change.

We started by increasing the temperature to 2 degrees at a time. We then allowed 24 hours of run time and recorded the amp draw, discharge PSI, and the number of running compressors. We monitored for issues in the downstream process. From this point, we allowed for one week of no issues and raised the temperature until the set point matched the process machine with the lowest chilled water set point.

Over 20 chillers were targeted to raise temperatures. An example of kWh consumption change is shown in *Figure 5.30* from one of the respective chillers.

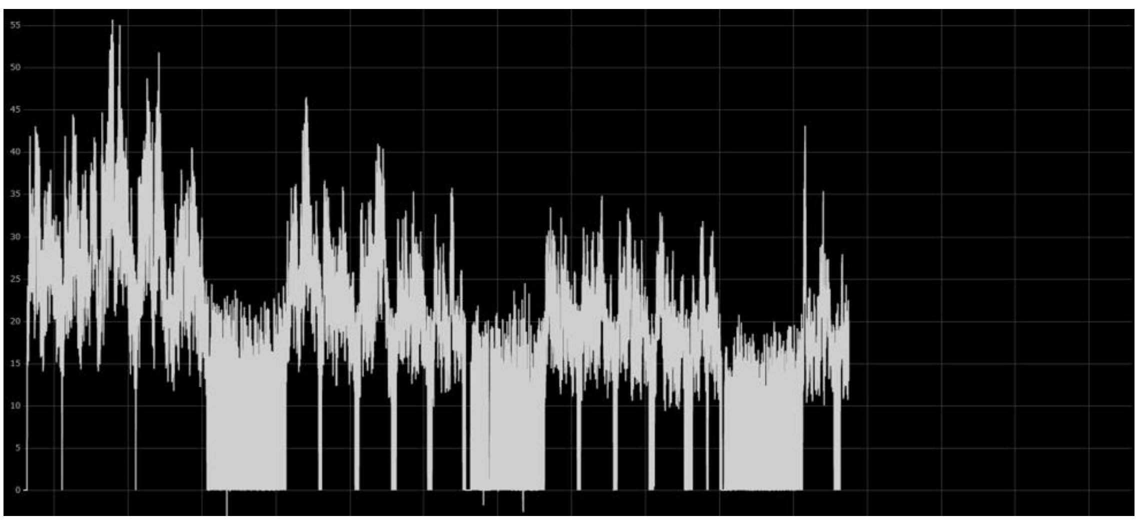


Figure 5.30: kWh improvement from temperature change (Contributed by Author: Alec Ernst)

We changed the set point from 45 to 60 degrees in one scenario. The result was an improved running capacity, as shown in *Figure 5.31*.

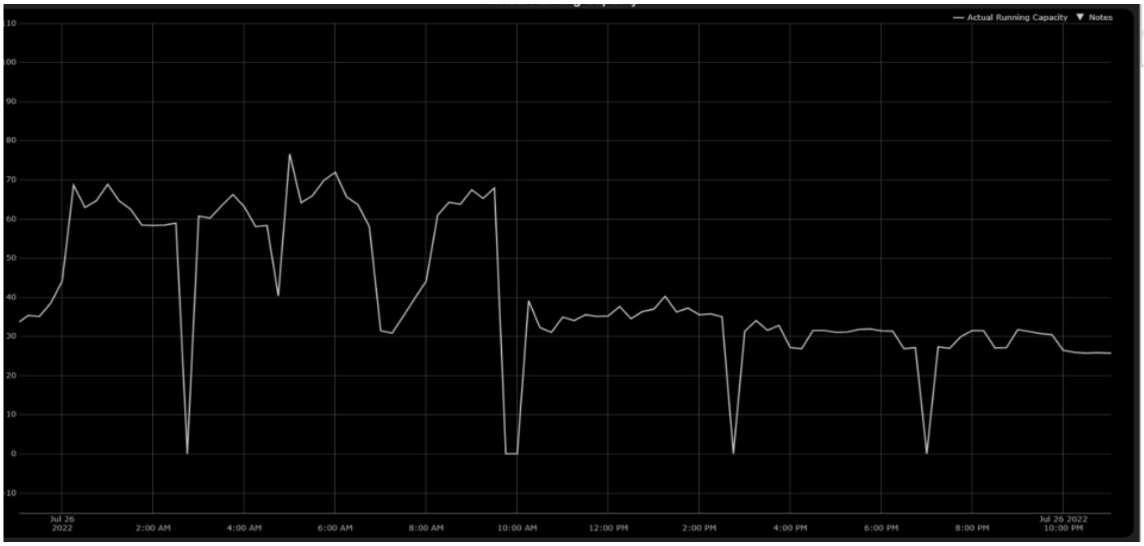


Figure 5.31: Chiller running capacity change (Contributed by Author: Alec Ernst)

The researcher and team noted from this study that there would be an increase in equipment life and system cooling capacity when increasing the temperature set points. There was also assumed to be less maintenance, water consumption, equipment wear and water treatment needed, and less carbon emissions. The results of chiller temp changes from April 2022 through January 2023 are listed in *Table 5.4.*

Table 5.4: Chilled Water Temp Setting improvements (Contributed by Author: Alec Ernst)

Type	**Electric Savings (kWh)**	**Water Savings (Gallons)**	**Carbon Savings (Tonnes)**	**Savings ($s)**
Chiller Temp	406,000	170,000	174.5	$32,000

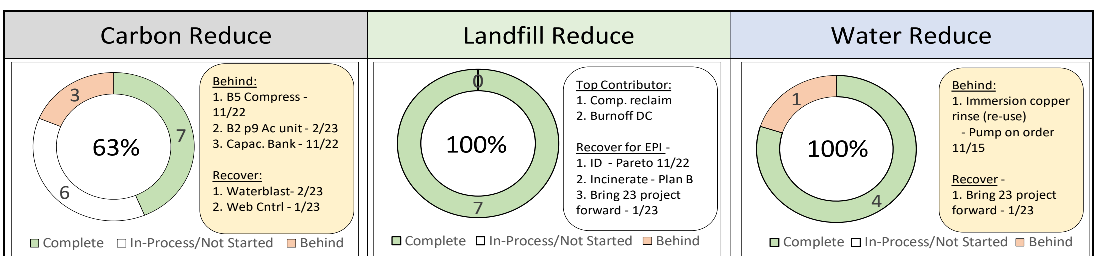
This project is being carried out to adjacent facilities and trialed across multiple plants. *Figure 5.32* shows a list of activities that are in the process of being completed or have been completed during this same time frame. Included in this are waste and water savings projects.

FY22 EPI Projects						
	Carbon		Landfill & Waste		Water	
1	LED Light Replacement	Energy Efficiency	Reduce Paint usage (22T/month) Sludge(15T)	Reduce	B2 CT-7 (raise water temp)	Reduce
2	B2 Central chiller-2 (raise water temp)		Wood Waste Reduce		13 Chillers (raise water temp)	
3	13 Remaining Chillers (raise water temp)		Cardboard convert to returnables		DC wash	
4	Capacitor Banks (increase power factor - B1, B3, B5)		Reclaim components from defective parts	Reclaim & Recycle	Chrome Reduction rinse re-use in Chrome E-Strip Rinse	Reclaim & Recycle
5	Fix air leaks (30/month)		Incinerate paint sludge (Under review) Waste to Energy		Immersion Copper Rinse re-use in Nitric Rinse	
6	Central chiller - B1		Bldg. 1 Compactor			
7	Utilize web control to adjust temp based on occupancy		Convert Injection Machines (Hydraulic --> Electric) (Reduce Oil)	Technology Improve	Waterblast	Technology Improve
8	Convert to battery powered lifts		Burnoff/Evaporate water from D.C.			
9	Replace AC unit B2 Paint booth - P9					
10	Maximize boiler efficiency					
11	Resin dryer operating hours					
12	Web Control for additional occupancy	Monitor & Control				
13	B1 AMU (controlling temp of facility by web control)					
14	B3 Spot Cooling (controlling temp of facility by web control)					
15	B10 AC Reduction (control temp of facility by web cntrl)					
16	B5 AMU (controlling temp of facility by web control)					
17	New waterblast machine	Technology Improve				

Figure 5.32: FY22 Project List (Contributed by Author: Alec Ernst)

5.9.2 Environmental & Business Savings

These projects had significant savings and are tracked monthly throughout the FY year, as shown in *Figure 5.33*.



	Carbon Reduce		Landfill Reduce		Water Reduce
TGNA FY Target:	4,235 metric tonnes	TGNA FY Target:	~~60~~ 117 metric tonnes	TGNA FY Target:	11,954 cubic meters
Internal FY Target:	4,450 metric tonnes	Internal FY Target:	~~67~~ 165 metric tonnes	Internal FY Target:	20,870 cubic meters
Target to Date Cum:	1,741 metric tonnes	Target to Date Cum:	38 metric tonnes	Target to Date Cum:	11,019 cubic meters
Actual to Date Cum:	1,415 metric tonnes	Actual to Date Cum:	212 metric tonnes	Actual to Date Cum:	9,392 cubic meters

Figure 5.33: Status of Activities (Contributed by Author: Alec Ernst)

From the start of FY22 to January 2023, the activity has generated savings from projects, as shown in *Table 5.5*.

Table 5.5: FY Results to Date (Contributed by Author: Alec Ernst)

FY 22 Results to Date	
Energy Savings (kWh)	>1M
Energy Savings ($s)	>125K
Carbon savings (tonnes)	>4K
Facility Gas (ft^3)	>150K
Water (gallons)	>175K

Each of these savings is a significant improvement for the facility. During the case study at the facility, favorable impacts on downtime, productivity, quality, and other critical business KPIs were also noted. They remain on track with meeting this year's carbon, water, and waste reduction goals but are still slightly above the target in landfill. A potential gasification project is being analyzed for future feasibility to help close gaps.

5.9.3 Manufacturing Paradigm Shifts

Although these studies are in their early stages, several key areas are being looked at to reduce further reliance on carbon-intense manufacturing methods and optimization of current equipment. One area under review is transitioning from reaction injection molding to pellet injection molding. The current state weighed against the improved state is shown in *Figure 5.34*.

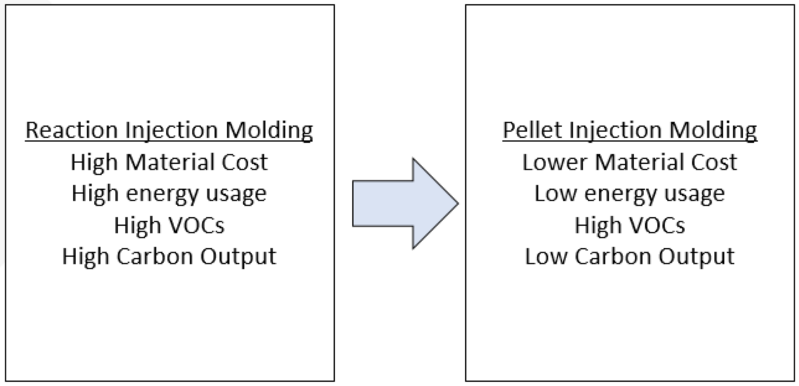


Figure 5.34: RIM vs PIM molding (Contributed by Author: Alec Ernst)

Other investigations include the following.

- Injection – hydraulic to electric
- Heating Efficiency – direct heat generation from heat transfer
- Reduce painting – Right sized equipment and new development of paint machine/gun
- New pressure resistance test methods
- AC install – renewed plating to reduce pressure and temperature in rectifier.

The company realizes that the simple projects with high payback and low investment will become smaller over time. In order to continue realizing these benefits and remain in step with future regulations and internal targets, two areas are being deployed. The first is to utilize software to monitor, control and manage the facility and its utilities.

5.9.4 Monitoring Software

The researcher and team wanted to remain in control of the improvements long after the project ended. They chose a building automation software package called *WEBCTRL® Building Automation System* from Automated Logic. (Automated

Logic, 2023) This web-based platform was chosen as ideal for the company as it was web-based, so it would be better at integrating with other systems than a native desktop application. Data sharing, collaboration, centralized security, and reduced hardware costs are also beneficial.

The purpose of the software is to manage energy conservation measures, identify fundamental operational problems at the facility and analyze the results. It allows for real-time data analysis, the ability to stay in control and notify users when critical failures happen or alarms are activated. *Figures 5.35, 5.36, and 5.37* show examples and capabilities of the WebCTRL® software utilization at the facility.

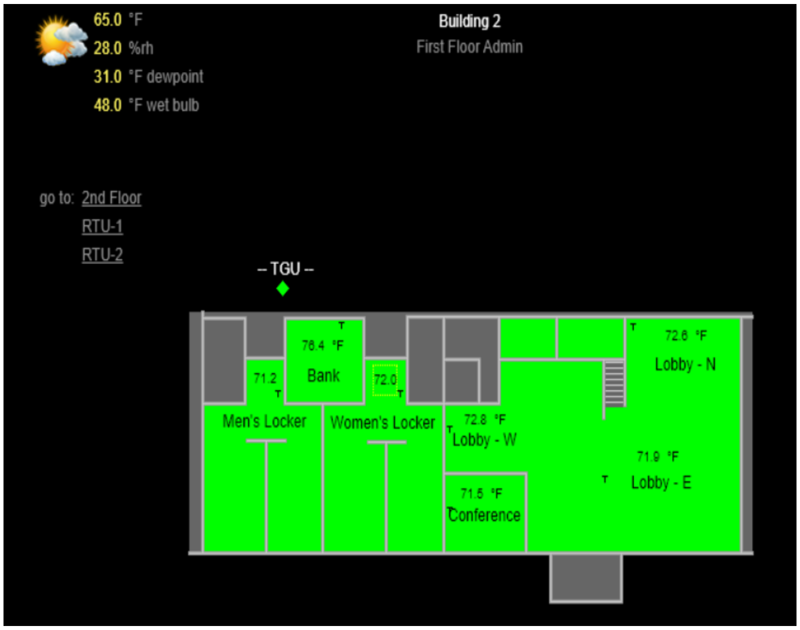


Figure 5.35: Plant layouts: Occupied vs Unoccupied Scheduling (Contributed by Author: Alec Ernst)

Figure 5.36: AMU – Optimization, Control & Analysis (Contributed by Author: Alec Ernst)

Figure 5.37: Energy Metering (Contributed by Author: Alec Ernst)

5.10 Discussion

The researcher intends to utilize the software and tie in the Internet of Things (IoT) software, plant KPI, utility billing, and carbon output to display in a common area. This will further educate and keep employees engaged, understanding that small improvements can yield significant results. It will also show them that they can help make a difference.

The second is to investigate renewable energy sources that would benefit the company with resources favorable to the area. *Renewable energy is not only being sought after to meet future regulations or internal targets; it is being investigated further to protect the country and the facility's energy security. The need for energy security will be discussed further in Chapter 6. A feasibility study on renewable energy will be reviewed in Chapter 7, which ties in with the case study facility in Chapter 5.*

5.11 Summary

The experimental and qualitative approaches used in the study are limited to bias in the following areas. The first key limitation is that there will be differences in efficiency, optimization, and feasibility from plant to plant based on the business model, resources, and current state efficiency. As COVID-19 has finally been laid to rest, a change in the landscape of the labor force has resulted, in part, from inflation. Significant turnover and absenteeism have created a new culture. However, companies can still harness the value of improvements by furthering their integration of intelligent software, such as that presented in Chapter 4. Access to the information presented within this Chapter and the adjoining chapters will help drive that success, as many simple improvements are shared among all plants. The second limitation is that this study was time-based, and although results show favorable, the company and budgetary constraints may handcuff other companies.

The approach in this Chapter was to evaluate the capability of mitigating global temperature change by reducing carbon emissions in manufacturing facilities. The primary mechanism is process optimization, efficiency improvements, and technology advancements. *This Chapter achieved the aim of the study showing the capability of a manufacturing plant today to not only improve emissions from energy consumption but to impact the business's bottom line positively. Evaluations on impact emission reductions, conducting improvements in energy efficiency, and comparing effects of improvements were explored in depth. This leads to Chapter 6, highlighting the need for further energy security to protect the industry.*

CHAPTER SIX

6.0 Applying Focus: Energy Security

*This Chapter is taken from the paper titled "***A Review & Analysis of Energy Security in the United States***" Co-authors on this work include:* ***Tomomewo S. Olusegun.*** *They contributed to this work by providing help and guidance through the literature review and analysis of current state. I have contributed more than 90 % of the effort to this work. In addition, 2 key objectives will outline the overall chapter. The first, is providing a brief analysis into the current constraints affecting the manufacturing industry. The second, is to explore and analyze future energy security projections and concerns.*

Abstract

To gauge a country's energy security, you must consider many factors, including political, economic, social, technical, and environmental. A balanced energy resource mix is crucial to a country's energy security. *To determine that the United States is appropriately positioned in terms of energy security, we will investigate that if the United States, or any country for that matter, is dependent on a single source of energy, they will leave themselves at a higher level of risk for economic collapse and overall instability. To test this hypothesis specifically, this writing investigates the risk and stability of the current system through baselining and benchmarking by energy type. Journal entries, past, and projected issues will all be rounded to provide a projection for current and future success.*

The goal is to optimize that energy mix to promote efficient and safe use, transportation, and production while limiting dependence on any single source to promote flexibility and prevent security issues. In conclusion, the United States is well positioned and taking energy security seriously, having little issue sustaining its current energy security score. With continued determination and improvements in efficiency and technology advancement, the United States will be well prepared for the years to come without heightened security risk to the country's energy infrastructure.

6.1 Introduction

Energy is vital in almost every sector in the United States and worldwide. Transportation of goods, businesses, and industries such as healthcare, residential homes, and travel all rely heavily on energy to stay in operation. Society and our economy are rapidly consuming and improving technology, so production and obsolescence compete with one another. Walking down almost any street, you will see cars, street lights, and people on cell phones, all requiring energy. Walk inside a residential house or business, and you will see televisions, cooking appliances, washing machines, computers, and video game consoles all requiring energy. Each of these items makes up our culture and way of life.

On the national scale, cheap energy has become essential to function in modern society. Militaries use energy to transport goods, and hospitals need energy to help save lives. Energy is not only important to our economy but also to our national security. Countries must have an uninterrupted availability of energy sources at affordable prices (IEA, 2019). Is energy security an issue for the United States? In recent polls, Americans have expressed concern over energy security due to shortages in food, fuel price spikes, availability of energy sources at an affordable price, and economic growth (Hagen & Pijawka, 2015). These concerns could ultimately lead to economic destabilization or even war.

For energy security in the United States, global markets must be stable, domestic supplies must be plentiful, and a mixed bag of energy technology must be available. Instability within the world, supply constraints, and non-proven technology, along with other economic concerns, show that energy security is an issue that should be at the top of the United States agenda.

Energy security is not new to the world or the United States. Energy security can be traced back to the prehistoric age when early humans started to control fire (Navikau, 2020). Survival strategies accounted for the availability, affordability, and resilience of flammable materials in prehistoric times. Fast forward to modern times, and during the 1960s and into the 1970s, the United States and the world were in an energy crisis facing petroleum shortages and elevated prices (History, 2023).

Two of the worst crises during this period were the 1973 oil crisis and the 1970 energy crisis (Clark et al., 2021). Interruptions in Middle Eastern oil exports were triggered heavily by the Iranian Revolution and Yom Kippur War (Barsky, 2004). The effects of each crisis yielded a recession during mid-1970. Many different nations stockpiled strategic oil reserves as they feared the onslaught of diminishing energy reserves. Oil prices rose to all-time highs, and major producing regions benefited economically as it created difficulties for the nations relying on energy exports (Hamilton, 2013).

The energy crisis the United States currently faces is the demand for limited natural resources (Clark et al., 2021). Natural resources are pulled from the environment and take years to form. These natural resources include coal, gas, oil, and others to satisfy our daily use. Our society has become so fast-paced that we disregard that the resources we use daily for our lives are not finite (UN Secretary-General, 1987). If the price of gas does not fluctuate at the pump, most would never connect the fact that resources are even being used. The country, and the citizens within, must work together to make the most efficient use of these resources and do so responsibly from production and resource attainment through the end user. Growing demands in resource use will eventually cause us to run out of specific resources.

The energy crisis is something to be concerned about locally and globally. There are key factors currently affecting the energy crisis. The world's population is increasing, modern medicines are becoming more effective, and therefore the average lifespan is longer than it once was. The global population in 2022 was 8 billion people (UNDESA, 2022) (Roser & Rodess-Guirao, 2019). The global population is projected to increase to 9.7 billion by 2050 and 10.3 billion people by 2100 (UNCS, 2022). This information is displayed in *Figure 6.1*.

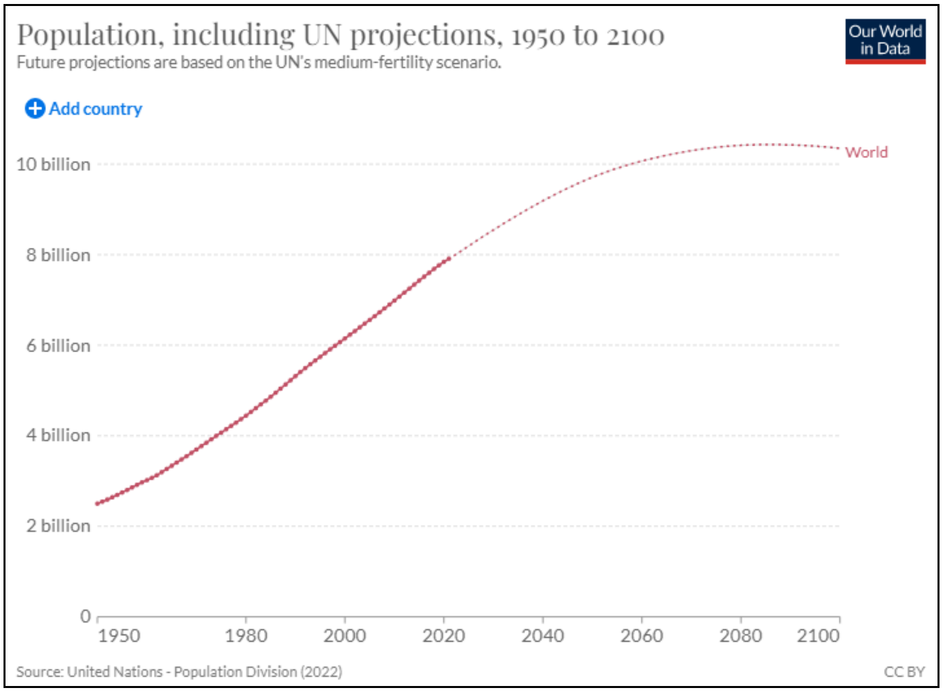


Figure 6.1: Global Population Projection: 1950-2100 (Roser, and Rodess-Guirao, 2019)

In order to transport and provide food to everyone daily, it takes an abundance of energy. If that energy comes from non-finite resources, complete depletion of the resources will happen over time as the world consumes faster than the resources can replenish. Overconsumption is a direct result of overpopulation. Equipment that is outdated and inefficient at power plants has not been removed. The equipment is still making money for the factories, so it has not been obsoleted as it should. Performance and efficiency in industrialized settings should be kept up to date so that energy is not wasted. Distribution systems need to be upgraded and optimized to keep energy moving efficiently without waste. These are just a few of the issues faced by the United States and the world regarding energy security and the crisis that may ensue if each is not handled appropriately. If left without countermeasure, the effects can become grave to the point of economic collapse (CEF, 2021).

6.2 The Clean Energy Revolution

Today the United States, and its president, Joe Biden, are investigating and planning for a clean energy revolution. Biden's energy and climate change goal is to act with diligence and ambitiously. *Table 6.1* lists the top items that the United States is currently focused on regarding energy security (The White House, 2022).

Table 6.1: U.S. Energy Security Top Focus Items (The White House, 2022).

Focus	**Brief Description**
Methane pollution limits	New and existing oil and gas operations.
Net-zero emissions	Economy wide by 2050.
World summit	Engage leaders in major greenhouse gas-emitting nations of the world.
Climate technology research	Promote clean energy and innovation.
Deploy clean technology	Utilize the economy to drive success.
Environmental justice	Prioritize across federal agencies.
Creation of jobs	Through the prevention and reduction of climate crisis.
Accountability	Hold polluters and abusers to standards.
Stand with workers	Make sure no one is left without a job in the changing energy market.

Theoretically, each focus point in *Table 6.1* collectively aims to diversify our energy production and consumption to a renewable and clean approach. Creating new jobs and replacing those lost is a win-win situation. However, there could be a dark side, and this approach may also threaten our energy security.

Throughout the past decade, the United States has achieved energy security at its maximum due to reliable coal and natural gas production. For example, hydraulic fracturing of shale deposits, known as fracking, produces 67 % of the United States' natural gas (Huimin et al., 2022) (USDOE, 2013). Some consider stopping oil production to be detrimental and suicidal to the energy security of the United States. Destroying fossil fuels and mandating unreliable solar and wind energy will cause issues in dependence on unreliable countries and make domestic energy undependable overall.

This could turn the United States into a third-world grid. For example, the equipment needed to produce and transmit the energy could be sourced from countries in Asia. The United States could become vulnerable to other leading countries pursuing fossil fuel projects worldwide through weak policies. This will ultimately cause the global balance of power to shift. Energy freedom will be required, yet there are more efficient routes as the global economy relies on nation-to-nation transactions (Epstein, 2021).

As a nation, we stand together on the issue of energy security. However, the means to achieve and sustain energy security creates a divide. On one side, clean and renewable energy paves the way for the future. On the other side, fossil fuels and the traditional approach are key. In this review of past and present research, our goal is to examine both sides and determine if the United States is positioned appropriately in terms of energy security. Dependence on any single energy source will likely leave the country at a higher risk for economic collapse and overall instability.

This review aims to examine each of the following key points, which will ultimately conclude with testing our hypothesis. Is the United States adequately positioned in energy security?

1. The important role energy security plays in our nation.

2. Types of energy available, traditional vs non-traditional.

3. The United States' stance on energy security.

4. The United States is rated against the World in Energy Security.

5. Considerations of energy security and the pathway to success.

The article is meant to bring both facts and professional-level opinions to the table to formulate what is considered to be the best possible outlook for the United States in terms of energy security.

6.3 The Importance of Energy Security to the United States

The United States has had the luxury of being one of the world's top producing, consuming, and industrialized nations. It took hard work, knowledge and determination, appropriate policy mandates, and effectiveness to achieve that status. However, today's world is rapidly changing, and developing nations are making their way to the world stage. This can be both an advantage and disadvantage to the United States. On the good side, these nations are increasing their consumption rate. If the United States is producing something they desire, it leaves them in the position to prosper as the nation demands more.

Conversely, countries are becoming more dependent as they become more developed. As developing nations increase investments in clean and renewable technologies, the United States risks falling behind the geopolitical race (Bulinghaus et al., 2020). Trade is one of the key aspects of energy security, and the United States is tied to international markets and price fluctuations. Navigating and optimizing their position within the global energy market is key to becoming an energy-conscious and secure nation.

Energy security has been on the radar of every U.S. president since Richard Nixon was in office. This undoubtedly shows that it is a top priority to the nation. Past energy security measures include Project Independence in 1973, enacted due to the OPEC oil embargo (Metcalk, 2013). Since then, the International Energy Agency was established to coordinate supply and demand activities among nations. The Strategic Petroleum Reserve was also established to contain sufficient oil to cover 90 days of net imports. This has been frowned upon throughout different presidencies as giving the ability to manipulate oil prices. There is an undoubted difference in opinion between each presidency but also between economists and policymakers. The top three reasons energy security is important to the United States include energy independence/dependence, vulnerability, and proliferation.

6.3.1 Energy Independence & Dependence

Energy independence eliminates the need to import energy from foreign nations. Relying on something other than another country would allow the United States to stabilize and grow its economy. Energy prices fluctuate based on demand and supply, affecting not only our country but also our homes and businesses. Budgets become hard to control and predict with the uncertainty of what will change next.

The opposite side of this is dependence. If the United States becomes solely dependent on any single energy source from a foreign country, they become at its mercy. Any disruption in the supply chain or within that country's economy will directly affect our nation's consumption. One example is the importation of oil from the Middle East. This leaves the door open to countries such as Japan and Germany to side with the Middle East versus the U.S. in times of conflict as they, too, are dependent nations.

6.3.2 Vulnerability

Terrorist attacks constantly threaten the U.S. infrastructure and those of the nations they import from. Leaving our nation and the economic workhorse that it is vulnerable. This also leaves the industrial sector, which is crucial to our economic system, at risk of instability. Emerging economies are starting to account for greater percentages of the world's energy use. Countries they are allies with or in conflict with will create concerns. This will ultimately leave the world's supply lines vulnerable to political and military attacks.

The U.S. imports almost 20% of its net primary energy today (USEIA, 2022). With this, defense budgets have increased. Other areas in which the U.S. is left vulnerable include foreign energy companies, unreliable exporters, and hostile powers. *Figure 6.2* shows significant events throughout the last four decades that have shaped pricing.

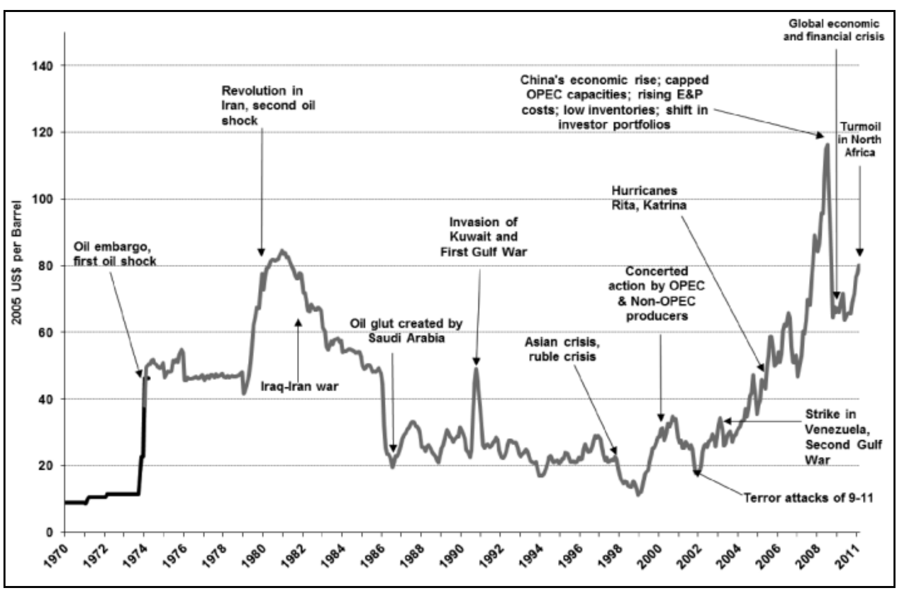


Figure 6.2: Oil Price and Major Political Events (Cherp, 2020)

6.3.2 Proliferation

Since the onset of the nuclear power devices being used in wartime fashions, the United States has aimed to reduce proliferation risks. This started during the Carter administration when India detonated a nuclear device (Deutch, 2004). Nuclear fuel and technologies are becoming globally available, and the risk of these technologies carries dire consequences if they are in the wrong hands. There is not a sound enough method for checks and balances to be put in place and policed from nation to nation and continent to continent.

Energy security should be studied for a multitude of reasons. One of these reasons is that energy security must evolve as the world evolves. We must investigate diversity in resources and energy supplies and the transmission and techniques required to deliver it. As a nation, we must explore the complexity between scalability and energy security, review obstacles, and develop countermeasures to be prepared and able to overcome each hurdle (Pasqualetti, 2012).

Table 6.2 displays energy security issues in both the short and long term. Identifying, understanding, researching, developing countermeasures, and creating a plan will allow adaptation without failure.

Table 6.2: Overview of concerns and indicators (Cherp, 2020)

Energy Sector	**Energy Security Concerns**	
	Short Term	**Long Term**
Oil	Exposure to the global oil market	Global oil scarcity
Gas	Exposure to global gas markets Demand side vulnerabilities	
Coal	Exposure to the global coal market	

Nuclear	Aging infrastructure Capacity to replace existing fleet	
Hydro	Exposure to risk of dam failure or sabotage	Effects of climate change
Electricity	Exposure to imported fuels Exposure to a single fuel market	Adequate capacity
Transport	Exposure to imported fuels	Demand side vulnerabilities
Industry	Exposure to imported fuels Demand side vulnerabilities	
Residential and commercial	Exposure to imported fuels	Demand side vulnerabilities Adequacy of provision
Energy for export	Exposure to imported fuels	
Cross-sectoral	Exposure to imported fuels Overall resilience of primary fuels Exposure to energy price volatility	Demand side pressure

From those mentioned above, it is rather apparent why this issue is important enough to study scientifically. The Department of Energy has commissioned these individuals to study the limiting factors and fundamental bottlenecks in the implementation of alternative energy technologies and how this will affect each sector, and how we will adapt. In order to gain energy sustainability and opportunity, we must place this matter at the highest importance and progress the research instead of regressing.

Would it be worth imagining a world that allowed for energy independence? Would it be worth it? If every country had the luxury of generating enough energy for itself, that would be one less point of contention worldwide (USDOE, 2008). Developing goals, following through, and allowing funds to do so will be very important today and into the future.

6.3.3 The Need for Energy Resilience

Traditional energy comes from coal, oil, and natural gas. These energies are developed, stable, and in demand. Most everyone can agree that these sources are used frequently daily. Non-traditional energy comes from renewable or alternative sources that nature provides. These can include wind, solar, water, and biomass. It is very important to have a diverse portfolio when it comes to energy. In order to make every form stay continuously efficient, research and development will be needed. In order to provide research and development, funding will need to be in place. The research and development into energy security allow for the achievement of both societal and political goals. *Energy security* is the vessel that allows for economic prosperity and progression and quality of the environment. It is imperative that funding is appropriated into the proper places so that we remain resilient to threats, boost our economy, save our environment, and pave the way for the future of our children.

In a journal article titled, Sustainability and risk- a review of energy security, Darton Axon discusses energy security and its heightened awareness throughout the United States and the world. One crucial point was that most countries are utilizing methods to gauge where they stand in energy security. This method, however, has resulted in little change to policy. Future research is suggested to develop more robust methods and analysis approaches (Axon & Darton, 2021).

In another journal article titled "Journal of Cleaner Production," Benjamin Sovacool gives insight from the consumer's perspective. Their attitudes, views, and beliefs were reviewed, and surveys were handed out to hundreds of United States residents. The summarized results included seven key areas held by consumers as important to the topic. These 7 included energy research and development, affordability of energy services, environmental pollution, climate change adaption and mitigation, energy democracy, and security of fuel supply (Sovacool, 2011).

6.4 United States Baseline Energy Consumption and Production

A 2019 United States Energy Information Administration study found that domestic energy production turned out to be greater than energy consumption, as shown in. This was the first time that this had happened since 1957.

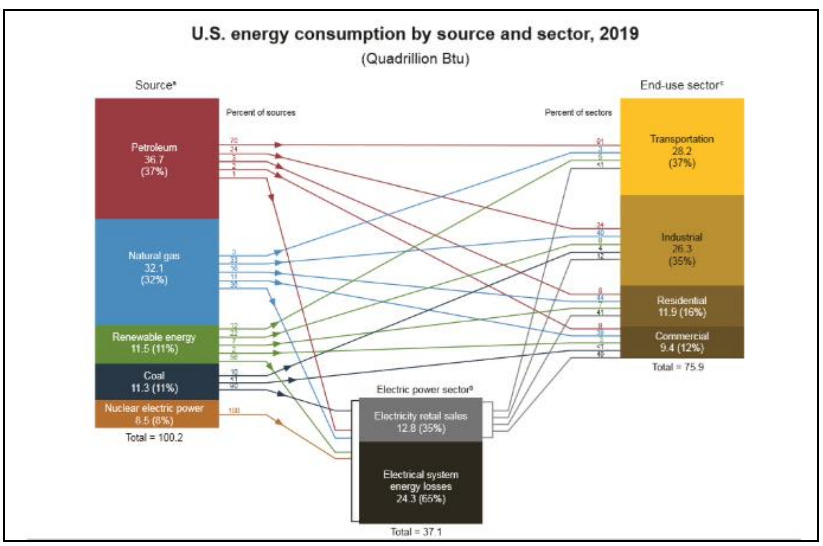


Figure 6.3: U.S. Energy Consumption 2019 (USEIA, 2020)

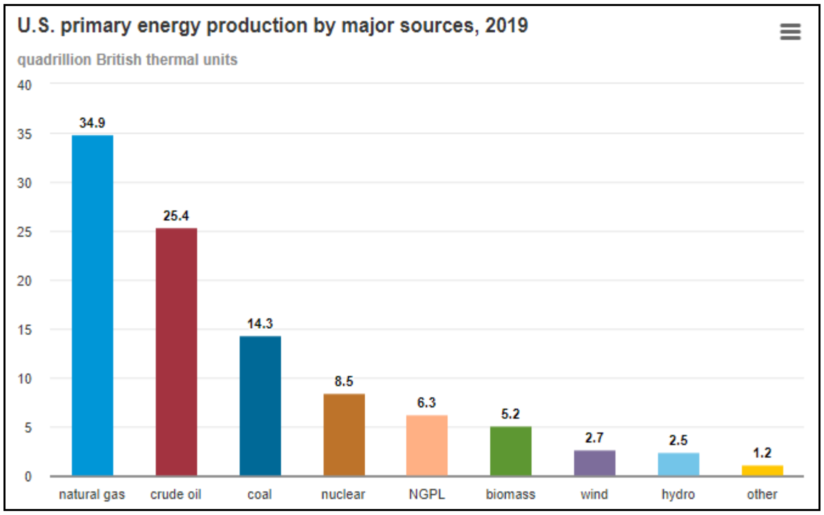


Figure 6.4: U.S. Energy Production 2019 (USEIA, 2020)

Looking at both *Figure 6.3 and Figure 6.4*, it is reasonable to say that energy use within the United States varies considerably. Record high wind and solar energy production in 2019 has caused production and consumption to reach new highs. Fossil fuels, including petroleum, natural gas, and coal, accounted for about 80% of total U.S. primary energy production within that year (USEIA, 2020).

The United States is considered one of the world's largest energy importers. Through the 1950s, the U.S. was relatively self-sufficient. From the mid-1950s through 2005, the U.S. began importing natural gas to support demand and crude oil and petrol products.

Now let us look at the data and statistics more in-depth, as displayed in *Table 5.3*. Natural gas as a source leads to total energy production. Petroleum leads in the total energy consumption category. Electric power leads by sector and in energy trade importing. Natural gas is at the top of the list for electricity generation, and petroleum leads to CO2 emissions. Capturing and utilizing data as a baseline will help to determine direction, strategy, and next steps. The current mix within the United States gives the appearance that they are well diversified when it comes to energy consumption and production.

Table 6.3: Energy statistics in the U.S. 2019 (USEIA, 2020)

Total Primary Energy Production	**101.04 quadrillion British thermal units (Btu)**
By fuel/energy source	**share of total**
Natural Gas	35 %
Petroleum (crude oil and natural gas plant liquids)	31 %
Coal	14 %
Renewable	12 %
Nuclear	8 %
Total energy consumption	**100.17 quadrillion BTU**
By fuel/energy source	share of total
Petroleum (crude oil and natural gas plant liquids)	37 %
Natural gas	32 %
Renewables	11 %
Coal	11 %
Nuclear	8 %
By sector and share of total U.S. primary energy consumption	share of total

Electric power	37 %
Transportation	28 %
Industrial	23 %
Residential	7 %
Commercial	5 %

6.5 Data Collection & Analysis

According to the Global Energy Institute, the forecast for energy security in the United States predicts a low-risk rate. The energy security of the United States in 2019 was the most secure it has been since 1970 (GEI, 2020). Since 2011, the total risk score has dropped by over 30 points. This drop was primarily attributed to the U.S. shale revolution (Nakhle, 2019). The lower the index value, the lower the risk level. This index is measured based on 37 different metrics. The index ranges from measurements in geopolitical, reliability, and environmental risks. Key change points that allowed for lower risk scores, displayed in *Figure 6.5*, included the United States becoming a net exporter of energy in 2019 (Barsky & Kilian, 2004). In 2019, the United States also led the world in natural gas production. Covid-19 may change the short-term forecast, but many risks will likely be low in 2021-2040.

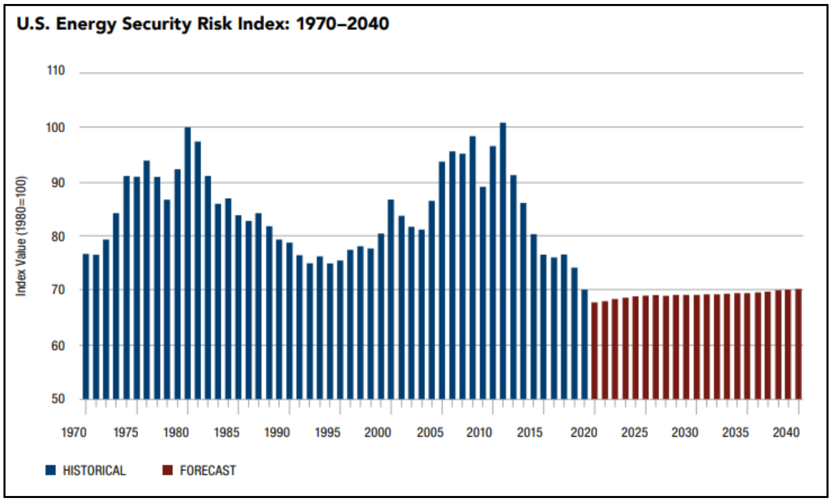


Figure 6.5: U.S. Energy Security Risk Index: 1970-2040 (GEI, 2020)

The concern, however, is that the landscape of the world and the United States is changing. With a focus on environmental issues due to climate change, it is hard to sustain practices that positively support reduced energy risks while at the same time negatively impacting the environment. This places the most significant contributor, oil production from shale, into a not-so-favorable category for climate change (Curley, 2022). Greenhouse gas emissions from shale are considered to be 20 % greater compared to coal (Climate Center, 2011). This is from the amount of carbon dioxide produced when the gas is burned and the methane that leaks out while the well is exploited (Climate Action, 2011).

In a simulation using EN-Roads software, the effect of variables market price of electricity to the end user as well as CO2 emissions and ultimately the temperature change by 2100. *Figure 6.6* demonstrates a status quo scenario.

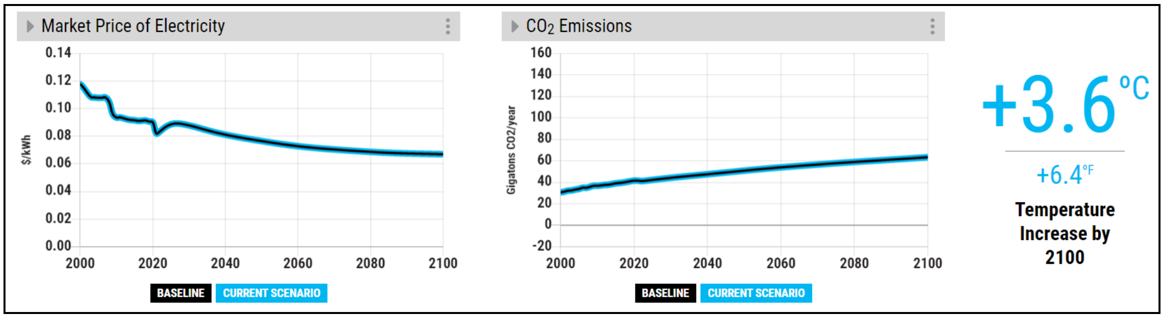


Figure 6.6: Status Quo Scenario – Market Price of Electricity & Resultant CO_2 Emissions (EN-Roads, 2023)

Figure 6.7 displays a high tax scenario.

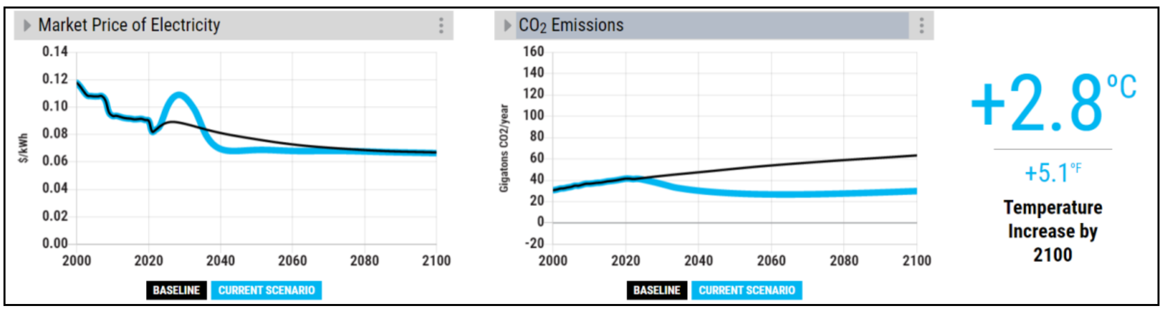


Figure 6.7: High Carbon Tax Scenario - Market Price of Electricity & Resultant CO_2 Emissions (EN-Roads, 2023)

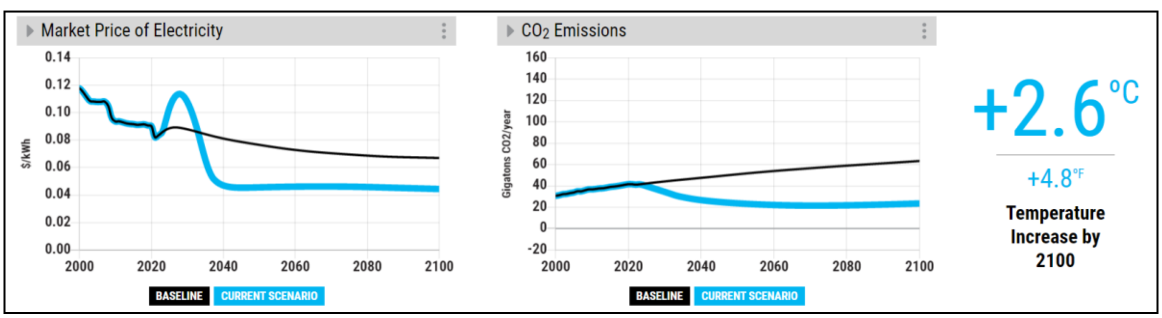


Figure 6.8: Very High Carbon Tax Scenario & Highly Subsidized Renewables – Market Price of Electricity & Resultant CO_2 Emissions (EN-Roads, 2023)

The simple answer may be to tax carbon to the fullest to promote change, displayed in *Figure 6.7*. For a negative impact not to be felt by the end user, technological advancements and renewable alternative energy sources, *Figure 6.8*, must be deployed to provide a realistic roadmap for the sector. Subsidies should be put in place to incentivize the industry to continue technological advancement to promote competition, thus driving the market price down and gaining the complete confidence of the end user.

6.6 United States Current State of Art

It is well known that disruptions in supply chains, whether from the onset of Covid-19 or the Suez Canal crisis of 2021, significantly impact our economy. As the commodity supply is below the demand threshold, prices start to rise. This, in effect, creates a challenge as importing raw materials for manufacturing and production will create the need to rely on clean energy imports. The Russia-Ukraine war has led to fuel prices and raised concerns about energy security. Energy security, however, is separate from energy independence. Competition is rising globally, and the U.S. is relying on foreign manufacturing and supply chains for the technologies it wants to deploy (Gordan et al., 2023). U.S. manufacturing can help to stay competitive and build the U.S. economy through efficiency and competitiveness to reduce reliance on foreign materials. This will be further explored in subsequent chapters.

6.7 Risk and Proposal

According to recent articles, research, and current state data metrics, the United States appears well-positioned regarding energy security. Short-term focus proposed items include stability and sustainment. Long-term improvement strategies should include research and development. Access to new energy technologies, climate change, limiting their impact on energy securities and affordability of new technologies as they emerge. Continuous improvement and keeping energy security, diversity of the energy mix, and risk mitigation will allow the United States to stay at the forefront. *Figure 6.9* shows a matrix and roadmap for energy stabilization and risk alleviation. As long as domestic energy production remains solid and stable, risk should be relatively low.

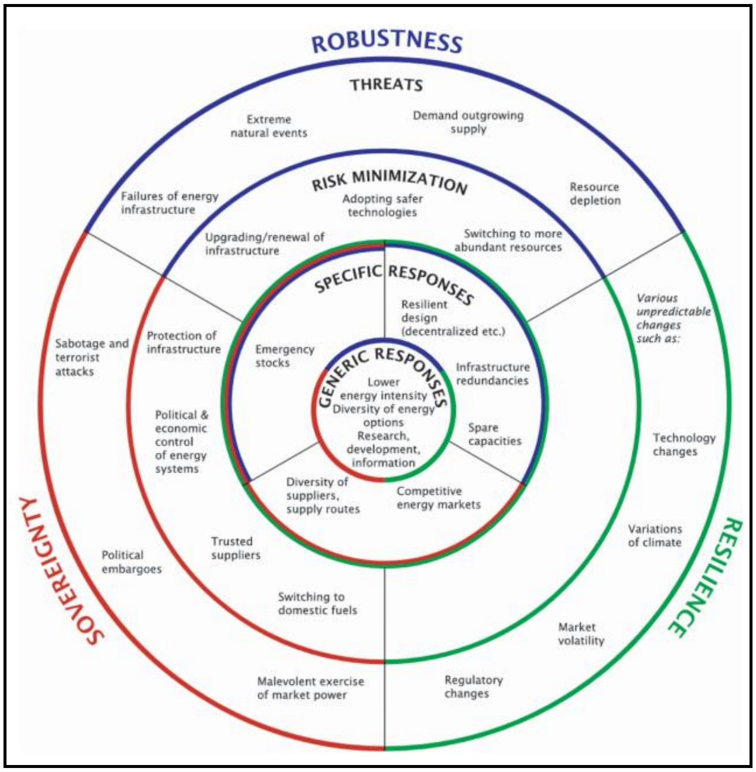


Figure 6.9: Three perspectives on energy security (Cherp, 2020)

6.8 Summary

Energy security is important to both the end consumer and the United States government. Issues that are present and could have profound impacts on the United States' current status of a low energy security risk threshold include the political instability of producer countries that the U.S. does business with. Other potential issues include competition over supplies and manipulation in the market. Terrorism, natural disasters, and over-reliance on any one source will also present issues. The United States must learn from past issues, such as those in the 1970s, and harness what they have done right in reducing potential concerns to remain stable in energy security.

The objective of gathering relevant information and datasets to determine if the United States is correctly positioned regarding energy security has been achieved. It is understood that the United States is both sound and responsible in its energy security achievements. Considerations should be taken in four key areas.

The first area is policy; it will be key as transitions into new technologies are made. The second is that the United States must continue to minimize risks through the protection of disruptions to its energy supply. The third is to control reliance on domestic and foreign resources and technologies. The fourth area is to protect energy systems from threats.

High-level energy security issues are under control. Diverse technology usage, domestic and foreign energy mix, importing and exporting, and risk hedge are all examples. Once considered, micro-issues that may become bigger over time are those that we are currently seeing. Interruptions in the supply chain due to chip shortages. Power outages in Texas are causing supply chain issues across the United States and jeopardizing the local's way of life. Continuous risk analysis should be done, and playbooks for handling known repeating issues must be created and optimized.

For overall improvement suggestions, policy needs to be rated against energy security. The correlation between each will tell the tale of whether what is being implemented positively or negatively affects energy security. The United States must remain sensitive to energy security and not dismiss it. They must remain efficient, and policies effected and up to date to keep with the technology. One key area of improvement is transportation. Today, the transportation sector within the United States relies heavily *on oil. The small blip of Covid-19 changed the U.S. status from heavily importing to exporting. Will this status remain or revert to what it once was?*

Cognizance and prioritization will allow energy security success in the future.

CHAPTER SEVEN

7.0 Deployment: Renewable Energy Integration

The majority of this Chapter is taken from the paper titled ***"Analysis of Biomass, Converting Wood to Energy: Missouri as a Case Study in Feasibility"*** *published in the* ***"American Journal of Energy Research Volume 10, 2022 – Issue 1"****. Co-authors on this work include:* **Tomomewo S. Olusegun.** *The co-author contributed to this work by providing help and guidance through the literature review and analysis of current state. I have contributed more than 90 % of the effort to this work. A brief exploration and analysis into the current and future state of renewable energy will be explored. In addition, 3 key objectives will be targeted. The first, is to explore current state renewable energy opportunities. The second, is to investigate the feasibility of deploying renewable energy technology. The third, is to evaluate improvements and the effect on business. This study will be then be translated into the case study to show feasibility at the plant level for opportunities in alternative energy.*

Abstract

In 2021, the United States President, Joe Biden, launched an initiative to generate net-zero carbon emissions from the U.S. by 2050. In order to complete this task, commitments must be made to research the most efficient methods in the production, transmission, and storage of alternative and renewable energy sources. Foreseen obstacles include capital costs, environmental, wildlife, and economic concerns, political agendas by the state, fossil fuel prices, and concerns about greenhouse gas emissions. Developing sustainable, viable systems that promote health,

safety, and economic growth must be coordinated with policy changes. The first step of the process at a local level is to baseline the production and consumption of the current energy systems in order to make an educated decision on which system or systems to utilize. Suppose Missouri can expand its biomass energy generation mix. In that case, it will be able to drive down the current consumption-to-production ratio of 8:1, thus, expanding its overall energy mix and ultimately leaving the state in a position to sell energy to neighboring states. To test this hypothesis specifically, this writing investigates process risk, project value, design, building, decommissioning planning, flexibility, capacity, and adaptability. Journal entries, past, and projected issues have been rounded out to provide a projection for current and future success. This will better position Missouri to support the overall agenda of net-zero carbon emissions by 2050. Missouri is well-positioned to launch a successful wood-to-energy program and well-prepared to minimize dependency on energy imports outside their state border.

7.1 Introduction

As the world looks to move past the global pandemic known as Covid-19 and return to a new normal, leaders, businesses, and individuals must regain focus on what is truly important. Now more than ever, most of the world realizes the value of security, safety, and a healthy future. In support of this, we need to be willing to put in the time, energy, and effort to improve our environment. We must act to preserve our world for future generations through pollution reductions so that the world we hand off is equal to, if not better, than the one we currently live in.

From 2019 to 2020, the world as we knew it changed. Through the many hardships in health and the economy, almost every individual has been affected somehow. Although hard to see, benefits can be achieved by taking a step back, slowing down, and determining what is important and how to improve. Energy creation and consumption are close to the top of the list.

One source of energy creation that shows promise is biomass, wood-to-energy. Credits have become available for residential biomass heating systems. In Wisconsin, for example, biomass is considered one of the state's largest renewable energy sources. In a state report, wood and biomass produce about ten times as much of the state's electricity as hydro. Wisconsin is suited for biomass production through available timber, paper, and farming sectors. In 2020, a fifth of Wisconsin's renewable electricity generation came from biomass, equating to roughly 1 in 33 homes heated by use of wood.

Proper forest management allows for healthy forests and wildlife while also preventing wildfires. Proper forest management makes large amounts of wood biomass available in the form of residue and logs. Many residential households use this wood to heat their homes; however, health risks from the fine particle inhalation of burning off account for around 39-47 % of premature deaths, based on a Harvard study (Layperson, 2021).

Wood biomass for energy has a bright future and is an incredibly resilient renewable resource. Benefits will be achieved through proper management, policy, design, and control, and negative impacts and risks to our health and the environment will be suppressed.

Wood is composed primarily of the following, which also affect the optimal processing methods.

1. Cellulose: Structural cell wall, 50 % dry weight makeup.

2. Hemicellulose: Cell wall, 30 % dry weight makeup.
3. Lignin: Polymer, 20 % dry weight makeup.
4. Mineral Elements: Nitrogen, Sulfur, Chlorine, and heavy metals (USA, 2008).

Current state studies show that multi-stage biomass gasification technology may be one way to improve the energy sector.

This technical analysis and review aim at utilizing best practices and lessons learned in the industry to prepare Missouri for the transition to self-sufficiency with less reliance on imported energy. The scope of the study is limited to the availability of resources within the borders of the state of Missouri, including materials, supply, consumption, transportation, storage, and transmission.

Also, this analysis aims to analyze and evaluate the potential installment of wood-to-energy biomass energy processes within the state of Missouri and determine if it is a viable system in terms of cost and sustainability. We will conclude by logically answering the question: Does biomass wood-to-energy system have a place in Missouri's energy portfolio?

7.2 Missouri's Energy Profile

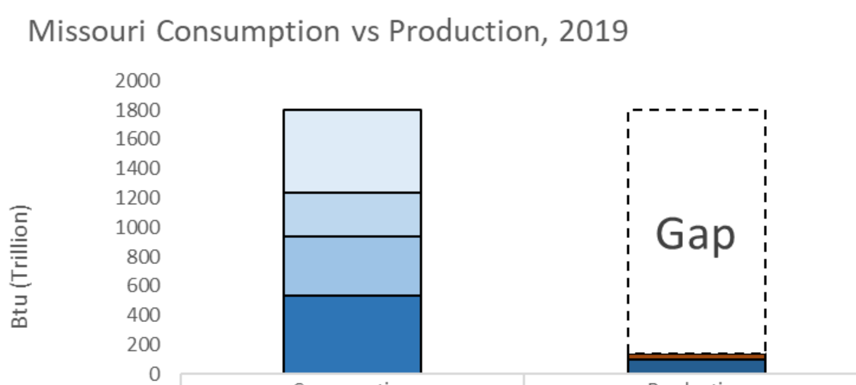
Agricultural farms are abundant in rural Southeast Missouri, with plentiful green trees. Missouri can expand its energy systems mix to alternative systems, utilizing available resources to mitigate pollution and carbon emissions. One such alternative system that has been relatively untapped with resources available in Missouri is biomass conversion to energy. Many current, past, private, and government-funded projects in the biomass sector have advanced the industry and can support Missouri in its endeavor.

Several natural resources, such as zinc, copper, limestone, and coal, are available in Missouri. Mining these resources requires energy from the residential, commercial, industrial, and transportation industries. In 2019, Missouri's transportation sector led energy consumption with 567 trillion British thermal units (BTU), closely followed by the residential sector at 530 trillion BTU. The industrial and commercial sectors made up 40% or 707 trillion BTU. The state consumes eight times more energy than it currently produces (USEIA, 2021).

Figure 7.1: Map of the United States with Missouri highlighted (Missouri 2021)

Missouri is considered to be a central transfer point for the United States. It is located at the interchange of the two longest rivers in the United States, Missouri, and the Mississippi. This allows raw materials to move by the river to transfer points and then to final destinations throughout the country. Missouri’s population is around 6.1 million as of July 1, 2019 (Missouri, 2021). The largest cities in the state are Kansas City, St. Louis, and Springfield, making up around 1M of the total population.

Figure 7.1 shows the location of Missouri, highlighted in red, in the United States. As of 2019, Missouri had a low production-to-consumption ratio, at 8 to 1, as shown in Figure 2.



	Consumption	Production
Gap		1666.3
Energy Production Biofuels		37
Energy Production Nuclear Electric Power		96
Energy Production Crude Oil		0.5
Energy Production Coal		4.2
Energy Consumption Transportation	567	
Energy Consumption Industrial	300	
Energy Consumption Commercial	407	
Energy Consumption Residential	530	

Figure 7.2: Data showing production versus consumption gap for Missouri in 2019 (USEIA, 2021)

This gap, as shown in *Figure 7.2*, between production and energy consumption rate can be concerning. It could be assumed from this information that the state needs to do more to promote energy generation and clean energy generation.

7.3 Energy Consumption in Missouri

Coal and natural gas lead overall consumption by sector, while biomass is in the bottom 25% (USEIA, 2021).

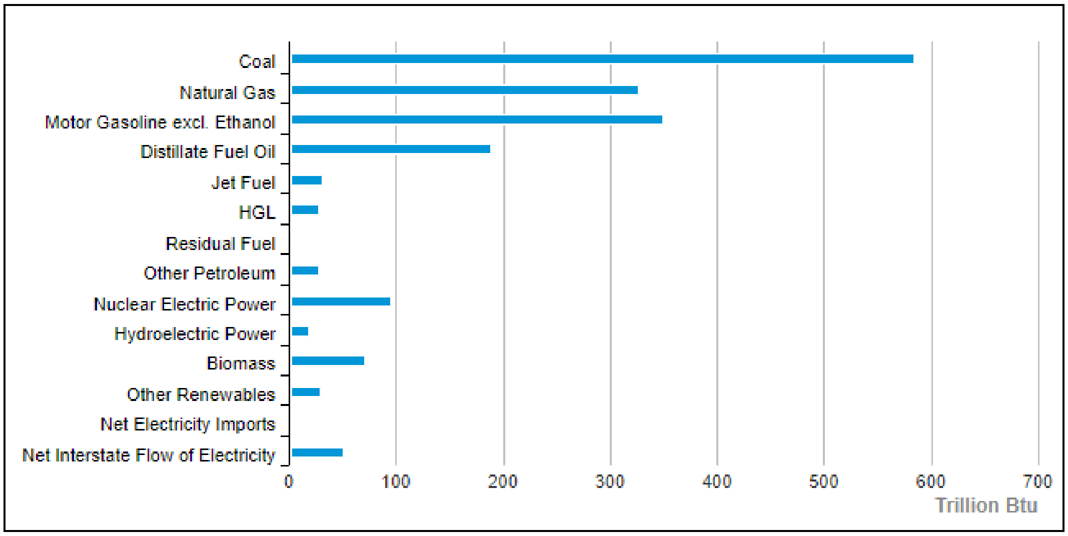


Figure 7.3: Missouri Energy Consumption Estimates, 2019 (Lin et al. 2021)

Table 7.1: Missouri Energy Indicators (USEIA, 202)

Demography	**Missouri**	**Share of U.S.**	**Period**
Population	6.2 million	1.9 %	2020
Civilian Labor Force	3.1 million	1.9 %	May 2021
Economy	Missouri	U.S. Rank	Period
Gross Domestic Product	$321.7 billion	22	2020
Gross Domestic Product for the Manufacturing Sector	$37,972 million	22	2020
Per Capita Personal Income	$51,177	37	2020
Vehicle Miles Travelled	79,168 million miles	14	2019
Land in Farms	27.8 million acres	12	2017
Climate	Missouri	U.S. Rank	Period

Average Temperature (^{o}F)	5.8	19	2021
Precipitation (in)	46.3	16	2020

A relatively large expansion window exists for renewables and biomass to operate in Missouri. Strategically increasing the proportion of the bottom 25% of the product mix, shown in *Figure 7.3*, will increase energy production internally while decreasing the state's carbon footprint. Energy indicators show stability and progression within the state rankings concerning the United States.

Missouri makes up 1.9 % of the United States population, as shown in *Table 7.1*, with a matching labor force. The economy in Missouri is strong, and the climate shifts from hot summers to cold winters. Below are the critical metrics of Missouri.

1. Missouri is ranked 22 in the United States for GDP, at $321.7 billion.
2. The average temperature is around 55.8 o F.
3. Farmland makes up around 27.8 million acres of land.
4. Six major crude oil pipelines pass through Missouri.
5. Missouri ranks 3rd in the nation in biodiesel production.
6. Missouri is one of two states that require 10 % ethanol in gas.
7. Missouri's single plant accounts for 11 % of electricity generation.

Table 2 shows the environmental energy indicators in Missouri. As coal-fired capacity has decreased since 2011, natural gas in the power sector has increased. Coal fuels about 70 % of electricity generation, and 80 % The state's top power plants are coal-fired (USEIA, 2021). Some have started to switch to natural gas, whiles other areas of generation include hydropower and wind farms. There are only three hydroelectric power plants with storage in Missouri. These include the Taum Sauk, Clarence Cannon, and Harry Truman plants. The rivers in Missouri offer expansion potential for future hydropower projects beyond those listed. Investor-owned companies supply power to major urban areas, while electric cooperatives supply most of the remainder. Electricity pricing per kilowatt hour (kWh) in Missouri falls in the lowest 20 % of all states within the United States.

Missouri ranks within the top one-third of states in ethanol consumption and has the third-largest biodiesel production capacity in the nation due to robust policy initiatives (USEIA, 2021). However, key areas need to be considered for analysis and improvement. Renewable energy production is high within ethanol at 1.8 %, and energy consumption is low within biomass at 0.2 %. Missouri's ethanol consumption is ranked high at 16 in the U.S., and emissions in carbon dioxide equate to 3.3 % of the U.S. Each of these metrics, displayed in *Table 7.2*, shows the need and potential for improvements.

Table 7.2: Missouri Environmental Energy Indicators (Liu, et al. 2014)

Renewable Energy Capacity	**Missouri**	**Share of U.S.**	**Period**
Total Renewable Energy Electricity Net Summery Capacity (Utility Scale Units)	2.856 MWh	1.1 %	As of April 2021
Ethanol Plant Nameplate Capacity	297 million gal/year	1.7 %	2020
Renewable Energy Production	Missouri	Share of U.S.	Period

Utility-Scale Hydroelectric Net Electricity Generation	191,000 MWh	1.0 %	Apr-21
Utility-Scale Solar, Wind, and Geothermal Net Electricity Generation	655,000 MWh	1.4 %	Apr-21
Utility-Scale Biomass Net Electricity Generation	7,000 MWh	0.2 %	Apr-21
Small-Scale Solar Photovoltaic Generation	38,000 MWh	0.8 %	Apr-21
Fuel Ethanol Production	6,597,000 barrels	1.8 %	2019
Renewable Energy Consumption	Missouri	U.S. Rank	Period
Renewable Energy Consumption as a Share of State Total	6.7%	37	2019
Fuel Ethanol Consumption	7,378,000 barrels	16	2019
Total Emissions	Missouri	Share of U.S.	Period
Carbon Dioxide	123.9 million metric tons	2.3%	2018
Electric Power Industry Emissions	Missouri	Share of U.S.	Period

Carbon Dioxide	57,516,000 metric tons	3.3%	2019
Sulfur Dioxide	81 thousand metric tons	6.4%	2019
Nitrogen Dioxide	42 thousand metric tons	3.1%	2019

Through emerging countries and advanced technology, energy consumption is happening rapidly. Pollution and emissions are causing irreparable damage to our environment, and our society based on traditional sources is exhausting resources faster than they can be replenished. The need to expand our energy mix and the immediate need for action is only sometimes apparent.

Missouri must expand energy sources to mitigate energy security risks and become self-sustaining through areas they are capable of, such as wood-to-energy and biomass. If the state of Missouri decides not to continue on its quest of efficiently and sustainably expanding potential renewable resources into energy, many scenarios may take effect. These can include environmental damage through increased carbon emission and purchasing versus producing energy, causing an increased energy security risk. Another possibility if Missouri does not choose to expand its energy resources is that climate change may happen more rapidly, which could cause damage to plants and animals, flooding, and ultimately putting human life at risk.

Funding studies in biomass for Missouri allows for potential benefits to the state, the renewable energy sector, and the future of wood-to-energy conversions. Benefits that may be yielded through funding include supporting the U.S. initiative to become net zero in carbon emissions. Creating education opportunities for colleges and research institutes will support future grant and funding opportunities. Other benefits that may be realized are reducing landfills and improving land value, water resources, and wildlife habitat while minimizing dependence on other energy-producing states.

Wood-to-energy biomass in Missouri can add value to the state through the appropriate funding channels and efficient use of those funds. With proper analysis and research, the benefits and an optimistic attitude will allow for an efficient energy system approach. Ultimately, this may yield setting new industry standards.

7.4 Wood-to-Energy Biomass

Biomass is a renewable organic material that is generated from plants or animals. In Missouri, biomass is primarily used to provide energy using biodiesel and ethanol fuels from soybeans, corn, and other crops. Missouri is ranked fourth in the nation in biodiesel production capacity and second in production in the US, with eight biodiesel plants in operation (USDOE, 2021). Missouri's biomass energy systems can be expanded by utilizing other biomass materials (USEIA, 2021).

Wood biomass to the world and Missourians is not a new concept. Wood is utilized in heating homes in many countries through wood stoves or fireplaces (Magdziarz et al., 2016). It is common to see smoke exiting the chimneys of residential homes in the winter months.

7.4.1 Conventional Wood-Biomass Processing Methods

Several methods are utilized to turn wood biomass into energy. These methods include the following.

1. Thermal

    (i) Combustion – burning biomass to produce heat

    (ii) Gasification – heating organic materials with free oxygen to produce a hydrogen-rich gas.

    (iii) Pyrolysis – heating organic materials without free oxygen

2. Thermochemical – decomposition of organic matter for biofuel production.

3. Chemical

    (i) Hydrothermal liquefaction – a process in which the biomass molecules are hydrolyzed by water.

    (ii) Carbonation – a process of heating in an oxygen-free environment in which biomass is converted into a charcoal-type material

4. Biochemical – using bacteria, microorganisms, and enzymes to breakdown biomass

5. Physical processes – burning oil (USDOE, 2004).

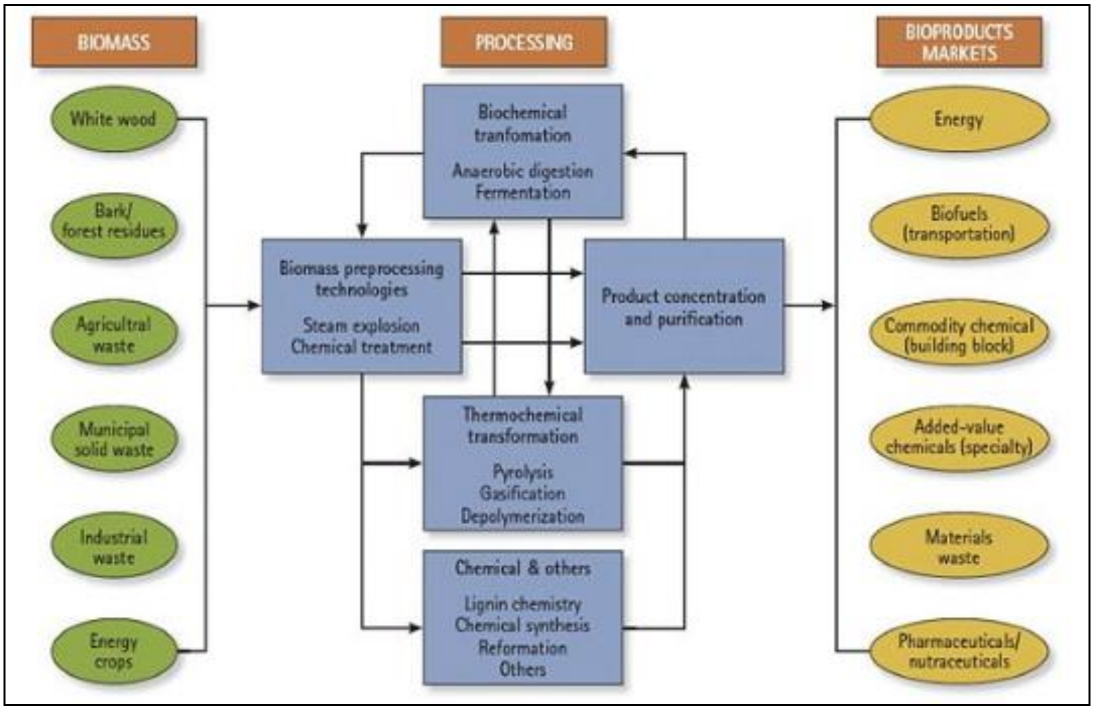


Figure 7.4: Biomass Processes (Li et al. 2016)

Figure 7.4 shows a schematic representation of biomass-to-energy conversion through standard processing methods.

In simple form, the process can be grouped into four main steps.

1. Feedstock – Raw materials used for processing which are converted into another product or fuel. These resources are renewable in biomass, including crop waste, woody materials, and forest residues. These materials are categorized as those that are not favorable to be sold or the residues that are left after logging timber.

2. Pre-processing – Several appropriate, efficient biomass pre-processing controls exist, such as drying, sizing, shredding, and chemically treating the feedstock for optimal processing. The greater consistency and repeatability in the feedstock, the greater the chance of running high efficiency in the conversion step or downstream process. Biomass feedstock consistency and variability directly affect the cost and approach to pre-

processing. Improving the pre-processing system to manage variation, improve quality control and remain cost-effective is equally important (USEIA, 2021).

3. Conversion – Wood-to-energy biomass can be converted through direct combustion, chemical, physical, biochemical, thermochemical, and biological conversions. Each process has its advantages and disadvantages based on the application and energy end-use. For example, chemical or biological conversion is most suitable for converting biomass to liquid fuel. At the same time, direct combustion is the most appropriate conversion method to convert wood biomass for heating purposes.

4. End-user consumption – Wood has been used as a heating and energy source for centuries. In 2020, wood and wood waste accounted for 5.5 % of industrial end-use energy consumption (UME, 2017). Wood biomass will continue to be utilized as a fuel for residential and commercial heating, providing electricity and chemicals such as biodiesel.

7.5 Missouri's Transition Challenges

Missouri relies heavily on receiving energy from outside sources, as shown in Figure 2. Missouri can transition from a top consumer of energy to a top producer. In order to do so, Missouri can target industries that are within the scope of available resources. Biomass is one such resource that Missouri has successfully tapped into, mainly through crops. Innovations within wood biomass are suited well for the resources available in the region. Missouri has 15 million wooded acres that provide abundant resources for biomass. This woody biomass consists of trees, limbs, needles, wastes, and other residues. Although this wood is being used to drive the economy through logging, milling, and building materials, it can also provide opportunities for energy.

In order to increase the energy production rate against the consumption rate while maintaining a clean profile, Missouri can adapt and traverse into alternate methods and materials such as wood-to-energy biomass. It can support increased energy production. It is a relatively new innovation, and materials are largely available in Missouri. Research and studies have been done at various levels. However, the system has yet to be brought to market. This technical analysis of the proposed introduction of a wood-to-energy biomass system will challenge and countermeasure some of the current issues in the process chain of biomass production, as shown in *Table 7.3*, and challenges that Missouri as a state face, as shown in *Table 7.4.*

Table 7.3: Challenges for Missouri (Contributed by Author: Alec Ernst)

Challenges for Missouri
1. Production ratio against consumption ratio is low.
2. Security at risk due to dependence on imported energy.
3. Alternative / renewable energy programs lacking.
4. Long-term plan not in place to promote clean energy production.

Table 7.4: Challenges for Biomass (Contributed by Author: Alec Ernst)

Challenges for Biomass
1. Emission of pollutants, example: volatile organic compound (VOCs), CO_2
2. Deforestation potential
3. High costs
4. Supply constraints

Transitioning into a clean biomass process using the wood-to-energy process can benefit Missouri and other states' similar geography. When utilizing the wood-to-energy technology, each state can contribute to realizing the United States achieving net-zero emissions by 2050.

7.6 Case Studies

7.6.1 Case Study by U.S. Department of Energy

The U.S. Department of Energy's research center in Bioenergy is composed of 5 research areas. These areas focus on supply and sustainability, development, deconstruction and separation, conversion of biomass to biofuels, and enabling technologies.

The Great Lakes Bioenergy Research Center is focused on supply and sustainability. They reported that the development and breakdown of nitrogen and carbon cycling are essential for creating sustainable biofuel landscapes through research and testing. Using the latest tools in chemical engineering, the Joint Bioenergy Institute transformed biomass sugars into energy-rich fuels. These microbes can quickly ferment complex sugars, which can be used as biofuels. Farmland degradation, economic impacts, and variability in feedstock were all considered in each study.

In development, high-yield perennials were analyzed as domestic feedstock, while advances were made in studies of Populus and switchgrass. Genetic engineering was identified as an improvement to plant processing through augmentation. An innovative pretreatment method that reduces enzyme loadings and increases yields was developed in deconstruction and separation. Next-generation deconstruction was developed by avoiding chemicals and instead utilizing plant organic solvents to break down biomass into cellulose and lignin.

The benefits discovered through the bioenergy research project also impacted other sectors, including human health and sustainable agriculture. One example is higher-value forage plants through lignin control, making them easier to break down and convert into biofuel (UME, 2017).

7.6.2 Case Study by the University of Missouri Columbia

In 2008, the University of Missouri-Columbia decommissioned a coal-fired boiler for a more carbon-friendly alternative. Through research and analysis, the University opted for a biomass-fed boiler. Researchers evaluated the available renewable resources in the region, ranging from debris from natural disasters and mill waste to logging residues and opportunities for forest management to grow and harvest small trees. Careful analysis and consideration were taken to launch the project without harming future forest stabilization and protecting local landowner interests. The project was officially launched in 2012, and the 75-million-dollar plant came online (MDNR, 2021).

Credited with being the biggest sustainable energy project on an American university campus at the time, the boiler accounted for 25 % of the total electrical and thermal energy used on campus (Potter, 2012). The boiler consumes around 100,000 tons of biomass annually through semi-truck delivery with covered silo storage. The biomass consumed ranges from switchgrass, corn stover, and sustainably sourced wood. This project has been deemed a success, which has allowed for ongoing project goals to be created to utilize biomass in adjacent boilers and further decrease greenhouse gas emissions by up to 50 % while utilizing up to 100 % biomass. Other benefits are reducing coal usage by 25 % and creating similar projects that will create even more local jobs (UME, 2017).

7.6.3 Case Study by Manomet

A study conducted by Manomet for the Massachusetts Department of Energy Resources aimed to study biomass and its complexities in sustainability and the effectiveness of carbon policy. Researchers in this study examined the wood biomass available from Massachusetts forests and potential ecological impacts and greenhouse gas implications. Data and results showed feasibility, and greenhouse gas implications provided relevant information that ultimately reformed biomass policies. Recommendations include harvesting improvements and forest creations to encourage ecological value, retention of standing dead trees, and developing guidelines to make them easy to follow and practice (USDA, 2020).

7.7 Significance / Scientific Merits

Wood biomass is a renewable resource that has played an important role in the environment, energy, and economy. World dependence on conventional non-finite resources, such as petroleum and oil, has caused constraints in our economy and national security. Military and farm vehicles run on diesel fuels, which support our food supply. As the United States moves towards net-zero carbon emissions, it is important to capitalize on three key areas shown in phases in *Table 7.5*.

Table 7.5: Key Areas and Phases for Clean Energy Transition

Key Area	Phase timing	Focus and Improvements
Enhancing the environment - Reducing current energy source emissions	Short-Term	1. Forest management, health, and habitat. 2. CO_2 offset and greenhouse gas reductions 3. Reduce forest fire risk by removing excess biomass (USDA, 2020).
Enhancing the economy - Utilize renewable resources to diversity or hybrid the energy system mix	Mid-Term	1. Jobs created by the state and for the state. 2. Ability to set pricing internally. 3. Landowner value through forest excess biomass reduction
Enhancing the economy - Transition out of conventional resources into carbon-free energy sources	Long-Term	1. Developing sustainable energy systems that can be benchmarked. 2. Improved efficient processing. 3. Forest management and wood utilization.

Each area is important for studying wood-to-energy biomass in-depth to move the technology and policy forward to create a relevant energy system.

7.8 Wood-to-Energy Biomass Expansion in Missouri

Through prior research, case studies, and benchmarking of Missouri's resource and energy portfolio, it is acceptable to analyze biomass facilities to increase the percentage of this renewable resource in Missouri's renewable energy product mix. Missouri has 15 million acres of forest, covering 34 % of the state. The breakdown for forestland by ownership is shown in *Figure 7.5*.

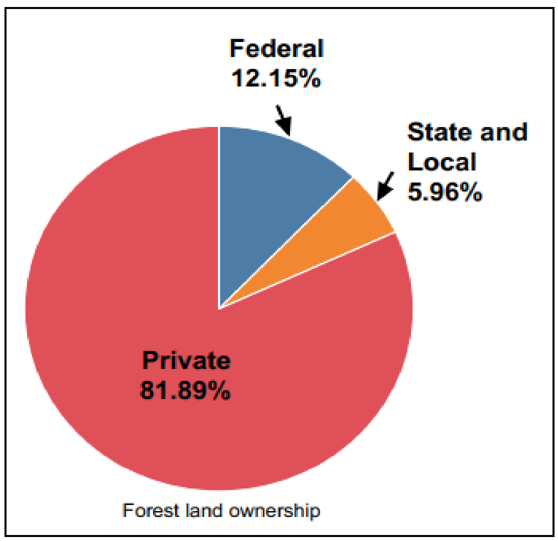


Figure 7.5: Forestland distribution in Missouri (Metz and Zhang, 2015)

Figure 7.6 illustrates the number of live trees on forestland in Missouri as of 2019. As shown, live trees decreased marginally between 2014 and 2019.

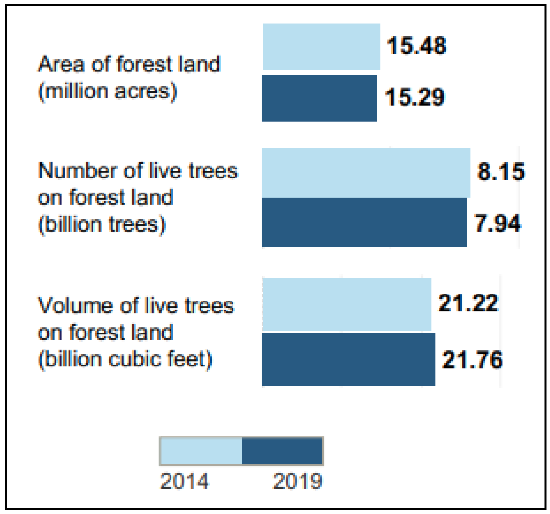


Figure 7.6: Number of live trees, 2014 - 2019 (USDA, 2020)

According to a similar study titled Biomass Potential (McCormick et al., 2015), it is assumed that each acre of forestland can produce a cord of wood annually. Each cord weighs roughly 1.5 tons dry and 2.5 - 3 tons green. Heat values per pound of wood are at 6,429 BTU based on the heat density in dry wood. Through analysis and research, we must determine how much wood is available for harvesting in Missouri to support the state's energy demand.

7.8.1 Wood Type Availability

Missouri's 15 million acres of forest are concentrated heavily in the central and southeastern parts of the state, as shown in *Figure 7.7*.

These forests are home to 89 species of trees. Most of these are hardwoods, primarily red oak, white oak, black walnut, and hickory. Each type of wood is processed through about 400 primary processors comprised of sawmills, cooperage mills, post mills, and charcoal plants. There are over 1000 secondary processing shops, such as furniture, cabinet, and flooring producers (Li et al., 2016). *Table 7.6* shows examples of Missouri's top 10 wood export products by rank and dollar value.

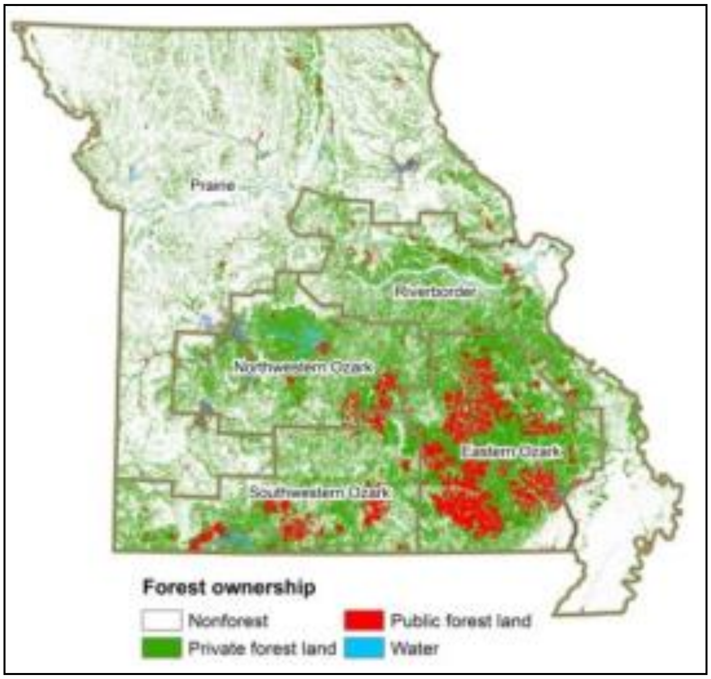


Figure 7.7: Missouri forests layout (Li et al. 2016)

Table 7.6: Top 10 Missouri forest export products (Mo Ag, 2015)

Renewable Energy Capacity	Forest Products	Year 2016
1	Hardwood Lumber	$61,819,000
2	Hardwood Logs	$31,800,000
3	Wooden Casks/Barrels	$29,779,000
4	Ties	$11,777,000
5	Wood Charcoal	$6,418,000
6	Softwood Logs	$5,432,000
7	Wood Chips	$3,678,000

8	Densified Wood	$2,657,000
9	Builders Joinery	$1,971,000
10	Wooden Cases	$1,665,000

From each of these processes, waste is generated, which can be turned into fuel to provide energy.

7.8.2 Energy Supply Validation

The residential, commercial, industrial, and transportation sectors consume nearly 1,804 trillion BTU of energy annually. The potential 15 million acres of forest converted to heat values is 289,305 trillion BTU.

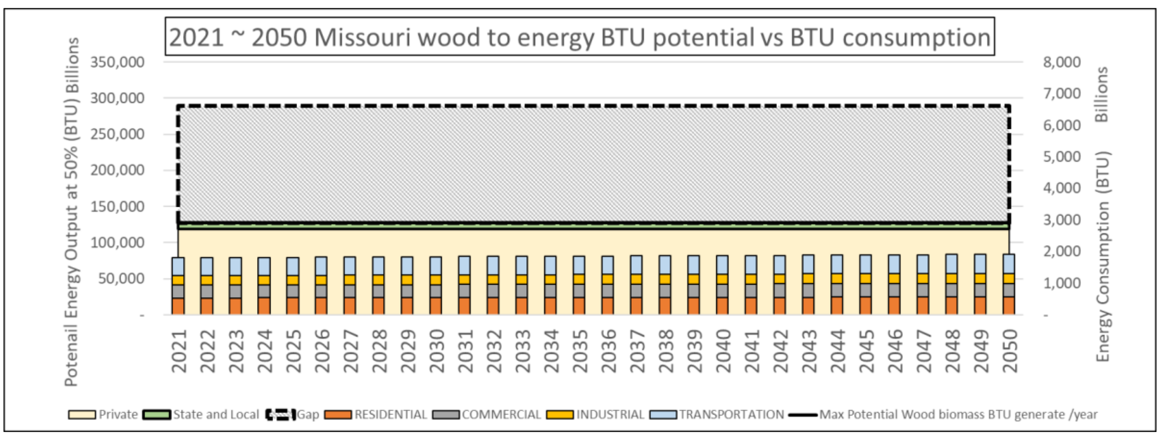


Figure 7.8: Missouri Consumption against forest potential heat value at 100 % efficiency (Contributed by Author: Alec Ernst)

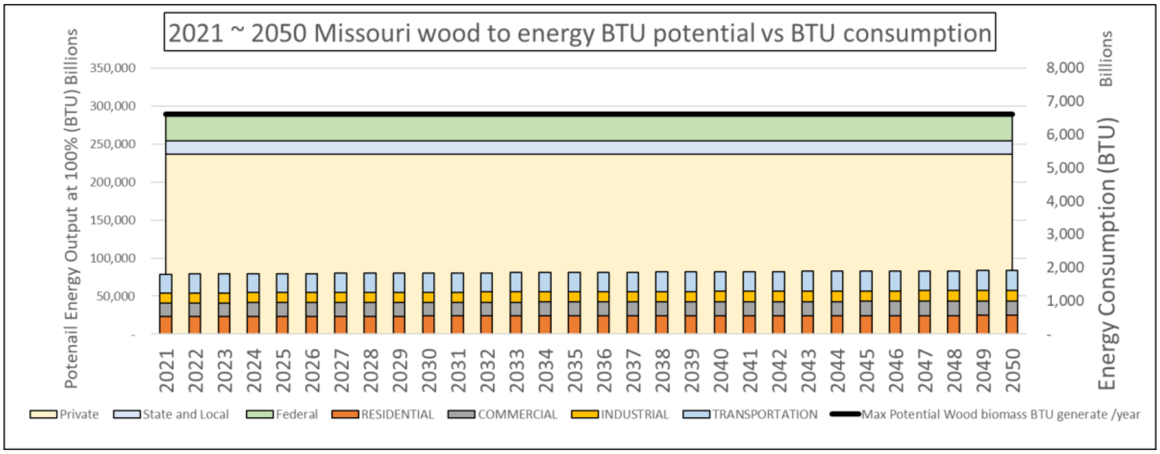


Figure 7.9: Missouri Consumption against forest potential heat value adjusted 50% (Contributed by Author: Alec Ernst)

7.8.3 Probable Land Availability

Figure 7.8 assumes that 100 % of all Missouri forest acreage can be harvested into energy. Assuming 100 % conversion of this available forest acreage to energy is not realistic, though, as other end-uses to forest wood benefit Missouri. These include hardwood lumber for building both locally and exporting. We must start by utilizing what is within the state's control. This includes the 6 % state-owned forestlands. Gaining confidence in residential landowners to take part in the program is essential. It is assumed within this writing that 50 % of all residential landowners will participate in allowing their land to be harvested, as incentives to do so would outweigh any potential detriment to their property value or environment. It is also assumed that all state and local land would be 50 % utilized for the program, as other programs still utilize forest wood.

Total BTU potential is at 127,077 trillion BTUs. This allows for less economic impact from programs contributing to around 9.7 billion in Missouri's economy. These programs include exports to China, Canada, France, and many other countries. End-uses range worldwide from flavoring wines to furniture and hardwood flooring (Li et al., 2016).

Figure 7.9 shows conservative assumptions adjusted from the maximum available wood-to-energy conversion. These include a 50 % contribution of forest acreage in the private sector, 50 % in the state sector, and 0 % from the federal sector. This allows for minimizing risks during the program launch.

7.9 Wood-to-Biomass Methods Analysis

Based on the wood resources in Missouri, the energy needs of the state, and adjacent projects, wood-to-biomass has great potential. Based on the application, consider which conversion method is the most efficient for wood-to-biomass conversion.

After compiling research and developing a matrix of the core processes of wood-to-energy conversion, it is reasonable to conclude that each process has unique advantages and purpose, as shown in *Table 7.7*. For example, if gas prices continue to climb, pyrolysis can make economic sense as fuel alternatives become attractive.

Table 7.7: Conversion process decision matrix (Zafar, 2021)

Type	**Process**	**Life Cyle Eff. (High / Med / Low)**	**CO_2 Emiss. (High / Med / Low)**	**Market Options**	**Avail. (Yes / No)**	**Cost (LCOE $/kWh)**	**Rating**

	Combustion						
Thermo-chemical	Combined Heat and power	H	M	Heat	Y	0.23	1
	Gasification	M	M	Fuel gas	Y	0.45	2
	Pyrolysis	H	M	Ethanol, aerosol	Y	0.35	3
Bio-chemical	Biological	H	M	Biodiesel	Y	0.3	4
	Physical	M	L	Methane	Y	0.25	5
Mechanical	Mechanical	M	M	Transport Fuel	Y	0.42	6

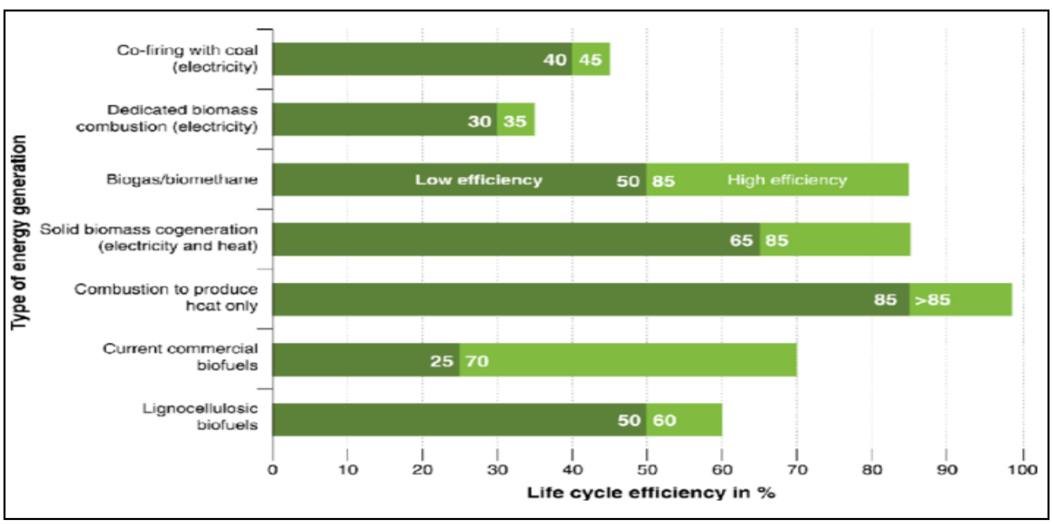


Figure 7.10: Net efficiency range biomass-to-energy pathways (Hansen, 2013)

Currently, the most widely used system would be a combined heat and power combustion type system, which also has a high life cycle efficiency, as shown in *Figure*

7.10. This system promotes overall efficiency improvement by avoiding distribution and transmission losses and reducing emissions substantially. Each technology is gaining traction, and expanding the process mix will be vital to remaining flexible and sustainable. Consideration of needs and wants is most important.

In order to yield maximum efficiency in the shortest time, we must consider proposing the systems approach in phases.

Phase 1: (2021-2030)

The primary targeted system that needs to be considered is a combined heat and power system. This type of energy system allows for high-efficiency gains as the waste heat is converted into energy (Zafar, 2021). In order to yield success in this stage, confidence must be instilled by being thorough and responsible through the following steps.

1. Demonstrate and display positive impact and gain public buy-in.
2. Immediate reduction of emission potential.
3. Utilization of current space, no additional land consumed.
4. Improve efficiency gains of existing plants.
5. Utilize current waste, mill, debris, and logging.
6. New Plant analysis and design phase (determine how many plants are for capacity).
7. Benchmark best practices.
8. Continue to monitor water quality, wildlife, and economy.

Phase 2: (2030-2040)

Develop policies and programs with landowners and local businesses and develop new harvesting systems. Create new adaptable plants by utilizing the levelized cost of energy and life cycle efficiency. Flexibility, commissioning, and decommissioning are key. Action items applicable in phase 2 consist of the following.

1. Harvesting system for small tree quick turnaround.
2. Hybrid systems.
3. Landowner incentives (pricing per acre).
4. Forest management program.
5. Optimize capture and reduction strategies.
6. Installation of a new plant.
7. Continue to monitor water quality, wildlife, and economy.

Phase 3: (2040-2050)

The goal is to get to net-zero carbon emissions while being self-sufficient. Policy changes must take shape to support buy-in at all levels, from consumers to state officials. In order to achieve sustained success in the future, the following actions can be employed.

1. Benchmark best practices
2. Set sell prices to other states
3. Continue to monitor water quality, wildlife, and economy

Step Approach to Succeed

1. Research and development: Initial phase complete, proceed with tracking changes, availability, pricing.
2. Information: Continue to track data, develop a knowledge base, and target

sectors.

3. Assessments: Further assess economics, resource availability, and technical requirements.

4. Strategic Analysis: Follow market, develop a sustainability plan, review and deploy portfolio, track costing.

5. Interface: Align policy, educate the population, and transfer technology to adjacent sectors.

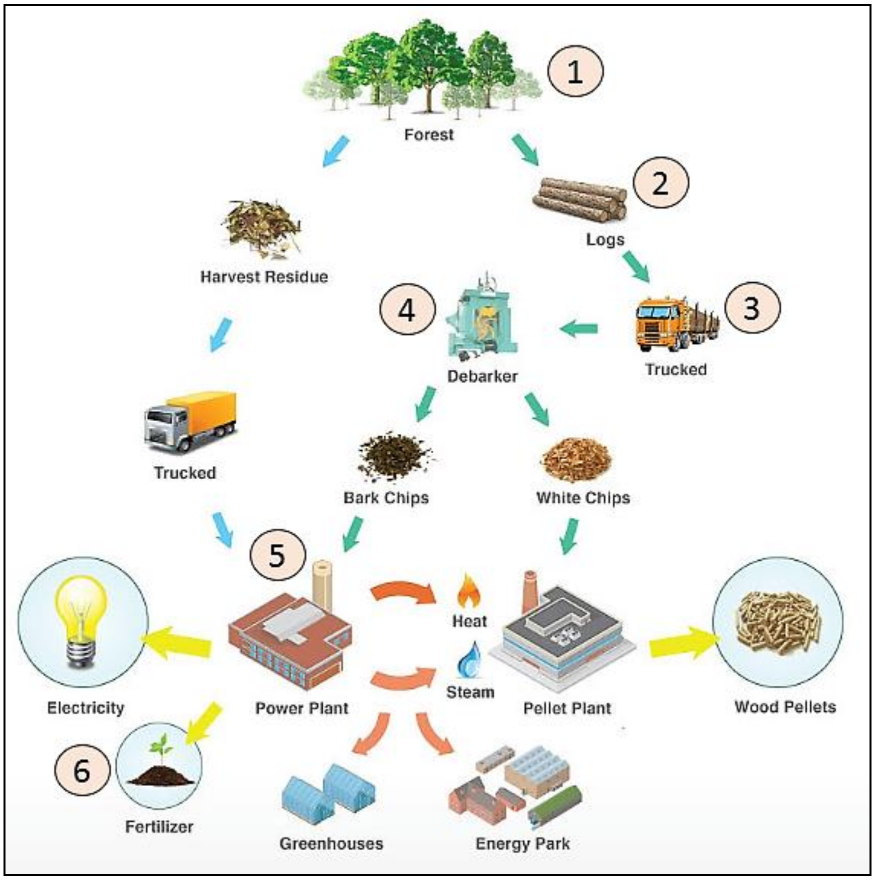


Figure 7.11: Biomass Process, Wood to energy (IDEA, 2021)

Figure 7.11 represents a sample biomass-to-energy process Missouri could adopt to minimize carbon output from conventional energy processes while enhancing its renewable energy mix.

Table 7.8: Biomass wood-to-energy processing steps

Steps	Process	Pros	Risk
1. Forest harvesting management	Missouri has programs and policies in place to	• Good forest management - Value added land - Less risk of forest	• Without proper forest management risk increases.

	harvest, forests safely.	fire	- Wildlife - Drinking water - Land preservation
2. Harvest residue and logs	Wood residue and logs are collected	• Renewable resources can improve forest health	• Processing should be done with care to avoid damage and loss of restoration.
3. Transportation	Moving wood residue and logs to the processing site	• Seamless production • Easy to manage	• Some transportation methods are unsafe to handle and can harm the environment.
4. De-barker	Sizes the logs down to a management	• Makes the processing simpler, can use smaller	• Adds a step to the process, utilizes more

	size	equipment as the logs are smaller.	energy.
5. Power Plant	CHP plants allow for up to 80 % or greater efficiency.	• Existing coal-fired plants can be co-fired. - Reduce loss of efficiency and energy. - CHP technology is around 8.3 cents/kWh - Emissions can be reduced by up to 50 % (IDEA, 2021).	• Capital intensive • Levelized Cost of Energy (LCOE) can be higher than running a coal-fired plant.
6. End-use energy	How the energy is consumed by the end customer.	• Provides energy to humans to support their daily lives. - Power - Fuels - Chemicals - Heating processes	• If not processed properly can cause risk to humans and wildlife.

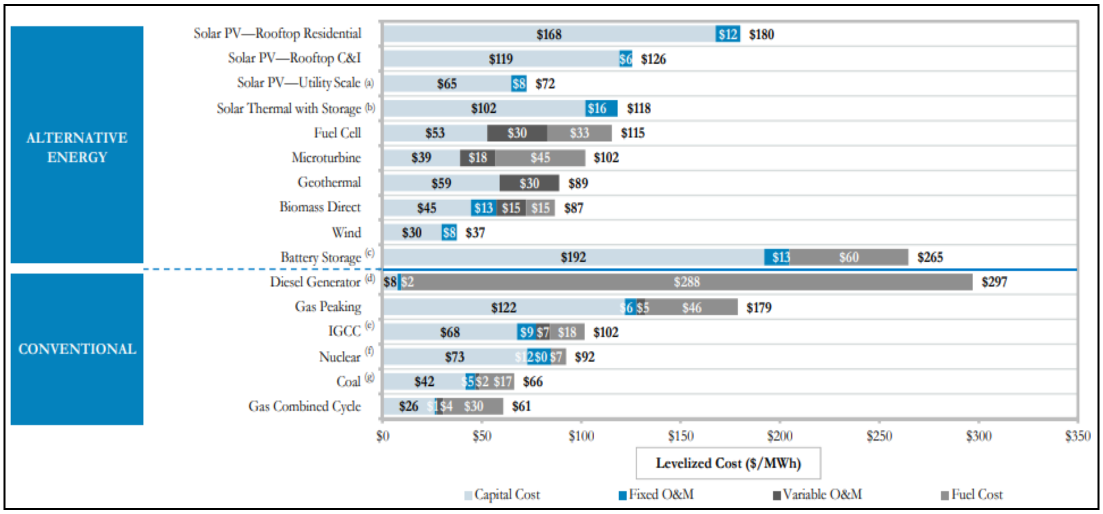


Figure 7.12: Levelized Cost of Energy comparison low-end (Lazard, 2014)

Levelized cost of electricity (LCOE) is an important metric that measures the net present cost of electricity over a plant's lifetime. It is calculated by dividing the operating expenditures by the energy production, and the result is then added to the capital expenditures. This metric allows comparison and investment analysis across various methods, as shown in *Figure 7.12*.

As shown in *Figure 7.12*, the levelized cost of energy from biomass, an alternative energy source, is comparable to that of nuclear, a conventional source.

7.10 Policy Reform

Short-term: Allow changes to occur locally, control, and launch value-added activities today to protect tomorrow. Develop phases of policy that align with phases of transition. Allow for credits to be increased to gain buy-in at the local level.

Long-term: Full transition into clean, renewable, safe energy practices, such as wood-to-energy at market scale. Continuous research and development will allow technology to match policy and regulations in the future. Increased biomass supply, from utilizing a significant amount of resources from federal, private, and state, will promote the development of more renewable energy opportunities. Funding and tax credit opportunities will increase as policy expands to include all biomass feedstock. Policies need to align with safe and healthy forest harvesting practices to reduce risk potential.

7.11 Risk Potential

Safety/Health/Environmental: There are always risks with any process. Wood-to-energy risks present just the same. Safety is the most important priority. Regulations must be in place to safely harvest wood from the tree state to the energy state. Other risks are de-valuing land, adverse environmental impacts, and higher costs than traditional energy. If process control is not in place, pollution will result in deforestation, causing wildlife and existing water resources to be jeopardized. Policy change will help to countermeasure these risks.

7.12 Long-term Outlook

Emission reduction: Biomass wood-to-energy can support emission reductions over time. The theory of one tree taken and one planted at the same pace allows for a net-zero carbon impact. Theoretically, burning biomass will not have more carbon impact than processing crops. Proper planting programs will allow carbon dioxide to be captured by the trees.

Economy: Incentives to landowners, tax credits to companies, and the creation of new jobs will allow the economy to thrive over time. Good policy initiatives will allow for expansion instead of harming the local economies.

7.13 Conclusion

Wood-to-energy biomass has the potential to be a significant renewable energy source for Missouri. With proper implementation, wood-to-energy biomass will support sustainable, efficient opportunities for the state to reduce the energy consumption to production ratio of 8 to 1 while supporting the 2050 directive of net-zero carbon emissions. Ultimately, this can leave Missouri in a position to become a benchmark for the sector with future options for selling to adjacent consumers.

Learning from previous studies' concerns and harnessing the benefits will allow for greater acceptance and yield in the sector. Developing clean, efficient methods to power our future in today's high-paced, technologically advanced world is more important than ever. With 15 million acres of renewable forest, this project is ideal for the state. Sustainable forest management and policy will allow for mitigated risk.

There are many processes to consider when processing wood biomass, and through research, development, and technological advancement, these processes will allow for reduced costs of processing the wood into energy. Ultimately, this will drive down the levelized cost of biomass energy to energy, which is now comparable to that of traditional energy sources, such as nuclear energy, as shown in *Figure 7.12*. Wood-to-biomass processing may only be applicable in some areas based on transmission and transportation issues, adding additional costs to the supply chain. These plants and initiatives must be strategically located and carried out to yield the highest efficiencies.

The takeaways of this analysis are that Missouri can further explore its resources. The developments from the Bioenergy research project are great examples of pilot programs under the government's control. Public and private companies will benefit from the findings by enlisting research centers to research and advance technology and capability. In combined heat and power plant conversions, carbon emission reductions can equal 50 % or greater over standard coal-fired plants. Missouri has the ability over time to become self-sufficient and non-reliant on energy imports.

Other improvement steps include co-generation and a mix of renewables and traditional energy resources. One such method in reducing emissions is improved carbon storage and dissipation through sequestration. Missouri can consider all areas of improvement in current emissions reductions, energy consumption, transportation, and processing. Reducing wasted steps, and streamlining the process, will allow for quicker efficiency gains. We will be able to over-achieve the goal of reducing emissions at a local level while supporting national goals. The next step is to design the overall process, followed by a design review.

7.14 Applying Biomass-to-Energy Feasibility to Research Case Study

In May 2015, an afforestation project was deployed on the facility's grounds where the case study occurred in Missouri. Over 1400 volunteers, plant workers, and their families planted 22,000 fast-growing trees, the capability of maturity within 1 to 5 years, on over 200 plus acres. The purpose of this was to promote the afforestation of factories. The approach and method were circular, so the trees naturally replenished themselves over time. The following data can be generated assuming these 22,000 trees can sustain growth.

Equation 7.1 is the conversion of kW to BTU/hr., where P is Btu/hr. (Rapid Tables, 2023).

Equation 7.1

$$P_{(\text{BTU/hr.})} = 3412.142 \cdot P_{(\text{kW})}$$

The data is used to convert plant consumption in BTU against tree generation in BTU, as shown in *Table 7.9*.

Table 7.9: High Level Feasibility Analysis against Case Study (Contributed by Author: Alec Ernst)

High Level Analysis					
KPI	Consumption (Btu Annual)	Acreage	Potential BTU Produced at 100% (Yield and maturity)	Potential BTU Produced at 50% (Yield and maturity)	Break Even point (90%)
Electric	341,200,000	40	384,000,000	192,000,000	345,600,000

Data analysis shows that the project would be feasible at the current level. Forty acres of wooded area generating mature trees at two years, with a maturity and yield rate of 100 %. The probability of this would be low as some trees would not mature and others would not be capable of being processed. Potential improvements to close the gaps and guarantee success would be as follows.

1. Increase the acreage of trees to 80 acres.
2. Plant ideal trees that mature in 1 year.

7.15 Options in Solar Panel Technology

Solar technology is one of the leading renewable energy technologies available at the market scale today, as previously discussed. During the study at the plant, an analysis was considered for the placement of a micro "solar farm" to analyze the feasibility on-site. Calculations were considered based on data from energy suppliers, past weather conditions, current and projected electricity costs, consumption of electricity, and grid readiness. Layout optimization was analyzed for the best use of space to allow for manufacturing expansion, solar panel capacity, and future expansion while optimizing the gain from the technology.

Other analysis includes purchasing panels versus contracting a power purchase agreement. *Table 7.10* shows the study in detail.

Table 7.10: Analysis of Solar Panel Install (Contributed by Author: Alec Ernst)

No	Location	Capacity (kw)	Own or PPA	Implementation Cost	ROI (Years)	Electricity cost reduction effectiveness ($/year)	CO2 reduction effectiveness (t-CO2/year)
①	Roof	1,022	Own	1,986,768	21.3	70,825	1160
			PPA	0	-	4,107	
②	East	338	Own	531,450	17.3	24,677	390
			PPA	0	-	1,418	
③	South	306	Own	479,215	17.2	22,413	360

PPA	0	-	1,283

Figure 7.13 displays the layout in accordance with data from *Table 7.10*.

Figure 7.13: Layout for Solar Panel Install (Contributed by Author: Alec Ernst)

7.16 Summary

Renewable energy technology is available, and the facility has the potential to utilize it to not only reduce carbon output but also to save energy costs, thus impacting the bottom line. In order to fully realize these positive impacts, a pilot program must be considered. From this point, advancements can be made by analyzing issues during the pilot program. Utilizing the resources available to the facility shows an opportunity that will also allow for further improvements in energy security. Further studies should also be considered to optimize renewable energy by utilizing energy storage to level production and consumption.

CHAPTER EIGHT

8.0 Summary of Research Results

8.1 Introduction

In this part of the thesis, the researcher summarizes the findings and the results of Chapters 4, 5, 6, and 7 in line with the objectives and overall research questions. This is arranged in a logical sequence in accordance with the flow of the thesis for easy navigation. This will be followed by a general conclusion highlighting the overall work.

8.2 Summary of Work

This study has investigated the potential to mitigate global temperature change by reducing carbon emissions in manufacturing facilities through efficiency improvements, process optimization, and technological advancements. The work was broken down into four phases. Phase 1 was to identify the major constraints in manufacturing that act as barriers to emissions. Phase 2 examined whether deploying an increase in energy efficiency and new manufacturing techniques affects emissions and business KPIs. An on-site study in the state of Missouri was conducted in addition. Phase 3 was to explore the current state of energy security in the U.S. and determine if it impacted emissions reductions in the manufacturing sector. Phase four saw the researcher conduct a feasibility study to determine if deploying renewable energy affects emissions and energy security. During each research phase, the overall results aligned with the hypothesis.

8.3 Abstract

Manufacturing is an integral part of our country's flow of products and people and a top contributor to carbon emissions, promoting global temperature rise. During processing, toxic substances are emitted across the value chain. These emissions account for nearly 25% of all greenhouse gas emissions in the United States and the World. Until 2023, an accessible pathway for manufacturing companies to transition to net-zero emissions hasn't been made readily available. The current research was conducted to determine if reducing carbon emissions in manufacturing facilities through efficiency improvements, process optimization, and technology advancements can mitigate global temperature change.

This quantitative, mixed-method approach was conducted by investigating major constraints and evaluating the current state of energy security in manufacturing. A feasibility study was conducted on deploying biomass-to-energy as the primary energy source for the facility and the state of Missouri. A case study was conducted at an automotive manufacturing facility to measure efficiency improvements in a real-life context. The research shows that emissions reductions from manufacturing favor the ability to impact global temperature change. Education was found to be the top constraint by cost and impact. Energy security within the sector and the United States is favorable at an index value lower than 70. Improvements in energy efficiency and new processing methods showed favorable business savings (+$125k) and emissions reductions (-200k tons) in less than a year. The feasibility of biomass-to-energy showed being able to become a primary supplier of energy to the plant and Missouri. Findings indicated that it is necessary to promote and mesh education, technology growth, and energy-saving efforts to have a favorable impact on global temperature change.

8.4 Summary of Findings

In this study, a series of research questions were conducted to gain valuable information and ultimately test the hypothesis. In Chapter 1, the researcher determined the need for the study by identifying the primary reasoning for global climate change. An analytical approach was used to determine that atmospheric carbon concentrations, primarily driven by human activities, have changed the pace of climate change today. From this point, the hypothesis was denoted. In addition, EN-Roads software and a series of model equations were brought in to provide checks and balances so that the results could further authenticate the study. An experimental case study, feasibility study, and qualitative analysis were used as the primary methods to test each chapter.

8.4.1 Research Question #1

The research question is restated below from section 1.8.1.1 in Chapter One. *What are the major constraints in manufacturing that act as barriers to emissions?*

Objectives

i. To *investigate the top constraints in manufacturing* that act as road blocks to emissions reductions.
ii. To evaluate *which variables have the greatest effect* on emissions reductions.

8.4.1.1 Findings

Although several constraints will act as barriers to a company's emissions reductions, a few key variables should be considered above all. A decision matrix was deployed through a qualitative and exploratory approach, and the results are shown in Table 3.6. The top variables to consider are education, business and economics, and awareness based on establishing a pattern or consistent trend through the five significant areas. The highest constraint to emissions reductions within the industry was found to be education. This is displayed in *Figure 4.1*. Listed below are *Table 4.6 and Figure 4.1* for convenience.

Table 4.6: Consolidation and Priority Rating of Barriers in Emissions Reductions (Contributed by Author: Alec Ernst)

Primary Barrier	Influence (High, Mid, Low)	Control by the Facility	Long-term or Short-Term	Cost Incurred ($ low, $$$ high)	Priority Rating
Lack of awareness and education	H	Y	S	$	1
Cultural resistance	H	Y	S	$	3
Political & regulation	H	N	L	$$$	4
Economic and business considerations	H	Y	S	$$	2
Technological limitations	H	N	L	$$$	5

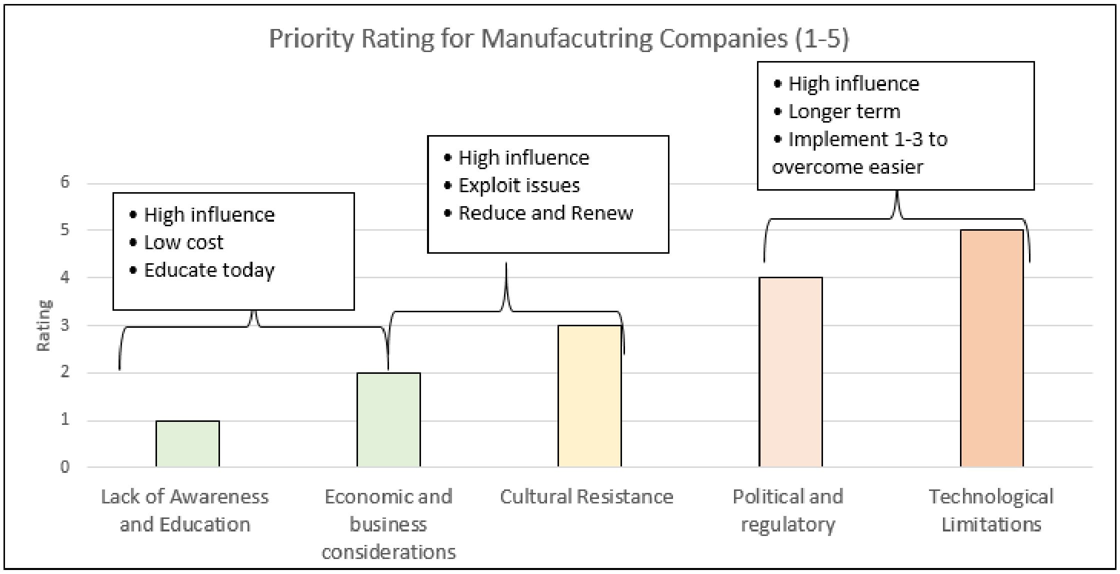


Figure 4.1: Priority Rating for Manufacturing Companies (Contributed by Author: Alec Ernst)

8.4.2 Research Question #2

The research question is restated below from section 1.8.1.2 in Chapter One.

Will deploying an increase in energy efficiency and new manufacturing techniques have an effect on emissions and business KPI?

Objectives

i. To *evaluate impact on emissions reductions* by collect data utilizing measurement tools through qualitative and quantitative measures.

ii. To *conduct improvements in energy efficiency* aimed at carbon emissions reductions.

iii. To *compare effects of improvements on KPI metrics* such as defect rate, short time stoppage, and equipment downtime.

8.4.2.1 Findings

Chapter Five provided a case study at a manufacturing plant in Missouri. This provided valuable experimental and conceptual data to understand the potential for a net-zero transition today fully. Industry-available tools and analysis metrics were used to test energy efficiency activities and their impacts. Three key areas were explored compressed air, power factor improvement, and chiller temperature changes. The utilization of management and control software was introduced as a long-term control method. Dashboard and monthly management tools have been put into place. The results of conducting these experiments and evaluating the impacts are repeated below in *Figure 5.33* and *Table 5.5. One fundamental limitation discovered is that business models, budgets, and resources significantly affect a company's ability to reduce carbon emissions.*

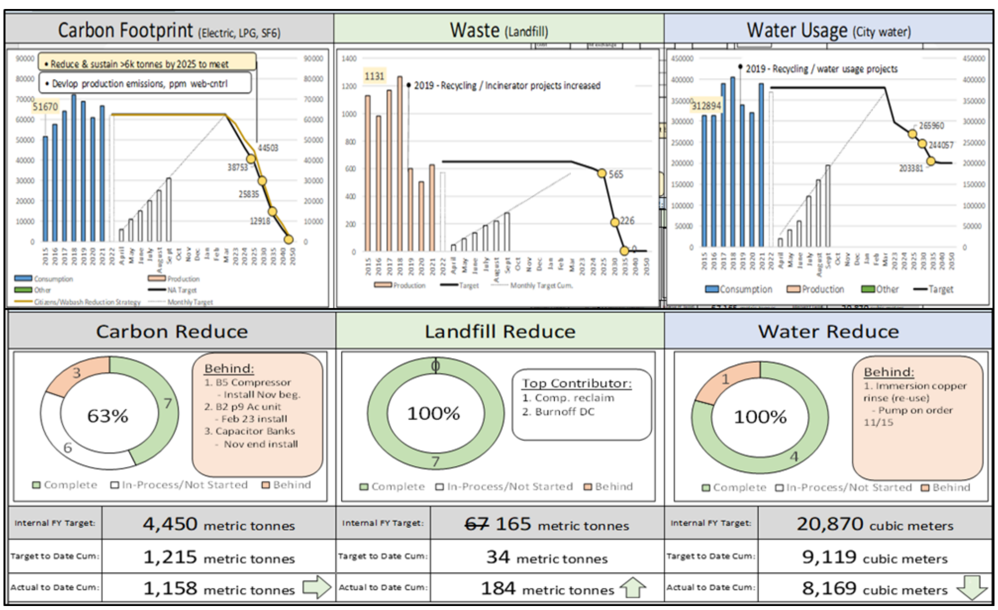


Figure 5.33: Status of Activities (Contributed by Author: Alec Ernst)

Table 5.5: FY Results to Date (Contributed by Author: Alec Ernst)

FY 22 Results to Date	
Energy Savings (kWh)	2.5M
Energy Savings ($s)	125K
Carbon savings (tonnes)	200K
Facility Gas (ft^3)	150K
Water (gallons)	175K

8.4.3 Research Question #3

The research question is restated below from section 1.8.1.3 in Chapter One.

Do energy security and regulations in policy correlate to a positive or negative effect on emissions in manufacturing?

i. To *investigate policy* in accordance with energy security and sustainability.

ii. To *evaluate the current state and future projection of energy security* within the United States.

8.4.3.1 Findings

Chapter Six aimed to heighten awareness of the current state of energy security by exploring gaps to a net-zero transition through a glimpse into the current state of energy security. The United States is the primary subject of the evaluation and how it affects the critical manufacturing industry. Exploration of the effects of business KPIs on emissions effects stemming from activities generated was also considered. Internal, state, and government policies today and into the future are explored to give a reasonable understanding of how areas in taxation, regulation of emissions, and technology adoption will have at the local, country, and potential world levels.

Key results from the study show that the energy security risk is relatively low within the United States. As of 2019, the shale revolution became vital in transitioning the U.S. back to an exporter. Other key findings are that there is a saturation in infrastructure and that most U.S. manufacturing equipment needs to be updated, although it makes money. Key findings to consider are listed below. *One limitation is that when we only considered one key independent variable. Taxing carbon shows a decline in total primary energy and an increase in the market price of energy*. *Table 8.1* and *Figures 6.6, 6.7, and 6.8* are displayed for reference.

Table 8.1: Key Results from Energy Security Study (Contributed by Author: Alec Ernst)

Key Finding	**Resultant Outlook**
Rapid Changes in the World	- Population increase - Overconsumption - Developing nations increasing investments - Manufacturing equipment obsolete

Expand our capability	- Energy technology available not optimized
	- Promote societal and political goals
	    - Resilience
	    - Quality of environment
	    - Prosperity

Policy	- Further evaluated against energy security - Promote clean and green technologies - Protect from threats and disruptions - Promote energy efficiency & RE. - Reward for reducing and reusing. - Protect the end consumer and promoting energy equity.

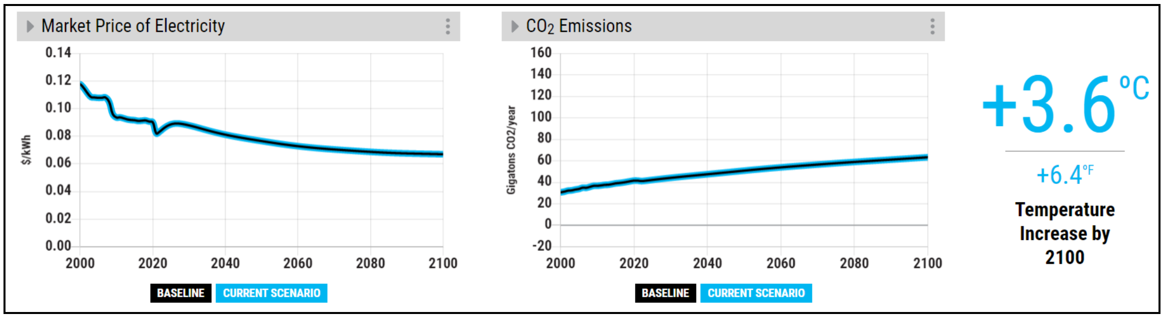


Figure 6.6: Status Quo Scenario – Market Price of Electricity & Resultant CO_2 Emissions (EN-Roads, 2023)

Figure 6.7 displays a high tax scenario.

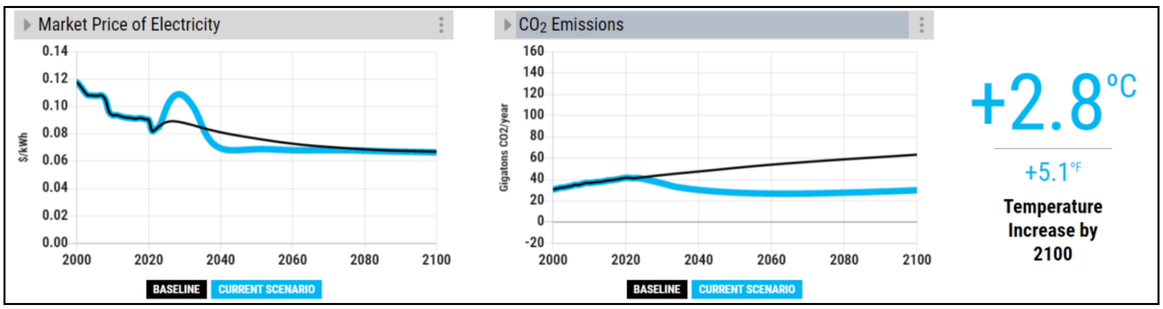


Figure 6.7: High Carbon Tax Scenario - Market Price of Electricity & Resultant CO_2 Emissions (EN-Roads, 2023)

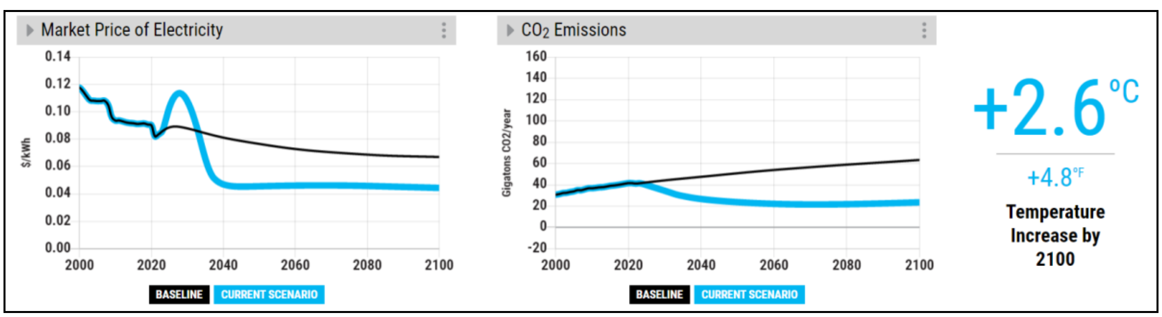


Figure 6.8: Very High Carbon Tax Scenario & Highly Subsidized Renewables – Market Price of Electricity & Resultant CO_2 Emissions (EN-Roads, 2023)

8.4.4 Research Question #4

The research question is restated below from section 1.8.1.4 in Chapter One.

Can deploying renewable energy have an effect on emissions and energy security?

i. To *explore current state renewable energy opportunities* within the state of Missouri.

ii. To investigate the *feasibility of deploying renewable energy* technology in the state of Missouri.

Evaluate improvements and the *effect on business and emissions reductions*.

8.4.4.1 Findings

Chapter Seven explored the use of renewable energy technology as a primary means of energy consumption. A feasibility case study conducted by the author and Dr. Tomomewo S. Olusegun at the state level is translated to the plant level. Biomass-to-energy was the primary focus; however, considerations in solar panel technology were also reviewed. Key results obtained from this study show three key points. The first is that biomass-to-energy within Missouri shows feasibility as a primary energy source. *Figures 7.8 and 7.9* are displayed for reference. The second is that biomass-to-energy at the case study facility shows feasibility as a primary energy source. *Table 7.9* is displayed for reference. *The limitation found within this study is that wood is also used as an economical source in Missouri. This may not show business favorable over providing new primary energy.* The third is that solar panel technology at the case study facility offers opportunities to reduce carbon emissions. *Table 7.10* is displayed for reference.

First Key Point: *Biomass-to-energy* capability of becoming a primary energy source in Missouri.

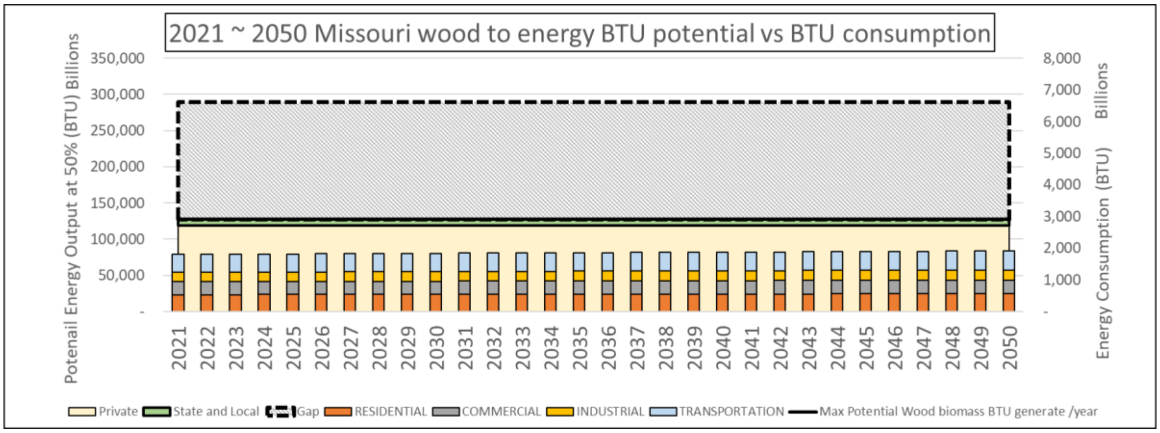


Figure 7.8: Missouri Consumption against forest potential heat value at 100 % efficiency (Contributed by Author: Alec Ernst)

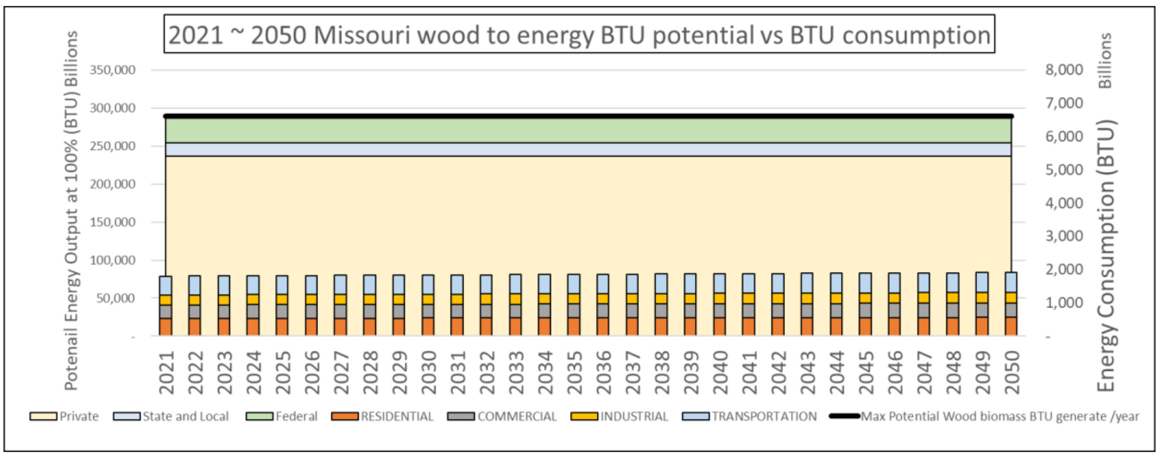


Figure 7.9: Missouri Consumption against forest potential heat value adjusted 50% (Contributed by Author: Alec Ernst)

<u>Second Key Point:</u> *Biomass-to-energy* capability of becoming a primary energy source at the case study facility.

Table 7.9: High Level Feasibility Analysis against Case Study (Contributed by Author: Alec Ernst)

High Level Analysis					
KPI	Consumption (Btu Annual)	Acreage	Potential BTU Produced at 100% (Yield and maturity)	Potential BTU Produced at 50% (Yield and maturity)	Break Even point (90%)
Electric	341,200,000	40	384,000,000	192,000,000	345,600,000

Third Key Point: Solar panel install feasibility at the site of the case shows emissions reductions and business-favorable metrics using the East location and PPA approach.

Table 7.10: Analysis of Solar Panel Install (Contributed by Author: Alec Ernst)

No	**Location**	**Capacity (kw)**	**Own or PPA**	**Implementation Cost**	**ROI (Years)**	**Electricity cost reduction effectiveness ($/year)**	**CO2 reduction effectiveness (t-CO2/year)**
①	Roof	1,022	Own	1,986,768	21.3	70,825	1160
			PPA	0	-	4,107	
②	East	338	Own	531,450	17.3	24,677	390
			PPA	0	-	1,418	

③	South	306	Own	479,215	17.2	22,413	360
			PPA	0	-	1,283	

8.5 Discussion & Authentication of Results

The study results show the capability of answering and supporting the hypothesis. I have completed my data collection and analyzed the results appropriately. I have included all results relevant to my research questions descriptively and statistically. Each of the results from the research questions supports the hypothesis that *reductions in carbon emissions in manufacturing facilities, through optimization, efficiency improvements, and technology advancements, can mitigate global temperature change.* Expectations of the results and assumptions were in alignment.

Three key areas were considered from previous sections of this work to authenticate the study further.

Chapter 1, section 1.6, references the first, utilizing EN-Roads software. The second key point considers a model showing a possible scale for 100% impact. The third is to apply results to the carbon footprint of manufacturing. This aims to understand the potential effects of global temperature change the manufacturing industry is capable of based on the results shown in Chapter 8. *Table 1.12* is displayed here for reference.

Table 1.12: Simple Analysis of Carbon (Brulle et al. 2012) (Hafner et al. 2022)

Description	United States	Global
Manufacturing Companies	0.59 Million	10 Million
Annual Carbon Emissions (GtC)	1.1 GtC	15.0 GtC
Carbon (2.13GtC to 1PPM)	2.1	2.1
PPM by Year (Ann. Carbon Emissions/Carbon)	0.5	7.0
PPM to Temp. change	450	450
°C (2°C /450PPM) 1PPM = .004 °C	0.004	0.004
Temperature effect from Manufacturing (Annual) * (PPM/YR * °C)	0.002 °C	0.031 °C
Temperature effect from Manufacturing (0 change to 2050)	0.1 °C	0.9 °C
Temperature effect from Manufacturing (0 change to 2100)	0.2 °C	2.4 °C

First Key Point: Results show that senario three, referenced in *Figure 1.41*, is possible.

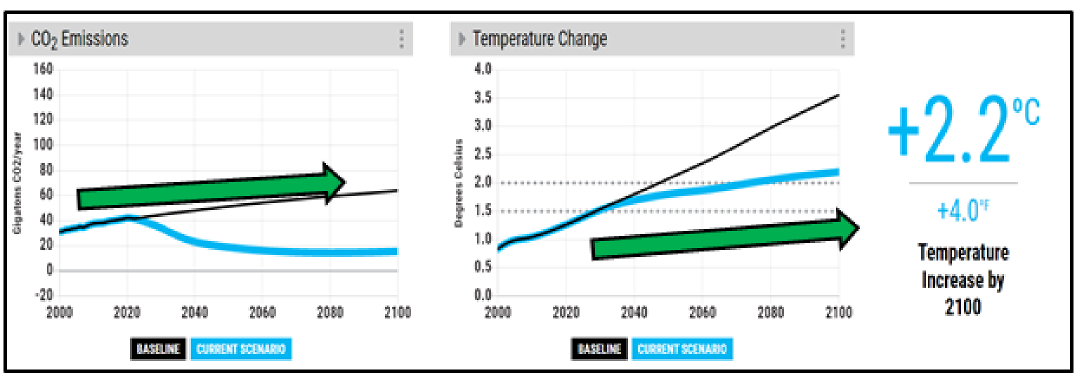
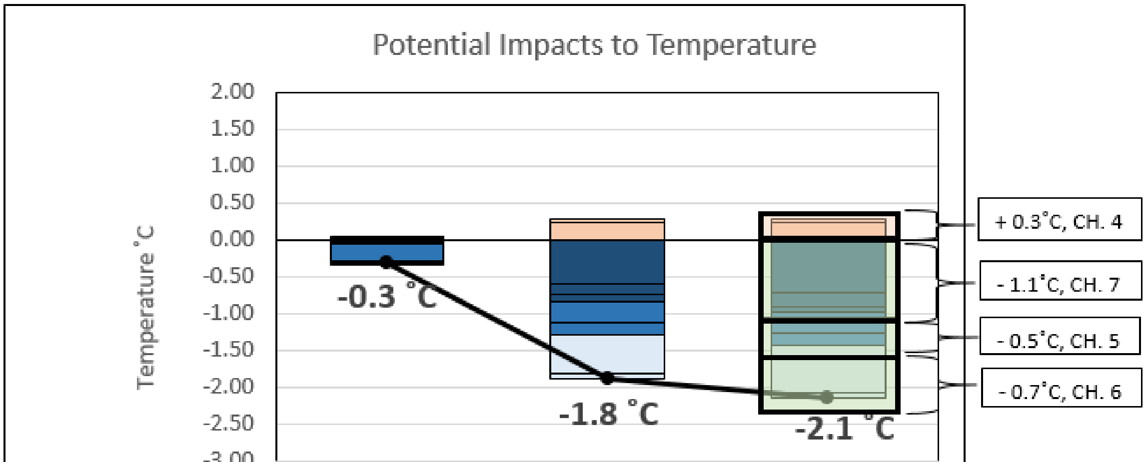


Figure 1.41: Scenario 3 – EN Roads Simulation (Climate Interactive, 2022)

Second Key Point: Results show that emissions mitigation is achievable and is more likely in some areas than others. This is shown in *Table 8.2 and Figure 8.1*.

Table 8.2: Probability Scenario by Area (Contributed by Author: Alec Ernst)

Area	**Items**	**Target Amount (˚C)**	**Probability Today**	**Probability 2050**	**Probability 2100**
Energy Supply	Renewables	-0.8	5%	75%	100%
	Carbon Price	-0.6	5%	75%	100%
	Coal Reduce	-0.2	5%	75%	100%
Buildings & Industry	Energy Efficiency	-0.3	75%	100%	100%
	Electrification	-0.2	0%	75%	100%
Carbon Removal	Afforestation	-0.1	5%	75%	100%
Land & Industry Emissions	Gases and Methane	-0.1	5%	75%	100%
Growth	Economic Growth	+0.2	0%	100%	100%
	Population	+0.1	0%	100%	100%



	2023	2050	2100
Other Constraints	0.00	0.04	0.04
Economic Growth	0.01	0.23	0.23
Gases and Methane	-0.01	-0.08	-0.08
Carbon Price	-0.04	-0.53	-0.63
Electrification	0.00	-0.15	-0.18
Energy Efficiency	-0.23	-0.30	-0.27
Afforestation	-0.01	-0.08	-0.08
Coal Reduce	-0.01	-0.15	-0.18
Renewables	-0.04	-0.60	-0.72
Total	-0.3	-1.9	-2.1

Figure 8.1: Potential Impacts to Temperature (Contributed by Author: Alec Ernst)

Looking into each section, highlighted in *Figure 8.1*, cascaded from *Table 3.1*, the probability for each grouping of key variables is reasonable across time based on the findings listed in previous sections. This also leads to the possibility of the scenario in *Figure 1.41*. Achievement of each scenario across time may require education, technological advancements, diversification of energy sources, corporate buying, and favorable policies.

<u>Third Key Point:</u> Applying a temperature impact per square foot in manufacturing is a reasonable metric to gauge a company's impact based on size. In the case study, the company has 1,445,346 manufacturing square feet. From an annual perspective, utilizing

the data from section 3.1, that equates to 4.41 x 10-13 °C/ sq ft * 1,445,346 **= 6.37 x 10-7 °C** of impact to temperature change.

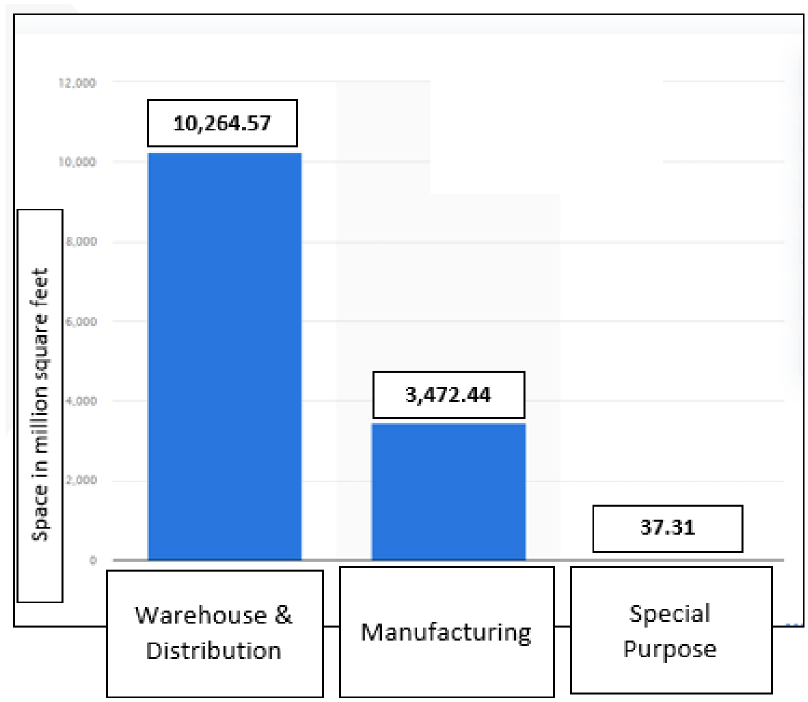


Figure 3.1: Total Square Feet of Manufacturing Space in the U.S. 2021 (Placek, 2021)

CHAPTER NINE

Chapter 9 provides an overarching conclusion to the research work summarized in four main points. ***Point one*** *will answer the hypothesis. Opportunities and shortfalls of the industry will give a reasonable assessment and contribution.* ***Point two*** *will summarize and reflect on the research process. The benefits and limitations of each core component of the research will be discussed.* ***Point three*** *will present opportunities in future research to build upon the work presented in this thesis.* ***Point four*** *will reveal contributions to the field, research and development, and general application to the industry.*

9.0 General Conclusion to Research Hypothesis

This research aimed to discover that *reducing carbon emissions in manufacturing facilities through optimization, efficiency improvements, and technology advancements can mitigate global temperature change.* Based on quantitative and qualitative analysis, in addition to an on-site case study, this thesis has shown how emissions reductions from manufacturing can impact global temperature change.

This was achieved through four main pillars

Point One: Identifying top constraints and barriers in emissions reductions in industrial manufacturing through an exploratory and qualitative research approach. Focusing on five critical areas and their respective top issues, I determined the top barriers that constrain the industry from quickly transitioning to a carbon-free state.

Point Two: Deploy energy-efficient improvements and new manufacturing approaches through a case study at a manufacturing plant in Missouri. Utilizing a six sigma approach to problem-solving, I was able to develop a usable pathway to achieve net-zero emissions through 2021.

Point Three – Analyze the current and future state of energy security in the United States and the manufacturing sector. I conducted qualitative and quantitative research to determine that the United States and manufacturing with the United States are well positioned in terms of energy security today and appear well positioned in the future.

Point Four – Explore the feasibility of biomass-to-energy as a primary energy source for the state of Missouri and at the case study site. I conducted a feasibility study to determine that both the state of Missouri and the manufacturing location could utilize biomass-to-energy as a primary energy source.

9.1 Research Process Reflection

I chose to conduct this research as it is relevant to the world, the industry, and me. There is currently no clear pathway to net-zero emissions for the manufacturing sector, so it is important to study this topic and provide real-time data to the industry showing reduction opportunities and sharing both the positive and negative impacts. I aimed to show that there is a problem, we can do something about it, and that even the smallest manufacturing facility or improvement can make a difference. I took the approach mentioned in the pillars above, as these are the key areas surrounding reducing emissions in the sector.

I blended quantitative, qualitative, experimental, and exploratory research. Ultimately, I governed the project using a six sigma approach, aiming to answer the problem technically. This proved beneficial in answering each research question and, ultimately, the hypothesis. I expected to discover that the industry could make a difference, and the results solidified that expectation. Ultimately, the results matched rather well with my expectations.

Before the research was performed, I expected to find, for point one, that awareness was the major constraint to emission reductions within the industry. Studies such as this are crucial to educating and bringing attention to the world and the industry. I agree with the findings (Fischetti, 2013) in that future customers and customer expectations will be receiving products produced in green factories. Results are also in line with the views of (Thomas et al., 2022) and (Brulle et al., 2012) that there are pessimistic views about the oil and gas industry. The findings from my research are in line with (Arshed et al., 2022). Education is key as embedded values, consumption, and lifestyle play a major role in the shift to emissions reductions.

In point two, I expected to find that activities within the industry by deploying energy-efficient reductions and new manufacturing technology would decrease emissions and positively impact business KPIs. This result matched what I expected; however, sustainability and control are key aspects. My findings align with (Samji et al., 2022), showing that technology needs to be enhanced for aging processes. It is a process that will take time to research, develop and adopt. It is not just one of the projects that can be completed and walked away from; a culture has to be created through education and awareness.

In point three, I expected that the United States and the manufacturing industry would have rated lower regarding energy security preparedness due to the shift to economic relief reviewed by (Birol, 2020). The results contradicted my thinking, showing that the United States is in a good position regarding energy security today and projected into the future.

In point four, I didn't fully expect biomass-to-energy to be capable of energizing the state of Missouri or the manufacturing facility. However, I did believe that it could make a significant impact. The results showed that it would be feasible to fully energy both the state of Missouri and the facility from the case study. This agrees with (Hafner, 2020) and the finding that resources are available and can be continuously revised for feasibility at a higher capacity.

9.2 Future Research & Opportunities

Upon conclusion of this research, answering the research questions and ultimately the hypothesis, further research should be considered in the following seven key areas.

1. The first area of future research is to understand the effect of consistently educating the world on climate change and how cultural differences impact perception.
2. The second area of opportunity is to further expand upon the case study to authenticate the capability of manufacturing in other industries, including textile, cement, and chemical.
3. The third area of opportunity is to focus research on why energy is not considered a prime cost in most businesses and is instead embedded in overhead and other areas of operations.
4. The fourth area that should be considered for future research is energy equity. Assuming renewable energy, energy reduction measures and self-reliance in energy will play a more significant role. Further research should consider the

effect this will have on the world economy and on nations whose primary export is fossil fuels and those we rely on for the import and export of manufacturing materials.

5. The fifth area of opportunity is to research further what role artificial technology will play in emissions reductions and climate change in the manufacturing industry.
6. The sixth area of opportunity that should be considered is to further case studies and pilot changes in policy for business and environmental impact.
7. The seventh area of opportunity that should be considered for research is understanding the total economic impact of utilizing biomass-to-energy or other renewables as a primary energy source for Missouri.

9.3 Contributions & Significance

The research presented supports the hypothesis. *Reducing carbon emissions in manufacturing facilities through optimization, efficiency improvements, and technology advancements can mitigate global temperature change. Previous studies and literature review* show that human factors and the manufacturing sector significantly contribute to climate change through emissions.

The research was to determine if the manufacturing sector could mitigate temperature change through a case study, feasibility study, and qualitative research. This is evident in the findings section based on *Figure 1.41, Table 1.12, and Table 8.2*. This ultimately led to the roadmap presented in *Figure 8.1,* showing that each area within the bounds or control of the manufacturing industry can impact global temperature change.

In addition, I presented a gauge highlighting the impact of temperature change by the square foot for companies to utilize in their research.

Ultimately, the findings confirmed that it is possible and that even the slightest improvement or the smallest company within the industry can make an impact. As different sectors within the manufacturing industry share similar technology and infrastructure, the essential parts of this study can apply to those industries. The United States and the World will continue to need reliable transportation. The automotive industry will remain critical in the years to come and has the opportunity to positively change the environment by starting today.

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APPENDICES

Electricity	America	0.4330	t-CO2/MWh	Electricity	Indonesia	0.7290	t-CO2/MWh
	Canada	0.02072	t-CO2/MWh		India	0.7260	t-CO2/MWh
		0.032	t-CO2/MWh		Taiwan	0.5870	t-CO2/MWh
		0.1490	t-CO2/MWh		UK	0.3049	t-CO2/MWh
	Mexico	0.4640	t-CO2/MWh		Czech	0.5300	t-CO2/MWh
	Brazil	0.1200	t-CO2/MWh		South Africa	0.9450	t-CO2/MWh
	China	0.7129	t-CO2/MWh	Heavy oil		2.9381	t-CO2/kL
		0.6485	t-CO2/MWh	Natural gas		1.8580	t-CO2/1000m3
		0.5422	t-CO2/MWh	LPG		2.8261	t-CO2/t
		0.6063	t-CO2/MWh	Purchased steam		0.0570	t-CO2/GJ
	Thailand	0.4770	t-CO2/MWh	Light oil		2.6753	t-CO2/kL
	Vietnam	0.4490	t-CO2/MWh				

Figure 11.1 Electric to Carbon Conversion Ratios for all plants worldwide (Contributed by Author: Alec Ernst)

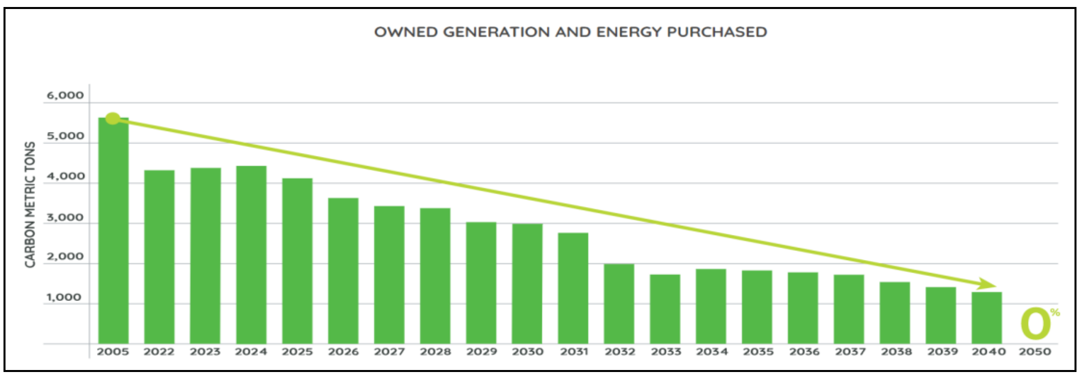

Figure 11.2 Owner and Energy Generation Purchased Carbon Metric Tons (Wabash, 2023)

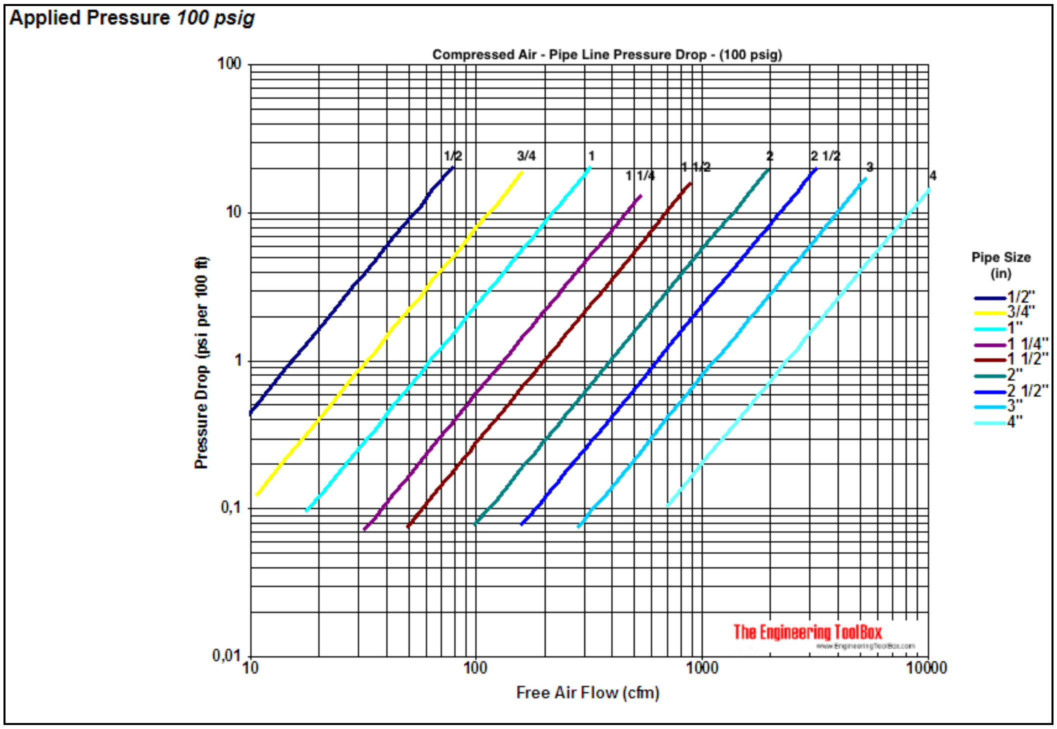

Figure 11.3 Owner and Energy Generation Purchased Carbon Metric Tons (Wabash, 2023)

Table 11.1: Compressed air pressure drop table (Engineering Toolbox, 2023)

Pressure Drop	**NOTE!** Pressure drops above 1 kg/cm2 (14-15 psi) are in general not relevant.										
Volume Flow FAD		NPS Pipe Size / Innside diameter (mm)									
		1/2		3/4		1		1 1/4		1 1/2	
		15.798		20.93		26.645		35.052		40.894	
(m3/min)	(cfm)	(kg/cm2)	(psi)	(kg/cm2)	(psi)	(kg/cm2)	(psi)	(kg/cm2)	(psi)	(kg/cm2)	(psi)
0.1	4	0.02	0.22								
0.2	7	0.06	0.80	0.01	0.20						
0.3	11	0.12	1.69	0.03	0.41	0.01	0.12				
0.4	14	0.20	2.88	0.05	0.71	0.01	0.21				
0.5	18	0.30	4.35	0.07	1.07	0.02	0.32	0.01	0.08		
0.6	21	0.43	6.09	0.10	1.49	0.03	0.45	0.01	0.11		
0.7	25	0.57	8.10	0.14	1.99	0.04	0.59	0.01	0.15		
0.8	28	0.73	10.38	0.18	2.54	0.05	0.76	0.01	0.19	0.01	0.09
0.9	32	0.90	12.90	0.22	3.16	0.07	0.95	0.02	0.24	0.01	0.11
1	35	1.10	15.68	0.27	3.84	0.08	1.15	0.02	0.29	0.01	0.13
1.2	42			0.38	5.38	0.11	1.61	0.03	0.41	0.01	0.19
1.4	49			0.50	7.16	0.15	2.14	0.04	0.54	0.02	0.25
1.6	56			0.64	9.16	0.19	2.74	0.05	0.70	0.02	0.32
1.8	64			0.80	11.40	0.24	3.41	0.06	0.87	0.03	0.40
2	71			0.97	13.85	0.29	4.14	0.07	1.05	0.03	0.49
2.2	78			1.16	16.52	0.35	4.94	0.09	1.25	0.04	0.58
2.4	85			1.36	19.40	0.41	5.80	0.10	1.47	0.05	0.68
2.6	92					0.47	6.73	0.12	1.71	0.06	0.79
2.8	99					0.54	7.72	0.14	1.96	0.06	0.91
3	106					0.61	8.77	0.16	2.23	0.07	1.03
3.5	124					0.82	11.66	0.21	2.96	0.10	1.37
4	141					1.05	14.93	0.27	3.79	0.12	1.75
4.5	159					1.30	18.57	0.33	4.71	0.15	2.18
5	177							0.40	5.73	0.19	2.65
5.5	194							0.48	6.83	0.22	3.16
6	212							0.56	8.02	0.26	3.71
6.5	229							0.65	9.30	0.30	4.30
7	247							0.75	10.67	0.35	4.94
7.5	265							0.85	12.12	0.39	5.61
8	282							0.96	13.66	0.44	6.32
8.5	300							1.07	15.28	0.50	7.07
9	318							1.19	16.99	0.55	7.86
9.5	335							1.32	18.77	0.61	8.69
10	353							1.45	20.64	0.67	9.55
15	530									1.42	20.22

Table 11.2: Orifice diameter against pressure (Engineering Toolbox, 2023)

Pressure(psig)	Orifice Diameter (inches)					
	1/64	1/32	1/16	1/8	1/4	3/8
70	0.29	1.16	4.66	18.62	74.4	167.8
80	0.32	1.26	5.24	20.76	83.1	187.2
90	0.36	1.46	5.72	23.1	92	206.6
100	0.4	1.55	6.31	25.22	100.9	227
125	0.48	1.94	7.66	30.65	122.2	275.5

Table 11.3: Energy Cost Savings Calculator - Usage (Capecart et al. 2009)

TOTAL ENERGY COST SAVINGS PER YEAR CALCULATOR (USAGE SAVINGS)							
LEAK DIAMETER INCHES	# OF LEAKS FOUND WITHIN 2 DEPARTMENTS (4 MACHINES)	LEAKAGE RATE (CFM) ACCORDING TO TABLE	KW/CFM	# OF HOURS	$ /KW HOUR (AVERAGE COMMERCIAL MISSOURI)	CONVERSION FACTOR ASSUMING ROUND HOLES	TOTAL COST SAVINGS PER YEAR

1/64	18	0.34	0.18	8736	0.0437	0.97	$ 420.55
1/32	20	1.35	0.18	8736	0.0437	0.97	$ 1,855.37

Table 11.4: Energy Cost Savings Calculator - Demand (Capecart et al. 2009)

TOTAL ENERGY COST SAVINGS PER YEAR CALCULATOR (DEMAND SAVINGS)							
LEAK DIAMETER INCHES	# OF LEAKS FOUND WITHIN 2 DEPARTMENTS (4 MACHINES)	LEAKAGE RATE (CFM) ACCORDING TO TABLE	KW/CFM	# OF MONT HS	DEMAND CHARGES (AVERAGE COMMERCIAL MISSOURI)	CONVERSION FACTOR ASSUMING ROUND HOLES	TOTAL COST SAVINGS PER YEAR
1/64	18	0.34	0.18	12	16.1400	0.97	$ 213.36
1/32	20	1.35	0.18	12	16.1400	0.97	$ 941.28

Table 11.5: Implementation and ROR (Capecart et al. 2009)

IMPLEMENTATION AND RATE OF RETURN					
# of leaks	$/leak	Labor / hour	total implementation cost	energy cost savings	ROR
38	$10.00	$17.00	$507.67	$3,431	0.1480

Table 11.6: Power Factor Improvement Table (Michaud, 2016)

Power Factor—Improvement Table

ORIGINAL POWER-FACTOR IN PER CENT	DESIRED POWER-FACTOR IN PER CENT																				
	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
40	1.541	1.568	1.594	1.619	1.642	1.671	1.695	1.723	1.745	1.777	1.807	1.833	1.862	1.893	1.926	1.963	1.996	2.037	2.085	2.146	2.291
41	1.475	1.502	1.526	1.551	1.579	1.605	1.632	1.660	1.682	1.714	1.740	1.770	1.799	1.830	1.863	1.896	1.933	1.974	2.002	2.063	2.225
42	1.410	1.438	1.464	1.489	1.508	1.541	1.561	1.589	1.611	1.643	1.676	1.689	1.718	1.749	1.882	1.832	1.852	1.893	1.941	2.002	2.161
43	1.349	1.376	1.402	1.427	1.450	1.480	1.503	1.531	1.553	1.585	1.615	1.641	1.670	1.701	1.734	1.771	1.804	1.845	1.893	1.954	2.100
44	1.291	1.318	1.344	1.369	1.395	1.421	1.448	1.476	1.498	1.531	1.557	1.586	1.615	1.646	1.679	1.712	1.749	1.790	1.838	1.899	2.041
45	1.235	1.265	1.291	1.316	1.342	1.365	1.395	1.423	1.445	1.478	1.501	1.533	1.562	1.593	1.626	1.656	1.696	1.737	1.785	1.846	1.985
46	1.180	1.207	1.233	1.258	1.283	1.310	1.336	1.364	1.386	1.419	1.446	1.474	1.503	1.534	1.567	1.602	1.637	1.678	1.726	1.787	1.930
47	1.128	1.5[illegible]3	1.181	1.206	1.274	1.257	1.287	1.315	1.337	1.370	1.392	1.425	1.454	1.485	1.518	1.548	1.588	1.629	1.677	1.738	1.877
48	1.077	1.104	1.130	1.155	1.180	1.208	1.236	1.264	1.286	1.319	1.343	1.371	1.400	1.431	1.464	1.499	1.534	1.575	1.623	1.684	1.828
49	1.029	1.056	1.082	1.107	1.136	1.159	1.189	1.217	1.239	1.272	1.295	1.327	1.356	1.387	1.420	1.450	1.490	1.531	1.579	1.630	1.779
50	.982	1.008	1.034	1.060	1.086	1.112	1.139	1.165	1.192	1.220	1.248	1.276	1.303	1.337	1.369	1.403	1.441	1.481	1.529	1.590	1.732
51	.936	.962	.988	1.014	1.040	1.066	1.093	1.119	1.146	1.174	1.202	1.230	1.257	1.291	1.323	1.357	1.395	1.435	1.483	1.544	1.686
52	.894	.920	.946	.972	.998	1.024	1.051	1.077	1.104	1.132	1.160	1.188	1.215	1.249	1.281	1.315	1.353	1.393	1.441	1.502	1.644
53	.850	.876	.902	.928	.954	.980	1.007	1.033	1.060	1.088	1.116	1.144	1.171	1.205	1.237	1.271	1.309	1.349	1.397	1.458	1.600
54	.809	.835	.861	.887	.913	.939	.966	.992	1.019	1.047	1.075	1.103	1.130	1.164	1.196	1.230	1.268	1.308	1.356	1.417	1.559
55	.769	.795	.821	.847	.873	.899	.926	.952	.979	1.007	1.035	1.063	1.090	1.124	1.156	1.190	1.238	1.268	1.316	1.377	1.519
56	.730	.756	.782	.808	.834	.860	.887	.913	.940	.968	.996	1.024	1.051	1.085	1.117	1.151	1.189	1.229	1.277	1.338	1.480
57	.692	.718	.744	.770	.796	.822	.849	.875	.902	.930	.958	.986	1.013	1.047	1.079	1.113	1.151	1.191	1.239	1.300	1.442
58	.655	.681	.707	.733	.759	.785	.812	.838	.865	.893	.921	.949	.976	1.010	1.042	1.076	1.114	1.154	1.202	1.263	1.405
59	.618	.644	.670	.696	.722	.748	.775	.801	.828	.856	.884	.912	.939	.973	1.005	1.039	1.077	1.117	1.165	1.226	1.368
60	.584	.610	.636	.662	.688	.714	.741	.767	.794	.822	.850	.878	.905	.939	.971	1.005	1.043	1.083	1.131	1.192	1 334
61	.549	.575	.601	.627	.653	.679	.706	.732	.759	.787	.815	.843	.870	.904	.936	.970	1.008	1.048	1.096	1.157	1.299
62	.515	.541	.567	.593	.619	.645	.672	.698	.725	.753	.781	.809	.836	.870	.902	.936	.974	1.014	1.062	1.123	1.265
63	.483	.509	.535	.561	.587	.613	.640	.666	.693	.721	.749	.777	.804	.838	.870	.904	.942	.982	1.030	1.091	1.233
64	.450	.476	.502	.528	.554	.580	.607	.633	.660	.688	.716	.744	.771	.805	.837	.871	.909	.949	.997	1.058	1.200
65	.419	.445	.471	.497	.523	.549	.576	.602	.629	.657	.685	.713	.740	.774	.806	.840	.878	.918	.966	1.027	1.169
66	.388	.414	.440	.466	.492	.518	.545	.571	.598	.626	.654	.682	.709	.743	.775	.809	.847	.887	.935	.996	1.138
67	.358	.384	.410	.436	.462	.488	.515	.541	.568	.596	.624	.652	.679	.713	.745	.779	.817	.857	.905	.966	1.108
68	.329	.355	.381	.407	.433	.459	.486	.512	.539	.567	.595	.623	.650	.684	.716	.750	.788	.828	.876	.937	1 079
69	.299	.325	.351	.377	.403	.429	.456	.482	.509	.537	.565	.593	.620	.654	.686	.720	.758	.798	.840	.907	1.049
70	.270	.296	.322	.348	.374	.400	.427	.453	.480	.508	.536	.564	.591	.625	.657	.691	.729	.769	.811	.878	1.020
71	.242	.268	.294	.320	.346	.372	.399	.425	.452	.480	.508	.536	.563	.597	.629	.663	.701	.741	.783	.850	.992
72	.213	.239	.265	.291	.317	.343	.370	.396	.423	.451	.479	.507	.534	.568	.600	.634	.672	.712	.754	.821	.963
73	.186	.212	.238	.264	.290	.316	.343	.369	.396	.424	.452	.480	.507	.541	.573	.607	.645	.685	.727	.794	.936
74	.159	.185	.211	.237	.263	.289	.316	.342	.369	.397	.425	.453	.480	.514	.546	.580	.618	.658	.700	.767	.909
75	.132	.158	.184	.210	.236	.262	.289	.315	.342	.370	.398	.426	.453	.487	.519	.553	.591	.631	.673	.740	.882
76	.105	.131	.157	.183	.209	.235	.262	.288	.315	.343	.371	.399	.426	.460	.492	.526	.564	.604	.652	.713	.855
77	.079	.105	.131	.157	.183	.209	.236	.262	.289	.317	.345	.373	.400	.434	.466	.500	.538	.578	.620	.687	.829
78	.053	.079	.105	.131	.157	.183	.210	.236	.263	.291	.319	.347	.374	.408	.440	.447	.512	.552	.594	.661	.803
79	.026	.052	.078	.104	.130	.156	.183	.209	.236	.264	.292	.320	.347	.381	.413	.447	.485	.525	.567	.634	.776
80	.000	.026	.053	.078	.104	.130	.157	.183	.210	.238	.266	.294	.321	.355	.387	.421	.459	.499	.541	.608	.750
81	.....	.000	.026	.052	.078	.104	.131	.157	.184	.212	.240	.268	.295	.329	.361	.395	.433	.473	.515	.582	.724
82	.....	.....	.000	.026	.051	.078	.105	.131	.158	.186	.214	.242	.269	.303	.335	.369	.407	.447	.489	.556	.698
83	.....	.....	.....	.000	.026	.052	.079	.105	.132	.160	.188	.216	.243	.277	.300	.343	.381	.421	.463	.530	.672
84	.....	.....	.....	.....	.000	.026	.053	.079	.106	.134	.162	.190	.217	.251	.283	.317	.355	.395	.437	.504	.645
85	.....	.....	.....	.....	.....	.000	.027	.053	.080	.108	.136	.164	.191	.225	.257	.291	.329	.369	.417	.478	.620

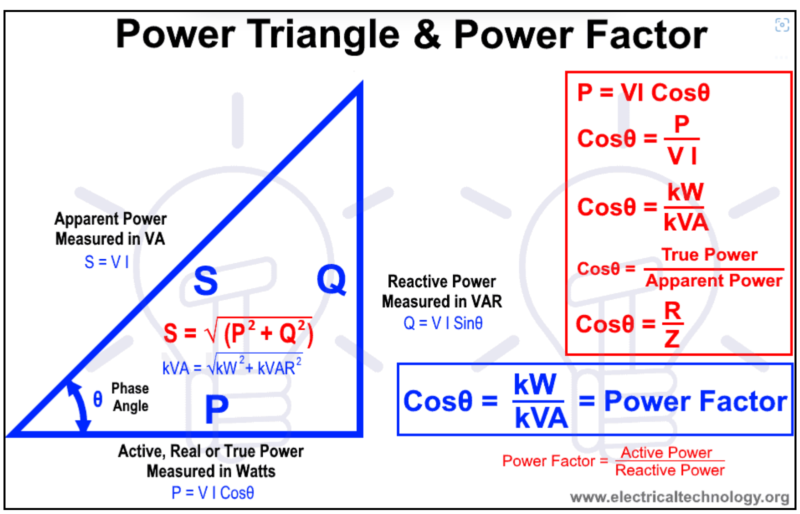

Figure 11.4: Power Factor & Power Triangle (Electrical Technology, 2023)

Model	6200 Series	6300 Series	6500 Series	6700 Series	6100 Series
HP	1/4 hp	1/3 hp	1/2 hp	3/4 hp	1 hp
Pump Type	Turbine				
Cooling Capacity @ 0°C	400 W	530 W	750 W	875 W	1000 W
Cooling Capacity @ +10°C	600 W	990 W	1150 W	1550 W	1925 W
Cooling Capacity @ +20°C	850 W	1400 W	1700 W	2300 W	2900 W
Maximum Pressure	100.00 psi	100.00 psi	100.00 psi	100.00 psi	100.00 psi
Maximum Pressure Flow Rate	3.50 gpm	3.50 gpm	3.50 gpm	3.50 gpm	3.50 gpm
Electrical Req. (VAC/Hz/Ph/A)	120/60/1/12.2 (60Hz) 240/50/1/6.8 (50Hz)	120/60/1/13.1 (60Hz) 240/50/1/7.3 (50Hz)	120/60/1/16 (60Hz) 240/50/1/8.9 (50Hz)	230/60/1/11.9 (60Hz) 240/50/1/11.9 (50Hz)	230/60/1/12.2 (60Hz) 240/50/1/12.2 (50Hz)

Figure 11.5: Manufacturing Spec for Chiller (Aimee O Driscoll, 2019)