CARBON EMISSION REDUCTION OF FORGE MANUFACTURING PROCESS

by

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LIST OF ABBREVIATIONS

BAS	Building Automation Systems
CCS	Carbon Capture Sequestration
CO2	Carbon Dioxide
DC	Direct Current
GHGs	Greenhouse Gasses
GISS	Goddard Institute for Space Studies
IIoT	Industrial Internet of Thing
kWh	KiloWatt hours
MMmt	Million Metric Tons
NAE	National Academy of Engineers
NASA	National Aeronautics and Space Administration
NREL	National Renewable Energy Laboratory
pH	potential of hydrogen
US	United States

GLOSSARY

Algorithm	A process or set of rules to be followed in calculations or other problem-solving operations, especially by a computer (ThinkAutomation, n.d.).
Alternative Hypotheses	The hypothesis used in hypothesis testing that is contrary to the null hypothesis. It is usually taken to be that the observations are the result of a real effect (Glen, 2012).
Carbamates	"A group of insecticides that includes such compounds as carbamyl, methomyl, and carbofuran "(Britannica, 2019).
Carbon Dioxide	A colorless, odorless gas produced by burning carbon and organic compounds and by respiration (UCAR, 2006).
Chemical Amines	Compounds and functional groups that contain a basic nitrogen atom with a lone pair (Block & Smith, 2018).
Green House Gasses	A gas that contributes to the greenhouse effect by absorbing infrared radiation, e.g., carbon dioxide and chlorofluorocarbons (EPA, 2018).
Infrared Light	Electromagnetic radiation with wavelengths longer than visible light but shorter than radio waves (NASA, 2010).
Microprocessors	An integrated circuit that contains all the functions of a central processing unit of a computer (Wardynski, 2019).
Null Hypothesis	A statistical hypothesis that is tested for possible rejection under the assumption that it is true (usually that observations are the result of chance) (Glen, 2012).
Photovoltaics	The branch of technology concerned with the production of electric current at the junction of two substances (SEIA, 2021).
Semiconductive	A solid substance that has a conductivity between that of an insulator and that of most metals, either due to the addition of an impurity or because of temperature effects (Washington EDU, n.d.).
Solar Irradiance	The output of light energy from the entire disk of the Sun, measured at the Earth (Dubar, 2008).
Two Sample T-Test	Used to test the difference (d0) between two population means (JMP, n.d.).

Ultra-Violet Light A form of electromagnetic radiation with wavelength from 10 nm to 400 nm , shorter than that of visible light, but longer than X-rays (Science Mission Directorate, 2010).

ABSTRACT

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The United States' (U.S.) manufacturing sector contributes 22% of man-made carbon dioxide (CO2) which makes up 407.4 parts per million of the global atmosphere (EPA, 2020; Lindsey, 2019). The U.S manufacturing facilities consumed 26% of energy consumption, which accounted for 5.27 billion metric tons of CO2 emissions in 2018 (EIA, 2019a ,EIA, 2019b). The combustion of fossil fuels is a major cause of the flux of CO2 emission (Blasing et al., 2005). Electricity produced from coal burning generated 60% of CO2 emission, 38% of CO2 emission came from oil burning, and 20% came from natural gas burning during the year of 2019 (EIA, 2020b). The U.S. manufacturing sector emits CO2 emissions from direct factors; material processing, and indirect factors; consuming electricity. The increase of CO2 and other GHGs cause environmental changes that are affecting the livelihood of every species on earth (Rabiaia et. al., 2020). The problem statement will be measured by comparing the adoption of 25% solar energy sources replacing fossil fuel sources within U.S. based manufacturing plants. Developing a solar energy solution and implementing a carbon sequestration method for manufacturing facilities is aligned with the National Academy of Engineering, Develop Carbon Sequestration Methods (NAE, n.d.).

Keywords: Carbon emission, solar energy, carbon sequestration

CHAPTER 1. INTRODUCTION

1.1 The Problem

The United States (U.S.) manufacturing sector plays a major role in the consumption of electrical energy. The U.S. manufacturing sector contributes 22% of man-made carbon dioxide (CO2) which makes up 407.4 parts per million of the global atmosphere (EPA, 2020; Lindsey, 2019). The manufacturing sector relies on the electricity produced by dirty fuel sources including natural gas and coal (EIA, 2020c). The CO2 released during energy production utilizing dirty fuel sources is causing an increase of the CO2 concentration within the atmosphere resulting in environmental issues around the globe (Al-Ghuassian, 2018, Rabiaia et. al., 2020). The U.S. manufacturing industry consumed 32% of the U.S. energy that was produced in 2019 (EIA, 2020c). The U.S. consumed 4,118 billion kilo-Watt-hours (kWh) of electric energy in 2019 (EIA, 2020d). The U.S. consumed 16.2% of the entire world's energy consumption in 2019 (EIA, 2020b). Electricity generated utilizing fossil fuel produced 63% of the U.S. electricity consumed (EIA, 2020b). U.S. electricity production in 2019 primarily came from coal and natural gas plants (EIA, 2020a). Coal burning electricity production plants produced 60% of the electrical power during 2019 (EIA, 2020a). Electricity power plants utilizing natural gas as a primary fuel source produce 38% of the electrical power (EIA, 2020a). The combustion of fossil fuels is a major cause of the change of CO2 emission (Blasing et al., 2005). The concentration of carbon emission has continued to increase globally year over year. The CO2 concentration has increased 100 times faster than the natural cycle during the past 60 years (Lindsey, 2020).

The U.S. manufacturing sector emits CO2 emissions from direct factors; material processing, and indirect factors; consuming electricity. The U.S. consumed 31 trillion cubic feet of natural gas in 2019 (EIA, 2020b). The U.S. manufacturing industry consumed 33% of the total natural gas consumption, second to the electric power generation in 2019 (EIA, 2020b). Electricity generated utilizing dirty fuel sources produced 1,619 million metric tons (MMmt) of CO_2 emissions (EIA, 2020a). Based on the 4,118 billion kWh of consumed energy, 0.786 kg of CO_2/kWh (1.73 pound of CO_2/kWh) was released in 2019 (EIA, 2020a). Providing an increase of 74% from the previous year of 0.449 kg of CO_2/kWh (0.99 pounds of CO_2/kWh) (EIA, 2020a).

New technologies have been developed that can help in the reduction of CO_2 emissions. The newer technology ranges from the implementation of energy efficient equipment, implementation of renewable energy, and carbon sequestration (Berger et al., 2019, Rabiaia et. al., 2020). Capital investment to improve U.S. manufacturing facilities have lagged. The average age of fixed assets within U.S. manufacturing facilities is 23 years (BEA, 2020). Green energy technology has continued to advance during the last 20 years. Building management technology has become more energy efficient. Renewable energy technology has decreased in price, with solar photovoltaics (PV) panels decreasing 82% between 2010 – 2019 (IRENA, 2020). The utilization of localized renewable energy sources and implementing carbon sequestration systems across the U.S. manufacturing sector is needed to help with the decrease of CO_2 concentration in the atmosphere.

Renewable energy technology efficiency has increased over the years and the cost of implementation has decreased. Renewable energy produced 11.4% of the U.S. consumed energy during 2019 (EIA, 2020e). Renewable energy, specifically solar, has increased in growth by 49% yearly (SEIA, 2020). The cost of installation of solar has decreased by 70% over the last decade

(SEIA, 2020). Implementing renewable energy at the site level would reduce the load and electrical consumption of dirty fuel sources (The Renewable Energy Hub, 2018).

Renewable energy will prevent more emission from occurring, but Earth already has a concentration of CO2 that will need to be remedied (Riebeek, 2010). Carbon sequestration is the method of removing CO2 from the atmosphere either geologic or biologic (USGS, n.d.). Carbon sequestration is made up of three steps, capture, transportation, and storing (CCS, n.d.). The CO2 is separated from the rest of the gases emitted after the fuel is burned during the capture process (CCS, n.d.). The CO2 is then converted into liquid form and transported via tanker, ship or pipe (CCS, n.d.). The liquid CO2 is then stored within a geological rock formation buried deep beneath the earth's surface (CCS, n.d.). Earth has wells of liquid CO2 that have formed naturally over time, making semi-permanent storage of extracted CO2 possible (Xiao et. Al., 2011). If there are natural instances of liquid CO2 stored beneath the Earth's surface, filling empty wells with man-made CO2 is possible (Xiao et. Al., 2011).

The effects of CO2 emission are a global issue attracting the attention of major governments in several countries (UNFCCC, n.d.). The United Nations has created the United Nations Framework Convention on Climate Change (UNFCCC) secretariat to facilitate international government with climate change negotiations (UNFCCC, n.d.). UNFCCC facilitated the Paris Agreement which brought together 197 countries to agree to reduce CO2 emissions and mitigate climate change (UNFCCC, n.d.) within the 197 countries' respective countries. California has signed an executive order to reach carbon neutrality by 2045 and to move to 100% clean energy sources (Executive Department State of California, 2018).

1.2 The Impact of CO_2 Emissions

The U.S. manufacturing facilities consumed 26% of energy consumption, which accounted for 5.27 billion metric tons of CO_2 emissions in 2018 (EIA, 2019a, EIA, 2019b). The increased concentration of CO_2 contributes to the cause of global warming (Al-Ghussian, 2018). Global warming is the increase of the average temperature of the surface of the Earth due to the increased concentration of greenhouse gasses (GHGs) (Al-Ghussian, 2018). Greenhouse gasses are made up of "water vapor, methane, ozone, carbon dioxide, chlorofluorocarbons, and nitrous oxide" (Al-Al-Ghussian, 2018). Between 1950 and 2015 the concentration of carbon dioxide has increased by 30% (Al-Ghussian, 2018).

The combustion of fossil fuels is a major cause of the flux of CO_2 emission (Blasing et al., 2005). Coal burning electricity generation produced 60% of CO_2 emissions, 38% of CO_2 emission came from oil burning, and 20% came from natural gas burning during electricity generation in 2019 (EIA, 2020b). Carbon dioxide made up 407.4 parts per million of the global atmosphere in 2018 (Lindsey, 2019). The CO_2 concentration increased to 409.8 parts per million of the global atmosphere during 2019 (Lindsey, 2020).

The increase of CO_2 and other GHGs cause environmental changes that are affecting the livelihood of every species on earth (Rabiaia et. al., 2020). National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies (GISS) conducts studies routinely to determine the average temperature of the Earth's surface (NASA, 2020). Since studies have begun, between 1880 and 2014, the average temperature of the Earth has increased 0.8ºC (Al-Ghuassian, 2018). The National Oceanic and Atmospheric Administration, the Japan Meteorological Agency, and the Met Office Hadley Centre in the United Kingdom conducted similar studies of independently utilizing the same data as GISS (Hansen et al., 2010). The individual values of temperature change from each respective study varied, however the upward trend were similar (Hansen et al., 2010). If the current trends of CO_2 emissions continue, scientists predict an increase of 2ºC – 6ºC in the 21st century (Al-Ghuassian, 2018). Increasing surface temperature of the Earth causes drastic climate change. Over the course of 72 hours, Fort Collins, Colorado saw an outdoor temperature of 90ºF followed by 0.3 inches of snow followed by an outdoor temperature of 100ºF, during September of 2020, (Cappucci, 2020).

The ecosystem is affected from the effects of CO2 concentration. The ocean absorbs CO2 and excessive heat from the environment, absorbing 30% of the CO2 from the atmosphere (Logan, 2010). Since the 1800s the increased CO2 concentration has caused a 0.1 drop in the potential of hydrogen (pH) level of the ocean which is a 30% change in PH level (Logan, 2010). The ocean absorbs 80% of the heat trapped by GHGs. The increased temperature of the ocean reduces the percentage of oxygen (Logan, 2010). If the oxygen is decreased drastically marine species will become extinct (IUNC, n.d.). Since 1980, 30% to 50% of the coral reefs have died due to increased temperature of the ocean and increased acidity (The National Academy, 2019).

The forests and other green lands provide a natural remedy of CO2, consuming the CO2 from the atmosphere (Choi and Manousiouthakisa, 2020). Plants absorb carbon at the rate of their assimilation or photosynthesis during the natural process (Choi and Manousiouthakisa, 2020). Studies have shown that the plants have responded to the current increased concentration of CO2 by an increased gross primary production (Cernusak et al., 2019). The increased production by the plants is only noted in specific CO2 concentration areas and not seen globally (Zheng et al., 2018). Studies show that plants previously stored 1.85 times the amount of CO2 that is currently being stored within plants (Crowther et al., 2015). The issue is the rate of emission of man-made CO2 versus the rate of assimilation. The parts per million for CO2 within the atmosphere increased by 2.4% from 2018 to 2019 (Lindsey, 2019, Lindsey, 2020). The increase in the concentrated CO2 shows CO2 emissions are being emitted faster than plants can assimilate. Deforestation adds to the increase of the CO2 concentration (Derouin, 2019). Derouin (2019) estimated 3.9 million square miles of forest have been cut down in the 20th century removing 3.9 million square miles of natural carbon sequestration.

1.3 How the Problem is Measured

Excessive yearly CO2 emissions causes the concentration of CO2 in the atmosphere to increase. The amount of CO2 emissions will be quantified based on the annual energy consumption of a forge manufacturing plant located in Fontana, Ca, sized at 40,000 sq-ft of manufacturing area. The plant has office space that accounts for roughly 4,500 sq ft. The plant's major use of electricity is office space, seven (7) industrial air compressors, and open manufacturing space T12 high bay lighting. The forge manufacturing plant utilizes natural gas furnaces to process material. The problem statement was measured by comparing the adoption of 10% solar energy sources replacing fossil fuel sources within the Company's U.S. based manufacturing plants. The CO2 emissions was compared to a before and after state of electric demand. A 10% decrease of electric usage is predicted with the implementation of solar renewable energy and building automation systems (BAS). Additional CO2 emission reduction was sought from implementing carbon sequestration technology. The CO2 emission is quantified based on the fuel source and amount of fuel consumed. The CO2 emissions from the natural gas combustion furnace system with a carbon sequestration system implemented was compared to a natural gas combustion furnace system without a carbon sequestration system. A 10% reduction of CO2 emission was assumed for the carbon sequestration system.

The EPA (2020) provides an equation that can predict carbon emissions based on electricity due to increased energy efficiency or renewable energy, as illustrated in Figure 1.1., on page 7.

$$C = E * 7.07*10^{-4} \text{ metric tons } CO_2/kWh$$

Figure 1.1 Carbon Emission due to Electricity Generation

C is the total CO2 emission emitted from the consumption of electricity and E equales the total kilo-Watt-hours (kWh) of energy consumed (EPA, 2020).

The EPA (2020) provides an equation that can predict carbon emissions based on the combustion of natural gas, as described in Figure 1.2, below.

$$C = Ng * 0.0053 \text{ metric tons } CO_2/\text{therm}$$

Figure 1.2 Carbon Emission Due to Natural Gas Combustion

C is the total CO2 emission emitted from the combustion of natural gas and Ng equal the total therms of natural gas consumed (EPA, 2020). Figure 1.1, on page 7, and Figure 1.2, on page 7, provides an equation to calculate and quantify the amount of CO2 emitted from electricity production and natural gas combustion. The calculated consumption was quantitively compared to a process utilizing 10% less electricity and 10% CO2 captured during natural gas combustion.

Certain state governments require reporting of energy usage and CO2 emissions (CARB, 2020). The annual energy usage of the forge manufacturing plant between 2018 – 2019 was studied. The energy usage data was provided from a company called Cotopaxi who specializes in energy consulting. Cotopaxi works with energy providers to collect and trend consumption data. Cotopaxi has collected data for the forge manufacturing plants from 2015 to present. The reduction of the CO_2 will be observed during the study and will provide guidance for similar implementation at varying manufacturing plants.

1.4 Connection to the NAE Grand Challenge

The U.S. National Academy of Engineers (NAE) established the 14 grand engineering challenges (NAE, n.d.). The 14 grand engineering challenges consist of:

> advance personalized learning, make solar energy economical, enhance virtual reality, reverse-engineer the brain, engineer better medicines, advance health informatics, restore and improve urban infrastructure, secure cyberspace, provide energy from fusion, prevent nuclear terror, manage nitrogen cycle, develop carbon sequestration methods, and engineer the tools of scientific discovery (NAE, n.d.).

The 14 grand challenges presented by the NAE are challenges that top engineers, artists, scientists, politicians, and other scientific disciplines deemed challenges shared around the world (NAE, n.d.). The 14 grand challenges are needed to ensure the longevity of Earth's survival and the existence of humanity (NAE, n.d.). Developing a solar energy solution and implementing a carbon sequestration method in manufacturing facilities is aligned with the National Academy of Engineering, develop carbon sequestration methods (NAE, n.d.).

1.5 Introduction Summary

The GHG emissions must be reduced by 60-80% in order to avoid an average surface temperature increase of 2.0^{o}C (Psarras, 2020). Reducing CO_2 emission would yield benefits environmentally (Al-Ghussian, 2018). The manufacturing industry ranks third in electricity consumption and CO_2 emission from transportation. (EIA, 2020h). The reduction of CO_2

emissions and reduction of the CO_2 concentrations within the atmosphere is important due to current environmental phenomenon (Al-Ghussian, 2018). Utilizing solar energy at a site level can potentially reduce the load on the traditional electric grid, and dirty energy production (Rabiaia et. al., 2020). Reduction of CO_2 emission and becoming carbon neutral is not enough (Randers & Goluke, 2020). The current CO_2 concentration within the atmosphere will need reduction (Randers & Goluke, 2020). Natural sources of the carbon sequestration are being destroyed with deforestation (Derouin, 2019). The current trend of CO_2 emission cannot continue without serious consequences to the environment (Randers & Goluke, 2020). The implementation of localized solar energy, building automation, and carbon sequestration systems will reduce energy usage and CO_2 emission on a local level of the manufacturing facility being conducted (Rabiaia et. al., 2020, Psarras et. al., 2020, Thabet et. al., 2020). Carbon dioxide emission will not see reductions from one technology or one single solution, as CO_2 emissions are inevitable for specific processes, i.e., steel and cement production (Vega et al., 2018). The CO_2 reduction will come from several different technologies working collectively to achieve a common goal (Vega et al., 2018).

CHAPTER 2. REVIEW OF LITERATURE

2.1 Importance and Impact of Carbon Dioxide (CO2)

The effects of climate change are becoming more drastic every year (Al-Ghuassian, 2018). Scientists and engineers have studied the effects of climate altering events since the early 1970s and started reporting the temperature data in the 1980. Carbon dioxide (CO2) was the suspected main contributor to increased global surface temperature (Hassen et al., 2010). Carbon dioxide plays an important role due to the characteristic of absorbing infrared light waves directed from the sun and capturing heat (Al-Ghuassian, 2018). Al-Ghuassian (2018) provides an explanation on the phenomenon. Greenhouse gasses (GHGs) allow the Earth to maintain a temperature that supports life (Al-Ghuassian, 2018). The CO2 traps heat from the incoming sun rays keep the Earth's temperature habitable (Al-Ghuassian, 2018). The increase of GHG concentration will cause an increase in absorbed sun rays resulting in increased surface temperature (Al-Ghuassian, 2018). Based on Al-Ghuassian (2018) the sun emits three wave types: visible, ultra-violet, and infrared (Al-Ghuassian, 2018). The infrared carries about half of the solar energy within the emitted light (Al-Ghuassian, 2018). As the solar rays pass through the atmosphere, CO2 and methane absorb the infrared waves (Al-Ghuassian, 2018). The sun rays then hit the surface of the Earth and reflect short infrared waves back into the atmosphere (Al-Ghuassian, 2018). The short infrared waves reflected from the Earth's surface are then absorbed by CO2 (Al-Ghuassian, 2018).

Carbon dioxide plays a crucial role in maintaining the global temperature (Al-Ghuassian, 2018). The increase of CO2 concentration causes an increase of the absorbed infrared waves emitted from the sun and the absorbed infrared waves radiated off the Earth's surface (Al-

Ghuassian, 2018). The earth experiences natural CO2 cycles (NASA, 2020). Figure 2.1 below shows NASA's modeled carbon cycle of the earth.

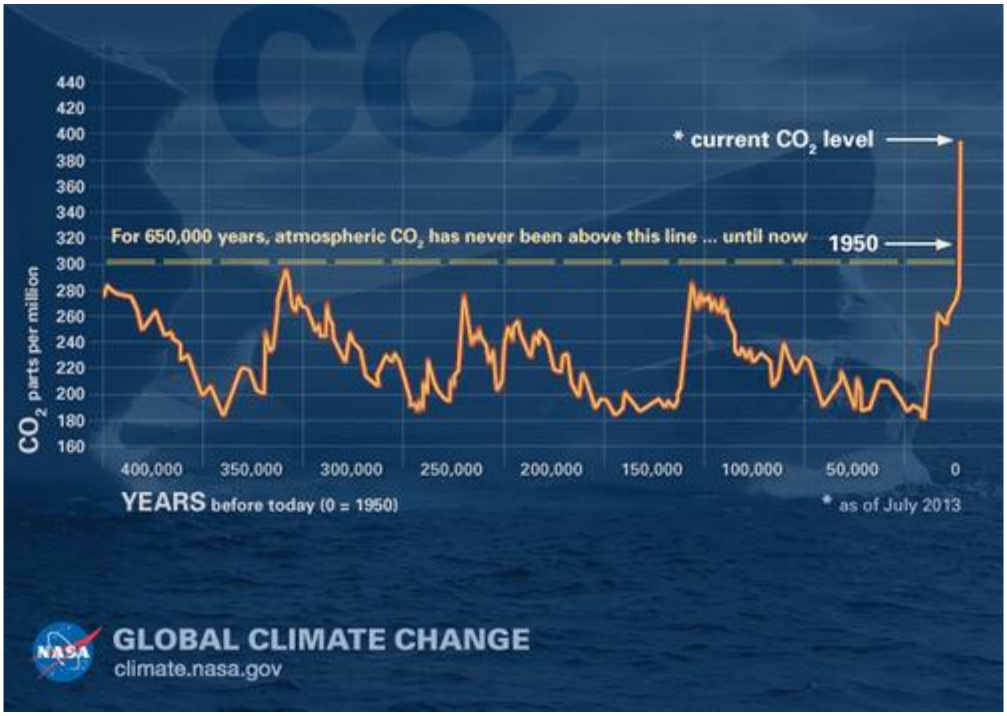

Figure 2.1 The concentration of carbon dioxide in the atmosphere. Reproduced from: Climate change: How do we know? NASA Global Climate Change Center, https://climate.nasa.gov/evidence/

Observed in Figure 2.1 above, the CO2 cycle has a predictable rise and fall with the cycle repeating roughly every 100,000 years. Figure 2.1 depicts the highest-level CO2 concentration the Earth has experienced during year 1950. The CO2 concentration continued to rise, showing no evidence of continuing the natural CO2 cycle (Al-Ghussian, 2018). Man-made CO2 has increased the concentration of CO2 to exceed levels known to occur naturally (Al-Ghussian, 2018). Scientists are uncertain how the Earth will respond in order to return to its natural cycle, if possible (Randers & Goluke, 2020).

2.2 The Effects of CO2 Increase

The evidence of global warming and climate change is present (Al-Ghussian, 2018). When an area records a record low temperature during winter months, skeptics would argue that global warming and climate change are not occurring (Liptak, 2019). Global warming is the increase of the average global temperature (Al-Ghussian, 2018). Several different scientific organizations have conducted studies and concluded that the average global temperature has increased over the decades (Hansen et. al., 2010). The National Aeronautics and Space Administration has concluded that the temperature has risen 2^{o}F degrees since 1880 (NASA, 2020). The National Oceanic and Atmospheric Administration (NOAA) has recorded a rise of 1.69^{o}F since 1880 (NOAA, 2020). Figure 2.2 below shows the trending average global temperature from 1850 – 2019.

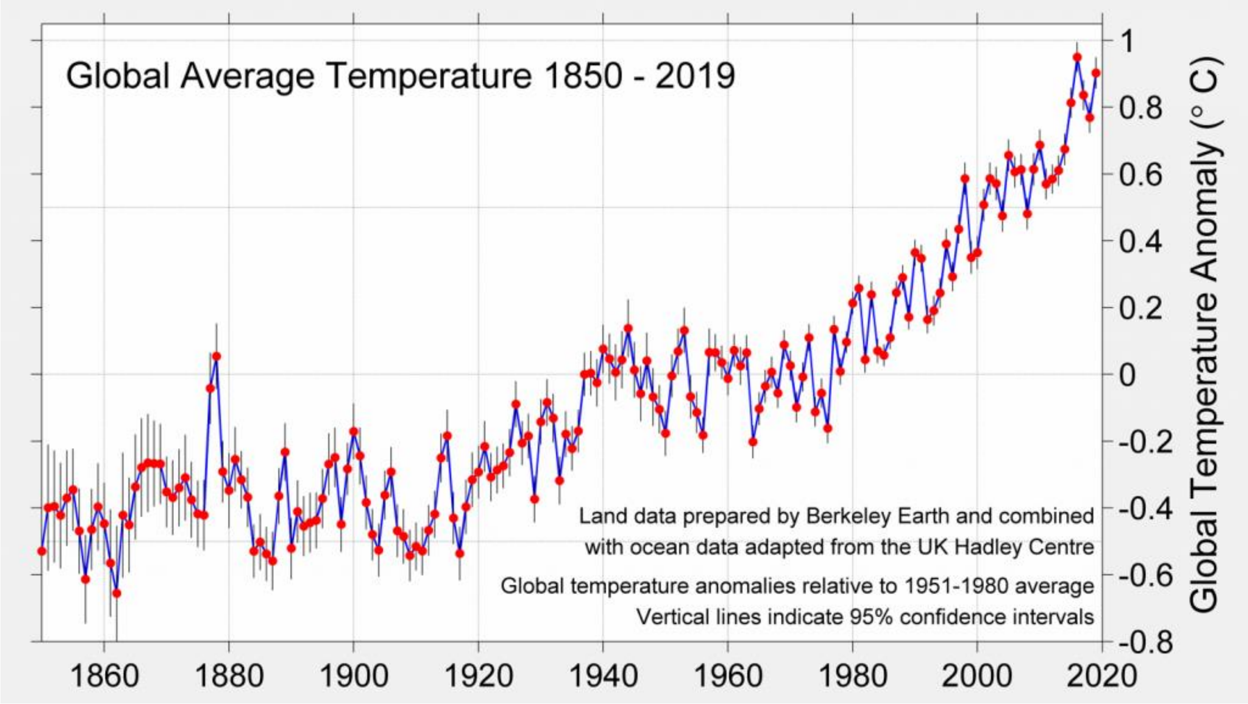

Figure 2.2 Global Average Temperature 1850 – 2019 (Berkeley Earth, 2019)

From Figure 2.2, assumptions are made. The global average temperature based on yearly averages typically fluctuate. Comparing any given year to another year does not properly depict a true conclusion. Example, the year 2000 shows a drop in average temperature from 1998. Looking at the range from 1998 to 2000, the temperature trend looked as if the average global temperature was dropping. Analyzing at the same graph the trend shows that from 2000 to 2019 average the global average temperature increased 0.5^{o}C.

The National Aeronautics and Space Administration (2020) predicts a 2^{o}C – 6^{o}C (3.6^{o}F – 10.8^{o}F) rise in the global temperature if current CO2 emission trends continue. Previous studies conducted between 1970 and 2007 have successfully predicted the rise of the average global surface temperature (Hausfather et al., 2019). Climate models must make assumptions and use predicted CO2 emissions, as there is no way for someone to know what type of emission that will occur in the future (Hausfather et al., 2019). Hausfather et al. (2019) developed a method to account for the inaccurate predictions of future CO2 emissions. Hausfather et al. (2019) conducted a direct comparison of observed versus modeled temperature of 17 models. Within Hausfather's et al. study, 10 out of the 17 models show consistent comparison of observed versus modeled results prior to estimated future CO2 emissions (2019). Once the estimated CO2 emissions were adjusted Hausfather et al. (2019) noted that 14 out of the 17 models successfully predicted the increase of average global temperature. The National Aeronautics and Space Administration's simulated varying CO2 scenarios utilizing 21 climate models (Cole and Waller, 2015). The worst case resulting in a 6^{o}C change in average global temperature (Al-Ghuassian, 2018).

2.3 Carbon Sequestration

The technology already exists to capture CO_2 emissions from industrial and electrical processes (Psarras et al., 2020). Per Psarras et al. an estimate of half the CO_2 emission would be reduced if direct carbon capture sequestration (CCS) were installed (2020). The amine solvent is favorable to the amine's comparatively higher reactivity to CO_2 and low cost of production comparatively (Alkhatib et al., 2020). The draw back to amine solutions is the energy required to regenerate the solution (Alkhatib et al., 2020). Temperatures upward to 373 Kelvin are needed for the process of CO_2 separation (Alkhatib et al., 2020). The energy required to regenerate the solution would yield more natural gas burning to produce more energy to accomplish the regeneration, producing more CO_2 (Alkhatib et al., 2020). Amine solutions consist of water co-solvents (Alkhatib et al., 2020). The regeneration of the amine solution requires 50% of the heat duty to heat and vaporize the water from the solution During the CO_2 capture process (Alkhatib et al., 2020). The overall efficiency of the CO_2 capture process would be increased for manufacturing processes that utilizes high temperature furnaces. Utilizing the exhausted heat from the furnace would provide the energy required to heat and vaporize the water from the amine solution to separate the captured CO_2.

The amine group type plays an important role in how CO_2 is absorbed during the capture process (Cachaza et. al., 2018). The groups consist of primary amine, secondary amine, tertiary amine, and sterically hindered amine. (Cachaza et. al., 2018). The primary and secondary amine provide reaction rates above tertiary amine, and sterically hindered amine but yield lower carbon loads comparatively (Cachaza et. al., 2018). The primary and secondary amine need more energy to regenerate compared to the other groups (Cachaza et. al., 2018). Compared to primary and secondary, tertiary amine shows lower reaction rate but higher carbon loading and require less energy for regeneration compared to primary and secondary amine (Cachaza et. al., 2018).

Sterically hindered amines are intermediate, and behaviors cannot be characterized (Cachaza et. al., 2018). Compared to primary, secondary, and tertiary the sterically hindered show low stability of carbamates which increase the carbon loading with a high reaction rate comparatively (Cachaza et. al., 2018). Recent studies have developed new solvents that have increased CO2 absorption (Cachaza et. al., 2018). Blending the amine groups achieves improved results and combines favorable characteristics (Cachaza et. al., 2018). Utilizing more efficient CO2 absorbing solutions and energy optimization from the manufacturing process, CCS solutions can become a feasible option for industries within the manufacturing sector (Cachaza et. al., 2018).

The carbon sequestration process starts by capturing the emission carbon at the site level (CCS, n.d.). The exhaust fumes from the combustion process are captured and processed to separate the CO2 from the rest of the emitted gas (CCS, n.d.). Once separated the CO2 is then transported to the long-term storage location (CCS, n.d.). Figure 2.3 below describes an example of the carbon sequestration process.

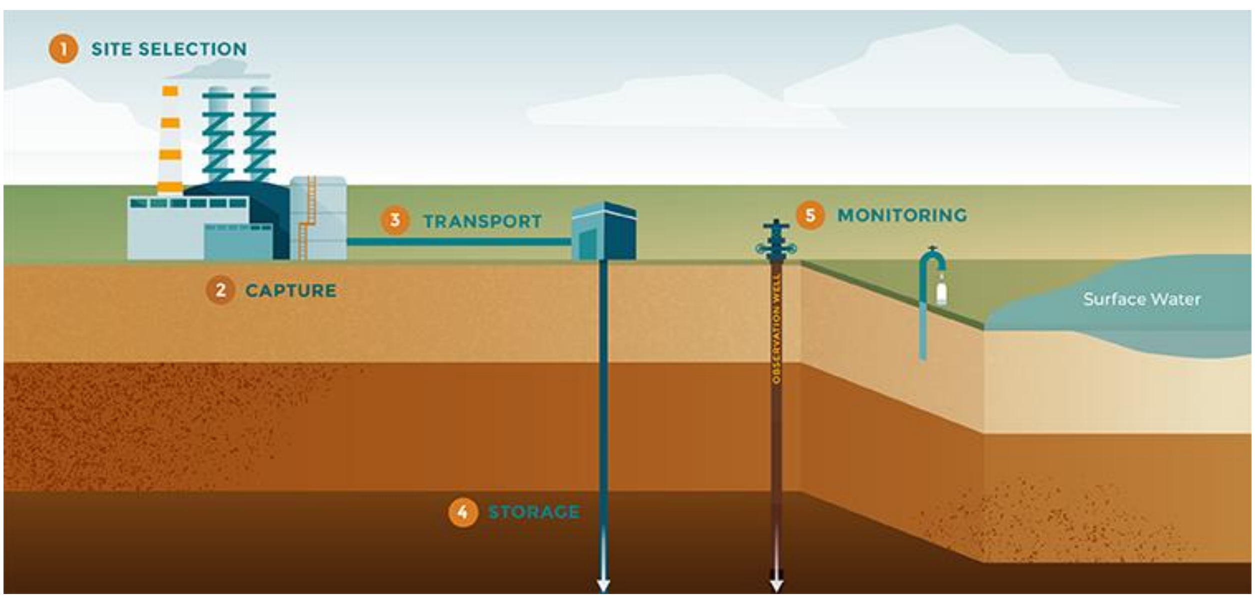

Figure 2.3 Site Carbon Sequestration Diagram (PCOR, 2020)

Carbon storage deep beneath the surface poses the greatest potential of long-term storage of CO2 (CCS, n.d.). Oil recovery techniques utilize CO2 to extract the remaining oil within reservoirs (Berger et al., 2019). The technique of pumping the CO2 into reservoirs is already common knowledge within the oil extraction sector (Berger et al., 2019). The Midwest Geological Sequestration Consortium has stored one million tons of CO2 in Mt. Simon Sandstone (Berger et al., 2019).

2.4 Solar Energy

The utilization of solar energy is not new technology, solar energy technology ranges back to the 7th century B.C. (U.S. Department of Energy, n.d.). Over time, research has been conducted to increase the efficiencies of the energy conversion system of solar energy technologies (Rabaia et al., 2020). Solar has seen an increase from producing 40 GW of energy in 2019 to 483 GW of energy in 2018. Solar is sought over the other renewable sources due to the abundance of solar energy sources and its relatively cheaper price of installation (Rabaia et al., 2020). Solar systems are scaled for residential systems and industrial systems (Rabaia et al., 2020). The maintenance of the systems is relatively low compared to other renewable sources (Rabaia et al., 2020).

The sun delivers 1000W/m2 of solar radiation at sea level on a clear day (Dupont, Koppelaar, & Jeanmart, 2020). Photovoltaic solar panels absorb the solar radiation and converts the energy into usable electrical energy (Solar Calculator, n.d.). Figure 2.4, on page 17, depicts the cycle of solar energy absorption by a photovoltaic solar cell.

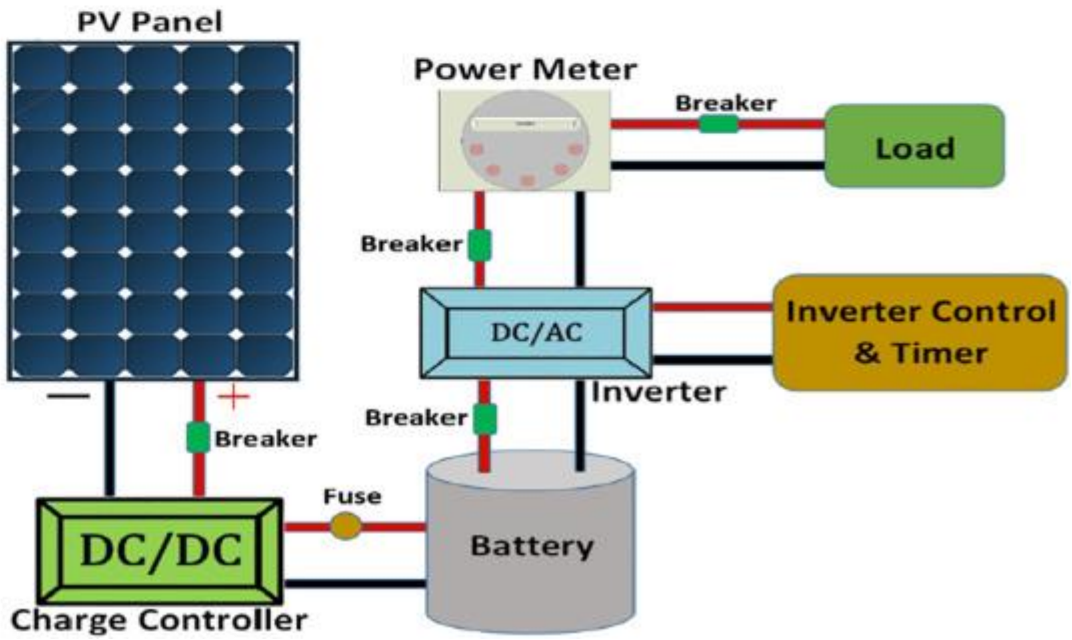

Figure 2.4 Photovoltaic Solar Panel Schematic (Rabaia et al., 2020)

The sunlight enters the photovoltaic cells and causes electrons to flow (Solar Calculator, n.d.). The photovoltaic cells deliver direct current (DC) (Solar Calculator, n.d.). The electricity produced by the photovoltaic cells flow through an inverter to convert DC to alternating current (Solar Calculator, n.d.). The systems then either utilizes the energy or in the case in Figure 2.4 the PV system sends the excess energy to the grid (Solar Calculator, n.d.). There are PV energy setups that incorporate a battery to store the access energy (Solar Calculator, n.d.).

To generate electricity, photovoltaic cells utilize semiconductors that absorb photons from the solar rays produced by the sun (Solar Calculator, n.d.). Figure 2.5 on page 18 provides an image of the process.

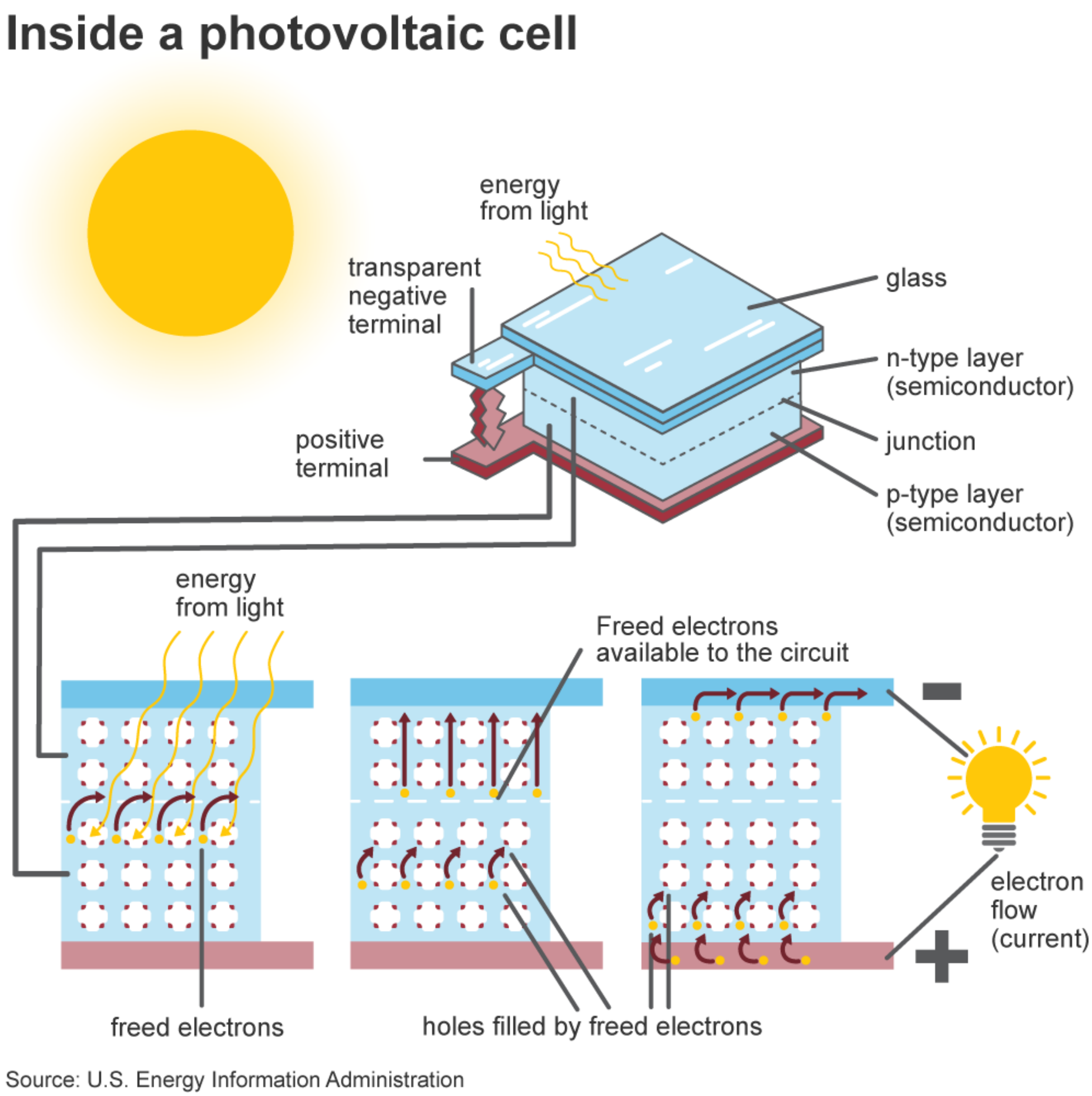

Figure 2.5 Inside a photovoltaic cell (EIA, 2020f)

The sunlight penetrates the semiconductor material (EIA, 2020f). Freed electrons cycle through the circuit (EIA, 2020f). The semiconductive material is treated so that the electrons that are set free are the front electrons (EIA, 2020f). The treatment of the semiconductive material allows for the electrons to flow from the back to the front, in a predictable manner (EIA, 2020f). When the electrons flow from the back to the front, an imbalance is created which creates voltage potential (EIA, 2020f).

Photovoltaic solar cells have a cell conversion efficiency ranging from 17.4% to 47.1% depending on the technology and application (University of Michigan, 2020). Photovoltaic solar cells have a module conversion efficiency of 11.7% to 38.9% (University of Michigan, 2020). The cost of solar panels has been reduced by 89% since 2009 (University of Michigan, 2020). The average cost of solar installation was $0.11/kWh for all sectors in 2019 (University of Michigan, 2020). The production of photovoltaic solar panels requires energy from dirty fuel sources to manufacture the solar cell (Rabiaia et. al., 2020). Over a photovoltaic (PV) panel lifetime the PV panel produces three to six times the energy than required to produce the photovoltaic panel (University of Michigan, 2020). Photovoltaic solar panels pose the best reduction of reliance on dirty fuel sources (Rabiaia et. al., 2020). Reducing the kW produced by dirty fuel sources reduces the CO2 emitted into the environment.

2.5 Energy Management System

Energy management systems helps to show the managerial, technical, and economical decisions needed to establish efficient energy use (Mason and Grijalva, 2019). Energy management systems utilizes scheduling and usage data to reduce wasted energy (Coban and Onar, 2019). The reduced energy usage provides a reduction in energy cost and reduction in CO2 emissions (Mason and Grijalva, 2019). Energy management systems utilize sensors, operational data, and advanced algorithms (Mason and Grijalva, 2019). Reinforcement learning algorithms are utilized to allow the energy management system to learn trends and make decisions without human interaction (Mason and Grijalva, 2019). As microprocessors become cheaper and the computing power increases, energy management systems are able to control more complex systems at an initial lower investment (Mason and Grijalva, 2019).

CHAPTER 3. RESEARCH METHODOLOGY

3.1 Research Methodology Overview

The increase of CO2 and the increase in the concentration of CO2 in the atmosphere, caused by combustion of various fuel sources, was the problem analyzed. The amount of CO2 emitted from a single source was quantified. The percentage of CO2 emitted from a single source was calculated for comparison. The amount of CO2 emitted based on electricity consumption was calculated using the equation below in Figure 3.1 (EPA, 2020).

$$C = E * 7.07*10^{-4} \text{ metric tons CO2/kWh}$$

Figure 3.1 Carbon Emission due to Electricity Generation

The amount of CO2 emitted based on natural gas combustion was calculated using the equation below in Figure 3.2 (EPA, 2020).

$$C = Ng * 0.0053 \text{ metric tons CO2/there}$$

Figure 3.2 Carbon Emission Due to Natural Gas Combustion

The electric and natural gas data collected was gained from one manufacturing plant located in Fontana, California. The plant reported all of its electricity and natural gas usage to the state of California through the Cotopaxi strata program. Historical data was accessed to provide an electrical and natural gas usage baseline for comparison. The strata program is a web-based energy management program developed by Cotopaxi (Cotopaxi, n.d.). The strata program was connected to Industrial Internet of Things (Iiot) measurement devices collecting usage data. The electrical and natural gas consumption data was captured and stored in the cloud. The IioT devices connected collected energy usage. A natural gas flow meter IioT device was connected to determine total usage of natural gas. The collected data was displayed on custom dashboards based on user’s needs. Figure 3.3, on page 21, shows the basic overview of the strata program.

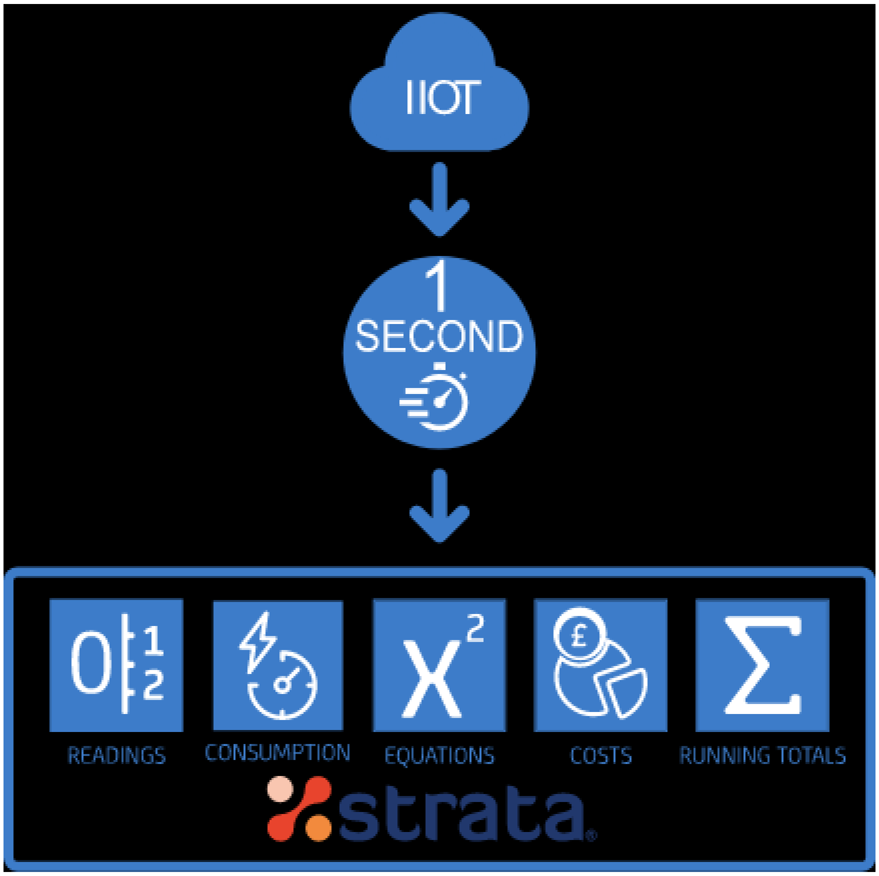

Figure 3.3 Strata data collection overview (Cotopaxi, n.d.)

The problem statement was measured by comparing the adoption of 10% solar energy sources replacing fossil fuel sources within the Company's U.S. based manufacturing plants. The research sought to implement solar energy generation to reduce the load on commercial power plants. The reduced load decreased the CO2 emission from the electricity generation utilizing dirty fuel. The research sought to implement carbon capture sequestration system that reduced CO2 emitted from combustion of natural gas during direct processes. Energy management systems reduced the CO2 emission further by scheduling and monitoring processes that waste energy.

3.1.1 Research Environment

The environment of the research took place at a forge manufacturing plant located in Southern California. The plant utilized natural gas furnaces to process material for forging. The plant utilized pneumatic forging hammers powered by seven electrically driven air compressors. The plant has a STRATA hosted utilities reporting system that collected data from 2015 to present. The utilities captured are natural gas consumption and electricity consumption. The forge building has approximately 3460m^2 (32,243ft^2) of available area for photovoltaic solar panel installation. The forge has a total of 21 natural gas furnaces where a carbon capture sequestration system would be suitable.

3.1.2 Sample Population, Participants ("N"), and Validation

The sample size of the research was defined as one (1) forge manufacturing plant located in Fontana, California, located in southern California. The specific sample size consisted of one (1) forge manufacturing plant sized at roughly 40,000 square feet and one (1) office space sized at roughly 4,500 square feet. The forge manufacturing plant consumes electricity and natural gas as energy sources.

The major consumptions of electricity consist of seven (7) air compressors. The plant has three (3) air compressors that operate on 2300v and four (4) air compressors that operate on 480v. The air compressors support four (4) pneumatic hammers utilized to process material. The plant utilizes four (4) electrically driven hydraulic mills, one (1) electrically driven hydraulic press, and six (6) electrically driven hydraulic miscellaneous equipment. The major consumption of natural gas for the plant are 21 natural gas burning furnaces. The furnaces combust the natural gas to heat material to process over various pneumatic hammers and electrically driven hydraulic equipment. The Forge Plant operates at five (5) days a week and 16 hours a day. The furnaces are in a constant “on” state during the week and the furnaces are turned off on weekends. All other pieces of equipment are powered on when needed.

Assumptions made during the study are as follows. All electricity generated and consumed were delivered from the same sources. The electricity being generated for the Forge Plant was provided by Southern California Edison (n.d.) Mountain View Facility located in Redlands, CA. Southern California Edison purchases 80% of its power from other plants (Southern California Edison, n.d.). The Mountain View power generation plant utilizes both natural gas and steam turbines to generate electricity. The electricity generated from the natural gas turbines was assumed as the primary source. The electricity will be provided to one (1) forge manufacturing plant and office space. The electrical consumption of the manufacturing plant and office space are separated, and consumption was captured from two separate monitoring meters.

The amount of electric energy produced by a solar array system relates directly to solar radiation produced. The amount of solar radiation varies per month and per geographic location. The monthly average solar radiation per Southern California was assumed to provide the input solar radiation for the proposed solar array.

Variables within the study consists of the following data points collected. The solar radiation varies per geographic location and time of the year. National Renewable Energy Laboratory (NREL) provided data for the average monthly solar radiation data collected per geological location from 1998 – 2016 (n.d.). The plant’s energy use, natural gas and electricity, varied on a monthly basis, in turn, the amount of CO2 emission produced varied on a monthly basis.

3.1.3 Statistical Measures (Quantitative and Qualitative)

A quantitative study was conducted comparing the generated CO2 emissions from the current operation versus a CO2 reduction. The solar panel array system provides electricity reducing the need of electricity generated by dirty fuel source, providing a reduction of CO2 emissions. Each month provided varying solar radiation causing the solar array system to produce varying by a level of electricity. A two-sample T-test was conducted to determine if significant variance was present between collected CO2 emissions versus the CO2 emission with a 10% reduction. The two-sample T-test determined if a significant difference was present between the mean of two independent data sets.

3.1.4 Limitations and De-limitations

Limitations included the current utilities data collection system. The electrical data was collected directly from SCE and utilities meters. The collected data was limited to the date range of tracking, one year. Data prior to 2020 was preferred, due to global pandemic energy usage data being skewed lower from unforeseen plant shutdowns.

3.2 Research Instruments

Research instruments utilized included Cotopaxi software to collect historical energy usage data. Cotopaxi is an energy consultant that provides energy management solutions and software for trending data. Cotopaxi has collected utility usage data from 2018 for the forge manufacturing plant. Cotopaxi collected data of electrical usage and CO2 emissions of the plant. The National Renewable Energy Laboratory (NREL) PVWatts calculator was utilized to size a photovoltaic(PV) solar panel array system (NREL, n.d.b). The PV system was sized based on available square footage of the forge manufacturing plant (NREL, n.d.b). PVWatts calculation was used to estimate the size and potential electricity produced by the cell based on the geological location and size of the PV cell (NREL, n.d.b). The overall process was surveyed. The survey determined the useful work performed based on energy consumption.

3.3 Procedures for Data Collection

Cotopaxi (n.d.) provided a strata system that collects utility data. Cotopaxi's system was utilized to obtain historical utility usage data for electrical usage and natural gas consumption. The strata collected daily usage for the forge manufacturing plant beginning 2015. The research only utilized data from 2018 to present. The usage was collected based on the utility providers meter reading. Comparison data was calculated based on current usage.

3.4 Presentation of Data

Data was collected and compared using tables. The monthly average current usage of electricity was compared to a PV system sized appropriately to fit a top of the forge manufacturing plant's roof. Example Table 3.1 below served as an example table of captured electricity utility data.

Table 3.1 CO2 emission saved utilizing 10% energy consumption provided by PV solar panels

	Jan 2018	Feb 2018	Mar 2018	Apr 2018	May 2018	Jun 2018	Jul 2018	Aug 2018	Sep 2018	Oct 2018	Nov 2018	Dec 2018
Energy Consumption												
Potential Solar Array Energy Production												
CO2 Emissions Saved												

Similar comparisons were conducted on natural gas consumption and CO2 emitted during combustion. Example Table 3.2 on page 26 describes natural gas consumption, CO2 emissions, and CO2 reduction by month during the research term.

Table 3.2 CO2 captured during natural gas consumption

	Jan 2018	Feb 2018	Mar 2018	Apr 2018	May 2018	Jun 2018	Jul 2018	Aug 2018	Sep 2018	Oct 2018	Nov 2018	Dec 2018
Natural Gas Consumption												
CO2 Emitted												
CO2 Emissions Saved for Carbon Capture System												

The energy management system proposed reduced energy consumption by scheduling non-value-added processes. Utilizing an energy management system to schedule equipment to turn off during non-value-added intervals can potentially reduce CO2 emitted due to reduced energy consumption. A comparison of average daily usage versus non-value-added energy consumption was compared. Example Table 3.3 below will show the comparison between current energy usage versus non-value-add energy usage showing potential cost saving utilizing scheduling software.

Table 3.3 Usage Comparison

Current Energy Usage	
Non-Value-Added Energy Usage	
Percent of Energy saved with Energy Management System Scheduling	

3.5 Return on Investment (ROI)

The main reason companies chose not to invest in solar energy systems was the cost and return on investment (ROI). A ROI analysis was conducted based on the PV array implementation. A separate ROI analysis was conducted based on both the cost of carbon capture sequestration system and implementation of PV arrays.

3.6 Summary

The research methodology provided in chapter three supports the steps to achieve a statistically significant study. Utilizing a two-sample t-test at a 95% confidence interval the research will provide results that will be repeatable. The two-sample t-test was chosen as it compares the means of one sample to another. Through the two-sample T-test the average monthly CO_2 emissions is compared directly to the average monthly CO_2 emission of a 10% reduction. Utilizing a 95% confidence interval provides the support the results have a 95% chance of repeating the same results for the population. Chapter four will provide the results of the study and the significance of the findings.

CHAPTER 4. RESULTS

4.1 Electrical Consumption Comparison

Cotopaxi (n.d.) has collected utility usage data for the Forge manufacturing plant since 2018. The utility usage data collected for the Forge manufacturing plant include electricity consumption. The electricity consumption data for the year of 2018 is displayed on Table 4.1 below. Table 4.1 compares the current usage trends compared to a 10% reduction utilizing a solar panel array system. Table 4.1 displays the calculated CO2 emissions saved. The CO2 emissions saved were based on electricity produced by the solar panel array system, reducing the demand from power plants by 10%.

Table 4.1 CO2 emission saved utilizing 10% energy consumption provided by PV solar panels

	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18
Energy Consumption (kWh)	488,891	856,704	1,028,762	955,126	1,163,098	1,046,566	1,033,808	1,159,807	1,052,288	1,190,054	1,145,935	917,779
Potential Solar Array Energy Production (kWh)	48,889	85,670	102,876	95,513	116,310	104,657	103,381	115,981	105,229	119,005	114,594	91,778
CO2 Emissions Saved (mTons)	35	61	73	68	82	74	73	82	74	84	81	65

Analyzing the electrical energy consumption profile in Table 4.1, the average consumption increased during the fall months. The forge manufacturing plant consumed 11% more energy in the fall months. As energy usage increases, so does CO2 emissions. The forge manufacturing plant consumed 488,891 kWh of electricity which accounted for 35 mTon of CO2 during January 2018. Comparatively, in February 2018, the forge manufacturing plant consumed 856,704 kWh of electricity which accounted for 61 mTons of CO2 emissions, 26 mTons higher than January. Discussed further in sub-section 4.2 on page 30, solar irradiance is at the highest point in spring and summer months, allowing a solar panel array system to convert more solar rays into energy, off-setting increased electrical energy consumption. The collected data allows for a comparison of current CO2 emission versus operation with reduced CO2 emissions. A two-sample T-test was conducted to verify if a statistically significant reduction of CO2 emissions was present by reducing the electricity consumption from dirty fuel source power plants. Figure 4.1 below displays the results of a two-sample T-test. The two-sample T-test compared the mean monthly CO2 emission of current electrical consumption versus a 10% reduction of electrical consumption.

Two-Sample T-Test and CI: 10% reduction (CO2 Electricity), CO2 Emission (Electricity)

```
Two-sample T for 10% reduction (CO2 Electricity) vs CO2 Emission (Electricity)

                                              SE
                           N  Mean  StDev  Mean
10% reduction (CO2 Elect  12   638    122    35
CO2 Emission (Electricit  12   709    136    39


Difference = μ (10% reduction (CO2 Electricity)) - μ (CO2 Emission
(Electricity))
Estimate for difference:  -70.9
95% CI for difference:  (-180.7, 38.9)
T-Test of difference = 0 (vs ≠): T-Value = -1.34  P-Value = 0.194  DF = 21
```

Figure 4.1 Two-Sample T-test Results for Electricity CO2 Emission

The two-sample T-test was set up with a 95% confidence interval. The null hypothesis states that the mean CO2 emission from electricity consumption was equal to the mean CO2 emission of electricity consumption at a 10% reduction. The alternative hypotheses states that the mean CO2 emission from electricity consumption was not equal to the mean CO2 emission of electricity consumption at a 10% reduction. The two-sample t-test returned a P-value of 0.194, failing to reject the null hypothesis. A 10% reduction in electricity consumption does not provide a statistically significant reduction in CO_2 emissions. To provide a statistically significant amount of CO_2 reduction, a larger solar panel array system is needed to produce more electricity.

4.2 Solar Panel Array Configuration

PVWatts by NREL (n.d.b) provides an online tool to build a solar panel array system. The PVWatts tool calculates the potential electricity production from the solar panel array system based on the solar irradiation of the desired geological location. Figure 4.2 below provides a description of the PV solar panel array system sized.

PV System Specifications *(Commercial)*

DC System Size	800 kW
Module Type	Premium
Array Type	Fixed (open rack)
Array Tilt	20°
Array Azimuth	180°
System Losses	14.08%
Inverter Efficiency	96%
DC to AC Size Ratio	1.2

Figure 4.2 Forge Manufacturing Plant Photovoltaic (PV) Solar Panel array System

The 800-kW solar panel array systems will provide the Forge manufacturing plant with the desired 10% reduction of demand from traditional power plants. Figure 4.3, on page 31, displays the estimated electricity energy produced from the PV solar panel array based on the geological location's solar irradiance.

Month	Solar Radiation (kWh / m2 / day)	AC Energy (kWh)	Value ($)
January	4.43	85,463	10,093
February	5.16	89,814	10,607
March	6.18	117,703	13,901
April	6.62	122,015	14,410
May	7.15	132,056	15,596
June	7.73	137,392	16,226
July	7.69	141,395	16,699
August	7.75	141,858	16,753
September	6.89	123,132	14,542
October	5.95	111,853	13,210
November	4.97	91,942	10,858
December	4.15	81,656	9,644
Annual	6.22	1,376,279	$162,539

Figure 4.3 PV Solar Panel array Electricity Production and Cost Savings

Solar radiation is the amount of solar light delivered by the sun (Nasa, 2008). The sun radiates approximately 25% more radiation in the summer months compared to other seasons. The increased radiation of the summer months is contributed to the fact that the days are longer in the summer months. The sun rays are hitting the earth at a more direct angle during the summer months compared to winter months, causing more direct radiation (Lumen, n.d.).

4.3 Natural Gas Reduction Comparison

Cotopaxi (n.d.) collected natural gas consumption for the forge manufacturing plant along with the electricity consumption. The natural gas consumption data for the year is displayed on Table 4.2 below. Table 4.2 compares the current usage trends compared to a 10% reduction utilizing carbon capture sequestration (CCS) technology. Table 4.2 displays the calculated CO2 emissions saved.

Table 4.2 CO2 emission saved utilizing 10% carbon sequestration technology

	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18
Natural Gas Consumption (dth)	13090	12124	12076	10136	12787	12522	11967	13790	12749	14671	13078	9682
CO2 Emitted (mTons)	694	643	640	537	678	664	634	731	676	778	693	513
CO2 Emissions Saved for Carbon Capture System	69	64	64	54	68	66	63	73	68	78	69	51

Due to the nature of work performed at the forge manufacturing plant, the natural gas consumption profile displayed in Figure 4.2 is unavoidable. The natural gas consumption did not vary significantly, within 4,000 dth per month. December provided lower natural gas consumption due to the plant’s annual holiday period shutdown of entire plant. A two-sample T-test was conducted to verify if a significant reduction of CO2 emissions was present by capturing the CO2 from natural gas furnace combustion. Figure 4.4, on page 33, displays the results of a two-sample T-test. The two-sample T-test compared the mean monthly CO2 emission of current operation versus a 10% reduction of utilizing CCS technology.

Two-Sample T-Test and CI: 10% reduction (CO2 Natural Gas), CO2 Emission (Natural Gas)

```
Two-sample T for 10% reduction (CO2 Natural Gas) vs CO2 Emission (Natural Gas)

                                                SE
                           N    Mean  StDev   Mean
10% reduction (CO2 Natur  12   591.0   66.2     19
CO2 Emission (Natural Ga  12   656.6   73.6     21


Difference = μ (10% reduction (CO2 Natural Gas)) - μ (CO2 Emission (Natural
Gas))
Estimate for difference:  -65.7
95% CI for difference:  (-125.1, -6.3)
T-Test of difference = 0 (vs ≠): T-Value = -2.30  P-Value = 0.032  DF = 21
```

Figure 4.4 Two-Sample T-test Results for Natural Gas CO2 Reduction

The two-sample T-test was set up with a 95% confidence interval. The null hypothesis states that the mean CO2 emission from natural gas combustion was equal to the mean CO2 emission of natural gas combustion at a 10% reduction. The alternative hypotheses states that the mean CO2 emission from natural gas combustion was not equal to the mean CO2 emission of natural gas combustion at a 10% reduction. The two-sample t-test returned a P-value of 0.034, rejecting the null hypothesis. A 10% reduction in natural gas combustion CO2 emissions provides a statistically significant reduction in CO2 emissions.

4.4 Carbon Sequestration Investment

Schmelz, Hochman, and Miller (2020) provided a study that determined an estimated cost of storage of CO2 emissions from natural gas combustion systems. The cost of storage of the CO2 emission was determined by cost of capture of the CO2 emission, cost of transportation of the CO2 emission, and cost of storage of the CO2 emission (Schmelz et al., 2020). Schmelz et al. (2020) found that the cost to capture and store carbon was $80-$90 per ton for natural gas combustion. Based on the proposed CO2 emission captured with the CCS technology, a CCS system will cost $63K - $71K a year.

4.5 Forge Operation Wasted Energy and Energy Management

Solar panel array systems and CCS technology are beneficial when energy is consumed for a value-added process. The forge manufacturing plant wastes energy and an energy management system will assist with making the plant more energy efficient. The forge manufacturing plant operates five days a week at 16 hours a day. Energy was wasted due to machines running during an idle state of the process during the working day. Energy was wasted due to lighting in the forge and office in an “always on” state. Air compressors are utilized to process material during operations. Air compressors are in an “always on” state even when value-added operations are not being performed. Value-added tasks are operations that are required to produce needed material, excluded tasks are those such as transportation, waiting between cycles, and operational breaks. Figure 4.5, on page 35, depicts the energy consumption schedule, showing total hours of non-value-added waste.

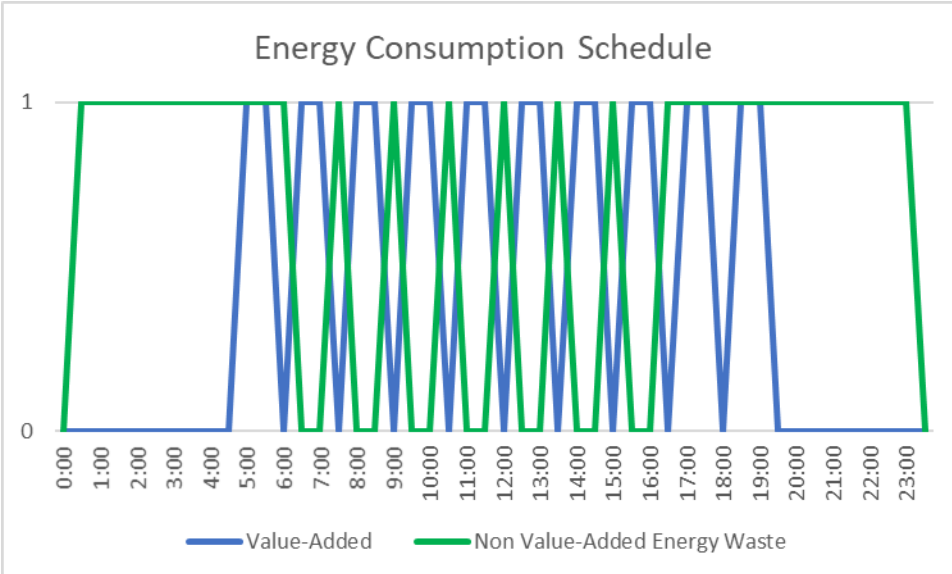

Figure 4.5 Forge Energy Consumption Schedule

Analyzing Figure 4.5 above, value-added times are noted during time where physical production of material was occurring. Non-value-added times are noted during breaks, waiting periods, and non-working hours. If the systems are not manually shut-off the systems will continue to consume energy. The forge manufacturing plant experiences 16 hours of non-value-added energy consumption within a working day with eight hours of value-added energy consumption. Table 4.3 below depicts the wasted energy, value added energy, and potential energy saved.

Table 4.3 Value-added energy consumption versus non-value-added energy consumption

Current Daily Average Energy Usage	24,726kWh
Daily Average Non-Value-Added Energy Usage	2,957kWh
Percent of Energy saved with Energy Management System Scheduling	12%

Reducing non-value-added energy usage will reduce CO2 emission. On average, 12% of the daily energy consumption of the forge manufacturing plant was lost to non-value-added processes. 2,957 kWh of electrical energy is wasted due to equipment being energized but not producing any product. Controlling the non-value-added processes with an energy management system will assist in energy reduction and CO2 emission reduction. Energy management systems are capable of scheduling and controlling systems that are running idle when not in use. Utilizing an energy management system will allow the forge to schedule lighting and compressors commanding the equipment "on" when needed and "off" when processes are idle. Implementation of an energy management system will provide an energy usage profile free of wasted energy, providing data to size a solar array system for less consumption.

4.6 Return on Investment

According to Energy Sage (2019) the average cost for a commercial solar panel array system cost $2.87 per Watt produced. Based on Energy Sage's (2019) average cost, the 800-kW solar panel array system costs $ 2,296,000. Based on Figure 4.3, on page 31, the 800-kW solar panel array system was estimated to produce 1,376,279 kWh a year saving $162,539 annually. Based on the annual cost savings, in 14.12 years the sum of the annual savings will equal the initial investment. The average life of a solar panel array system is 25 – 30 years. Over 30 years the 800-kW solar panel array system will yield $4,876,170 in savings. Based on the initial investment and the annual savings over the life of the solar panel array system, the investment will see a 112% return on investment. Combining the cost of CCS system, a yearly investment of $71K is added to the cost of operation. Combining the yearly savings from solar panel array with the yearly cost of CCS, the manufacturing plant will see savings of roughly $92K. Providing a ROI of 20% and payback in 25 years.

4.7 Conclusions

The goal of the research was to provide a combination of green solutions that can achieve a statistically significant CO_2 reduction. Chapter four analysis collected utility usage data from the forge manufacturing plant to determine the statistical significance. Based on the utility usage data, a 10% reduction in electrical consumption from power plant, utilizing solar panel array system, does not provide a statistically significant reduction in CO_2 emissions. A greater reduction in consumption of electricity is required in order for the electrical reduction to become beneficial statistically significant. A larger solar panel array system is not plausible due to the limited space available for installation. The CCS system sized to provide a 10% CO_2 reduction during natural gas combustion provides a statistically significant reduction based on the natural gas usage.

Individually the two separate systems have advantages and disadvantages. The Solar panel array system does not provide a statistically significant CO_2 reduction, however utilizing the proposed solar panel array system to produce electricity will provide significant cost savings by reducing load on electricity producing power plants. The CCS system does provide a statistically significant reduction in CO_2 emissions. The CCS system does not provide any financial benefits, the CCS is only an additional operational cost. Collecting and storing CO_2 emission does not provide any financial cost savings. Combining the financial benefits and cost of both solar panel array system and CCS system a 25-year payback is provided.

The combined CO_2 reduction of CCS and solar panel array system was not statistically significant. Figure 4.6, on page 38, provides a two-sample T-test comparing the combined CO_2 reduction.

Two-Sample T-Test and CI: Total Reduction, Total CO2 Emissions

```
Two-sample T for Total Reduction vs Total CO2 Emissions

                                         SE
                       N  Mean  StDev  Mean
Total Reduction       12  1229    155    45
Total CO2 Emissions   12  1366    172    50


Difference = μ (Total Reduction) - μ (Total CO2 Emissions)
Estimate for difference:  -136.6
95% CI for difference:  (-275.4, 2.2)
T-Test of difference = 0 (vs ≠): T-Value = -2.05  P-Value = 0.053  DF = 21
```

Figure 4.6 Two-Sample T-test Results Total CO2 Reduction

The two-sample T-test was set up with a 95% confidence interval. The null hypothesis states that the mean total CO2 emission from natural gas combustion and electrical consumptions was equal to the mean total CO2 emission of natural gas combustion and electrical consumptions at a 10% reduction. The alternative hypotheses states that the mean total CO2 emission from natural gas combustion and electrical consumption was not equal to the mean total CO2 emission of natural gas combustion and electrical consumption at a 10% reduction. Two sample T-test returned a P-value of 0.053, failing to reject the null hypothesis. To provide a combined CCS system and solar array system that provide statistically significant CO2 reductions, an increase in CO2 captured by CCS system is needed. Increasing the size of solar panel array system is not allowable due to limited space to physically install the system.

CHAPTER 5. SUMMARY, CONCLUSION, AND RECOMMENDATIONS

5.1 SUMMARY

The global increase in CO2 emitted into the atmosphere was the focus of the research. The manufacturing sector contributes to the increase in the CO2 concentration in the atmosphere by emitting 22% of man-made CO2 in 2019 (EPA, 2020). The reduction of the CO2 concentration through carbon sequestration process is one of the Grand Engineering Challenges (2020, NAE, n.d.). Excessive CO2 within the atmosphere causes drastic environmental changes (Rabiaia et. al., 2020).

As discussed in chapters one, page four, the Earth has seen a 0.8^{o}C increase in average global temperate since 1880 (Al-Ghuassian, 2018). Carbon dioxide characteristics of absorbing the incoming solar rays and capturing the heat, assisted with the rise in the average global temperature (Al-Ghuassian, 2018). The increased CO2 concentration also affects the natural state of the ocean (The National Academy, 2019). The ocean has seen 30% to 50% of its coral reef life die due to varying levels of acidity from the absorption of CO2 (The National Academy, 2019).

The current CO2 concentration has reached levels higher than ever seen during the natural CO2 cycle (Al-Ghussian, 2018). The Earth will need to reduce the amount of CO2 emitted for the Earth and physically remove CO2 from the atmosphere to reduce the current CO2 concentration (Al-Ghussian, 2018). If the current levels of CO2 concentration remain, NASA (2020) predicts a 2^{o}C – 6^{o}C rise in global average temperature in the next decade. Carbon sequestration can help to reduce the rising average global temperature by removing the CO2 from the atmosphere and storing the CO2 underground. Scientists are unsure if the CO2 concentration will assume the natural CO2 cycle observed in Figure 2.1 on page 11 (NASA, 2020). Utilizing renewable energy could reduce the amount of CO emitted, by reducing the reliance on energy produced by high CO_2 emitting sources. Solar energy production provides more energy compared to other renewable energy due to the amount of solar irradiance provided by the sun (NASA, 2008). Solar energy production provides more efficient energy conversion and costs less compared to other renewable energy sources (University of Michigan, 2020). Carbon sequestration and solar energy production do not account for wasted energy consumption. Energy management systems could provide a solution to reduce wasted energy. The energy management system could learn production cycles and schedule the delivery of electrical energy only when it is needed (Mason and Grijalva, 2019). To address the current CO_2 concentration and amount of CO_2 emitted, multiple solutions will need to work together (Vega et al., 2018).

5.2 CONCLUSION

The research sought to reduce the CO_2 emissions, from a forge manufacturing plant, by 10% from natural gas combustion and electrical energy consumption. The 800kW solar photovoltaic system was sized to provide the forge manufacturing plant with the sought 10% reduction in electrical energy consumption. A carbon sequestration system was sized to reduce CO_2 emissions by 10% by capturing CO_2 emitted from natural gas combustion during material processing for the forge manufacturing plant. The forge manufacturing plant collected utility data providing monthly data of electrical energy consumption and natural gas consumption to provide a comparison.

To validate a statistically significant reduction of CO_2, the normal operating electrical energy and natural gas consumption was compared to a 10% reduction in electrical energy and natural gas consumption. A 10% reduction of electrical energy consumption does not provide a statistically significant decrease, at confidence interval of 0.05. Reducing the CO2 emitted during natural gas combustion by 10% provided a statistically significant decrease, at a confidence interval of 0.05. Combining the CO2 reduction of the carbon sequestration system with the reduction from the solar PV array system does not provide a statistically significant reduction, at a confidence interval of 0.05. The carbon sequestration will need to capture more CO2 for the combined systems to provide a statistically significant reduction, as the solar PV array system size is maxed due to limited real estate.

5.3 RECOMMENDATIONS

If the current trend of CO2 emission continues the environment will continue to experience climate change. To assist with the CO2 reduction at the forge manufacturing plant, the following recommendations are made. Implementing the carbon sequestration system will provide beneficial CO2 reduction. The carbon sequestration system comes with an operational cost and provides no financial benefits. To offset the cost of the carbon sequestration system the implementation of a solar photovoltaic system is recommended. The solar photovoltaic system does not provide a statistically significant reduction in CO2 emissions, however, the solar photovoltaic system provides financial benefits. The solar photovoltaic system will provide $4,876,170 in saving over the course of its life, from electrical energy produced. A carbon sequestration system alone would add an operational cost of $71K. Implementing the solar photovoltaic system will save $92K, taking into account the operational cost of the carbon sequestration system. Implementing an energy management system is also recommended based on the average of 16 hours wasted on non-value-added time. The energy management system will show the amount of electrical energy wasted. The energy management system would reduce the amount of wasted energy by scheduling on and off electrical systems. At a confidence level of 95% the combined carbon sequestration and solar array solution was not statistically significant. The combined carbon sequestration and solar array solution was statistically significant at a confidence interval of 94.7%. Based on the confidence interval of 94.7%, implementing all three systems will provide a CO_2 reduction that would make an impact statistically.

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APPENDIX A. FORGE MANUFACTURING PLANT RAW ELECTRICAL CONSUMPTION

Date	**SCE meter 2 (kWh)**	**Date**	**SCE Meter 3 (kWh)**	**Total (sum)**
17/01/2018 00:00:00	35,299.20	22/01/2018 00:00:00	1,648.80	36,948.00
18/01/2018 00:00:00	39,728.00	23/01/2018 00:00:00	1,996.80	41,724.80
19/01/2018 00:00:00	36,905.60	24/01/2018 00:00:00	1,771.20	38,676.80
20/01/2018 00:00:00	29,320.00	25/01/2018 00:00:00	1,725.60	31,045.60
21/01/2018 00:00:00	15,432.00	26/01/2018 00:00:00	1,879.20	17,311.20
22/01/2018 00:00:00	34,862.40	27/01/2018 00:00:00	1,821.60	36,684.00
23/01/2018 00:00:00	40,526.40	28/01/2018 00:00:00	1,665.60	42,192.00
24/01/2018 00:00:00	35,742.40	29/01/2018 00:00:00	2,181.60	37,924.00
25/01/2018 00:00:00	35,246.40	30/01/2018 00:00:00	2,114.40	37,360.80
26/01/2018 00:00:00	32,739.20	31/01/2018 00:00:00	2,064.00	34,803.20
27/01/2018 00:00:00	24,865.60			24,865.60
28/01/2018 00:00:00	12,753.60			12,753.60
29/01/2018 00:00:00	32,252.80			32,252.80
30/01/2018 00:00:00	30,174.40			30,174.40

31/01/2018 00:00:00	34,174.40			34,174.40
1/2/2018 0:00	30,755.20	1/2/2018 0:00	2,359.20	33,114.40
2/2/2018 0:00	29,169.60	2/2/2018 0:00	2,421.60	31,591.20
3/2/2018 0:00	17,217.60	3/2/2018 0:00	2,071.20	19,288.80
4/2/2018 0:00	14,179.20	4/2/2018 0:00	1,970.40	16,149.60
5/2/2018 0:00	28,924.80	5/2/2018 0:00	2,052.00	30,976.80
6/2/2018 0:00	29,350.40	6/2/2018 0:00	2,289.60	31,640.00
7/2/2018 0:00	37,886.40	7/2/2018 0:00	2,222.40	40,108.80
8/2/2018 0:00	40,369.60	8/2/2018 0:00	2,460.00	42,829.60
9/2/2018 0:00	41,582.40	9/2/2018 0:00	1,776.00	43,358.40
10/2/2018 0:00	35,292.80	10/2/2018 0:00	1,334.40	36,627.20
11/2/2018 0:00	13,185.60	11/2/2018 0:00	1,044.00	14,229.60
12/2/2018 0:00	36,758.40	12/2/2018 0:00	952.8	37,711.20
13/02/2018 00:00:00	40,896.00	13/02/2018 00:00:00	1,389.60	42,285.60
14/02/2018 00:00:00	34,929.60	14/02/2018 00:00:00	1,795.20	36,724.80
15/02/2018 00:00:00	30,544.00	15/02/2018 00:00:00	1,804.80	32,348.80
16/02/2018 00:00:00	33,422.40	16/02/2018 00:00:00	1,627.20	35,049.60
17/02/2018 00:00:00	21,888.00	17/02/2018 00:00:00	2,080.80	23,968.80
18/02/2018 00:00:00	11,476.80	18/02/2018 00:00:00	1,821.60	13,298.40
19/02/2018 00:00:00	9,950.40	19/02/2018 00:00:00	427.2	10,377.60
20/02/2018 00:00:00	31,070.40	20/02/2018 00:00:00	1,459.20	32,529.60
21/02/2018 00:00:00	38,761.60	21/02/2018 00:00:00	1,984.80	40,746.40
22/02/2018 00:00:00	36,051.20	22/02/2018 00:00:00	2,097.60	38,148.80
23/02/2018 00:00:00	35,449.60	23/02/2018 00:00:00	1,884.00	37,333.60
24/02/2018 00:00:00	23,006.40	24/02/2018 00:00:00	1,819.20	24,825.60
25/02/2018 00:00:00	12,124.80	25/02/2018 00:00:00	1,840.80	13,965.60
26/02/2018 00:00:00	27,486.40	26/02/2018 00:00:00	1,891.20	29,377.60

27/02/2018 00:00:00	31,214.40	27/02/2018 00:00:00	1,992.00	33,206.40
28/02/2018 00:00:00	33,216.00	28/02/2018 00:00:00	1,675.20	34,891.20
1/3/2018 0:00	33,929.60	1/3/2018 0:00	1,809.60	35,739.20
2/3/2018 0:00	31,488.00	2/3/2018 0:00	1,896.00	33,384.00
3/3/2018 0:00	21,011.20	3/3/2018 0:00	1,713.60	22,724.80
4/3/2018 0:00	13,196.80	4/3/2018 0:00	1,968.00	15,164.80
5/3/2018 0:00	35,278.40	5/3/2018 0:00	1,706.40	36,984.80
6/3/2018 0:00	39,046.40	6/3/2018 0:00	1,891.20	40,937.60
7/3/2018 0:00	41,193.60	7/3/2018 0:00	2,004.00	43,197.60
8/3/2018 0:00	38,809.60	8/3/2018 0:00	2,008.80	40,818.40
9/3/2018 0:00	40,411.20	9/3/2018 0:00	1,996.80	42,408.00
10/3/2018 0:00	30,153.60	10/3/2018 0:00	2,112.00	32,265.60
11/3/2018 0:00	14,078.40	11/3/2018 0:00	2,104.80	16,183.20
12/3/2018 0:00	35,404.80	12/3/2018 0:00	2,436.00	37,840.80
13/03/2018 00:00:00	34,332.80	13/03/2018 00:00:00	1,972.80	36,305.60
14/03/2018 00:00:00	33,731.20	14/03/2018 00:00:00	1,920.00	35,651.20
15/03/2018 00:00:00	32,320.00	15/03/2018 00:00:00	1,944.00	34,264.00
16/03/2018 00:00:00	33,955.20	16/03/2018 00:00:00	2,116.80	36,072.00
17/03/2018 00:00:00	26,332.80	17/03/2018 00:00:00	1,864.80	28,197.60
18/03/2018 00:00:00	13,374.40	18/03/2018 00:00:00	1,896.00	15,270.40
19/03/2018 00:00:00	32,633.60	19/03/2018 00:00:00	1,562.40	34,196.00
20/03/2018 00:00:00	34,384.00	20/03/2018 00:00:00	1,905.60	36,289.60
21/03/2018 00:00:00	31,667.20	21/03/2018 00:00:00	1,948.80	33,616.00
22/03/2018 00:00:00	33,795.20	22/03/2018 00:00:00	2,208.00	36,003.20
23/03/2018 00:00:00	33,388.80	23/03/2018 00:00:00	1,840.80	35,229.60
24/03/2018 00:00:00	27,768.00	24/03/2018 00:00:00	2,030.40	29,798.40
25/03/2018 00:00:00	13,361.60	25/03/2018 00:00:00	1,569.60	14,931.20

26/03/2018 00:00:00	32,084.80	26/03/2018 00:00:00	1,749.60	33,834.40
27/03/2018 00:00:00	33,956.80	27/03/2018 00:00:00	1,377.60	35,334.40
28/03/2018 00:00:00	36,568.00	28/03/2018 00:00:00	1,336.80	37,904.80
29/03/2018 00:00:00	41,561.60	29/03/2018 00:00:00	1,629.60	43,191.20
30/03/2018 00:00:00	41,315.20	30/03/2018 00:00:00	2,342.40	43,657.60
31/03/2018 00:00:00	29,033.60	31/03/2018 00:00:00	2,332.80	31,366.40
1/4/2018 0:00	14,814.40	1/4/2018 0:00	2,025.60	16,840.00
2/4/2018 0:00	19,323.20	2/4/2018 0:00	410.4	19,733.60
3/4/2018 0:00	32,425.60	3/4/2018 0:00	1,900.80	34,326.40
4/4/2018 0:00	35,593.60	4/4/2018 0:00	2,294.40	37,888.00
5/4/2018 0:00	36,324.80	5/4/2018 0:00	2,260.80	38,585.60
6/4/2018 0:00	38,713.60	6/4/2018 0:00	2,136.00	40,849.60
7/4/2018 0:00	27,729.60	7/4/2018 0:00	1,790.40	29,520.00
8/4/2018 0:00	12,723.20	8/4/2018 0:00	1,543.20	14,266.40
9/4/2018 0:00	31,046.40	9/4/2018 0:00	2,522.40	33,568.80
10/4/2018 0:00	37,316.80	10/4/2018 0:00	2,632.80	39,949.60
11/4/2018 0:00	37,809.60	11/4/2018 0:00	2,342.40	40,152.00
12/4/2018 0:00	36,832.00	12/4/2018 0:00	1,737.60	38,569.60
13/04/2018 00:00:00	33,761.60	13/04/2018 00:00:00	2,340.00	36,101.60
14/04/2018 00:00:00	28,084.80	14/04/2018 00:00:00	2,308.80	30,393.60
15/04/2018 00:00:00	10,265.60	15/04/2018 00:00:00	2,246.40	12,512.00
16/04/2018 00:00:00	29,908.80	16/04/2018 00:00:00	1,876.80	31,785.60
17/04/2018 00:00:00	32,219.20	17/04/2018 00:00:00	1,891.20	34,110.40
18/04/2018 00:00:00	32,480.00	18/04/2018 00:00:00	2,047.20	34,527.20
19/04/2018 00:00:00	33,488.00	19/04/2018 00:00:00	2,313.60	35,801.60
20/04/2018 00:00:00	34,209.60	20/04/2018 00:00:00	2,212.80	36,422.40
21/04/2018 00:00:00	22,248.00	21/04/2018 00:00:00	2,035.20	24,283.20

22/04/2018 00:00:00	10,700.80	22/04/2018 00:00:00	1,932.00	12,632.80
23/04/2018 00:00:00	31,155.20	23/04/2018 00:00:00	2,215.20	33,370.40
24/04/2018 00:00:00	37,401.60	24/04/2018 00:00:00	2,697.60	40,099.20
25/04/2018 00:00:00	35,481.60	25/04/2018 00:00:00	2,304.00	37,785.60
26/04/2018 00:00:00	36,998.40	26/04/2018 00:00:00	2,095.20	39,093.60
27/04/2018 00:00:00	38,494.40	27/04/2018 00:00:00	2,121.60	40,616.00
28/04/2018 00:00:00	31,368.00	28/04/2018 00:00:00	2,284.80	33,652.80
29/04/2018 00:00:00	15,144.00	29/04/2018 00:00:00	2,217.60	17,361.60
30/04/2018 00:00:00	38,352.00	30/04/2018 00:00:00	1,975.20	40,327.20
1/5/2018 0:00	44,190.40	1/5/2018 0:00	2,328.00	46,518.40
2/5/2018 0:00	43,347.20	2/5/2018 0:00	2,409.60	45,756.80
3/5/2018 0:00	39,246.40	3/5/2018 0:00	2,260.80	41,507.20
4/5/2018 0:00	40,113.60	4/5/2018 0:00	2,486.40	42,600.00
5/5/2018 0:00	28,576.00	5/5/2018 0:00	2,757.60	31,333.60
6/5/2018 0:00	12,648.00	6/5/2018 0:00	2,515.20	15,163.20
7/5/2018 0:00	37,139.20	7/5/2018 0:00	2,215.20	39,354.40
8/5/2018 0:00	46,598.40	8/5/2018 0:00	2,575.20	49,173.60
9/5/2018 0:00	44,900.80	9/5/2018 0:00	2,419.20	47,320.00
10/5/2018 0:00	45,822.40	10/5/2018 0:00	2,392.80	48,215.20
11/5/2018 0:00	40,713.60	11/5/2018 0:00	2,236.80	42,950.40
12/5/2018 0:00	31,152.00	12/5/2018 0:00	1,776.00	32,928.00
13/05/2018 00:00:00	14,297.60	13/05/2018 00:00:00	2,042.40	16,340.00
14/05/2018 00:00:00	39,625.60	14/05/2018 00:00:00	1,975.20	41,600.80
15/05/2018 00:00:00	42,180.80	15/05/2018 00:00:00	2,119.20	44,300.00
16/05/2018 00:00:00	41,587.20	16/05/2018 00:00:00	2,172.00	43,759.20
17/05/2018 00:00:00	42,494.40	17/05/2018 00:00:00	1,718.40	44,212.80
18/05/2018 00:00:00	43,804.80	18/05/2018 00:00:00	1,843.20	45,648.00

19/05/2018 00:00:00	32,164.80	19/05/2018 00:00:00	1,605.60	33,770.40
20/05/2018 00:00:00	13,841.60	20/05/2018 00:00:00	1,857.60	15,699.20
21/05/2018 00:00:00	33,923.20	21/05/2018 00:00:00	1,972.80	35,896.00
22/05/2018 00:00:00	38,571.20	22/05/2018 00:00:00	2,534.40	41,105.60
23/05/2018 00:00:00	43,166.40	23/05/2018 00:00:00	2,306.40	45,472.80
24/05/2018 00:00:00	44,579.20	24/05/2018 00:00:00	2,248.80	46,828.00
25/05/2018 00:00:00	39,720.00	25/05/2018 00:00:00	2,251.20	41,971.20
26/05/2018 00:00:00	22,793.60	26/05/2018 00:00:00	2,308.80	25,102.40
27/05/2018 00:00:00	16,500.80	27/05/2018 00:00:00	2,282.40	18,783.20
28/05/2018 00:00:00	15,056.00	28/05/2018 00:00:00	441.6	15,497.60
29/05/2018 00:00:00	37,651.20	29/05/2018 00:00:00	1,089.60	38,740.80
30/05/2018 00:00:00	41,153.60	30/05/2018 00:00:00	1,305.60	42,459.20
31/05/2018 00:00:00	41,539.20	31/05/2018 00:00:00	1,550.40	43,089.60
1/6/2018 0:00	39,932.80	1/6/2018 0:00	1,353.60	41,286.40
2/6/2018 0:00	26,057.60	2/6/2018 0:00	748.8	26,806.40
3/6/2018 0:00	14,574.40	3/6/2018 0:00	741.6	15,316.00
4/6/2018 0:00	32,646.40	4/6/2018 0:00	1,118.40	33,764.80
5/6/2018 0:00	42,139.20	5/6/2018 0:00	816	42,955.20
6/6/2018 0:00	41,667.20	6/6/2018 0:00	580.8	42,248.00
7/6/2018 0:00	41,161.60	7/6/2018 0:00	532.8	41,694.40
8/6/2018 0:00	41,675.20	8/6/2018 0:00	988.8	42,664.00
9/6/2018 0:00	32,481.60	9/6/2018 0:00	621.6	33,103.20
10/6/2018 0:00	14,515.20	10/6/2018 0:00	328.8	14,844.00
11/6/2018 0:00	35,844.80	11/6/2018 0:00	909.6	36,754.40
12/6/2018 0:00	41,945.60	12/6/2018 0:00	703.2	42,648.80
13/06/2018 00:00:00	41,208.00	13/06/2018 00:00:00	765.6	41,973.60
14/06/2018 00:00:00	39,985.60	14/06/2018 00:00:00	907.2	40,892.80

15/06/2018 00:00:00	35,411.20	15/06/2018 00:00:00	544.8	35,956.00
16/06/2018 00:00:00	25,982.40	16/06/2018 00:00:00	792	26,774.40
17/06/2018 00:00:00	13,126.40	17/06/2018 00:00:00	451.2	13,577.60
18/06/2018 00:00:00	37,176.00	18/06/2018 00:00:00	775.2	37,951.20
19/06/2018 00:00:00	39,462.40	19/06/2018 00:00:00	981.6	40,444.00
20/06/2018 00:00:00	40,417.60	20/06/2018 00:00:00	1,250.40	41,668.00
21/06/2018 00:00:00	43,022.40	21/06/2018 00:00:00	1,279.20	44,301.60
22/06/2018 00:00:00	40,345.60	22/06/2018 00:00:00	2,006.40	42,352.00
23/06/2018 00:00:00	28,784.00	23/06/2018 00:00:00	1,060.80	29,844.80
24/06/2018 00:00:00	11,544.00	24/06/2018 00:00:00	1,732.80	13,276.80
25/06/2018 00:00:00	33,680.00	25/06/2018 00:00:00	2,397.60	36,077.60
26/06/2018 00:00:00	34,857.60	26/06/2018 00:00:00	2,388.00	37,245.60
27/06/2018 00:00:00	38,059.20	27/06/2018 00:00:00	2,589.60	40,648.80
28/06/2018 00:00:00	40,281.60	28/06/2018 00:00:00	2,620.80	42,902.40
29/06/2018 00:00:00	37,683.20	29/06/2018 00:00:00	2,450.40	40,133.60
30/06/2018 00:00:00	23,996.80	30/06/2018 00:00:00	2,462.40	26,459.20
1/7/2018 0:00	12,545.60	1/7/2018 0:00	2,248.80	14,794.40
2/7/2018 0:00	33,691.20	2/7/2018 0:00	2,157.60	35,848.80
3/7/2018 0:00	36,403.20	3/7/2018 0:00	2,174.40	38,577.60
4/7/2018 0:00	22,481.60	4/7/2018 0:00	679.2	23,160.80
5/7/2018 0:00	37,302.40	5/7/2018 0:00	1,694.40	38,996.80
6/7/2018 0:00	38,611.20	6/7/2018 0:00	2,320.80	40,932.00
7/7/2018 0:00	27,694.40	7/7/2018 0:00	2,512.80	30,207.20
8/7/2018 0:00	12,963.20	8/7/2018 0:00	2,325.60	15,288.80
9/7/2018 0:00	37,419.20	9/7/2018 0:00	2,385.60	39,804.80
10/7/2018 0:00	41,456.00	10/7/2018 0:00	2,618.40	44,074.40
11/7/2018 0:00	42,179.20	11/7/2018 0:00	2,630.40	44,809.60

12/7/2018 0:00	43,880.00	12/7/2018 0:00	2,299.20	46,179.20
13/07/2018 00:00:00	44,084.80	13/07/2018 00:00:00	2,234.40	46,319.20
14/07/2018 00:00:00	29,240.00	14/07/2018 00:00:00	1,984.80	31,224.80
15/07/2018 00:00:00	14,491.20	15/07/2018 00:00:00	2,210.40	16,701.60
16/07/2018 00:00:00	34,252.80	16/07/2018 00:00:00	2,232.00	36,484.80
17/07/2018 00:00:00	46,641.60	17/07/2018 00:00:00	2,380.80	49,022.40
18/07/2018 00:00:00	41,532.80	18/07/2018 00:00:00	2,138.40	43,671.20
19/07/2018 00:00:00	42,844.80	19/07/2018 00:00:00	2,198.40	45,043.20
20/07/2018 00:00:00	41,576.00	20/07/2018 00:00:00	2,253.60	43,829.60
21/07/2018 00:00:00	27,049.60	21/07/2018 00:00:00	2,076.00	29,125.60
22/07/2018 00:00:00	13,316.80	22/07/2018 00:00:00	2,119.20	15,436.00
23/07/2018 00:00:00	32,624.00	23/07/2018 00:00:00	2,140.80	34,764.80
24/07/2018 00:00:00	31,795.20	24/07/2018 00:00:00	2,172.00	33,967.20
25/07/2018 00:00:00	32,872.00	25/07/2018 00:00:00	2,263.20	35,135.20
26/07/2018 00:00:00	30,537.60	26/07/2018 00:00:00	2,428.80	32,966.40
27/07/2018 00:00:00	29,912.00	27/07/2018 00:00:00	2,258.40	32,170.40
28/07/2018 00:00:00	21,347.20	28/07/2018 00:00:00	2,407.20	23,754.40
29/07/2018 00:00:00	12,400.00	29/07/2018 00:00:00	2,073.60	14,473.60
30/07/2018 00:00:00	25,115.20	30/07/2018 00:00:00	2,253.60	27,368.80
31/07/2018 00:00:00	27,324.80	31/07/2018 00:00:00	2,349.60	29,674.40
1/8/2018 0:00	31,048.00	1/8/2018 0:00	2,112.00	33,160.00
2/8/2018 0:00	39,020.80	2/8/2018 0:00	2,258.40	41,279.20
3/8/2018 0:00	40,705.60	3/8/2018 0:00	2,359.20	43,064.80
4/8/2018 0:00	30,617.60	4/8/2018 0:00	2,174.40	32,792.00
5/8/2018 0:00	17,843.20	5/8/2018 0:00	2,071.20	19,914.40
6/8/2018 0:00	35,044.80	6/8/2018 0:00	1,668.00	36,712.80

7/8/2018 0:00	34,801.60	7/8/2018 0:00	2,258.40	37,060.00
8/8/2018 0:00	37,430.40	8/8/2018 0:00	2,167.20	39,597.60
9/8/2018 0:00	40,232.00	9/8/2018 0:00	2,114.40	42,346.40
10/8/2018 0:00	40,470.40	10/8/2018 0:00	2,376.00	42,846.40
11/8/2018 0:00	32,281.60	11/8/2018 0:00	2,011.20	34,292.80
12/8/2018 0:00	17,424.00	12/8/2018 0:00	2,196.00	19,620.00
13/08/2018 00:00:00	35,182.40	13/08/2018 00:00:00	2,275.20	37,457.60
14/08/2018 00:00:00	41,668.80	14/08/2018 00:00:00	2,284.80	43,953.60
15/08/2018 00:00:00	37,147.20	15/08/2018 00:00:00	2,037.60	39,184.80
16/08/2018 00:00:00	40,782.40	16/08/2018 00:00:00	2,018.40	42,800.80
17/08/2018 00:00:00	40,512.00	17/08/2018 00:00:00	2,287.20	42,799.20
18/08/2018 00:00:00	30,107.20	18/08/2018 00:00:00	2,280.00	32,387.20
19/08/2018 00:00:00	16,360.00	19/08/2018 00:00:00	2,133.60	18,493.60
20/08/2018 00:00:00	32,737.60	20/08/2018 00:00:00	1,778.40	34,516.00
21/08/2018 00:00:00	40,897.60	21/08/2018 00:00:00	2,676.00	43,573.60
22/08/2018 00:00:00	39,553.60	22/08/2018 00:00:00	2,616.00	42,169.60
23/08/2018 00:00:00	43,468.80	23/08/2018 00:00:00	2,690.40	46,159.20
24/08/2018 00:00:00	41,742.40	24/08/2018 00:00:00	2,337.60	44,080.00
25/08/2018 00:00:00	32,673.60	25/08/2018 00:00:00	1,384.80	34,058.40
26/08/2018 00:00:00	18,188.80	26/08/2018 00:00:00	1,202.40	19,391.20
27/08/2018 00:00:00	37,652.80	27/08/2018 00:00:00	2,270.40	39,923.20
28/08/2018 00:00:00	42,571.20	28/08/2018 00:00:00	2,361.60	44,932.80
29/08/2018 00:00:00	40,816.00	29/08/2018 00:00:00	1,593.60	42,409.60
30/08/2018 00:00:00	42,331.20	30/08/2018 00:00:00	1,821.60	44,152.80
31/08/2018 00:00:00	42,654.40	31/08/2018 00:00:00	2,023.20	44,677.60

1/9/2018 0:00	24,696.00	1/9/2018 0:00	1,951.20	26,647.20
2/9/2018 0:00	16,448.00	2/9/2018 0:00	1,694.40	18,142.40
3/9/2018 0:00	13,972.80	3/9/2018 0:00	441.6	14,414.40
4/9/2018 0:00	37,396.80	4/9/2018 0:00	1,588.80	38,985.60
5/9/2018 0:00	40,860.80	5/9/2018 0:00	2,275.20	43,136.00
6/9/2018 0:00	41,433.60	6/9/2018 0:00	2,181.60	43,615.20
7/9/2018 0:00	43,449.60	7/9/2018 0:00	1,980.00	45,429.60
8/9/2018 0:00	31,787.20	8/9/2018 0:00	1,864.80	33,652.00
9/9/2018 0:00	16,643.20	9/9/2018 0:00	1,286.40	17,929.60
10/9/2018 0:00	37,896.00	10/9/2018 0:00	2,013.60	39,909.60
11/9/2018 0:00	42,987.20	11/9/2018 0:00	2,342.40	45,329.60
12/9/2018 0:00	40,787.20	12/9/2018 0:00	2,296.80	43,084.00
13/09/2018 00:00:00	42,881.60	13/09/2018 00:00:00	1,984.80	44,866.40
14/09/2018 00:00:00	41,336.00	14/09/2018 00:00:00	1,545.60	42,881.60
15/09/2018 00:00:00	27,665.60	15/09/2018 00:00:00	2,035.20	29,700.80
16/09/2018 00:00:00	17,780.80	16/09/2018 00:00:00	1,711.20	19,492.00
17/09/2018 00:00:00	35,657.60	17/09/2018 00:00:00	1,478.40	37,136.00
18/09/2018 00:00:00	42,064.00	18/09/2018 00:00:00	2,215.20	44,279.20
19/09/2018 00:00:00	42,108.80	19/09/2018 00:00:00	1,999.20	44,108.00
20/09/2018 00:00:00	42,441.60	20/09/2018 00:00:00	2,220.00	44,661.60
21/09/2018 00:00:00	42,849.60	21/09/2018 00:00:00	2,085.60	44,935.20
22/09/2018 00:00:00	25,640.00	22/09/2018 00:00:00	1,399.20	27,039.20
23/09/2018 00:00:00	12,955.20	23/09/2018 00:00:00	1,070.40	14,025.60
24/09/2018 00:00:00	35,056.00	24/09/2018 00:00:00	1,696.80	36,752.80
25/09/2018 00:00:00	42,216.00	25/09/2018 00:00:00	1,557.60	43,773.60
26/09/2018 00:00:00	38,953.60	26/09/2018 00:00:00	933.6	39,887.20
27/09/2018 00:00:00	39,918.40	27/09/2018 00:00:00	1,219.20	41,137.60
28/09/2018 00:00:00	39,876.80	28/09/2018 00:00:00	1,274.40	41,151.20

29/09/2018 00:00:00	30,102.40	29/09/2018 00:00:00	556.8	30,659.20
30/09/2018 00:00:00	15,024.00	30/09/2018 00:00:00	501.6	15,525.60
1/10/2018 0:00	35,944.00	1/10/2018 0:00	1,197.60	37,141.60
2/10/2018 0:00	41,552.00	2/10/2018 0:00	916.8	42,468.80
3/10/2018 0:00	43,796.80	3/10/2018 0:00	710.4	44,507.20
4/10/2018 0:00	43,556.80	4/10/2018 0:00	806.4	44,363.20
5/10/2018 0:00	43,732.80	5/10/2018 0:00	727.2	44,460.00
6/10/2018 0:00	29,724.80	6/10/2018 0:00	470.4	30,195.20
7/10/2018 0:00	16,030.40	7/10/2018 0:00	705.6	16,736.00
8/10/2018 0:00	40,707.20	8/10/2018 0:00	897.6	41,604.80
9/10/2018 0:00	42,147.20	9/10/2018 0:00	1,401.60	43,548.80
10/10/2018 0:00	42,915.20	10/10/2018 0:00	1,732.80	44,648.00
11/10/2018 0:00	44,444.80	11/10/2018 0:00	1,836.00	46,280.80
12/10/2018 0:00	41,976.00	12/10/2018 0:00	1,380.00	43,356.00
13/10/2018 00:00:00	34,024.00	13/10/2018 00:00:00	991.2	35,015.20
14/10/2018 00:00:00	17,470.40	14/10/2018 00:00:00	1,512.00	18,982.40
15/10/2018 00:00:00	39,707.20	15/10/2018 00:00:00	1,752.00	41,459.20
16/10/2018 00:00:00	41,912.00	16/10/2018 00:00:00	1,980.00	43,892.00
17/10/2018 00:00:00	45,126.40	17/10/2018 00:00:00	1,996.80	47,123.20
18/10/2018 00:00:00	45,734.40	18/10/2018 00:00:00	1,706.40	47,440.80
19/10/2018 00:00:00	43,065.60	19/10/2018 00:00:00	1,629.60	44,695.20
20/10/2018 00:00:00	29,932.80	20/10/2018 00:00:00	1,680.00	31,612.80
21/10/2018 00:00:00	15,625.60	21/10/2018 00:00:00	1,639.20	17,264.80
22/10/2018 00:00:00	38,390.40	22/10/2018 00:00:00	1,408.80	39,799.20

23/10/2018 00:00:00	43,430.40	23/10/2018 00:00:00	1,164.00	44,594.40
24/10/2018 00:00:00	40,963.20	24/10/2018 00:00:00	1,420.80	42,384.00
25/10/2018 00:00:00	39,083.20	25/10/2018 00:00:00	1,288.80	40,372.00
26/10/2018 00:00:00	40,446.40	26/10/2018 00:00:00	14.4	40,460.80
27/10/2018 00:00:00	26,795.20	27/10/2018 00:00:00		26,795.20
28/10/2018 00:00:00	18,497.60	28/10/2018 00:00:00		18,497.60
29/10/2018 00:00:00	39,192.00	29/10/2018 00:00:00	1,113.60	40,305.60
30/10/2018 00:00:00	45,201.60	30/10/2018 00:00:00	12	45,213.60
31/10/2018 00:00:00	44,835.20	31/10/2018 00:00:00		44,835.20
1/11/2018 0:00	44,782.40	1/11/2018 0:00	1,437.60	46,220.00
2/11/2018 0:00	43,995.20	2/11/2018 0:00	1,490.40	45,485.60
3/11/2018 0:00	33,604.80	3/11/2018 0:00	1,519.20	35,124.00
4/11/2018 0:00	26,222.40	4/11/2018 0:00	1,212.00	27,434.40
5/11/2018 0:00	43,020.80	5/11/2018 0:00	1,334.40	44,355.20
6/11/2018 0:00	45,235.20	6/11/2018 0:00	1,344.00	46,579.20
7/11/2018 0:00	44,208.00	7/11/2018 0:00	1,668.00	45,876.00
8/11/2018 0:00	45,905.60	8/11/2018 0:00	1,792.80	47,698.40
9/11/2018 0:00	45,585.60	9/11/2018 0:00	2,042.40	47,628.00
10/11/2018 0:00	30,035.20	10/11/2018 0:00	2,157.60	32,192.80
11/11/2018 0:00	20,638.40	11/11/2018 0:00	1,903.20	22,541.60
12/11/2018 0:00	41,896.00	12/11/2018 0:00	1,627.20	43,523.20
13/11/2018 00:00:00	43,806.40	13/11/2018 00:00:00	2,203.20	46,009.60
14/11/2018 00:00:00	45,926.40	14/11/2018 00:00:00	1,948.80	47,875.20
15/11/2018 00:00:00	43,531.20	15/11/2018 00:00:00	1,468.80	45,000.00

16/11/2018 00:00:00	40,862.40	16/11/2018 00:00:00	1,605.60	42,468.00
17/11/2018 00:00:00	32,646.40	17/11/2018 00:00:00	916.8	33,563.20
18/11/2018 00:00:00	27,816.00	18/11/2018 00:00:00	890.4	28,706.40
19/11/2018 00:00:00	41,017.60	19/11/2018 00:00:00	1,377.60	42,395.20
20/11/2018 00:00:00	41,323.20	20/11/2018 00:00:00	1,036.80	42,360.00
21/11/2018 00:00:00	45,425.60	21/11/2018 00:00:00	410.4	45,836.00
22/11/2018 00:00:00	15,304.00	22/11/2018 00:00:00	259.2	15,563.20
23/11/2018 00:00:00	12,753.60	23/11/2018 00:00:00	252	13,005.60
24/11/2018 00:00:00	15,041.60	24/11/2018 00:00:00	1,341.60	16,383.20
25/11/2018 00:00:00	19,942.40	25/11/2018 00:00:00	1,464.00	21,406.40
26/11/2018 00:00:00	41,385.60	26/11/2018 00:00:00	1,557.60	42,943.20
27/11/2018 00:00:00	43,320.00	27/11/2018 00:00:00	1,771.20	45,091.20
28/11/2018 00:00:00	45,475.20	28/11/2018 00:00:00	1,113.60	46,588.80
29/11/2018 00:00:00	42,147.20	29/11/2018 00:00:00	991.2	43,138.40
30/11/2018 00:00:00	41,472.00	30/11/2018 00:00:00	1,471.20	42,943.20
1/12/2018 0:00	30,454.40	1/12/2018 0:00	1,084.80	31,539.20
2/12/2018 0:00	18,236.80	2/12/2018 0:00	1,140.00	19,376.80
3/12/2018 0:00	37,883.20	3/12/2018 0:00	1,461.60	39,344.80
4/12/2018 0:00	45,267.20	4/12/2018 0:00	1,171.20	46,438.40
5/12/2018 0:00	43,030.40	5/12/2018 0:00	561.6	43,592.00
6/12/2018 0:00	45,886.40	6/12/2018 0:00	1,293.60	47,180.00
7/12/2018 0:00	44,932.80	7/12/2018 0:00	1,584.00	46,516.80
8/12/2018 0:00	28,950.40	8/12/2018 0:00	554.4	29,504.80
9/12/2018 0:00	14,353.60	9/12/2018 0:00	324	14,677.60

10/12/2018 0:00	41,950.40	10/12/2018 0:00	1,466.40	43,416.80
11/12/2018 0:00	45,012.80	11/12/2018 0:00	1,622.40	46,635.20
12/12/2018 0:00	42,132.80	12/12/2018 0:00	2,064.00	44,196.80
13/12/2018 00:00:00	42,206.40	13/12/2018 00:00:00	1,905.60	44,112.00
14/12/2018 00:00:00	39,800.00	14/12/2018 00:00:00	1,704.00	41,504.00
15/12/2018 00:00:00	30,900.80	15/12/2018 00:00:00	1,444.80	32,345.60
16/12/2018 00:00:00	20,224.00	16/12/2018 00:00:00	912	21,136.00
17/12/2018 00:00:00	40,008.00	17/12/2018 00:00:00	1,994.40	42,002.40
18/12/2018 00:00:00	41,508.80	18/12/2018 00:00:00	2,407.20	43,916.00
19/12/2018 00:00:00	40,560.00	19/12/2018 00:00:00	1,735.20	42,295.20
20/12/2018 00:00:00	41,792.00	20/12/2018 00:00:00	1,300.80	43,092.80
21/12/2018 00:00:00	41,937.60	21/12/2018 00:00:00	1,848.00	43,785.60
22/12/2018 00:00:00	26,289.60	22/12/2018 00:00:00	1,951.20	28,240.80
23/12/2018 00:00:00	2,129.60	23/12/2018 00:00:00	926.4	3,056.00
24/12/2018 00:00:00	3,174.40	24/12/2018 00:00:00	372	3,546.40
25/12/2018 00:00:00	3,105.60	25/12/2018 00:00:00	360	3,465.60
26/12/2018 00:00:00	9,836.80	26/12/2018 00:00:00	1,920.00	11,756.80
27/12/2018 00:00:00	20,140.80	27/12/2018 00:00:00	1,420.80	21,561.60
28/12/2018 00:00:00	22,928.00	28/12/2018 00:00:00	890.4	23,818.40
29/12/2018 00:00:00	10,420.80	29/12/2018 00:00:00	1,432.80	11,853.60
30/12/2018 00:00:00	3,220.80	30/12/2018 00:00:00	650.4	3,871.20

APPENDIX B. FORGE MANUFACTURING PLANT NATURAL GAS CONSUMPTION RAW DATA

Date	SoCal Gas (dth)
1/1/2018	225.3
2/1/2018	515.6
3/1/2018	464.3
4/1/2018	457
5/1/2018	474.9
6/1/2018	311.2
7/1/2018	224.8
8/1/2018	443.8
9/1/2018	412.4
10/1/2018	445.7
11/1/2018	488.2
12/1/2018	514.6
13/01/2018 00:00:00	304.2
14/01/2018 00:00:00	212.9
15/01/2018 00:00:00	471.4
16/01/2018 00:00:00	487.8
17/01/2018 00:00:00	520.1
18/01/2018 00:00:00	504.6
19/01/2018 00:00:00	536.5
20/01/2018 00:00:00	325.2

21/01/2018 00:00:00	283.1
22/01/2018 00:00:00	538.9
23/01/2018 00:00:00	520.2
24/01/2018 00:00:00	549.7
25/01/2018 00:00:00	436.5
26/01/2018 00:00:00	416.7
27/01/2018 00:00:00	264.1
28/01/2018 00:00:00	200
29/01/2018 00:00:00	540.8
30/01/2018 00:00:00	387.7
31/01/2018 00:00:00	611.3
1/2/2018	500.7
2/2/2018	544.5
3/2/2018	235.6
4/2/2018	206.2
5/2/2018	551
6/2/2018	476.1
7/2/2018	552.9
8/2/2018	561.1
9/2/2018	520
10/2/2018	329.7
11/2/2018	280.3
12/2/2018	621.2
13/02/2018 00:00:00	532.2
14/02/2018 00:00:00	534.4
15/02/2018 00:00:00	481.3
16/02/2018 00:00:00	440.1
17/02/2018 00:00:00	257.2
18/02/2018 00:00:00	136.6

19/02/2018 00:00:00	211.1
20/02/2018 00:00:00	518.6
21/02/2018 00:00:00	589.9
22/02/2018 00:00:00	446.4
23/02/2018 00:00:00	569.2
24/02/2018 00:00:00	294.2
25/02/2018 00:00:00	255.8
26/02/2018 00:00:00	501.6
27/02/2018 00:00:00	451.8
28/02/2018 00:00:00	524.7
1/3/2018	414.2
2/3/2018	310.9
3/3/2018	229.5
4/3/2018	261.2
5/3/2018	498.1
6/3/2018	560
7/3/2018	463.7
8/3/2018	586.4
9/3/2018	522.8
10/3/2018	307.6
11/3/2018	286.5
12/3/2018	462.6
13/03/2018 00:00:00	411.5
14/03/2018 00:00:00	386.1
15/03/2018 00:00:00	464
16/03/2018 00:00:00	419.1
17/03/2018 00:00:00	262.9
18/03/2018 00:00:00	244.1
19/03/2018 00:00:00	404.6

20/03/2018 00:00:00	405
21/03/2018 00:00:00	427.6
22/03/2018 00:00:00	379.2
23/03/2018 00:00:00	332
24/03/2018 00:00:00	293.7
25/03/2018 00:00:00	187.9
26/03/2018 00:00:00	451.7
27/03/2018 00:00:00	392.1
28/03/2018 00:00:00	438.7
29/03/2018 00:00:00	498.5
30/03/2018 00:00:00	475.5
31/03/2018 00:00:00	298.1
1/4/2018	130.3
2/4/2018	228.8
3/4/2018	413.4
4/4/2018	380.6
5/4/2018	397.4
6/4/2018	437.7
7/4/2018	259.6
8/4/2018	176.6
9/4/2018	381.6
10/4/2018	351.7
11/4/2018	377.9
12/4/2018	347.8
13/04/2018 00:00:00	374.2
14/04/2018 00:00:00	242.2
15/04/2018 00:00:00	162.3
16/04/2018 00:00:00	414.7
17/04/2018 00:00:00	387.9

18/04/2018 00:00:00	327.1
19/04/2018 00:00:00	363.4
20/04/2018 00:00:00	342.1
21/04/2018 00:00:00	207.4
22/04/2018 00:00:00	163
23/04/2018 00:00:00	375.2
24/04/2018 00:00:00	447.1
25/04/2018 00:00:00	410.4
26/04/2018 00:00:00	450
27/04/2018 00:00:00	484.9
28/04/2018 00:00:00	354
29/04/2018 00:00:00	240.1
30/04/2018 00:00:00	506.6
1/5/2018	450.3
2/5/2018	426.3
3/5/2018	419.5
4/5/2018	394.4
5/5/2018	269.4
6/5/2018	245.8
7/5/2018	479.4
8/5/2018	529.3
9/5/2018	486.2
10/5/2018	507.8
11/5/2018	510
12/5/2018	312.6
13/05/2018 00:00:00	255.9
14/05/2018 00:00:00	526.3
15/05/2018 00:00:00	455.4
16/05/2018 00:00:00	472.1

17/05/2018 00:00:00	483.1
18/05/2018 00:00:00	515.2
19/05/2018 00:00:00	298.3
20/05/2018 00:00:00	270.2
21/05/2018 00:00:00	469
22/05/2018 00:00:00	490.6
23/05/2018 00:00:00	454
24/05/2018 00:00:00	468.6
25/05/2018 00:00:00	430.2
26/05/2018 00:00:00	230.6
27/05/2018 00:00:00	163.5
28/05/2018 00:00:00	274.6
29/05/2018 00:00:00	554
30/05/2018 00:00:00	468.3
31/05/2018 00:00:00	476.1
1/6/2018	370.1
2/6/2018	248.5
3/6/2018	266
4/6/2018	464.8
5/6/2018	485.9
6/6/2018	506.3
7/6/2018	469.2
8/6/2018	473.7
9/6/2018	303.8
10/6/2018	252.1
11/6/2018	514.5
12/6/2018	545
13/06/2018 00:00:00	516.1
14/06/2018 00:00:00	463.9

15/06/2018 00:00:00	367.3
16/06/2018 00:00:00	197
17/06/2018 00:00:00	291.3
18/06/2018 00:00:00	539
19/06/2018 00:00:00	467.7
20/06/2018 00:00:00	509.1
21/06/2018 00:00:00	483.9
22/06/2018 00:00:00	482.3
23/06/2018 00:00:00	320.2
24/06/2018 00:00:00	269.9
25/06/2018 00:00:00	496.9
26/06/2018 00:00:00	446.6
27/06/2018 00:00:00	564.3
28/06/2018 00:00:00	468
29/06/2018 00:00:00	436.3
30/06/2018 00:00:00	302.6
1/7/2018	221.5
2/7/2018	510.1
3/7/2018	459.6
4/7/2018	267.2
5/7/2018	547.4
6/7/2018	494.4
7/7/2018	289.2
8/7/2018	234.2
9/7/2018	460.7
10/7/2018	396.4
11/7/2018	453.2
12/7/2018	428.7
13/07/2018 00:00:00	375.2

14/07/2018 00:00:00	234.6
15/07/2018 00:00:00	226.2
16/07/2018 00:00:00	479.5
17/07/2018 00:00:00	536
18/07/2018 00:00:00	479.3
19/07/2018 00:00:00	461.7
20/07/2018 00:00:00	447.6
21/07/2018 00:00:00	233.3
22/07/2018 00:00:00	172.6
23/07/2018 00:00:00	469.9
24/07/2018 00:00:00	433.4
25/07/2018 00:00:00	428.2
26/07/2018 00:00:00	365.3
27/07/2018 00:00:00	380.5
28/07/2018 00:00:00	199.4
29/07/2018 00:00:00	210.1
30/07/2018 00:00:00	523.8
31/07/2018 00:00:00	547.9
1/8/2018	521.8
2/8/2018	488.2
3/8/2018	545.9
4/8/2018	310.5
5/8/2018	254
6/8/2018	532.5
7/8/2018	455.9
8/8/2018	464.9
9/8/2018	484.1
10/8/2018	466.3

11/8/2018	276.1
12/8/2018	290.8
13/08/2018 00:00:00	485.9
14/08/2018 00:00:00	492.1
15/08/2018 00:00:00	465.1
16/08/2018 00:00:00	535.2
17/08/2018 00:00:00	496.7
18/08/2018 00:00:00	248.8
19/08/2018 00:00:00	262.7
20/08/2018 00:00:00	505.7
21/08/2018 00:00:00	622.2
22/08/2018 00:00:00	499.2
23/08/2018 00:00:00	517.7
24/08/2018 00:00:00	516.4
25/08/2018 00:00:00	252.1
26/08/2018 00:00:00	269.7
27/08/2018 00:00:00	528
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29/08/2018 00:00:00	477
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31/08/2018 00:00:00	512
1/9/2018	223.3
2/9/2018	237
3/9/2018	289.8
4/9/2018	546.5
5/9/2018	502.6
6/9/2018	475.3

7/9/2018	585.7
8/9/2018	305.4
9/9/2018	255.2
10/9/2018	591.7
11/9/2018	563.3
12/9/2018	600.2
13/09/2018 00:00:00	559.2
14/09/2018 00:00:00	498.3
15/09/2018 00:00:00	250.7
16/09/2018 00:00:00	
17/09/2018 00:00:00	544.1
18/09/2018 00:00:00	550.9
19/09/2018 00:00:00	517.3
20/09/2018 00:00:00	527.5
21/09/2018 00:00:00	488.8
22/09/2018 00:00:00	204.5
23/09/2018 00:00:00	117.5
24/09/2018 00:00:00	679.8
25/09/2018 00:00:00	534
26/09/2018 00:00:00	516.1
27/09/2018 00:00:00	516.8
28/09/2018 00:00:00	532.8
29/09/2018 00:00:00	287.9
30/09/2018 00:00:00	246.5
1/10/2018	623.5
2/10/2018	564.5
3/10/2018	497.5
4/10/2018	530.6

5/10/2018	535.1
6/10/2018	209
7/10/2018	243.1
8/10/2018	634.9
9/10/2018	563.3
10/10/2018	567.7
11/10/2018	557.9
12/10/2018	489.7
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14/10/2018 00:00:00	292.8
15/10/2018 00:00:00	598.6
16/10/2018 00:00:00	576.7
17/10/2018 00:00:00	572.8
18/10/2018 00:00:00	565.1
19/10/2018 00:00:00	542.8
20/10/2018 00:00:00	211.2
21/10/2018 00:00:00	308.4
22/10/2018 00:00:00	526
23/10/2018 00:00:00	530.1
24/10/2018 00:00:00	552.5
25/10/2018 00:00:00	506
26/10/2018 00:00:00	496.1
27/10/2018 00:00:00	206.6
28/10/2018 00:00:00	190.9
29/10/2018 00:00:00	563.9
30/10/2018 00:00:00	596.7
31/10/2018 00:00:00	529.7

1/11/2018	534.5
2/11/2018	547.9
3/11/2018	280.9
4/11/2018	303.1
5/11/2018	582.1
6/11/2018	545.4
7/11/2018	523.4
8/11/2018	528.4
9/11/2018	529
10/11/2018	276.8
11/11/2018	233.7
12/11/2018	617.2
13/11/2018 00:00:00	536.3
14/11/2018 00:00:00	517.3
15/11/2018 00:00:00	552.4
16/11/2018 00:00:00	524.2
17/11/2018 00:00:00	237.1
18/11/2018 00:00:00	374.5
19/11/2018 00:00:00	625
20/11/2018 00:00:00	557
21/11/2018 00:00:00	503.2
22/11/2018 00:00:00	76.4
23/11/2018 00:00:00	50.9
24/11/2018 00:00:00	73.8
25/11/2018 00:00:00	294.5
26/11/2018 00:00:00	664
27/11/2018 00:00:00	518
28/11/2018 00:00:00	559
29/11/2018 00:00:00	505.9

30/11/2018 00:00:00	405.7
1/12/2018	191.1
2/12/2018	220
3/12/2018	420.7
4/12/2018	530.1
5/12/2018	469.9
6/12/2018	514.7
7/12/2018	494.5
8/12/2018	227.5
9/12/2018	259.5
10/12/2018	622.2
11/12/2018	583.1
12/12/2018	539.4
13/12/2018 00:00:00	547.6
14/12/2018 00:00:00	500.5
15/12/2018 00:00:00	288.2
16/12/2018 00:00:00	228.4
17/12/2018 00:00:00	615.9
18/12/2018 00:00:00	515.5
19/12/2018 00:00:00	521.4
20/12/2018 00:00:00	433.5
21/12/2018 00:00:00	453.5
22/12/2018 00:00:00	180.3
23/12/2018 00:00:00	0
24/12/2018 00:00:00	0
25/12/2018 00:00:00	0
26/12/2018 00:00:00	34.6
27/12/2018 00:00:00	124.7
28/12/2018 00:00:00	109.3

29/12/2018 00:00:00	38
30/12/2018 00:00:00	18