Green Steel and Concrete

Report of Findings

Authors: Shalom Alaka, Jack Pineo, Ayra Mensah, Ruby Miller, Maria Tierrafria

Carleton University

Recipient: Joanne Murray

OCDSB

Course Code: CCDP 2100 A

Team Number: 2

Submission Date: December 8, 2023

EXECUTIVE SUMMARY

The Report of Findings outlines environmentally friendly alternatives to the production of steel and concrete and how they can be implemented to reduce carbon dioxide emissions in the environment. The main approach discussed in this report is the use of green technologies including the use of Direct Reduced Iron tower, and Electric Arc Furnace to produce hydrogen green steel and green concrete. Carbon Capture and Utilization is involved in the effective management of carbon dioxide emissions from this production process.

Hydrogen green steel is made by using electrolysis to split up water molecules into hydrogen and oxygen. The hydrogen gas is used as a renewable energy source instead of coal in the direct reduced iron tower.

The Direct reduced iron tower uses chemical reduction to extract iron from its ore. This method of iron production uses less temperature and emits less CO2 than other iron production methods.

The Electric Arc Furnace takes steel scrap and iron ore and melts them using electromagnetism. Electromagnetism is used to combat the use of coking coal to heat the steel melt.

Environmentally friendly concrete is made by combining waste materials from furnaces and combining it with an acid or a base. This causes a reaction, creating a material which has the same properties as cement and can be used as a cement replacement in concrete. There is no CO_2 emitted in the process and it reuses waste materials.

Carbon capture and utilization is an effective way of taking care of the emissions of CO2 that are involved in the production of green steel and concrete. In the process of carbon capture, the adsorption theory is adopted to extract CO2 from the atmosphere and from there, the CO2 can be reduced to different useful forms.

TABLE OF CONTENTS

1.0 INTRODUCTION

The purpose of this report is to present research findings regarding green steel and concrete production of both steel and concrete, the materials are heated to very hot temperatures by burning fossil fuels. In the pursuit of environmentally safe and energy efficient processes, “green” steel and concrete are currently being researched and developed. The processes involved in creating these green materials have lower CO_2 emissions and involve recycling of materials. This report will touch on five topics that can be implemented to produce green steel and concrete and reduce CO_2 emissions in the environment. Section 2.0 is a brief overview of how steel and concrete are made. Sections 3.0 to 7.0 present the research findings of each member's process in the production of green steel and concrete. Section 3.0 explains the production of iron using the direct reduced iron tower, Section 4.0 describes steel production in an electric arc furnace. Section 5.0. explains how the hydrogen used in making green steel is produced, Section 6.0 gives details about how CO_2 is captured and utilized and Section 7.0 explains the production of green steel. Terms that require further description are italicized and found in the glossary of each section.

2.0 OVERVIEW OF HOW GREEN STEEL AND CONCRETE ARE MADE

10% of the world’s carbon emissions comes from the production of steel and concrete [1]. Many things in the modern world are made of these building materials, such as buildings, cars, boats, and roads. Since the production of both steel and concrete contributes negatively to the environment, it would be better to make these materials in a more environmentally friendly, or “green”, way. Green steel and concrete are made using renewable energy instead of burning fossil fuels. Figure 2.1 below illustrates how green steel and concrete are made in a more environmentally friendly way.

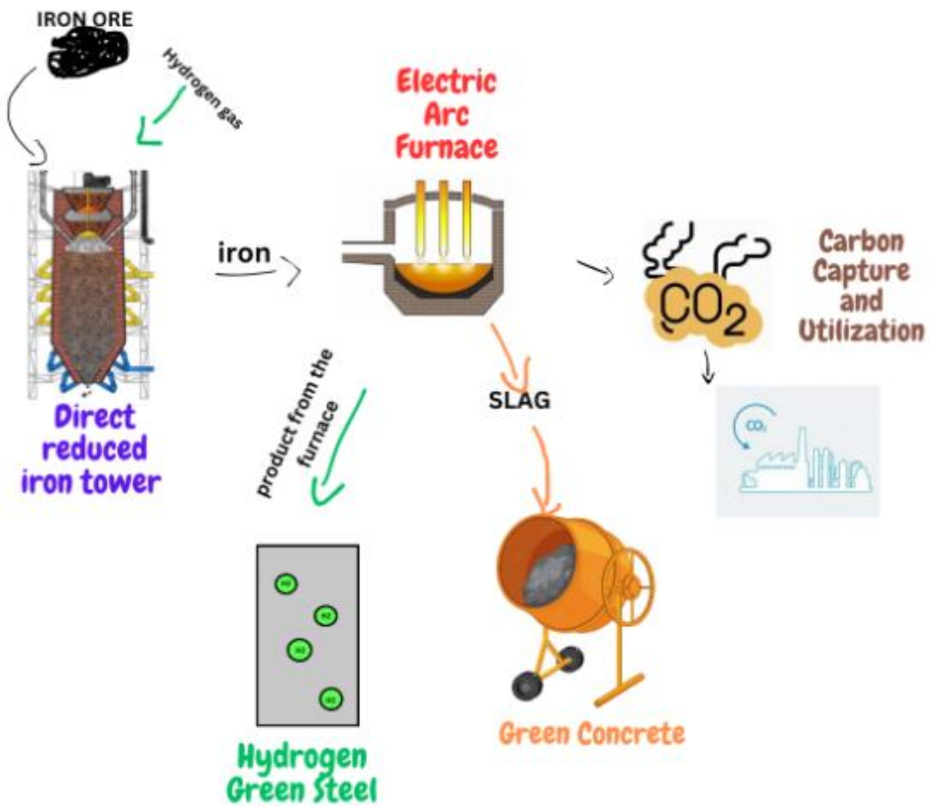

Figure 2.1: The production of steel and concrete including the direct reduced iron tower [2]. Electric arc furnace [3], hydrogen green steel [Ruby Miller], green concrete [4], and carbon capture and utilization [5].

The main ingredient in any type of steel is iron ore, which is purely mined iron. In the making of green steel and concrete, iron ore enters a direct reduced iron tower with hydrogen gas as its renewable energy source. The iron ore bonds with oxygen in the iron tower, producing direct reduced iron, and water, a safe by-product. The direct reduced iron then enters an electric arc furnace, which unlike the furnaces used in making regular steel, uses electromagnetism to generate heat, instead of coal. The main product from the furnace is hydrogen green steel. The furnace also has two by-products. One of the by-products is slag, which is recycled in order to make geopolymer green concrete. The other by-product is carbon emissions, which are captured and utilized elsewhere.

References

[1] M. Moynihan, “Steel, concrete, and climate change,” *IStruct*. [Website]. Available: https://www.istructe.org/resources/blog/steel-concrete-and-climate-change/. [Accessed Nov 26, 2023].

[2] “Direct Reduced Iron Process,” *Tec- Science* [Website]. Available: https://www.tec-science.com/material-science/steel-making/direct-reduced-iron-dri-process/. [Accessed Nov 26, 2023].

[3] “Electric Arc Furnace,” *Wikipedia*. [Website]. Available: https://en.wikipedia.org/wiki/Electric_arc_furnace. [Accessed Nov 26, 2023].

[4] brgfx, “Concrete Mixer Isolated Vectors,” *FreeP!k*. [Website]. Available: https://www.freepik.com/vectors/concrete-mixer-isolated. [Accessed Nov 26, 2023].

[5] “Carbon Capture and Decarbonization of Energy Systems | Clean Energy Research Centre,” cerc.ubc.ca. [Website]. Available: https://cerc.ubc.ca/research/carbon-capture-and-decarbonization-of-energy-system/. [Accessed Nov 26, 2023].

3.0 DIRECT REDUCED IRON TOWER (Shalom Alaka)

The purpose of Section 3 is to explain the use of the direct reduced iron tower for converting iron ore to reduced iron metal, in an environmentally safe way. Figure 1 below shows the direct reduced iron tower where the direct reduced iron (DRI) process occurs. This process can be explained using chemical reduction of metals.

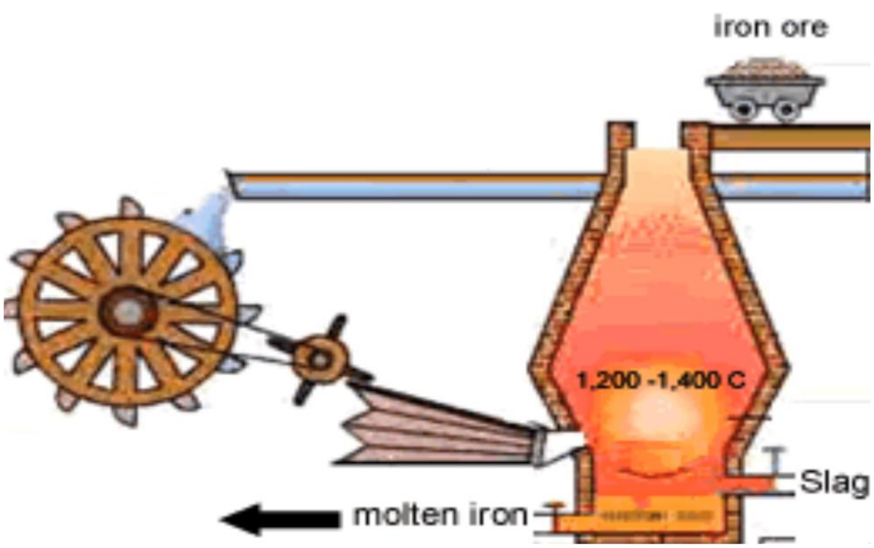

Figure 3.1: Direct reduced iron process [3, modified]

Section 3.1 explains the engineering theory, chemical reduction. Section 3.2 then gives details about direct reduced process and how it affects the environment. Section 3.3 concludes the report by summarizing the answer to the research question.

3.1 Chemical Reduction

Chemical reduction and chemical oxidation (redox) reactions are explained in terms of the transfer of oxygen, hydrogen, and electrons [1]. Chemical reduction is the loss of oxygen and gain of hydrogen in a reaction [1]. Chemical reduction also involves the gaining of electrons by an element in a reaction between two chemicals to become more stable [2].

Some common chemical reduction examples are introduced in Section 3.1.1. Section 3.1.2 explains chemical reduction in metals.

3.1.1 Common chemical reduction examples

A common example of a chemical reduction process is rusting. It occurs when iron reacts with oxygen in the presence of water [2]. This can be seen in Equations 3.1, 3.2 and 3.3 below.

Overall Equation:

$O_2 + Fe + H_2O \rightarrow FeO_3H_2O$ (3.1) [4]

Oxygen + Iron + Water → Iron Oxide (Rust)

Half Equations:

$O_2 + 4e^- \rightarrow 2H_2O$

Oxygen + electrons → Water (Reduction) (3.2)[5]

$Fe \rightarrow Fe^{2+} + 2e^-$

Iron (solid) → Iron (aq) + electrons (Oxidation) (3.3)[5]

Through the reaction shown in Equation 3.1, the iron is oxidized, and the oxygen is reduced [3]. The half reduction reaction in Equation 2 shows the reduction of oxygen as it gains electrons [5]. In Equation 3 iron solid is oxidized by losing electrons [5].

Another example of chemical reduction reaction is the combustion (burning) of hydrocarbons shown in Figure 3.2 below [6].

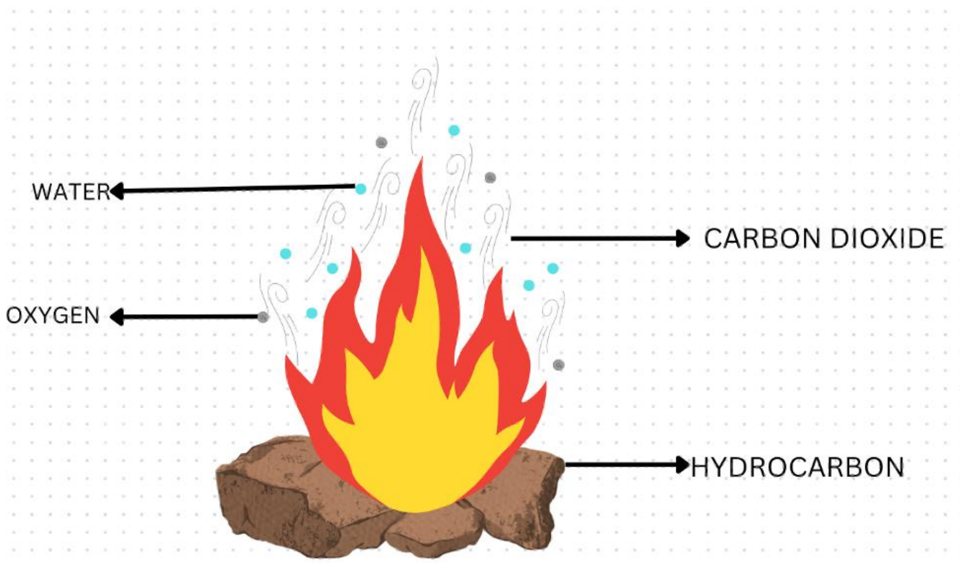

Figure 3.2: Combustion of hydrocarbons [Shalom Alaka]

When a substance combines with oxygen it makes an oxygen-containing compound of other elements [6]. When burning, oxygen is reduced. It gains electrons to become water (H2O) [7]. The process can also be seen in Figure 3.3 below.

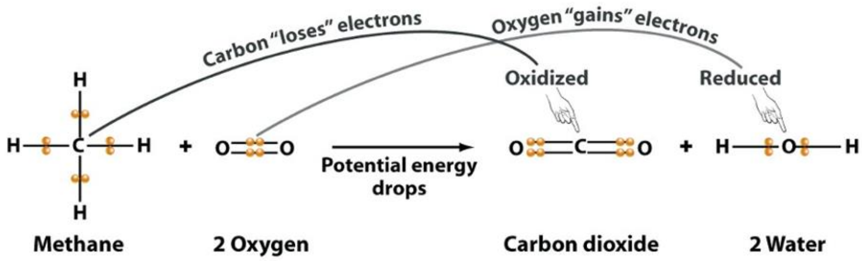

Figure 3.3: Combustion of methane [7, modified]

Methane, a hydrocarbon, combines with oxygen to make carbon dioxide and water [7]. Methane loses electrons and becomes oxidized while oxygen gains electrons and becomes reduced [7].

3.1.2 Chemical reduction of metals

Chemical reduction of metals refers to the loss in weight upon heating a metallic ore such as a metal oxide to extract the metal [8]. The loss of weight occurs because the metal oxide loses oxygen [8]. In other words, the metal ore was "reduced" to a metal [8]. The process can be seen in Figure 3.4 below.

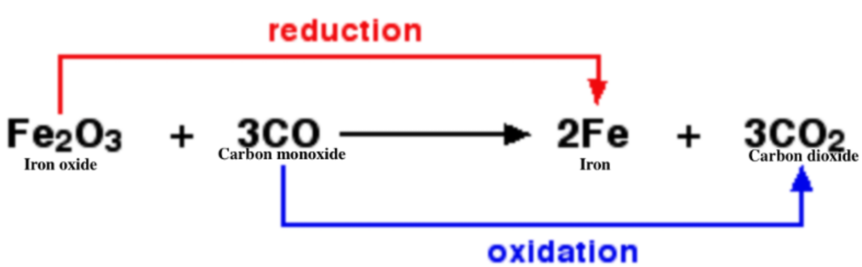

Figure 3.4: Reduction of iron ore [9, modified]

The reduction of iron oxide to metal shown in Figure 3.4 above can be used to explain chemical reduction of metals. The *reducing gases*, carbon monoxide removes oxygen from another substance, it takes in oxygen [9]. In the reaction, in Figure 4 above, the carbon monoxide is the reducing agent as it removes oxygen from iron oxide to make iron [9].

3.2 Direct Reduced Iron Process

The direct reduced iron process is a technology for the making of iron metal using chemical reduction [10]. The direct reduced iron produced by the DRI process is further used to produce steel and slag [10]. It offers an alternative to the usual way of making iron using traditional *blast furnaces*, which emits more than half of the harmful gases produced by the direct reduced iron process [10]. With the growing concern about climate change, DRI technology was developed to make iron with fewer CO2 emissions [10].

Section 3.1.1 explains the subtopic direct reduced tower. Section 3.1.2 explains how the DRI process produces environmentally safe iron.

3.2.1 Direct reduced iron tower

The direct reduced tower is a furnace structure used for the direct reduced iron process [10]. It extracts reduced iron (which is further processed to steel) from iron ore [10]. The heart of the direct reduction is the shaft furnace, which is filled from the top with iron pellets and lump ores [10]. The DRI Tower (shown in Figure 5 below) uses less energy, temperature and emits less harmful gases compared to the traditional *blast furnace*, making it more energy efficient [10].

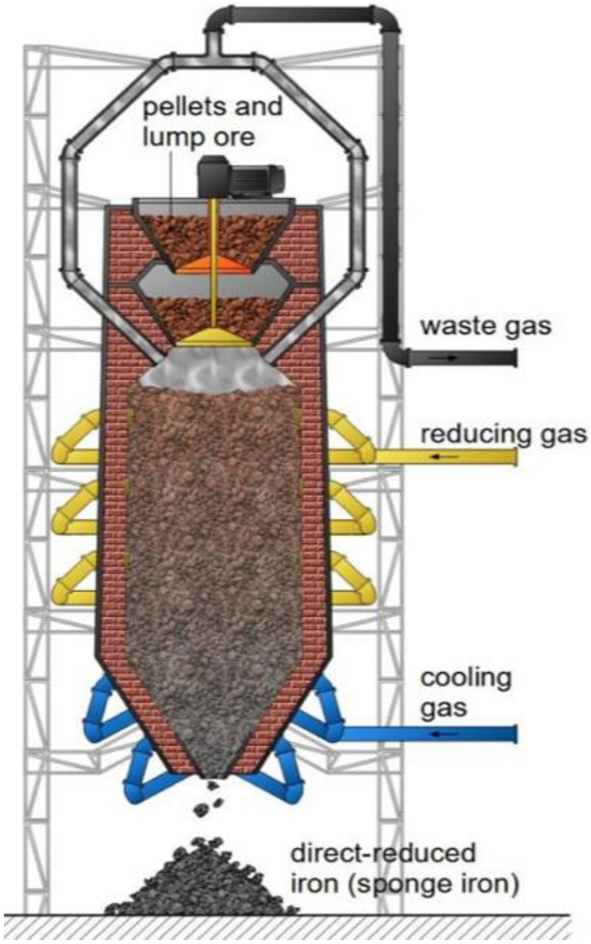

Figure 3.5: Direct reduced iron tower [10, modified]

During the process, *reducing gases,* carbon monoxide and hydrogen are blown into the tower through the inlet pipes and heated to temperature of approximately 1000 °C [10]. They reduce oxygen, causing the loss of oxygen from the iron ores [10]. This makes the iron ores crack on the surface producing reduced iron [10].

3.2.2 Environmentally safe iron production

The manufacturing industry's need for carbon neutrality has led to the creation of new technologies and carbon-free processes [11]. The DRI process is a key player in the carbon-free steel production process [11]. By using lower temperatures during the reduction process, DRI provides an improvement in carbon emissions and energy consumption [11].

In the DRI process the iron ore is reduced in the shaft furnace where the temperature is relatively lower than in a traditional *blast furnace* [10]. Depending on the production process, the DRI iron can then be fed either into an *electric arc furnace* to produce *green* steel [11].

3.3 Conclusion

The theory of chemical reduction can be used to explain how the direct reduced iron tower reduces iron from its ore, and how the DRI process can be optimized for green and environmentally friendly iron production [11]. The DRI process requires less temperature and emits less CO2 compared to the traditional *blast furnace* [11]. During the DRI process, the iron pellet and lump ore are put into the direct reduced iron tower [10]. The *reducing gases*, hydrogen and carbon monoxide are passed into the DRI tower [10]. The iron ore is reduced as the ore loses oxygen [10]. The impact of DRI makes iron production comparatively more energy efficient and safe for the environment [11].

Glossary

Blast furnace*:* The furnace structure used to produce industrial metals from its metal ores [12]. It is the old, traditional way that is not environmentally friendly as it emits greenhouse gases.

Electric arc furnace: It is a furnace that heats material by means of an electric arc [13]. This furnace works with electricity and uses less energy.

***Green**:* This means environmentally friendly, causing no harm to the environment. For example, the production of reduced iron with a direct reduced iron tower as it emits less greenhouse gases the traditional blast furnace.

***Reducing gases**:* These are compounds which react with atmospheric oxygen on heated surfaces [14]. They act as catalysts used to fasten speed up a reaction. In the direct reduced iron process carbon monoxide and hydrogen are the reducing gases.

References

[1] J. Clark, "Definitions of Oxidation and Reduction," *Chemistry LibreTexts*, Oct. 03, 2013. [Online]. Available: https://chem.libretexts.org/Bookshelves/Analytical_Chemistry/Supplemental_Modules_(Analytical_Chemistry)/Electrochemistry/Redox_Chemistry/Definitions_of_Oxidation_and_Reduction [Accessed Oct 04, 2023]

[2] "Reduction (chemistry)," *Wikipedia*, Oct. 11, 2021. [Online]. Available: https://simple.wikipedia.org/wiki/Reduction_(chemistry) [Accessed Oct 04, 2023]

[3] "Chemistry-blast furnace," Dynamics Science, [Online]. Available:http://www.dynamicscience.com.au/tester/solutions1/chemistry/cpercbnt/blstfnc1.html. [Accessed Nov 11, 2023]

[4] "Download Process of rusting chemical equation for free," *Vecteezy*. [Online]. Available: https://www.vecteezy.com/vector-art/1868434-process-of-rusting-chemical-equation [Accessed Oct 05, 2023]

[5] C.G," Oxidation – Reduction Reactions- ppt download," slideplayer.com, 2008. [Online]. Available: https://slideplayer.com/slide/13388250/. [Accessed Oct 11, 2023]

[6] “5.6: Redox Reactions in Organic Chemistry and Biochemistry,” *Chemistry LibreTexts*, Jun. 01, 2017. Accessed Oct. 05, 2023. [Online]. Available: https://chem.libretexts.org/Courses/University_of_South_Carolina__Upstate/USC_Upstate%3A_CHEM_U109_-_Chemistry_of_Living_Things_(Mueller)/05%3A_Introduction_to_Chemical_Reactions/5.6%3A_Redox_Reactions_in_Organic_Chemistry_and_Biochemistry [Accessed Oct 11, 2023]

[7] "In a combustion reaction, why is carbon in methane oxidized even though it starts and finishes with 8 electrons?" Chemistry Stack Exchange. [Online]. Available:

https://chemistry.stackexchange.com/questions/61852/in-a-combustion-reaction-why-is-carbon-in-methane-oxidised-even-though-it-start. [Accessed Oct 11, 2023]

[8] Wikipedia contributors “Redox” *Wikipedia, The Free Encyclopaedia.* Accessed Oct. 04, 2023.[Online].Available:https://en.wikipedia.org/wiki/Redox#:~:text=The%20word%20reduction%20originally%20referred,of%20oxygen%20as%20a%20gas. [Accessed Nov 1, 2023]

[9]“How does oxidation differ from reduction? + Example,” *Socratic.org*. [Online].Available:https://socratic.org/questions/how-does-oxidation-differ-from-reduction [Accessed Nov 1, 2023]

[10] “Direct Reduced Iron Process” *Tec- Science* [Website]. Available: https://www.tec-science.com/material-science/steel-making/direct-reduced-iron-dri-process/. [Accessed Sep 21, 2023].

[11] “DRI: the ‘direct’ route to greener steel - Materials Talks,” Aug. 15, 2023.[Online].Available:https://www.materials-talks.com/dri-the-direct-route-to-greener-steel/[Accessed Nov 7, 2023]

[12] Wikipedia contributors “Blast furnace,” *Wikipedia, The Free Encyclopaedia.* [Website]. Available: https://en.wikipedia.org/wiki/Blast_furnace. [Accessed Sep 26, 2023]

[13] Wikipedia contributors “Electric Arc Furnace,” *Wikipedia, The Free Encyclopaedia*. [Website] Available:https://en.wikipedia.org/wiki/Electric_arc_furnace. [Accessed Sep 26,2023]

[14] “What are reducing gases?” Sensirion. https://sensirion.com/media/documents/8CF4440E/6294E02F/Info_Note_Reducing_Gases.pdf. [Website] Available: (Accessed: Sep. 27, 2023).

4.0 ELECTRIC ARC FURNACE (Jack Pineo)

The engineering theory that is being studied is electromagnetism. Electromagnetism is a combination of an electric field, and a magnetic field [1]. The report of findings will explain electromagnetism and show the environmental benefits and drawbacks of the Electric Arc Furnace and the application of electromagnetism. Below is Figure 1 showing the sub-topic being studied in relation to all other sub-topics of the project. Glossary terms are *italicized.*

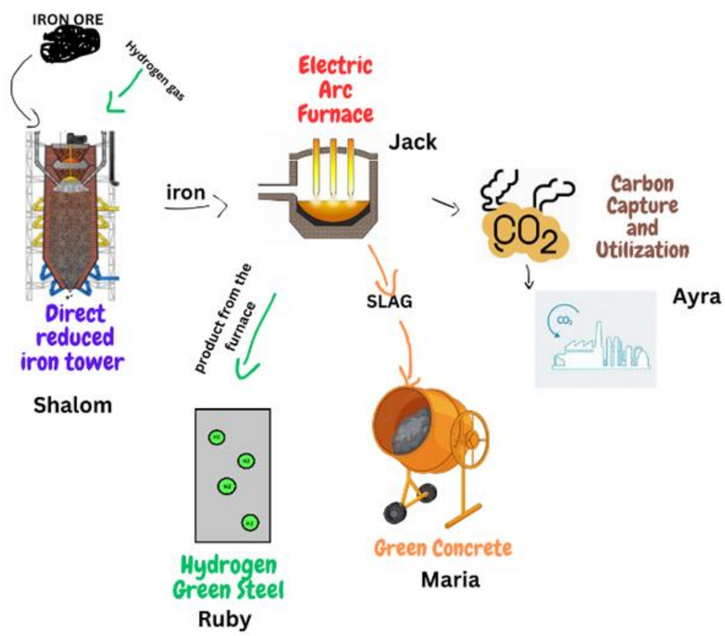

Figure 1: Production steps of green steel [Ruby Miller] and concrete [2] including: direct reduced iron tower [3], electric arc furnace [4], and carbon capture and utilization [5]

Figure 1 shows the process of producing *green steel*, beginning with the *Direct Reduced Iron Tower*, and then moving on to the Electric Arc Furnace, creating Hydrogen Green Steel.

There are *byproducts* released, which are collected through Carbon Capture and Utilization, and are used to make *Green Concrete*.

Section 4.1 outlines the theory of electromagnetism.

4.1 Electromagnetism

The engineering theory that is used in the Electric arc furnace is electromagnetism, which is how electric charges and *magnetic moments* physically interact [6]. It consists of an electric field, and a magnetic field. Figure 2 below shows how these fields interact.

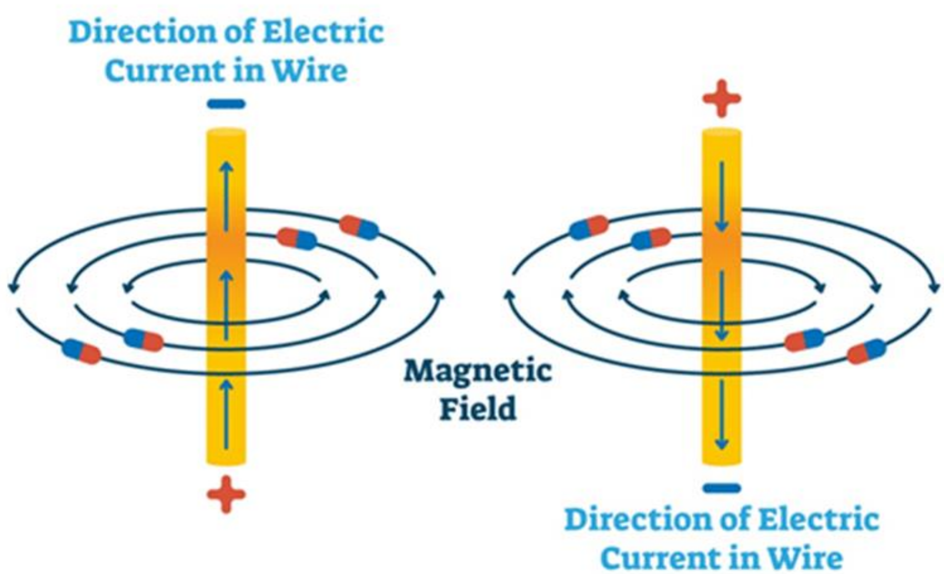

Figure 2: Electromagnetism [8]

As shown in Figure 2, the positive and negative symbols represent the electric field, the and the arrows showing the direction of the current moving from the positive to the negative. While the *electrons* are moving, a magnetic field is surrounding the electric field, forming the basis of electromagnetism. The moving electric field causes the magnetic field, and the moving magnetic field creates an electric field [7].

Electromagnetism can also be summed up in a numerical equation which is stated below in Equation 1.

$F = q(v \times B)$ (1) [8, pg. 1]

F is the force acted on a charged particle going through the electromagnetic field in N, q is the charge in coulombs, v is the velocity in m/s, and B is the *magnetic flux density* in Wbm^{-2}, or T[9].

In the following sample calculation, there is a charge $q = 2 \times 10^{-6}$C, velocity 5×10^{3} m/s in the positive x-direction. The magnetic field is 3×10^{-3} T:

$F = q(v \times B)$

$F = qvB\sin(\theta)$

$F = (2 \times 10^{-6}\ C)\ (5 \times 10^{3})\ (3 \times 10^{-3})\ (1)$

$F = 30 \times 10^{-6}$ N [9]

Section 4.1.1 describes how an electric field works, 4.1.2 explains the magnetic field, and section 4.2 outlines the role of electromagnetism in an Electric Arc Furnace.

4.1.1 Electric field

An electric field is an invisible force that is made through the attraction and repulsion of electric charges [11]. Figure 3 below shows how the electric field theoretically looks.

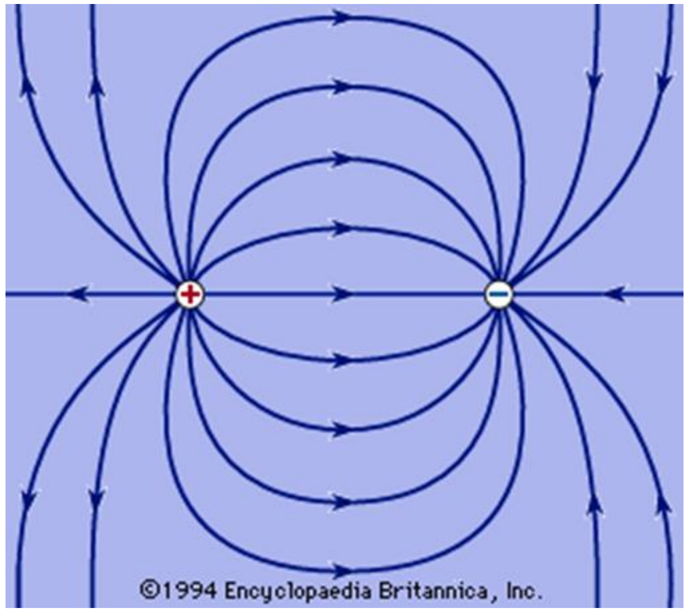

Figure 3: Electric field [7]

The electric field is very similar to the magnetic field. The electric field is between positive and negative charges whereas the magnetic field is between north and south poles. The direction of force acted on a positive charge is opposite to what is acted on a negative charge, shown in Figure 3 by the electric field lines going into the negative end, and moving away from the positive end [12].

4.1.2 Magnetic field

As seen in Figure 4 below, a magnetic field is the region around an electric charge. The electric charge being the arrows that go into the magnet, and the magnetic charge being the arrows circling around the magnet. The electric charge is shown within where the force of the magnetic charge acts [13].

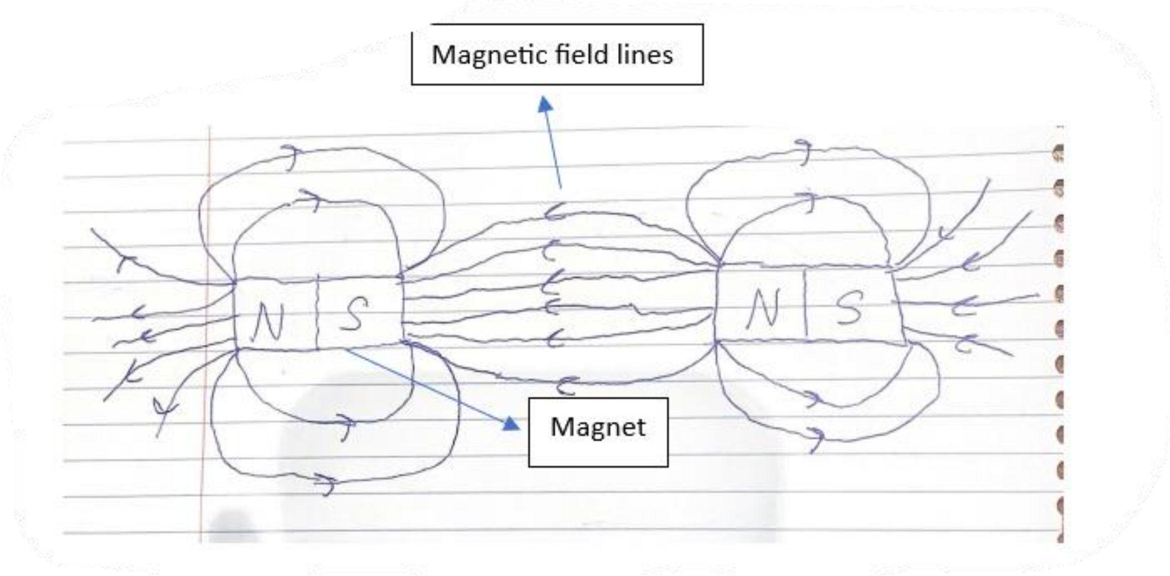

Figure 4: Magnetic field [Jack Pineo]

The magnetic field lines are invisible, and they are stronger at the north and south poles of the magnet. The poles create a swirling effect which can also be classified as a “spin” [14].

4.2 Electromagnetism in the Operation of an Electric Arc Furnace

The purpose of an electric arc furnace is to efficiently heat steel scrap to the point where it melts and creates *molten steel*.

Electricity is a major part of the electric arc furnace as it is what powers the furnace, as well as heats it. Figure 6 below show the electric arc furnace, showing the electricity heating the furnace.

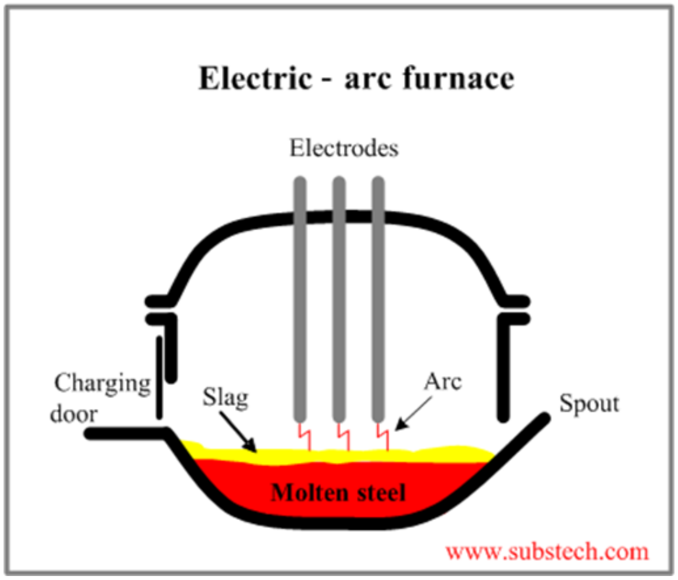

Figure 6: Electric Arc Furnace [13]

The sub-topic that is being studied is the Electric Arc Furnace. The Electric Arc Furnace uses electromagnetism to run [15]. An *electromagnetic stirrer* (EMS) seen in Figure 5 below is installed under the furnace floor without being in contact with the furnace [15]. This electromagnetic stirrer, or EMS, creates an electromagnetic field that runs through the furnace, which contains a magnetic field that generates the stirring effect by interacting with the electric field [15]. The stirring effect takes place because the magnetic field interacts with the electric field which creates a stir. This stirring effect heats the steel more efficiently.

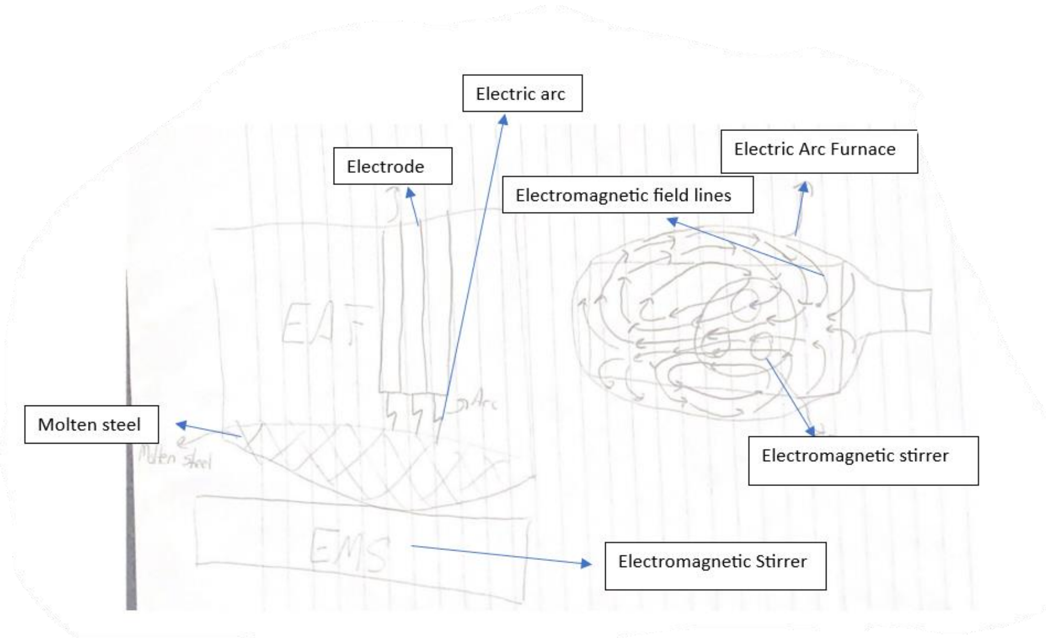

Figure 5: Electromagnetic stirrer [Jack Pineo]

In Figure 5 on the left, the EMS is installed under the furnace, and on the right, there is a top view showing the stirring effect.

Section 4.2.1 describes the role of electricity in the electric arc furnace, section 4.2.2 explains the role of magnetism in the furnace, and section 4.3 will point out the environmental benefits and drawbacks.

4.2.1 Electricity in the electric arc furnace

The *electric arcs* strike between the *electrodes* and the molten steel [16]. The arcs start at a low voltage, and these arcs are unstable until the steel scrap melts and falls to the bottom of the furnace creating the molten steel bath. At this point, the steel scrap melts and becomes molten steel, and the voltage of the arcs increase gradually until it reaches 6300^{o} F, or 3500^{o} C. This is where 85% of the steel scrap is melted [16].

4.2.2 Magnetics in the Electric Arc Furnace

A magnetic field is created in the furnace as the arcs make a current through the molten steel bath as seen in Figure 6 above that will also create an electromagnetic force [13]. The electromagnetic stirrer technology helps to create the magnetic field, which transfers heat more efficiently, as well as improves mass of the steel melt [14].

4.3 THE ENVIRONMENTAL BENEFITS AND DRAWBACKS OF AN ELECTRIC ARC FURNACE

The Electric Arc Furnace is often compared to *blast furnaces*. There are many benefits to using an Electric Arc Furnace over a blast furnace. Blast furnaces use *coking coal* whereas the electric arc furnace uses electricity [17]. This is a major environmental benefit as coking coal is very harmful to the environment. Some other reasons are that Electric Arc Furnaces are cheaper to produce and take up less space in a factory [17]. Finally, Electric Arc Furnaces are more efficient as they reach higher temperatures faster, producing products faster, and they have more precise controls of temperatures, making them safer. Although there are many benefits of an Electric Arc Furnace over a blast furnace, there are also environmental drawbacks. More specifically, the steel scrap that is used in the electric arc furnace is considered *industrial waste*. When the steel scrap is being melted, gas and particles can potentially leak through gaps in the oven [16]. Although there are drawbacks, the Electric Arc Furnace is the safer and more environmentally friendly alternative to the traditional blast furnace.

4.4 Conclusion

The Electric Arc Furnace, or EAF, uses electromagnetism to make Green Steel, by installing an Electromagnetic Stirrer to create a stirring effect in the molten steel, making the steel melt faster and more efficiently. The benefits of an EAF compared to blast furnaces are that it uses steel scrap instead of coking coal, it is cheaper and takes up less space in a factory, and EAFs are more efficient and safer than the traditional blast furnace.

GLOSSARY

Green steel: A more sustainable form of steel production [18].

Direct Reduced Iron Tower: Reducing iron ore using natural gas [19].

Byproducts: Something that is made when trying to make something else [20].

Green Concrete: Concrete that uses at least one waste material as a component [21].

Magnetic Moment: The measure of an object's likelihood to line up with the magnetic field [22].

Electron: A *subatomic particle* that is negatively charged [23].

Subatomic particle: Protons, neutrons, and electrons [24].

Protons: A positively charged subatomic particles [25].

Magnetic Flux Density: The amount of current per length of an electric charge placed 90^o to the magnetic field [26].

Molten Steel: Steel heated to such a degree that it becomes a thick liquid [27].

Electromagnetic Stirrer: Hardware that has a high level of stirring efficiency through the electrically conducting metal, and magnetic field [28].

Electric Arcs: Electricity flowing from two points, or *electrodes* [29].

Electrodes: Solid electric conductor carrying an electric current into non-metallic objects [30].

Blast Furnace: Vertical shaft furnace that produces liquid metals [31].

Coking Coal: Coal that transforms in the absence of air to create a plastic like substance called coke [32].

Industrial Waste: Material that is no longer usable after a manufacturing process [33].

REFERENCES

[1] “The Relationship Between Electricity and Magnetism,” *ThoughtCo* [Website]. https://www.thoughtco.com/introduction-electricity-and-magnetism-4172372 [Accessed Nov. 16, 2023].

[2] brgfx, “Concrete Mixer Isolated Vectors,” *FreeP!k*. [Website]. Available: https://www.freepik.com/vectors/concrete-mixer-isolated. [Accessed Sep 22, 2023].

[3] “Direct Reduced Iron Process,” *Tec- Science* [Website]. Available: https://www.tec-science.com/material-science/steel-making/direct-reduced-iron-dri-process/. [Accessed Sep 22, 2023].

[4] “Electric Arc Furnace,” *Wikipedia*. [Website]. Available: https://en.wikipedia.org/wiki/Electric_arc_furnace. [Accessed Sep 22, 2023].

[5] “Carbon Capture and Decarbonization of Energy Systems | Clean Energy Research Centre,” *cerc.ubc.ca*. [Website]. Available: https://cerc.ubc.ca/research/carbon-capture-and-decarbonization-of-energy-system/ [Accessed Sep. 22, 2023].

[6] C.S Baird, “Electromagnetism,” *McGraw Hill’s AccessScience* [Website]. https://www.accessscience.com/content/article/a223000?implicit-login=true#:~:text=Electromagnetism%20is%20the%20physical%20interaction,obey%20the%20laws%20of%20optics. [Accessed Oct. 25th, 2023].

[7] “Electricity & Magnetism,” *faculty.wcas.northwestern.edu* [Website]. https://faculty.wcas.northwestern.edu/infocom/Ideas/electric.html#:~:text=3)%20Electricity%20and%20magnetism%20are,together%2C%20rather%20than%20separately.) [Accessed October 26th, 2023].

[8] “Electromagnetism,” *Shalom Education* [Website]. https://www.shalom-education.com/courses/gcse-physics/lessons/magnetism-and-electromagnetism/topic/electromagnetism/#google_vignette [Accessed October 26th, 2023].

[9] “Magnetic force formula | Example of Calculation,” *Electricity – Magnetism* [Website]. https://www.electricity-magnetism.org/magnetic-force-formula/ [Accessed Nov. 18, 2023].

[10] A. Wolski, “Theory of electromagnetic fields.” https://cds.cern.ch/record/1400571/files/p15.pdf [Accessed October 30th, 2023].

[11] “Glossary: Electric field,” *greenfacts* [Website]. https://www.greenfacts.org/glossary/def/electric-field.htm#:~:text=Definition%3A,distance%20from%20the%20field%20source. [Accessed November 2nd, 2023].

[12] “electric field | Definition, Units, & Facts,” *Encyclopaedia Britannica* [Website]. https://www.britannica.com/science/electric-field [Accessed November 2nd, 2023].

[13] "Magnetic Field – Definition, History, Illustration, Intensity, Origin, Video, and FAQs," *BYJUS* [Website]. https://byjus.com/physics/magnetic-field/#:~:text=Magnetic%20Field%20is%20the%20region,and%20around%20a%20magnetic%20material [Accessed November 2nd, 2023].

[14] "Electromagnetic stirring and optimizing electric arc furnaces," *Metals* [Website]. https://new.abb.com/metals/abb-in-metals/references/electromagnetic-stirring-and-electric-arc-furnaces#:~:text=On%20an%20EAF%2C%20the%20EMS,that%20produce%20the%20stirring%20effect. [Accessed Nov. 5th, 2023].[14] "Electric Arc Furnace (EAF) [SubsTech]," *Substech* [Website]. https://www.substech.com/dokuwiki/doku.php?id=electric_arc_furnace_eaf#google_vignette [Accessed November 5th, 2023].

[15] A.N. Makarov, V.V. Rybakova, and M.K. Galicheva, "Electromagnetism and the Arc Efficiency of Electric Arc Steel Melting Furnaces," *Journal of Electromagnetic Analysis and Applications.* [Website]. https://www.scirp.org/html/5-9801496_47276.htm#:~:text=The%20arc%20current%20passes%20through,Figure%203(b)). [Accessed November 5th, 2023].

[16] S. Kadezabek, "Electric Arc Furnaces vs. Blast Furnaces | Service Steel," *Service Steel Warehouse* [Website]. https://www.servicesteel.org/resources/electric-arc-furnace-vs-blast-furnace#:~:text=Power%20supply%20%E2%80%93%20blast%20furnaces%20primarily,carbon%20dioxide%20than%20blast%20furnaces. [Accessed Nov. 5th, 2023]

[17] Michio Nakayama, "ADVANCED SOLUTIONS FOR ENVIRONMENTAL ISSUES IN EAF MELTSHOP," [Online]. https://steelplantech.com/wp-content/uploads/2013/11/2012-08_Advanced-Solution-Environmental-Issues-EAFmeltshop.pdf. [Accessed November 5th, 2023].

[18] "Metalshub – What exactly is 'Green Steel'?," *metals-hub* [Website]. https://www.metals-hub.com/blog/what-exactly-is-green-steel/#:~:text=As%20of%20today%2C%20there%20is,rate%20or%20green%20energy%20usage). Accessed Nov. 19, 2023].

[19] "The HBI direct reduction process," *voestalpine* [Website]. https://www.voestalpine.com/blog/en/innovation-en/the-hbi-direct-reduction-process/#:~:text=The%20direct%20reduction%20process,place%20in%20the%20reduction%20tower. [Accessed Nov. 19, 2023].

[20] "by-product," *CambridgeWords* [Website]. https://dictionary.cambridge.org/us/dictionary/english/by-product#:~:text=Meaning%20of%20by%2Dproduct%20in%20English&text=something%20that%20is%20produced%20as,by%2Dproduct%20of%20making%20butter. [Accessed Nov. 19, 2023].

[21] "Toward Green Concrete for Better Sustainable Environment," *Procedia Engineering* [Website]. https://www.sciencedirect.com/science/article/pii/S1877705814032494#:~:text=Green%20concr

ete%20is%20defined%20as,performance%20and%20life%20cycle%20sustainability. [Accessed November 19, 2023].

[22] "Magnetic Moment – Definition, Formation, Magnetic Dipole Force," *BYJUS* [Website]. https://byjus.com/physics/magnetic-moment/#:~:text=Asked%20Questions%20%E2%80%93%20FAQs-,What%20Is%20Magnetic%20Moment%3F,moment%20is%20a%20vector%20quantity. [Accessed November 19, 2023].

[23] "What is electron? – Definition from WhatIs.com," *WhatIs.com* [Website]. https://www.techtarget.com/whatis/definition/electron#:~:text=An%20electron%20is%20a%20negatively,electrons%20form%20an%20atom's%20nucleus. [Accessed November 19, 2023].

[24] "Subatomic Particles – Definition, Discovery, and Key Features," *BYJUS* [Website]. https://byjus.com/chemistry/subatomic-particles/#:~:text=A%20Subatomic%20particle%20is%20nothing,protons%2C%20electrons%2C%20and%20neutrons. [Accessed November 19, 2023].

[25] "DOE Explains…Protons," *Energy.gov* [Website]. https://www.energy.gov/science/doe-explainsprotons#:~:text=The%20proton%20is%20a%20subatomic,of%20the%20simplest%20element%2C%20hydrogen. [Accessed November 19, 2023].

[26] "What is magnetic flux density and it's unit?," *BYJUS* [Website]. https://byjus.com/question-answer/what-is-magnetic-flux-density-and-its-unit/ [Accessed November 19, 2023].

[27] "Molten Metal Definition," *Law Insider* [Website]. https://www.lawinsider.com/dictionary/molten-metal [Accessed November 19, 2023].

[28] "Electromagnetic Stirring :: Total Meteria Article," *totalmateria* [Website]. https://www.totalmateria.com/page.aspx?ID=CheckArticle&site=kts&NM=411#:~:text=Electromagnetic%20stirring%20(EMS)%20is%20the,the%20electrically%20conducting%20metal%20bath. [Accessed November 19, 2023].

[29] "What's an electrical arc?," *creativesafetysupply* [Website]. https://www.creativesafetysupply.com/qa/arc-flash/what-is-an-electrical-arc [Accessed November 19, 2023].

[30] "What is an electrode?," *BYJUS* [Website]. https://byjus.com/question-answer/what-is-an-electrode/ [Accessed November 19, 2023].

[31] "Blast furnace | metallurgy," *Encyclopaedia Britannica* [Website]. https://www.britannica.com/technology/blast-furnace [Accessed November 19, 2023].

[32] "Noncoking Coal – an overview | ScienceDirect Topics," *sciencedirect* [Website]. https://www.sciencedirect.com/topics/engineering/noncoking-coal#:~:text=Noncoking%20coals%20have%20higher%20ash,then%20solidifies%20to%20form%20coke. [Accessed November 19, 2023].

[33] “What Is Industrial Waste?,” *blog.idrenvironmental.com* [Website]. https://blog.idrenvironmental.com/what-is-industrial-waste#:~:text=Industrial%20waste%20is%20an%20all,Textile%20mills [Accessed November 19, 2023].

5.0 H_2 GREEN STEEL (Ruby Miller)

The purpose of Section 5 is to explain how the hydrogen used in making green steel is produced and how it reduces greenhouse gas emissions. Figure 5.1 below shows how green steel and concrete are made, and where the sub-topic discussed in Section 5.0: *H_2* green steel, fits in. The electrolysis process produced hydrogen gas, which is put into a direct iron tower with *iron ore*, then through an *electric arc furnace*, to produce *H_2* green steel. The by-products of the *electric arc furnace* are slag, which makes green concrete, and carbon emissions. Section 5.0 discusses the benefits of *H_2* green steel compared to steel.

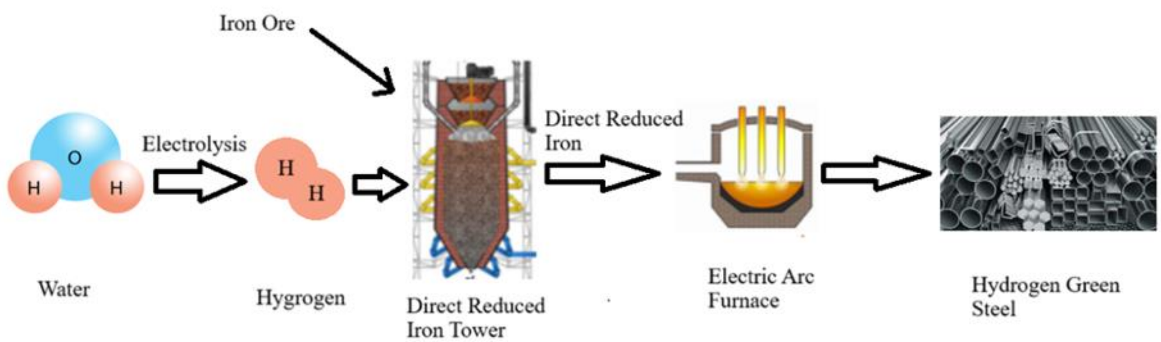

Figure 5.1: The production of hydrogen green steel [1][2][3][4]

Section 5.1 explains how the hydrogen used in making hydrogen green steel is produced through a process called electrolysis. Section 5.2 shows how using hydrogen gas instead of natural gases in the production of steel reduces greenhouse gas emissions.

5.1 The Production of Hydrogen

Section 5.1 explains how the hydrogen used in green steel is produced using a process called electrolysis. Section 5.1.1 describes how the electrolysis process works, and Section 5.1.2 shows how performing electrolysis on water produces hydrogen.

5.1.1 Theory of electrolysis

Electrolysis is the process of splitting up chemical compounds into the individual elements that make up them [5]. An example of a chemical compound that electrolysis can be performed on is water, H_2O, which can be split up into hydrogen and oxygen atoms [5]. The atoms in the water molecules are bonded together very strongly, which is why electrolysis is needed [6]. A water molecule is shown with its bonds in Figure 5.2 below.

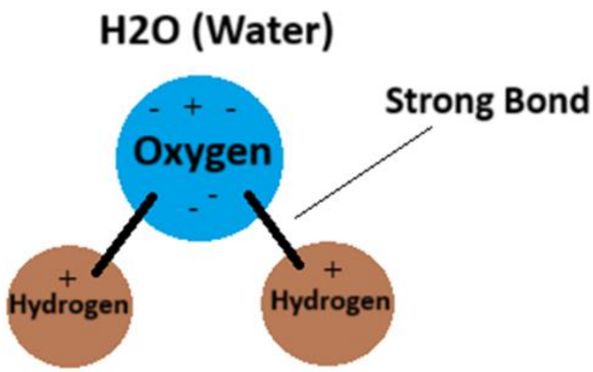

Figure 5.2: The elements (atoms) that make up water, held together by strong bonds [Ruby Miller]

All chemical compounds are made up of negative elements and positive elements that are attracted to each other [5]. The negative element has extra electrons and the positive one lacks electrons. They bond in order to share these electrons in order to become a neutral compound, like water, as shown with water as an example in Figure 5.2 above [6]. Atoms in a molecule are strongly bonded together, so they cannot be separated manually. The “electro” in electrolysis refers to the use of an electrical current, or flow of electrons, in order to split up the compound. This current is conducted through a negative *electrode* (*anode*), a piece of conducting metal, connected to a positive *electrode* (*cathode*) as seen in Figure 5.3 below [5]. In chemistry, opposites attract, meaning positive things attract negative things and vice versa. The negative electrode is negatively charged from the current, and it attracts the positive atoms in the compound [5]. The positive electrode attracts the negative atoms. Since the pull of the *electrodes* is stronger than the initial pull from the other atoms in the compound, the atoms will separate [5]. Figure 5.3 below illustrates the process of electrolysis.

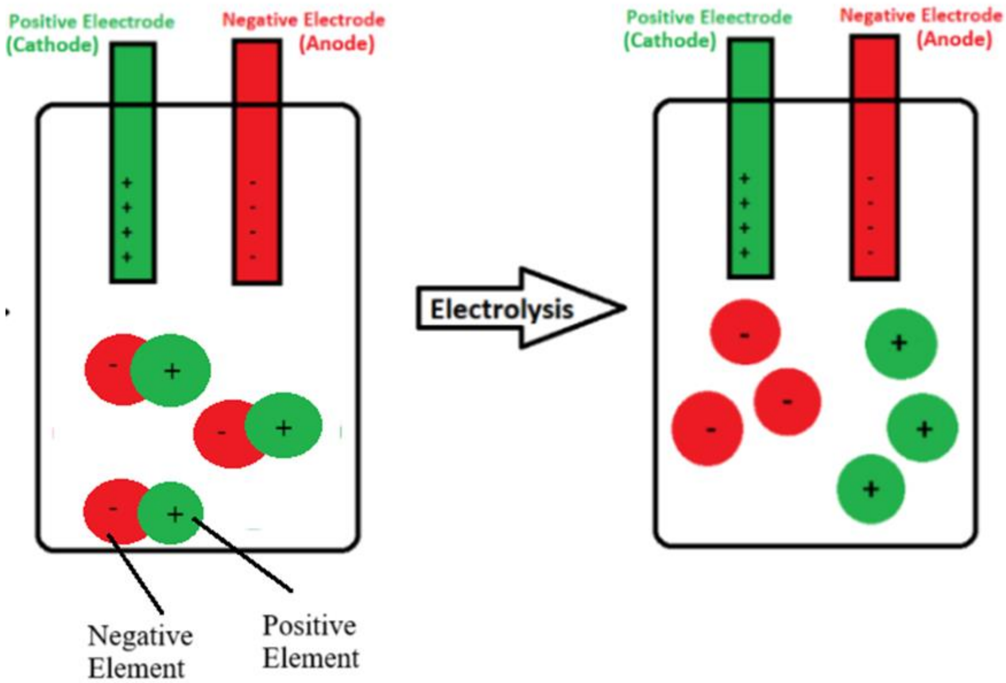

Figure 5.3: The process of electrolysis showing how charged electrodes split up negative (red) and positive (green) atoms [Ruby Miller]

Electrolysis can be used to purify dirty water. Dirty water, such as sewage or flood water, is made up of H_2O and other unwanted chemicals [7]. If electrolysis was performed on pure water, the products would simply be hydrogen and oxygen. The chemical equation in Equation 5.1 below represents the electrolysis process on water.

$H_2O \rightarrow H_2^+ + O^-$ (5.1) [8]

Water → Hydrogen gas + Oxygen

Since the dirty water has extra chemicals, an extra third product of waste will be produced. Once the hydrogen, oxygen, and waste are separated, the waste particles (the dirt at the bottom of the beaker in Figure 5.4 below) can be removed. The electrodes will be removed after, causing the pure hydrogen and oxygen atoms to re-bond with each other, making pure, filtered water. Figure 3.4 below shows the result of electrolysis on water with impurities as it works in water filters.

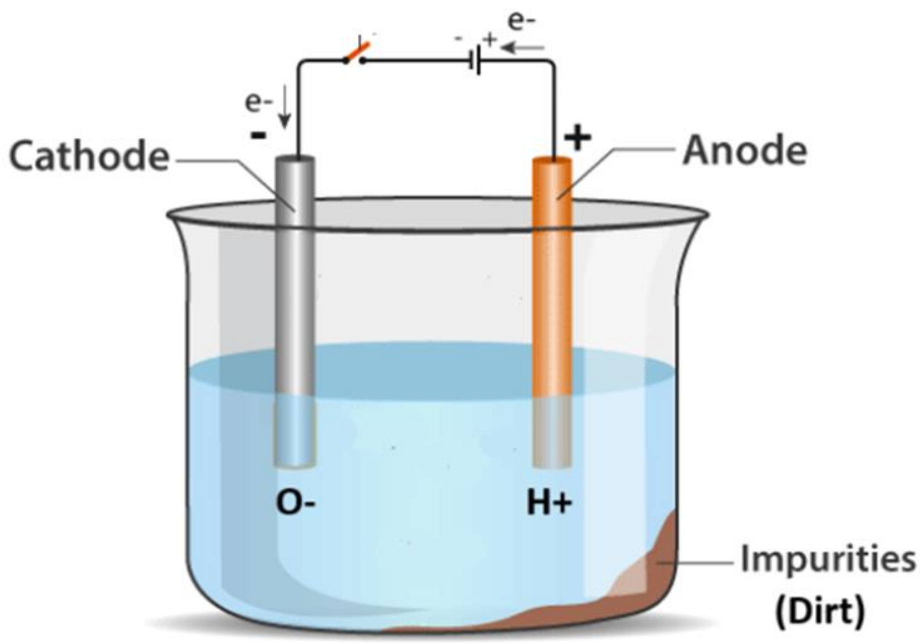

Figure 5.4: The separation of molecules in dirty water by electrolysis [9, modified]

Electrolysis can be used to "create" renewable energy in the form of hydrogen, using an electrolyser [10]. In order to use water as hydro energy, the water is collected and put into a large electrolyser, like the one pictured in Figure 5.5 below.

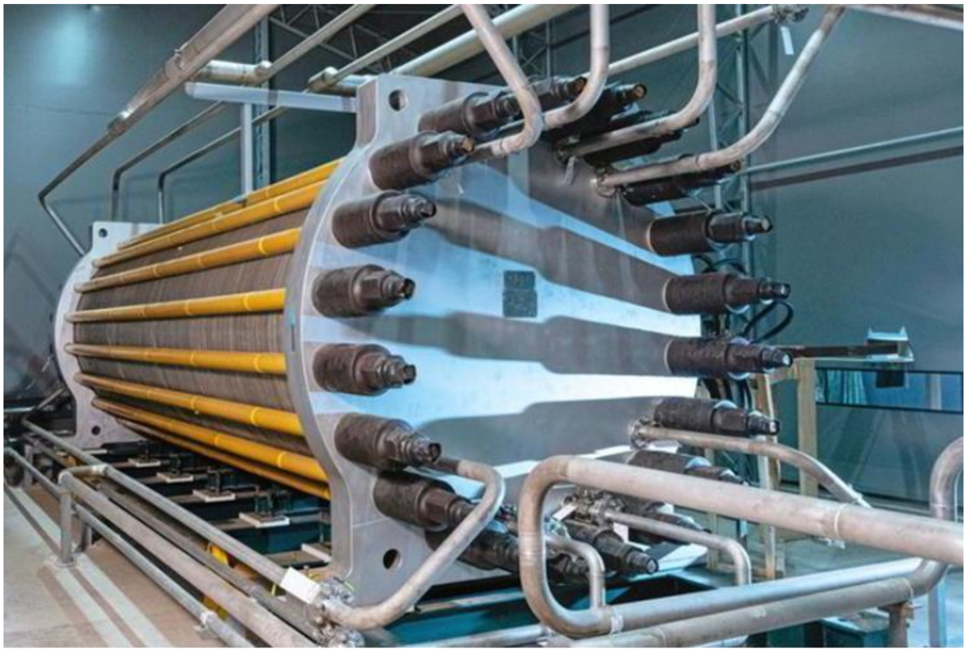

Figure 5.5: A large industrial electrolyser used to separate water into oxygen and hydrogen [10]. The pipes carry in the water and out the oxygen and hydrogen [10]

The water is split into oxygen and hydrogen through electrolysis [10]. The hydrogen can be used as renewable energy to power large vehicles, and electricity and heating in homes [11].

5.1.2 Electrolysis of pure water

As insinuated by the name, H_2 green steel is made using H_2, or hydrogen gas. Pure hydrogen gas is not commonly found in nature since it often bonds with other elements to form compounds [12]. One common molecule that hydrogen bonds with is oxygen, creating water. Unlike hydrogen gas, water is very commonly found in nature. In order to obtain the hydrogen gas needed to make green steel, a process called electrolysis is performed on water to separate water molecules into their base elements: hydrogen and oxygen. Hydrogen is missing electrons, meaning it is a positive element, and oxygen has extra electrons, meaning it is a negative element [6]. Since opposite charges attract, they bond together forming water. The water is placed in a container with two pieces of conducting metal called electrodes, as shown in Figure 5.6 below.

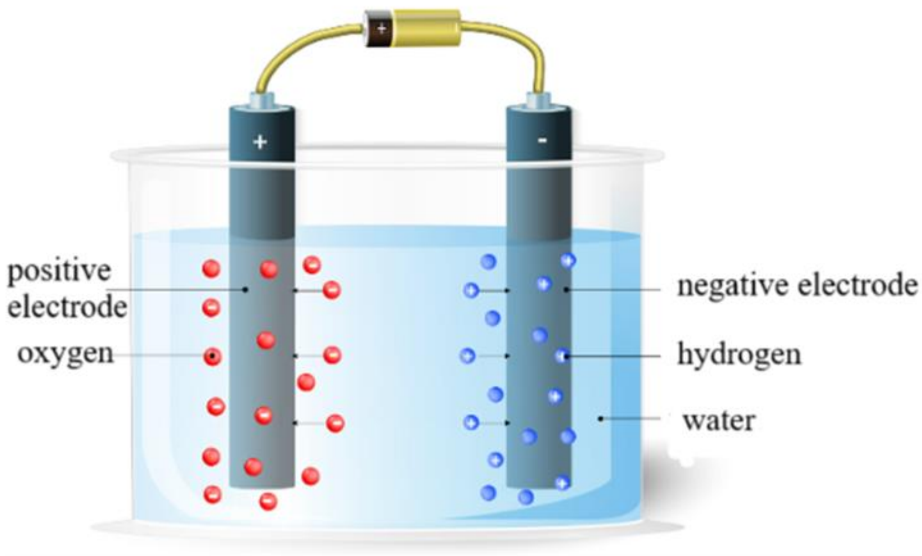

Figure 5.6: The process of electrolysis on water [13, modified]

One electrode is charged negatively and the other is charged positively. Since these electrodes are charged using strong electricity, they have a very strong attraction to the elements in the water [8]. The hydrogen will be more attracted to the negative electrode than the negative oxygen element, and the oxygen will be more attracted to the positive electrode [8]. This causes the oxygen and hydrogen to break their bonds with each other, fully separating them [8]. The separation of water by electrolysis is shown in the Equation 5.1 above.

5.2 Reducing Greenhouse Gas Emissions Through the use of Hydrogen as Energy

Section 5.2 explains how using hydrogen instead of natural gases as the energy source to produce steel reduces greenhouse gas emissions. Section 5.2.1 illustrates the production of steel using natural gases, and Section 5.2.2 shows how using hydrogen to produce green steel instead reduces greenhouse gas emissions.

5.2.1 Use of natural gas in steel

Today, steel is made by putting *iron ore* (raw mined iron) into a *direct reduced iron tower* with natural gasses such as carbon monoxide from coal [14]. The process is shown in Figure 5.7 below.

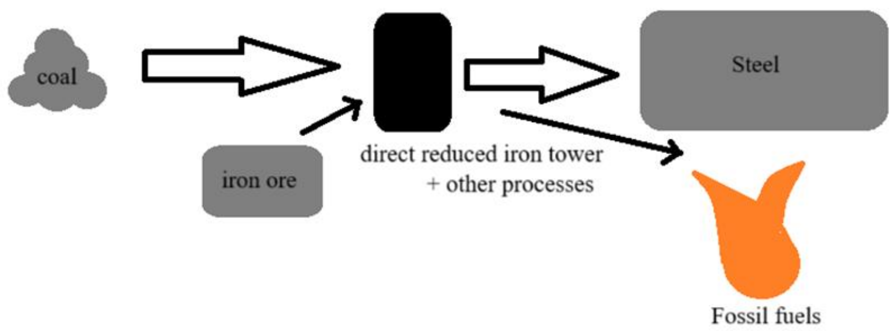

Figure 5.7: How the production of modern steel contributes to greenhouse gas emissions [Ruby Miller]

The carbon monoxide reacts with the *iron ore* and turns it into *direct reduced iron*, which is then processed further to become steel [14]. By using natural gasses, *fossil fuels* are burned, contributing to the world's greenhouse gas emissions, and therefore negatively impacting the environment through climate change.

5.2.2 Use of hydrogen in steel

Roughly 10% of the entire globe's greenhouse gas emissions come solely from the production of steel [15]. This negative impact can be reduced by using hydrogen gas produced from the electrolysis of water as the energy source in the *direct reduced iron* tower instead of natural gas. The process is illustrated in Figure 5.8 below.

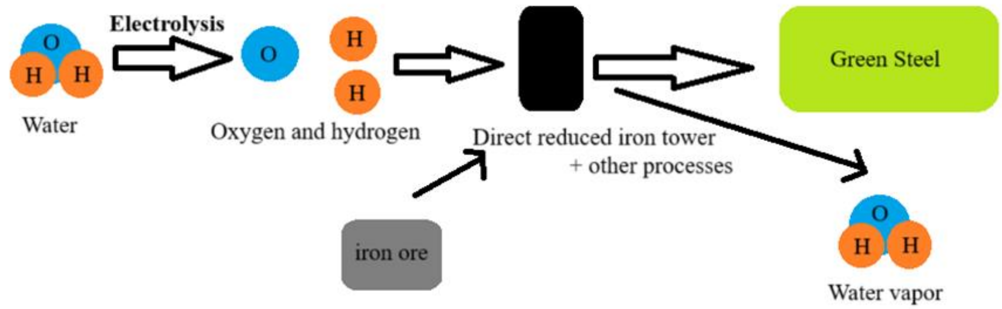

Figure 5.8: How using electrolysis to produce hydrogen reduces greenhouse gasses in H_2 green steel [Ruby Miller]

Hydrogen gas is a renewable resource, since it can be “made” over and over using electrolysis from water. When it reacts with the *iron ore*, instead of producing *fossil fuels*, it produces steam (water in gas form), which is not harmful to the environment [16].

5.3 Conclusion

Electrolysis can be performed on pure water by breaking the bonds that hold its components together, producing oxygen and hydrogen. This hydrogen reacts with *iron ore* to produce H_2 green steel. When using hydrogen, steam is a by-product instead of *fossil fuels*, which reduces greenhouse gas emissions.

Glossary

Anode: A negatively charged *electrode* [5]. Used to attract hydrogen atoms in the electrolysis of water to produce the hydrogen necessary to produce hydrogen green steel.

Cathode: A positively charged *electrode* [5]. Used to attract oxygen atoms in the electrolysis of water to produce the hydrogen necessary to produce hydrogen green steel.

Direct reduced iron (DRI): The output of a *direct reduced iron tower*, made by reacting iron ore and natural gases [10]. It is put into the *electric arc furnace* to produce green steel and concrete.

Direct reduced iron tower: Takes in raw iron ore and turns it into *direct reduced iron* [10]. The first step in the production of green steel and concrete since its output is an *electric arc furnace's* input.

Electric Arc Furnace: Takes iron that comes out of the *direct reduced iron tower*, and heats it up to high temperatures using electromagnetism instead of *fossil fuels* like *blast furnaces* [11]. Used to make the *iron ore* into green steel and concrete.

Electrode: Piece of conducting metal, such as graphite and copper [5]. Positive anad negative *electrodes* are used to split up water molecules in the electrolysis process used to produce the hydrogen necessary to make hydrogen green steel.

Fossil fuels: Found deep under Earth's surface, can be burned and, and produce a lot of harmful carbon emissions. Some examples include coal, oil, and natural gasses [15]. Used for energy for things like a *blast furnace*, a main step in the production of green steel and concrete.

H_2: Hydrogen gas, where two hydrogen atoms are bonded together. Not commonly found in nature, therefore must be "made" by processes like *electrolysis* [12]. H_2 made from *electrolysis* is mixed with *direct reduced iron* to make green steel and concrete.

Iron ore: Raw iron mined from sedimentary rocks [16]. The main ingredient in both steel and green steel, put into a *direct reduced iron tower* to make steel or an *electric arc furnace* to make green steel.

References

[1] "Properties of Water," *Chemistry Learner.* [Website]. Available: https://www.chemistrylearner.com/properties-of-water.html. [Accessed Nov 21, 2023].

[2] "Direct Reduced Iron Process," Tec- Science [Website]. Available: https://www.tec-science.com/material-science/steel-making/direct-reduced-iron-dri-process/. [Accessed Sep 13, 2023].

[3] "Electric Arc Furnace," Wikipedia. [Website]. Available: https://en.wikipedia.org/wiki/Electric_arc_furnace. [Accessed Sep 13, 2023].

[4] "Steel vs. Aluminum: How to Make the Best Choice for Your Project Design," *Kimsen.* [Website]. Available: https://kimsen.vn/steel-vs-aluminum:-how-to-make-the-best-choice-for-your-product-design-ne86.html. [Accessed Nov 21, 2023].

[5] K. Song, "Electrolysis," *LibraTexts: Chemistry.* [Website]. Available: https://chem.libretexts.org/Bookshelves/Analytical_Chemistry/Supplemental_Modules_(Analytical_Chemistry)/Electrochemistry/Electrolytic_Cells/Electrolysis. [Accessed Sep 9, 2023].

[6] P. Atkins, "chemical bonding," *Britannica*. [Website]. Available: https://www.britannica.com/science/chemical-bonding. [Accessed Sep 9, 2023].

[7] "Membranes, UV Light, and Electrolysis - Three Water Filtration Technologies," *PureChoice*. [Website]. Available: https://purechoice.co.uk/blog/membranes-uv-light-and-electrolysis-three-water-filtration-technologies. [Accessed Oct 2, 2023].

[8] "Hydrogen Production: Electrolysis," *Energy.gov*. [Website]. Available: https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis. [Accessed Oct 2, 2023].

[9] "Electrolysis and Electroplating," *Byju's*. [Website]. Available: https://byjus.com/physics/electrolysis-and-electroplating/. [Accessed Oct 2, 2023].

[10] L. Collins, "High-pressure alkaline electrolyser maker HydrogenPro to build new 500MW factory in Texas" *Hydrogen Insight*. [Website]. Available: https://www.hydrogeninsight.com/electrolysers/high-pressure-alkaline-electrolyser-maker-hydrogenpro-to-build-new-500mw-factory-in-texas/2-1-1422665. [Accessed Oct 3, 2023].

[11] S, Satyapal, "Hydrogen: A Clean, Flexible Energy Carrier," *Energy.gov*. [Website]. Available: https://www.energy.gov/eere/articles/hydrogen-clean-flexible-energy-carrier. [Accessed Oct 3, 2023].

[12] "Hydrogen," *Royal Society of Chemistry*. [Website]. Available: https://www.rsc.org/periodic-table/element/1/hydrogen: [Accessed Oct 29, 2023].

[13] K. Sugarman, "Hydrogen Through Electrolysis," *Ocean Geothermal Energy Foundation*. [Website]. Available: https://www.oceangeothermal.org/hydrogen-energy-electrolysis/. [Accessed Oct 29, 2023].

[14] "DRI Production," *International Iron Metallics Association*. [Website]. Available: https://www.metallics.org/dri-production.html. [Accessed Oct 29, 2023].

[15] M. Moynihan, "Steel, concrete and climate change," The Institution of Structural Engineers. [Website]. Available: https://www.istructe.org/resources/blog/steel-concrete-and-climate-change/. [Accessed Sep 9, 2023].

[16] "Green Steel Production" *H2 Steel*. [Website]. Available: https://www.h2greensteel.com/articles/green-steel-production. [Accessed Oct 29, 2023].

6.0 CARBON CAPTURE AND UTILIZATION (Ayra Mensah)

The purpose of Section 6 is to present research findings regarding how carbon dioxide can be captured and utilized. The amount of CO_2 released into the atmosphere yearly has reached 419 ppm [1]. The atmosphere's carbon dioxide content has increased by 50% in less than 200 years [1] and the production of steel and concrete contributes about 16% of those carbon emissions [2]. It has become critical to reduce the concentration and find better ways to either dispose off the CO_2 or put it to use. Figure 1.0 below seeks to demonstrate the pollution caused by CO_2 in the making of *green steel* and concrete.

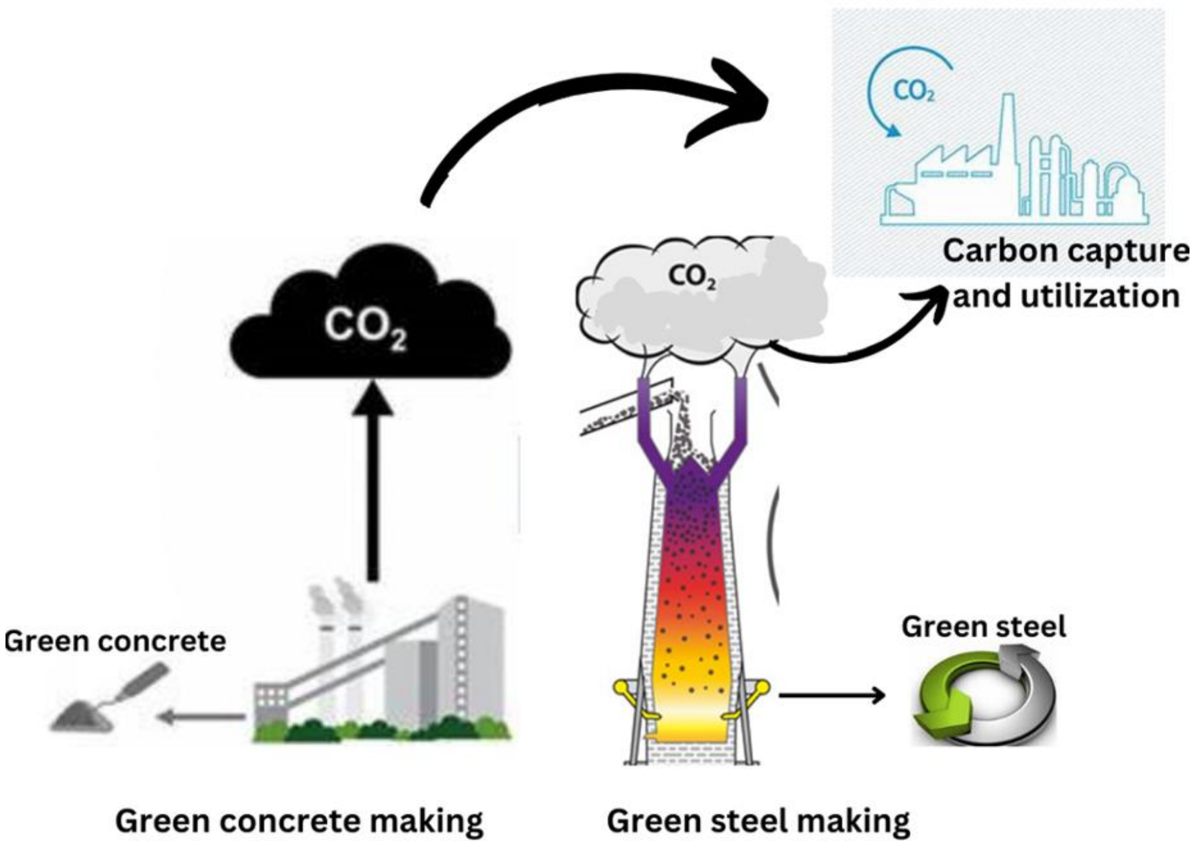

Figure 6.1: ***Green steel*** **and concrete production showing carbon dioxide emissions [3], [4 modified]**

Section 6.1 introduces the theory of *adsorption* and explains the mechanism involved. Section 6.2 details how the theory of *adsorption* can be used to explain how the capture of CO_2

benefits society and how can it be converted and used in a beneficial form to man. Finally, Section 6.3 provides the conclusion statement of this report. Glossary and references are provided at the end of the document.

6.1 Adsorption

In this section, there are two sub sections. Sub section 6.1.1 gives an overview of what the theory is about. Sub section 6.1.2 highlights the properties of an effective *adsorbent* material.

6.1.1 *Adsorption* theory

Adsorption is the buildup of dissolved solid, gas, or liquid (the *adsorbate* particles in Figure 6.2 below) to the surface of an *absorbent* (shown in Figure 6.2 below) [3]. Atoms, ions, and molecules do not penetrate the surface during *absorption*; instead, they stay as an adherent layer on the substance's surface [3]. *Adsorbent* is the surface that draws elements to it and *adsorbate* is the material that attaches to a surface. *Adsorption* occurs due to the internal forces of the *adsorbent* attracting the adsorbate to it [4]. *Desorption* is an alternate process that involves the release of atoms, molecules, or ions from or through a medium like a liquid or solid [3].

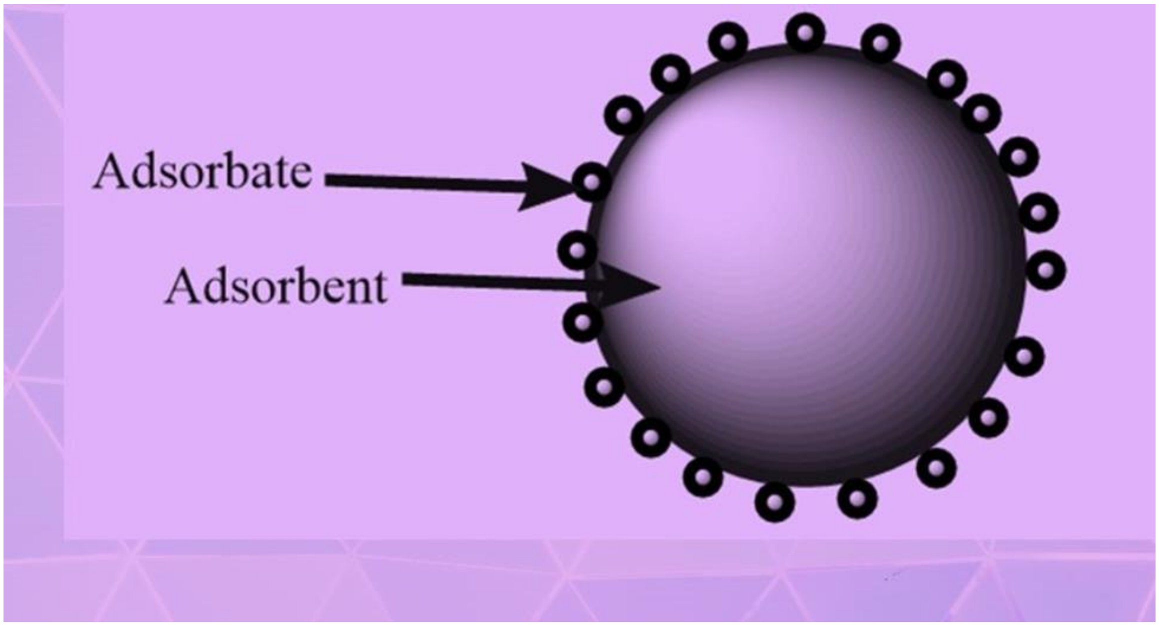

Figure 6.2: ***Adsorbent*** **and** ***adsorbate*** **[3]**

Adsorption involves forces from a nearby solid surface holding molecules that are diffusing in the gaseous phase [4]. Physical and chemical *adsorption* are the two types of *adsorption* that can be distinguished based on the characteristics of the forces that drive the attraction between the molecules of the *adsorbate* and the *adsorbent* [4]. *Van der Waals forces* draw the *adsorbate* molecules to the *adsorbent* surface during physical *adsorption* [4], and Figure 6.3 below shows what *Van der Waals forces* are. There are two primary types of *adsorption*: chemical *adsorption*, which forms chemical bonds with the *adsorbent* surface to provide an alternate method of capturing CO_2, and physical *adsorption*, which is driven by tiny forces without chemical bonding [5].

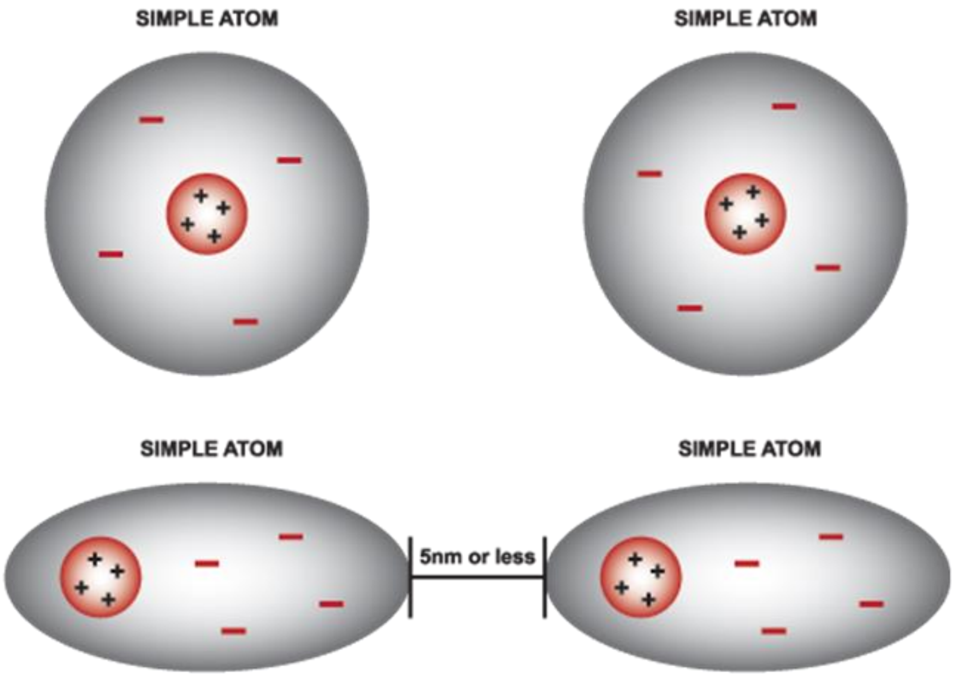

Figure 6.3: Demonstration of *Van der Waal forces* in *adsorption* [7]

Van der Waals forces are weak attractions between molecules or atoms that help them stick together. They are micro, temporary magnets that pull molecules closer when there's no strong force pushing them apart as shown in Figure 6.3 above. These forces are responsible for keeping gases, liquids, and some solids together, allowing them to act like fluids [7]. For example, geckos use *Van der Waals forces* to climb surfaces. Scientists recently measured these forces directly for the first time, which could have practical applications in the future [7].

6.1.2 *Adsorbent* examples

The main requirements for an *adsorbent* to be taken into consideration as a suitable candidate for carbon capture and storage as well as *biogas* upgrading applications are high surface area, high *porosity*, minimal *thermal degradation*, *chemical stability*, high *carbon dioxide selectivity*, and low *synthesis cost* [3]. Examples of efficient *adsorbent* materials include *zeolites* (which are microforms of *aluminum silicate* [8]) with distinct structures [3], ammonia-based *adsorbents* used in chemical *adsorption* processes, and activated carbon, which is well-known for its large surface area and *affinity* for CO_2 [3]. When there is moisture present, silica gel works well, and *porous organic polymers* (POPs) can increase the capacity of CO_2 *adsorption* [3]. Factors like *adsorption* capacity, selectivity, regeneration capabilities, and operating circumstances influence the choice of *adsorbent* material [10].

6.2 Carbon Capture Processes

The carbon dioxide *adsorption* process involves dissolving carbon dioxide in a medium by means of physical or chemical processes [3]. The process of carbon capture using *adsorption* is further discussed in the Section 6.2.1. Section 6.2.2 highlights uses of captured CO_2 from *green steel* and concrete production.

6.2.1 Carbon capture process

There are three steps involved in using *adsorption* for carbon capture. The process is depicted in Figure 6.4 below. Step 1 is selection of an adequate *adsorbent* material for the successful execution of this process. This *adsorbent* must have the capacity to extract CO_2 with selectivity from a mixture of gases, referred to as *flue gas* produced during combustion [4]. *Adsorption* and *desorption* are the two main stages that make up the core of the *adsorption* process. CO_2 molecules are drawn to the surface of the selected *adsorbent* material during the *adsorption* phase [10]. The adsorbed CO_2 is then released from the *adsorbent*'s surface during the *desorption* phase, which is an essential step in accomplishing *carbon capture and utilization*

[10]. To achieve the appropriate CO_2 concentration and replenish the *adsorbent* material for future usage, this cycle of *adsorption* and *desorption* is repeated [10].

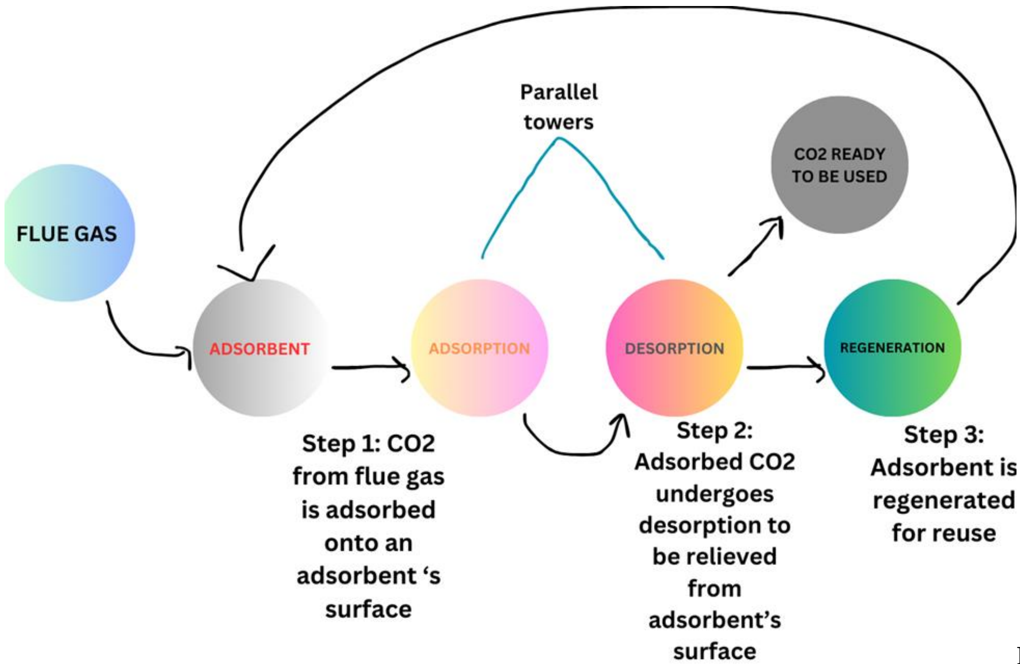

Figure 6.4: Process of carbon capture with *adsorption* simplified [Ayra Mensah]

In Step 2, the utilisation of parallel *adsorption* towers, one in the *adsorption* phase and the other in the *desorption* phase, helps in the alternation of roles to keep the cycle continuous. This step is an example of *reactor configuration* which refers to the specific design and arrangement of the equipment and components used to carry out the capture of CO_2 from a mixture of gases [10]. In Step 3, after the capture of CO_2, the *adsorbent* material is allowed to regenerate and be used again. This is an important feature in many carbon capture applications, such as those found in industrial facilities' post-combustion systems [10].

In Figure 6.5 below is an illustration of how activated carbon adsorbs CO_2 to aid the understanding of the process explained above.

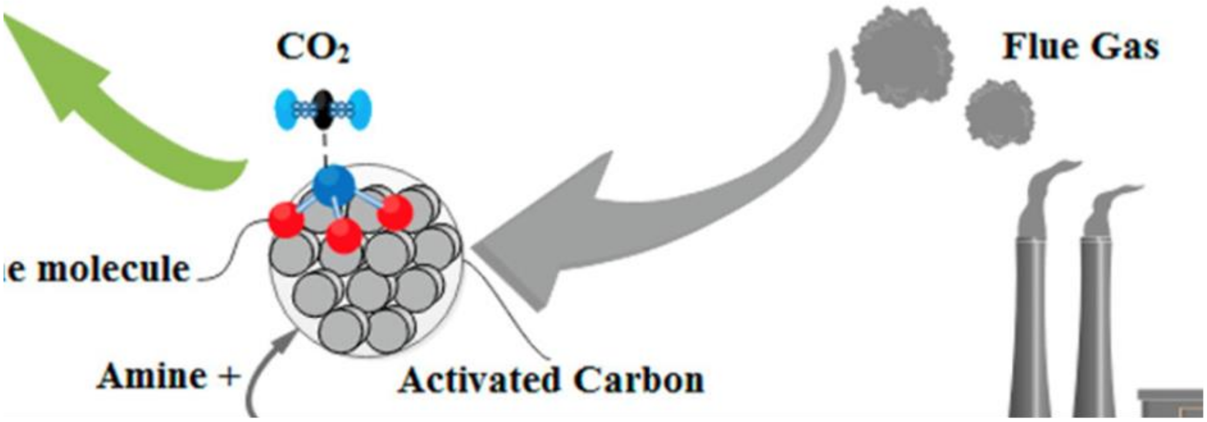

Figure 6.5: Process of CO_2 capture using activated carbon [9]

Figure 6.5 above focuses on the *adsorption* CO_2 from *flue gas*, using activated carbon generated from waste oil sands coke [9]. Typically, *flue gas* comprises between 13% and 60% CO_2 [9], therefore effectively capturing this gas is essential to reducing climate change. The activated carbon shows promise for efficient CO_2 capture when tweaked with various amines [9]. To maximise the performance of the activated carbon, variables such amine addition, *adsorption* temperature, and humidity are incorporated [9]. This strategy not only provides an affordable waste management solution, but it also tackles environmental issues related to carbon emissions.

6.2.2 Carbon utilization

Captured CO_2 can be transported over long distances. It is usually collected as a separate gas stream that can be compressed to increase its pressure and make it appropriate for storage or transportation [14]. There are many ways CO_2 can be used after being captured, as seen in Figure 6.6 below. The released CO_2 in *carbon capture and utilisation* (CCU) applications can be used in enhanced oil recovery activities or as a feedstock for a variety of industrial processes, including the synthesis of chemicals and fuels [13],[15]. The collected CO_2 can also be compressed and deposited in deep subterranean geological formations as this does not pose significant harmful effect on the environment [14].

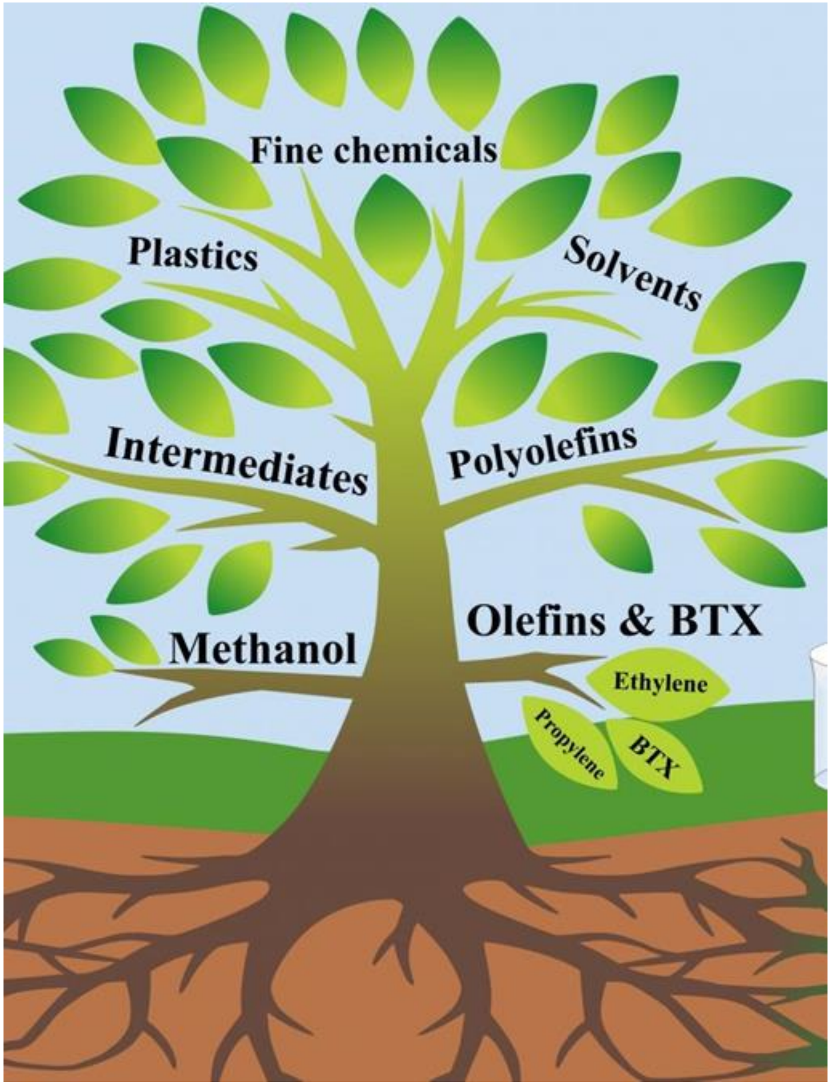

Figure 6.6: Some uses of Carbon dioxide [13]

Conclusion

In conclusion, the theory of *adsorption* is useful for CO_2 capture presenting a viable option for resolving environmental issues. The ability to capture carbon dioxide emissions from processes ensures a decrease in greenhouse gas emissions, which in turn helps to mitigate climate change and improve air quality. After the release of *flue gases* from industrial processes, CO_2 is retrieved from that mixture of gases with the help of an adsorbent. Then the captured CO_2 is separated from the adsorbent material to be utilized. The CO_2 that is gathered can be used in the synthesis of chemicals, fuels, and other synthetic materials. CO_2 can be an invaluable resource that has benefits for the environment and the economy. Therefore, the incorporation of efficient *carbon capture and utilisation* technology has the potential to fundamentally alter society and pave the way for a more ecologically conscious and sustainable future. As compared to the conventional method of making steel and concrete, green steel and green concrete production utilises *carbon capture and utilization* to ensure CO_2 emitted in the process is well disposed of or effectively utilized. This makes the latter production process more environmentally friendly than the former.

GLOSSARY

Adsorbate: This refers to a substance captured onto a surface of an attracting substance, such as carbon dioxide in carbon capture [11].

Adsorbent: This refers to a material that captures and holds adsorbate molecules, crucial in carbon capture and utilization [11].

Adsorption: This is the process of molecules sticking to a surface, a key mechanism in capturing and utilizing carbon dioxide [11].

Affinity: This refers to the attraction or liking between adsorbate and adsorbent molecules, influencing the effectiveness of carbon capture [7].

Aluminium silicate: This is a compound that may serve as an adsorbent for carbon capture due to its properties [8].

Biogas: This is a renewable energy source that may undergo carbon capture for reducing carbon dioxide emissions [21].

Carbon Capture and Utilization*:* It's the process of retrieving CO_2 that comes out when fossil fuels are burned and converting it into useful products [25]. This method makes the production of green steel and concrete more environmentally friendly than the conventional method.

Carbon dioxide selectivity: This is the ability of an adsorbent to preferentially capture carbon dioxide over other gases in carbon capture processes [10].

Chemical stability: This is the resistance of an adsorbent to chemical changes, important for long-term use in carbon capture [10].

Desorption: This refers to the release of adsorbed molecules from an adsorbent, a step in recycling materials used in carbon capture [11].

Flue Gas*:* This is the polluted air that comes out of factories and power plants consisting of greenhouse gases. CO_2 is captured from this polluted air during the process of carbon capture and utilization [25].

Green (as in "green steel" and "green concrete")**:** This refers to environmentally friendly i.e., has almost no negative impact on the environment [26].

Porosity: This is the presence of pores in an adsorbent material, enhancing its capacity to capture and store carbon dioxide [11].

Porous organic polymers: These are materials with high porosity, potentially useful as adsorbents for carbon capture [10].

Reactor configuration: This refers to the design of the system used for carbon capture and utilization processes [10].

Synthesis cost: This is the expenses associated with producing adsorbents for carbon capture applications [11].

Thermal degradation: This refers to the breakdown of adsorbent material due to high temperatures, influencing its lifespan in carbon capture [11].

Van der Waals forces: These are weak attractive forces between molecules, playing a role in adsorption in carbon capture [7].

Zeolites: These are crystalline materials with high porosity, explored for their potential in carbon capture and utilization [8], [10].

REFERENCES

[1] N. G. C. Change, "Carbon Dioxide Concentration | NASA Global Climate Change," *Climate Change: Vital Signs of the Planet*, 2023. [Website]. Available: https://climate.nasa.gov/vital-signs/carbon-dioxide/?_hsenc=p2ANqtz-8HpRVv9oVuSCF0VZQsQUZzqFhGtkLyw06Pme5RT0S-5vbMKKeT7887JYALC3WjAsIKVkac [Accessed Nov 20, 2023].

[2] A. Vaughan, "Steel and concrete are climate change's hard problem. Can we solve it?," *New Scientist*, 2019. [Website]. Available: https://www.newscientist.com/article/mg24432560-700-steel-and-concrete-are-climate-changes-hard-problem-can-we-solve-it/ [Accessed Nov 20, 2023].

[3] *Bing.com*, 2023. [Website]. Available: https://th.bing.com/th/id/OIP.TJPybdUcQgmmPzFHVbNm6AHaC3?rs=1&pid=ImgDetMain [Accessed Nov 20, 2023].

[4] *Bing.com*, 2023. [Website]. Available: https://th.bing.com/th/id/OIP.b-1UqwRjB0B-UaEdHgtASAHaEM?rs=1&pid=ImgDetMain [Accessed Nov 20, 2023].

[5] H. Zeng, X. Qu, D. Xu, and Y. Luo, "Porous Adsorption Materials for Carbon Dioxide Capture in Industrial Flue Gas," *Frontiers in Chemistry*, vol. 10, Jun. 2022, [Website]. Available: https://doi.org/10.3389/fchem.2022.939701. [Accessed Nov 01, 2023].

[6] *Socratic.org*, 2023. [Website]. Available: https://useruploads.socratic.org/s0koh2YSmKqKzZT3nl2L_van-der-waals-force.png [Accessed Nov 20, 2023].

[7] T. Puiu, "Direct measurement of Van der Waals force made for the first time," *ZME Science*, Jul. 05, 2013. [Website]. Available: https://www.zmescience.com/science/physics/direct-measurement-of-van-der-waals-force-made-for-the-first-time/ [Accessed Nov 20, 2023].

[8] "Zeolites - Definition, Formula, Zeolites Preparation, Structure, Uses," *BYJUS*. [Website]. Available: https://byjus.com/jee/zeolites/ [Accessed Nov 20, 2023].

[9] A. Gholidoust, J. D. Atkinson, and Z. Hashisho, "Enhancing CO_2 Adsorption via Amine-Impregnated Activated Carbon from Oil Sands Coke," *Energy & Fuels*, vol. 31, no. 2, pp. 1756–1763, Jan. 2017, [Website]. Available: https://doi.org/10.1021/acs.energyfuels.6b02800. [Accessed Nov 20, 2023].

[10] Anon, *"Study.com"*, 2022. [Website]. Available: https://study.com/academy/lesson/adsorption-definition-examples.html [Accessed Oct 11, 2023].

[11] K. Sharma, "Adsorption," *thechemistrynotes.com*, Dec. 15, 2022. [Website]. Available: https://thechemistrynotes.com/adsorption-its-types-and-applications/ [Accessed Oct 11, 2023].

[12] M. Karimi, M. Shirzad, José A.C. Silva, and A. E. Rodrigues, "Carbon dioxide separation and capture by adsorption: a review," *Environmental Chemistry Letters*, vol. 21, no. 4, pp. 2041–2084, Mar. 2023, [Website]. Available: https://doi.org/10.1007/s10311-023-01589-z. [Accessed Nov 01, 2023].

[13] F. Raganati, F. Miccio, and P. Ammendola, "Adsorption of Carbon Dioxide for Post-combustion Capture: A Review," *Energy & Fuels*, vol. 35, no. 16, pp. 12845–12868, Aug. 2021, [Website]. Available: https://doi.org/10.1021/acs.energyfuels.1c01618. [Accessed Nov 01, 2023].

[14] brgfx, "Concrete Mixer Isolated Vectors," FreeP!k. [Website]. Available: https://www.freepik.com/vectors/concrete-mixer-isolated. [Accessed Sep 13, 2023].

[15]" Direct Reduced Iron Process" *Tec - Science* [Website]. Available: https://www.tec-science.com/material-science/steel-making/direct-reduced-iron-dri-process/[Accessed Sep 13, 2023]

[16] "Electric Arc Furnace," Wikipedia. [Website]. Available: https://en.wikipedia.org/wiki/Electric_arc_furnace. [Accessed Sep 13, 2023].

[17] C. Schaschke, “Monte Carlo simulation,” in Dictionary of Chemical Engineering, Oxford University Press, p. 246. [Website]. Available: https://app.knovel.com/hotlink/pdf/id:kt00TW6BB3/dictionary-chemical-engineering/monte-carlo-simulation. [Accessed Sep 13, 2023].

[18] M. Moynihan, “Steel, concrete and climate change,” The Institution of Structural Engineers. [Website]. Available: https://www.istructe.org/resources/blog/steel-concrete-and-climate-change/. [Accessed Sep 9, 2023].

[19] “Direct Reduced Iron Process” *Tec- Science* [Website]. Available:

https://www.tecscience.com/material-science/steel-making/direct-reduced-iron-dri-process/.

[Accessed Sep 13, 2023].

[20] “Carbon Capture and Decarbonization of Energy Systems | Clean Energy Research Centre,” cerc.ubc.ca. [Website]. Available: https://cerc.ubc.ca/research/carbon-capture-and-decarbonization-of-energy-system/ [Accessed Sep. 17, 2023].

[21] “Carbon capture and use in chemical industry,” *EurekAlert!* [Website]. Available: https://www.eurekalert.org/news-releases/602733 [Accessed Nov 05, 2023].

[22] “DOE Announces $27 Million for Carbon Dioxide Transport Networks to Manage Carbon Emissions,” *Energy.gov*. [Website]. Available: https://www.energy.gov/fecm/articles/doe-announces-27-million-carbon-dioxide-transport-networks-manage-carbon-emissions [Accessed Nov 05, 2023].

[23] “CO2 Capture and Utilisation - Energy System,” *IEA*. [Website]. Available: https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage/co2-capture-and-utilisation [Accessed Nov 05, 2023].

[24] Mzconsultinginc.com, 2023. [Website]. Available: https://mzconsultinginc.com/blog/wp-content/uploads/2023/07/CO2-smoke-stack-1024x576.jpg [Accessed Nov 14, 2023].

[25] A. S. Reis Machado and M. Nunes da Ponte, “CO2 capture and electrochemical conversion,” Current Opinion in Green and Sustainable Chemistry, vol. 11, pp. 86–90, June 2018. [Website]. Available: https://doi.org/10.1016/j.cogsc.2018.05.009. [Accessed Sep 17, 2023].

[26] M. Moynihan, “Steel, concrete and climate change,” The Institution of Structural Engineers. [Website]. Available: https://www.istructe.org/resources/blog/steel-concrete-and-climate-change/. [Accessed Sep 9, 2023].

7.0 GREEN CONCRETE

The purpose of Section 7 is to explain how by-products from *blast-furnaces* as well as other eco-friendly materials can be used in the creation of *green* concrete. Figure 7.1 below shows the types of materials which go into making geopolymer concrete, also known as *green* concrete. It includes waste such as fly ash and slag, *acidic* or *alkaline* solutions, and recycled concrete *aggregate*.

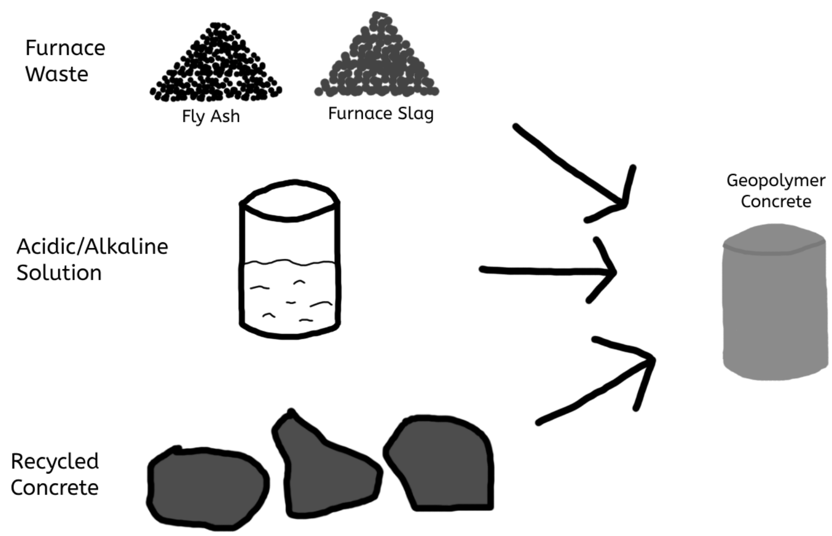

Figure 7.1: Materials which are used to make geopolymer concrete [Maria Tierrafria]

Section 7.1 explains the engineering theory of polymerization reactions. Section 7.2 goes into detail about the different options of *green* materials which can be used in *green* concrete and how they can be made by using polymerization reactions.

7.1 Polymerization Reactions

Section 7.1 explains the theory of polymerization reactions, which are used in the production of *green* concrete. Section 7.1.1 explains the basics of monomers and polymers. Section 7.1.2 explains how polymers are created. Section 7.1.3 explains what geopolymers are.

7.1.1 Monomers and polymers

A polymerization reaction starts off with a single monomer. A monomer is a very small molecule which has the ability to join together with other monomers [1]. This molecule is made up of a few elements [2]. For example, glucose is a monomer which is made up of carbon, hydrogen, and oxygen. A glucose monomer can then combine with other glucose monomers as shown in Figure 7.2 below. This creates a different product. One of these products is starch, which can be used as a thickener in baking and cooking [3].

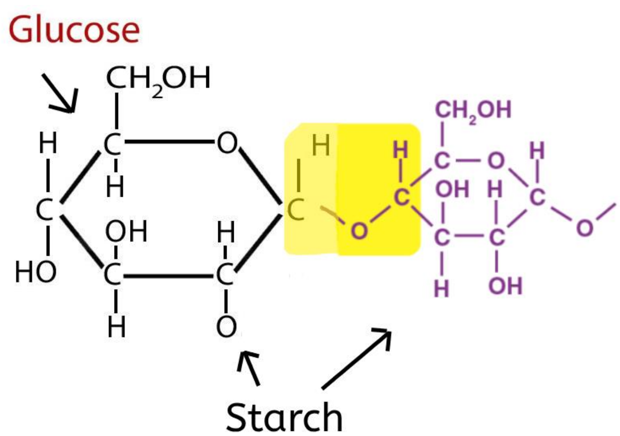

Figure 7.2: Two glucose monomers forming a starch polymer [4, modified], [5, modified]

7.1.2 Creating a polymer

Polymers are the result of these monomers combining to create a longer chain on account of being acted on by heat, pressure, or with the influence of another substance [6]. Along with chains, monomers can also combine to form sheets and other 3D shapes [7]. Polymerization is what the process of monomers turning into polymers is called.

Ethylene is an example of a monomer that is used as the first step to creating polymers used in products such as rubber, plastics and paint [8]. It is composed of carbon and hydrogen.

This monomer then combines with other ethylene monomers to form polyethylene. The process of combining ethylene monomers into polyethylene is shown in Equation 7.1 below.

$$C_2H_4 \rightarrow (C_2H_4)_n \qquad (7.1)\ [9]$$

Ethylene → Polyethylene

Figure 7.3 below gives a visual representation of the ethylene to polyethylene process which is shown in Equation 7.1 above [10]. Each element in the polymer is written out, with the bond lines being shown where each element connects. Multiple ethylene monomers, as seen on the left side of the equation, are joined together to form polyethylene, seen on the right. The concept of polymers being multiple monomers joined together can be seen by the repeating structure of the polyethylene polymer in figure 7.3 below.

Figure 7.3: Polymerization equation of ethylene [10 modified]

Polymers can be both natural and human-made [11]. Hair is a naturally made polymer that is seen on people [11]. DNA is another natural polymer which makes up human bodies [11]. Humans also use polymers and polymerization to create different products. These include polyester and nylon, both materials commonly used in clothing [12]. Human-made polymers can be manipulated to have different properties depending on what they are being made for. These properties include polymers made with increased strength, the ability to stretch, and ones that can be recycled [11].

7.1.3 Geopolymers

Geopolymer is a word used to distinguish a certain type of polymers [13]. These polymers are formed when an *aluminosilicate* combines with either an *acidic* or an *alkaline* solution.

7.2 Eco-friendly materials used in making green concrete

Section 7.2 explains what materials can be used in *green* concrete. 7.2.1 gives a brief explanation on what makes concrete emit CO_2. 7.2.2 and 7.2.3 show how concrete can be made more environmentally friendly by using geopolymer binders and recycled concrete aggregate.

7.2.1 The problems with concrete

Since the 1800s, Portland cement has been used as the binder for concrete [14]. Portland cement is made by taking materials such as limestone and clay, and heating them up at temperatures above 1500ºC [15]. The downside to Portland cement is that it has very high CO_2 emissions, creating approximately 0.85 kg of CO2 for every 1 kg of cement during the heating process [16]. Equation 7.2 below shows how limestone, $CaCO_3$, is broken down into lime, CaO, and carbon dioxide, CO_2, during the heating process.

$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2 \qquad (7.2)\ [17]$$

$$\text{Limestone} + \text{heat} \rightarrow \text{Lime} + \text{Carbon Dioxide}$$

7.2.2 Geopolymer binders with fly ash and furnace slag

Approximately 1000 million tons of fly ash and 400 million tons of furnace slag are produced every year . Instead of throwing it away as waste, fly ash and slag allows the replacement of Portland cement binders with geopolymer binders [20]. Figure 7.4 below shows how fly ash and slag together with *alkaline* and *acidic* solutions can form geopolymer binders, and that these binders hold the aggregates, sand and rocks, together to create geopolymer concrete.

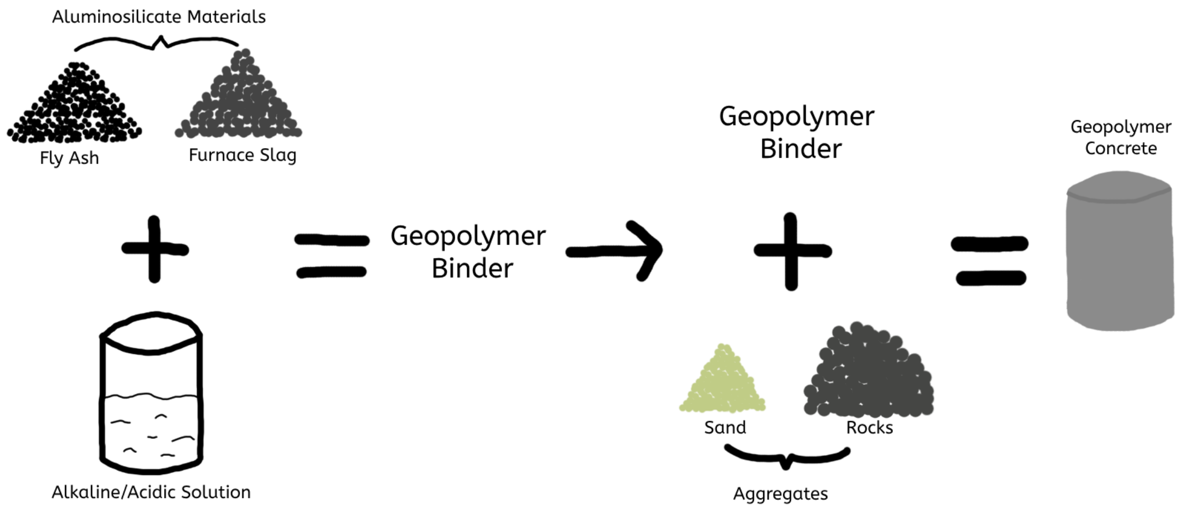

Figure 7.4: Process of creating geopolymer concrete [Maria Tierrafria]

Section 7.2.2 explains what fly ash and furnace slag are, as well as the benefits of using them to make geopolymer binders, and the overall benefits of geopolymer binders.

Fly ash and furnace slag

Fly ash is a fine and small non-combustible powder which remains left over when combustible materials are used in *blast furnaces* [18].

Furnace slag comes from the production of copper and steel [21]. Slag is the impurities of the steel or copper, and is removed once the metal has been processed in a *blast furnace* [22]. Figure 7.5 below shows the process of heating the metal ores and extracting the slag. The iron ore gets melted using hot air, then the liquid ore separated from the slag which floats on top [22].

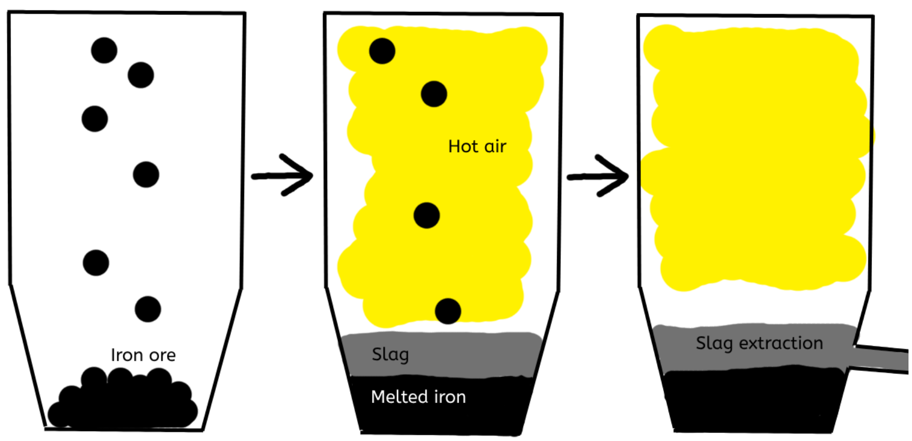

Figure 7.5: Process of melting iron ore and extracting the slag [Maria Tierrafria]

The slag is then dried and ground into a fine material that can be used to make a geopolymer binder[18].

Benefits of fly ash, furnace slag, and geopolymer binders

Fly ash benefits the structure and quality of concrete. Fly ash particles are able to fill in gaps in the concrete mixture which particles of Portland cement would not be able to reach [20]. This results in a stronger and higher durability concrete [18].

Furnace slag also has its benefits to being used in concrete. It reduces the concrete's permeability, making it more water resistant [18]. Using furnace slag in concrete also helps increase the concrete's strength [21].

Using fly ash and furnace slag reduces the amount of raw materials that need to be extracted to create binders for concrete [23]. The energy consumption needed to produce the concrete would also decrease, as the materials do not need to be processed to become usable [18]. Fly ash and slag do not emit CO_2 when used in concrete, so the overall CO_2 emitted also decreases [18].

7.2.3 Recycled Concrete Aggregate

Aggregates are what the binders in concrete are holding together [24]. They are made up of gravel, sand and/or crushed stones. Aggregates can be either fine or coarse, depending on the application of the cement that they are being put in.

Concrete itself is used as an eco-friendly *aggregate* [25]. Leftover concrete from large building projects can be crushed up into different sized aggregates and reused in future projects [25]. Figure 7.6 below shows leftover concrete being crushed into different sizes of aggregate, and then turning into new concrete.

Figure 7.6: Process of concrete debris turning into aggregate and then into new concrete products [26]

Using leftover concrete reduces how much raw material needs to be used each time concrete is made. Concrete is also non-biodegradable, so reusing it as aggregate reduces the amount of concrete waste left over [25].

7.3 Conclusion

Reducing the amount of CO_2 emissions from the concrete industry involves two main components: the aggregates which form the body of the concrete, and the binders which hold everything together and give concrete its ability to harden. Environmentally friendly binders made from fly ash and furnace slag take by-products from other industries [18]. This reduces the amount of raw materials that need to be extracted, as well energy consumed and any CO_2 emitted by needing to gather raw materials [23]. Using fly ash and slag also takes away the need to use CO_2 emitting Portland cement [16]. The aggregates in concrete can also be made in an environmentally friendly way, by reusing leftover concrete [25].

Glossary

Acidic: A solution which is an acid. A compound which releases hydrogen atoms when in water [27]. It can be used to combine with fly ash and slag to create geopolymers [18].

Alkaline: A solution which is an alkali [27]. It is over 7 on the pH scale because of its excess of hydroxide molecules [27]. It is used to combine with fly ash and slag to create geopolymers[18].

Aluminosilicate: A compound which is made up of both silicate and aluminum [28]. Fly ash and furnace slag are aluminosilicates [18].

Blast Furnaces: A furnace that uses strong blasts of air combined with fuels such a coal to melt down iron ores [29]. The coal used emits carbon gas, so electric arc furnaces are being researched as an alternative.

Green: Referring to something as *green* means that is environmentally friendly [30]. Geo-polymer concrete is considered *green* because it re-uses old materials and emits less CO_2 than Portland cement concrete [16].

References

[1] C. Schaschke, “Monte Carlo simulation,” in *Dictionary of Chemical Engineering*, Oxford University Press, p. 246. [Online]. Available: https://app.knovel.com/hotlink/pdf/id:kt00TW6BB3/dictionary-chemical-engineering/monte-carlo-simulation

[2Monomer Definition, Types & Examples - Video & Lesson Transcript,” study.com. Accessed: Oct. 04, 2023. [Online]. Available: https://study.com/WEB-INF/views/jsp/redesign/academy/lesson/seoLessonPage.jsp

[3What is starch? - Bake Info.” Accessed: Oct. 04, 2023. [Online]. Available: https://www.bakeinfo.co.nz/facts/bread/bread-ingredients/what-is-starch/

[4What is glucose and how does it work? | Vinmec.” Accessed: Oct. 04, 2023. [Online]. Available: https://www.vinmec.com/en/news/health-news/general-health-check/what-is-glucose-and-how-does-it-work/

[5Starch: Diagram, Structure and Features,” BYJUS. Accessed: Oct. 04, 2023. [Online]. Available: https://byjus.com/biology/starch-diagram/

[6]International Food Information Service, “Peel,” in *Dictionary of Food Science and Technology (2nd Edition)*, International Food Information Service (IFIS Publishing), p. 336. [Online]. Available: https://app.knovel.com/hotlink/pdf/id:kt006QEFX1/dictionary-food-science/peel

[7] C. Schaschke, “polymerization,” in *Dictionary of Chemical Engineering*, Oxford University Press. [Online]. Available: https://app.knovel.com/hotlink/pdf/id:kt00TW6K13/dictionary-chemical-engineering/polymerization

[8] “Q&A: How do plants respond to ethylene and what is its importance? | BMC Biology | Full Text.” Accessed: Oct. 08, 2023. [Online]. Available: https://bmcbiol.biomedcentral.com/articles/10.1186/s12915-016-0230-0

[9] “Making Plastics: From Monomer to Polymer.” Accessed: Oct. 08, 2023. [Online]. Available: https://www.aiche.org/resources/publications/cep/2015/september/making-plastics-monomer-polymer

[10] “Writing Formulas for Polymers,” Chemistry LibreTexts. Accessed: Oct. 03, 2023. [Online]. Available: https://chem.libretexts.org/Bookshelves/Organic_Chemistry/Supplemental_Modules_(Organic_Chemistry)/Polymers/Writing_Formulas_for_Polymers

[11] amy.dobos, “Polymers: from DNA to rubber ducks,” Curious. Accessed: Sep. 27, 2023. [Online]. Available: https://www.science.org.au/curious/everything-else/polymers

[12] I. M. Ward, P. D. Coates, and M. M. Dumoulin, “4.2 Overview of Fiber Processing,” in *Solid Phase Processing of Polymers*, Hanser Publishers. [Online]. Available: https://app.knovel.com/hotlink/pdf/id:kt003JY1Z1/solid-phase-processing/overview-fiber-processing

[13] J. Matsimbe, M. Dinka, D. Olukanni, and I. Musonda, “Geopolymer: A Systematic Review of Methodologies,” *Materials*, vol. 15, no. 19, p. 6852, Oct. 2022, doi: 10.3390/ma15196852.

[14] G. Scientific, “The History of Concrete,” Giatec Scientific Inc. Accessed: Oct. 30, 2023. [Online]. Available: https://www.giatecscientific.com/education/the-history-of-concrete/

[15] “Portland Cement - an overview | ScienceDirect Topics.” Accessed: Oct. 31, 2023. [Online]. Available: https://www.sciencedirect.com/topics/engineering/portland-cement

[16] “Cement and Concrete: The Environmental Impact,” PSCI. Accessed: Sep. 26, 2023. [Online]. Available: https://psci.princeton.edu/tips/2020/11/3/cement-and-concrete-the-environmental-impact

[17] E. Possan, W. A. Thomaz, G. A. Aleandri, E. F. Felix, and A. C. P. dos Santos, “CO2 uptake potential due to concrete carbonation: A case study,” *Case Stud. Constr. Mater.*, vol. 6, pp. 147–161, Jun. 2017, doi: 10.1016/j.cscm.2017.01.007.

[18] Z. Jwaida, A. Dulaimi, N. Mashaan, and M. A. Othuman Mydin, “Geopolymers: The Green Alternative to Traditional Materials for Engineering Applications,” *Infrastructures*, vol. 8, no. 6, Art. no. 6, Jun. 2023, doi: 10.3390/infrastructures8060098.

[19] “Steel Industry Co-Products.” Apr. 2021. Accessed: Oct. 31, 2023. [Online]. Available: https://worldsteel.org/wp-content/uploads/Fact-sheet-Steel-industry-co-products.pdf

[20] “Why use Fly Ash and Slag in Concrete?,” Bay-Lynx Manufacturing Inc. Accessed: Sep. 27, 2023. [Online]. Available: https://bay-lynx.com/education/why-use-fly-ash-and-slag-in-concrete/

[21] C. Gorse, D. Johnston, and M. Pritchard, “saddle-jib crane,” in *Dictionary of Construction, Surveying and Civil Engineering*, Oxford University Press. [Online]. Available: https://app.knovel.com/hotlink/pdf/id:kt00C1JZV1/dictionary-construction/saddle-jib-crane

[22] C. Jones and N. Russell, “Block,” in *Dictionary of Energy and Fuels*, Whittles Publishing. [Online]. Available: https://app.knovel.com/hotlink/pdf/id:kt010YTFU4/dictionary-energy-fuels/block

[23] Inamuddin, T. Altalhi, and A. Alrooqi, “10.1 Introduction,” in *Green Sustainable Process for Chemical and Environmental Engineering and Science - Natural Materials-Based Green Composites 2 - Biomass*, Elsevier. [Online]. Available: https://app.knovel.com/hotlink/pdf/id:kt0139F7G1/green-sustainable-process/geopolymer-introduction

[24] D. J. Poehls and G. J. Smith, “Air development,” in *Encyclopedic Dictionary of Hydrogeology*, Elsevier. [Online]. Available: https://app.knovel.com/hotlink/pdf/id:kt00CCP1LA/encyclopedic-dictionary/air-development

[25] Avalanche, “Why & How to Use Recycled Crushed Concrete,” Superior Groundcover. Accessed: Oct. 31, 2023. [Online]. Available: https://www.superiorgroundcover.com/why-use-crushed-concrete/

[26] F. Machinery, “Recycled Concrete Aggregate- How to Make It and What Is It Used for? | Fote Machinery.” Accessed: Nov. 01, 2023. [Online]. Available: https://www.ftmmachinery.com/blog/how-to-make-recycled-concrete-aggregate-and-what-is-it-used-for.html

[27] J. Daintith and E. Martin, “acid anhydrides (acyl anhydrides),” in *Dictionary of Science (6th Edition)*, Oxford University Press. [Online]. Available: https://app.knovel.com/hotlink/pdf/id:kt007X3SC1/dictionary-science-6th/acid-anhydrides-acyl

[28] “10.4: Aluminosilicates - Chemistry LibreTexts.” Accessed: Nov. 14, 2023. [Online]. Available: https://chem.libretexts.org/Bookshelves/General_Chemistry/Book%3A_Structure_and_Reactivity_in_Organic_Biological_and_Inorganic_Chemistry_(Schaller)/I%3A__Chemical_Structure_and_Properties/10%3A_Network_Solids/10.04%3A_Aluminosilicates

[29] C. J. Cleveland and C. Morris, “back-pressure turbine,” in *Dictionary of Energy (Expanded Edition)*, Elsevier. [Online]. Available: https://app.knovel.com/hotlink/pdf/id:kt007STFN1/dictionary-energy-expanded/back-pressure-turbine

[30] madhu nair, “Going Green: What Does it Mean and How to Start,” University of the People. Accessed: Sep. 26, 2023. [Online]. Available: https://www.uopeople.edu/blog/what-is-difference-between-going-green-and-sustainability/

8.0 CONCLUSION

Green steel and concrete are environmentally friendly alternatives to traditional steel and concrete. Hydrogen gas is made by using electrolysis, where water is split up into hydrogen gas and oxygen. The gas is then used in a direct reduced iron tower. A direct reduced iron tower uses chemical reduction to turn iron ore into reduced iron by removing its oxygen. This process uses a low heat, causing it to use low energy. It also emits less CO_2 when compared to the traditional blast furnace.

The iron produced in this way can be put into an electric arc furnace for further processing to create H_2 green steel. This furnace uses electromagnetism to melt steel fast and efficiently. When compared to blast furnaces, electric arc furnaces are cheaper, take up less space, and use electricity as opposed to coal. While the creation of H_2 green steel emits less CO_2 than tradition steel making, there is still some CO_2 that is emitted as a by-product. This can be offset by carbon capture and utilization. The process captures CO_2 in the atmosphere with the use of an adsorbent.

The captured CO_2 is then gathered and can be used to synthesis chemicals, fuels, and other synthetic materials. Slag, another by-product of steel making can be used to make geopolymer concrete with the help of geopolymers. These geopolymers use fly ash and furnace slag as one of the ingredients, and they replace traditional Portland cement within concrete production. Geopolymers reduce the amount of raw materials needed to be extracted. This in turn reduces the amount of energy consumed and CO_2 that would have been emitted in the extraction and processing of raw materials.

H_2 green steel and geopolymer concrete reduce the amount of energy needed and CO_2 emitted to create steel and concrete.

3010 Minto Center
Department of Mechanical and Aerospace Engineering
Faculty of Engineering and Design
Carleton University
1125 Colonel By Dr, Ottawa, ON K1S 5B6

Date: December 8, 2023

Joanne Murray
Ottawa Carleton District School Board

Dear Ms. Murray

Subj.: Project findings materials for green steel and concrete

we have enclosed our *Report of Findings – Green Steel and Concrete – Team 2*, and our *Blog Post – Green Steel and Concrete – Team 2*. We are engineering students in team 2 of Lisa Meyer's CCDP 2100 A course section at Carleton University, and we are submitting these files for the educational benefit of grade 10 high school students. Here is the link for our *Presentation of Findings – Green Steel and Concrete – Team* 2: https://www.youtube.com/watch?v=TBphYiJ09kE.

Green steel and concrete reduce the world's carbon emissions by recycling materials and replacing the use of fossil fuels with renewable energy sources. The process of making green steel uses a direct reduced iron tower turns iron ore into direct reduced iron using hydrogen gas. This iron goes into the electric arc furnace, which produces green steel, which is the more environmentally friendly version of modern steel. Slag, and carbon emissions are the by-products of the furnace. The slag is then used to make geopolymer concrete, which replaces Portland cement concrete. The carbon emissions are captured and reused.

Thank you so much for your time. We hope our report, blog post, and video will educate your high school students on environmentally friendly building materials. We hope they will learn about how green steel and concrete are made, and how they reduce carbon emissions in the environment. Thank you for considering our project. We believe that we can create a good impression on your students about the importance of environmentally friendly building materials. If you have any questions or would like to know more, please contact Ruby Miller at ruby.miller@cmail.carleton.ca.

Sincerely,

Ruby Miller

Ruby Miller

Encl.: Green Steel and Concrete - *Report of Findings – Team 2, Blog Post – Green Steel and Concrete – Team 2*

Table 6: Report of Findings: content requirements

Component	Description
Letter of Transmittal	See template on Brightspace > Resources. The letter of transmittal will be sent to the video and blog recipient (Joanne Murray – see template on Brightspace > Resources > Letter of transmittal template) Include this letter at the end of team report of findings.
FRONT MATTER	
Title page (p.i, though the page number does not appear on the page) (team element)	• title • type (purpose) of report • recipient • authors, your affiliation • date
Executive Summary (p.ii) (team element) Reader should be able to find a summary of project findings here	Informative summary of each team member's findings, one page maximum Begin the summary with a brief paragraph explaining the system your team researched. No references, no images.
Table of contents (p.iii) (team element)	

REPORT BODY	
Sec. 1: Introduction (p.1) (team element)	• Document purpose: to present research findings regarding…. • Document overview/roadmap (State what will be covered in Sections 2-6; refer to any appendixes.) (NOTE: Do not include team member names) • State how terms defined in the glossary are denoted through-out your report.
Sec. 2: Project overview Note: Use a more specifically-worded heading. (team element)	Team project overview including • Importance of the topic you have researched - environmental problem (including background research with references) • Statement of how your team's topic can address the stated environmental problems • Product / system image, with labelled components + descrip-tion of image (NOTE: Do not include team member names) ○ Note: figure should be numbered as 2.1 • Overall description of product / system • References section

INDIVIDUAL SECTIONS GO HERE

Sec. 7: Conclusion (team element)	• Tie together the findings of each team member. Provide an INFORMATIVE summary. (see Brightspace > Resources > Report of Findings Resource Material)