CARBFIX

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Abstract— *Hellisheidi geothermal power plant in Reykjavik, Iceland was at one point releasing around 40,000 pounds of carbon dioxide per year. In an effort to reduce this large amount of pollution, the power plant decided to inject their carbon emissions into the ground. After a year and a half their pumps broke down and scientists found calcium build up on the ends. The material was found to be the product of a reaction between water, the carbon dioxide, and basalt rock, marking the discovery of CarbFix. In 2007, CarbFix became a collaborative project founded by Reykjavik Energy, University of Iceland, CNRS (Centre National de la Recherche Scientifique- National Center for Scientific Research) in Toulouse, France, and the Earth Institute at Columbia University.*

CarbFix focuses on an industrial process in which carbon dioxide and hydrosulfic acid are captured and pumped deep into the earth where they chemically react to form a solid. While in a scrubbing system, carbon dioxide and hydrosulfic acid are separated from other gases and are dissolved into water. This mineral water is then pumped into basalt rock deep in the earth. Basalt rock acts as a good storage material because it is abundant and locks the carbon dioxide safely. When carbon dioxide and water are simultaneously exposed to basalt, a chemical reaction occurs which converts the gas into stable carbonate materials. As this process is still in the developing phases, there are a few drawbacks. However, the potential benefits (reducing harmful greenhouse gases) are worth overcoming these challenges.

Global warming is a current world issue that cannot be ignored. It poses a serious threat to humanity and to the condition of our planet. In recent years, global warming has reached new extremes never seen before. Carbon dioxide in earth's atmosphere has been recorded at the highest monthly average ever seen in modern times. This has serious consequences including rising sea levels from the melting of the polar ice caps, increased ocean acidity, changing climate patterns, overall increased global temperatures, and many more negative effects. CarbFix is a sustainable innovation that the UN's Intergovernmental Panel on Climate Change has declared "hugely important".

Key Words—CarbFix, Carbon capture and storage, Chemical Engineering, Environmental Engineering, Global Warming, Iceland.

FROM THE ATMOSPHERE TO EARTH- CREATION & NEED FOR CARBFIX

One of the most pressing issues today is greenhouse gas emission. This issue cannot be overlooked-it's in the news, taught in classrooms, and is the topic of many heated political discussions. With rising global temperatures and continued scientific evidence that this is a serious problem, many nations and their leaders have taken note. In 2005 the Kyoto Protocol went into effect, committing countries to reducing carbon emissions. According to Sigurdur R. Gíslason, professor in the Institute of Earth Sciences at the University of Iceland, and colleagues, the Kyoto Protocol "…commit[ed] countries to binding CO_2 emission reductions. During the first commitment period, 37 industrialized countries and the European community committed to reduce greenhouse gas emissions to an average of five percent below their levels in 1990" [1]. This prompted the Icelandic President, Dr. Olafur Ragnar Grimsson, to assemble a team to address this issue. Grimsson approached Einar Gunnlaugsson at Reykjavik Energy, Wally Broecker at Columbia University, Eric Oelkers at CNRS Toulouse, and Sigurdur Gislason at University of Iceland to design a project to help limit Iceland's greenhouse gas emissions [1].

These French, American, and Icelandic scientists started the CarbFix project in 2007 [2]. They had the initial goal to create a "demonstration project designed to show the world that CO_2 can be economically removed from the atmosphere and stored in basalt" [1]. This is an important first step in addressing global warming and climate change; many scientists believe that carbon capture and storage (CCS) is key to saving the planet. According to Tabbi Wilberforce, professor at the University of the West of Scotland, and colleagues, these scientists are correct [3]. Wilberforce explains how CCS works to help the environment by eliminating harmful gases that deplete the ozone layer, and further claims that "it is expected that the next few years will see CCS as one of the cheapest methods for minimizing greenhouse gases" [3]. To get the project started, Reykjavik Energy provided their Hellisheidi geothermal power plant, shown in the figure below.

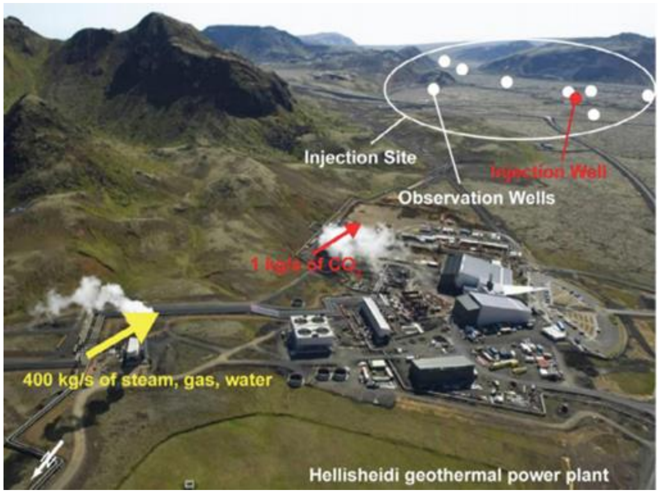

Figure 1 [2]
Photograph of the Hellisheidi Power Plant

Use of this power plant was very important; it allowed access to a CO_2 source, injection site, and monitoring wells. The original plan of CarbFix was to capture pure carbon right from Hellisheidi geothermal power plant's gas emissions [1]. In spring 2010, construction for a pilot gas capture plant was finalized. The overall cost of the pilot phase was around 12 million euros [1]. Two thirds of this cost were covered by national and international research programs in Europe and the United States. The pilot phase ran for ten years, starting in 2006 ending in 2016.

In March of 2010, it was discovered that the gas from Hellisheidi power plant's condensers contained oxygen. Because of this, the pilot gas separation plant had to be modified and repaired. In July, four months later, the pilot plant started operations. However, shortly after, the condensing equipment broke down. It wasn't until 2011 that the CarbFix injection system successfully dissolved and injected their initial goal of 175 tons of CO_2.

In 2012 construction workers working on a road close to the injection site damaged the gas pipe resulting in the shutdown of the pilot injection phase. While the site was shut down, collaborators continued to monitor the project. From this monitoring, it was found that "more than 95% of the CO_2 injected into the subsurface was mineralised within a year" [1]. Furthermore, the "carbonates that precipitated on the pump and within the pipes in the monitoring well contained the injected radioactive tracers" proving "carbon dioxide can be sequestered quickly and permanently in basaltic bedrock and thus reduce emissions of this greenhouse" [1]. This discovery marked the successful invention of CarbFix.

THE DEVELOPMENT AND CHEMISTRY BEHIND CARBFIX

In the Spring of 2010 the pilot gas capture plans for CarbFix were finalized. This pilot project was designed to separate CO_2 from the geothermal gas coming from Hellisheidi geothermal power plant's condensers [2]. The process begins with capturing the gas, and then separating the CO_2 and H_2S using a water scrubber [1]. The water scrubber washes CO_2 and H_2S from less soluble gases like, hydrogen gas, nitrogen gas, argon, and methane. The CO_2 and H_2S are separated from one another in a distillation column, and then are dissolved in distilled water, either before or during their injection into the basaltic rock [2]. When the CO_2 is injected into the basaltic rock, the reaction resembles a titration with the rock acting as a base that titrates into the aqueous carbonic acid [2]. This process releases cations, thus raising the pH to a level that precipitates the aqueous carbon [2]. The aqueous carbon precipitates because it reacts with cations to form stable carbonate materials:

$(Fe^{2+}, Ca^{2+}, Mg^{2+}) + CO_2 + H_2O = (Fe, Ca, Mg)CO_3 + 2H^+$ [2].

Figure 2 shows the details of the injection process. First showing the conventional injection of CO_2 into sedimentary rock, and then showing the CarbFix method of injecting CO_2-charged waters into basaltic rock at the Hellisheidi Plant [1].

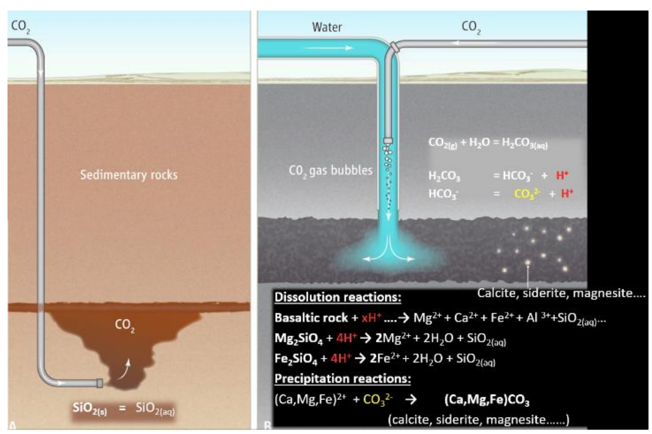

Figure 2 [1]
Injection process and relevant reactions

The reactions are shown more in depth, explaining both the dissolution and precipitation reactions. The precipitation reactions show the carbon reacting with divalent cations to form stable carbonate materials that will be permanently stored in the basalt.

A few months after the finalization of CarbFix's original pilot plans, the gas from the condensers were found to have contained oxygen [1]. After necessary adjustments were made, in July 2010 the pilot plant started operating with a three-week testing phase before the delivery of gas for injection. During the following months, components and equipment broke down regularly. It was then determined that the origin of these breakdowns was the "corrosion of the distillation column by H_2S interaction with its steel components" [1]. Because of this, the separation approach was abandoned, and in 2011 it was decided to begin CarbFix subsurface injection with pure purchased CO_2 and switch to injection of a combined CO_2-H_2S gas mixture.

The injection plan was to take CO_2 charged waters and inject it into basalt for two main reasons: "as CO_2-charged water is denser than freshwater this would limit the risk of the injected gas returning to the surface", and "as CO_2-charged water is acidic, it would promote the dissolution of basalt, which liberated divalent cations (e.g., Ca^{2+}, Mg^{2+}, and Fe^{2+}) into the solution promoting the eventual precipitation of stable carbonate minerals" [1].

The first tests of the injection system began in March 2011. Different tracers were used to label the injected CO_2 so that the CarbFix project managers could monitor the journey and destination of the injected carbon dioxide. It was found that the CarbFix injection system successfully dissolved and injected the 175 tons of pure CO_2 [1]. Due to this success, it was decided that the injection process would be continued.

During the fall of 2012, road construction was being conducted close to the injection site and the contractors severely damaged the gas pipe. As a result, the pilot injection phase was shut down, however monitoring continued [1]. With this monitoring, mass balance calculations were performed and they confirmed that more than 95% of injected carbon dioxide was mineralized within a year. Carbonates that precipitated on the pump and within the pipes in the monitoring well contained the carbon tracer, proving that CO_2 can be separated and stored in basaltic rock.

In 2014, CarbFix was upscaled to an industrial level. As of the summer of 2014, a water scrubbing tower was built next to the Hellisheidi geothermal plant. This water scrubbing tower captured a H_2S-CO_2 mixture by a condensation process [1]. Currently, these upscale operations are capturing 34% of CO_2 emissions and 68% H_2S emissions produced by the Hellisheidi plant. Continued efforts in developing this innovation are a part of the CarbFix2 project funded by the European Union [1]. These efforts will focus on developing the technology to store carbon dioxide in submarine basalts by injecting CO_2 charged seawater to the subsurface. This process could be very beneficial since sea water is inexpensive, and basaltic rock is abundant on the ocean floor. However, Gíslason explains, "The degree to which this technology is embraced, however, will depend on the passing of national legislations providing enough incentive or obligations for such solution to be applied at a large or even global scale" [1].

The CarbFix project has shown how effective and useful this process can be; CarbFix proved to be more effective and rapid than scientists had predicted. It was reported that "more than 95% of the CO_2 injected into the subsurface was mineralised within a year, and essentially all of the injected H_2S was mineralised within four months of its injection" [1], exemplifying that the CarbFix process has potential to quickly store large amounts of CO_2 in the basalt. Hopefully the rest of the world will not overlook this, and this project will gain the widespread support it needs to overcome all future challenges.

THE POTENTIAL CHALLENGES AND CONCERNS

No matter the innovation, gaining support is always a top concern. If the general public is against the project, it never stands the chance of being successful. In recognizing this, the managers and collaborators of CarbFix were always cognizant of the general public's concerns. Gíslason specifically states that, "…from the beginning, the CarbFix group consulted openly with relevant stakeholders such as the scientific, engineering and environmental sectors as well as non-governmental organizations and the general public" [1]. CarbFix wanted to be open about their process and worked to make sure everyone involved was informed as to what was happening each step of the process because this project, like most, is dependent upon public acceptance and economic factors [4]. The majority of this public acceptance is dependent on peoples' concerns with the effects carbon capture and storage have on the environment.

Carbon capture and storage systems often raise ethical concerns in regards to its potential effects on the environment. Researchers have investigated "the direct relationship between injection and induced seismicity for a long term and concluded that this storage process could lead to earthquakes, but the leakage of carbon dioxide is not a major challenge in terms of scaling up carbon capture and storage systems" [5]. This is a potential threat to the effectiveness of CCS. Capturing and reducing greenhouse gases is very important, but not at the risk of negative consequences like earthquakes. However, precautions can be taken to avoid this. Wilberforce describes some of these precautions: "Monitoring, permitting, and long-term care programs must be developed so that commercial and public sequestration sites can be developed and environmental protection insured" [3].

In addition to potential concerns, CarbFix has had to overcome setbacks and still faces some potential challenges. If a project doesn't admit to and acknowledge their drawbacks, then it will not evolve; facing and overcoming challenges is an integral part of developing any new innovation. The team members made sure "…the CarbFix project address[ed] these challenges with a multifaceted approach" [2]. Some of these concerns that CarbFix has had to address are, "overcoming the slow kinetics of mineral-fluid reactions, dealing with the large volume of source material required, reducing the energy needed to hasten the carbonation process, and leakage concerns" [6]. In dealing with the large volume of material, there needs to be a storage site suitable for storing all of the carbon dioxide. The site has to be porous and permeable in order for smoother injections with high volumes of CO_2 [7]. In order to lock the CO_2 in the ground and prevent leakage, the site must have impermeable rock caps. While these injections require large amounts of water-25 tons for every ton of CO_2- seawater can be used in the process; "Further application of the CarbFix approach may be best applied for storing CO_2 under the seafloor, which has abundant porous basalts adjacent to an almost inexhaustible supply of seawater" [1]. Nonetheless, this application raises the concern carbon dioxide leaking into the ocean. However, CO_2 charged water is more dense than freshwater and limits the risk of the injected gas returning to the surface [1].

Another concern in the carbon capture storage process of CarbFix is transportation. While storing the large amounts of source material is the main concern, transporting this material from the capturing site to the storage site is an important component. The *Outlook of Carbon Capture Technology and Challenges* points out the relevance in considering the transportation phase of CarbFix, saying "The key considerations that should be taken during the transportation of carbon dioxide are the compression of the gas to a supercritical state, and pipeline corrosion and the effect of fluid composition on the power that will be consumed" [3]. In order to achieve this, the pipeline can be recompressed at a distance beyond 150km. Transporting the CO_2 using pipelines in bulk also reduces the overall cost.

WHY CARBFIX IS RELEVANT- GLOBAL WARMING

Despite any and all potential concerns/challenges that face CarbFix, this innovation offers a solution to what some consider the biggest national security threat to the United States and the biggest threat to worldwide industrialized civilization, global warming. Soren Anderson and Richard Newell describe global warming in depth in their article *Prospects for Carbon Capture and Storage Technologies*. They write, "through the burning of fossil fuels, certain industrial processes, and various land use practices, we are contributing greatly to the accumulation of so-called greenhouse gases (GHGs) in the atmosphere, which trap heat and block outward radiation" [8]. This issue is growing, and is the worst it has ever been in recent years. Katherine Mast, a scientific and environmental journalist from Santa Fe, explains just how serious this issue has become. Mast explains how in May of 2018, "...an observatory in Hawaii measured earth's atmospheric carbon dioxide levels at 411 parts per million — the highest monthly average recorded in modern times, and a level the planet hasn't seen in at least 800,000 years" [8]. Furthermore, J.P. Martin Trusler stated in *The Annual Review of Chemical Biomolecular Engineering*, "There is now a broad scientific consensus that anthropogenic greenhouse gas emissions are responsible for a developing pattern of climate change, and that the scale of the problem calls for a multifaceted response, including major reductions in global CO_2 emissions" [4]. These reductions can be achieved by carbon capture and storage technology, and the CarbFix project is the most effective and productive method of CCS.

The following figure shows the amount of carbon that was captured by CCS technology globally between 2008 and includes projections through 2020.

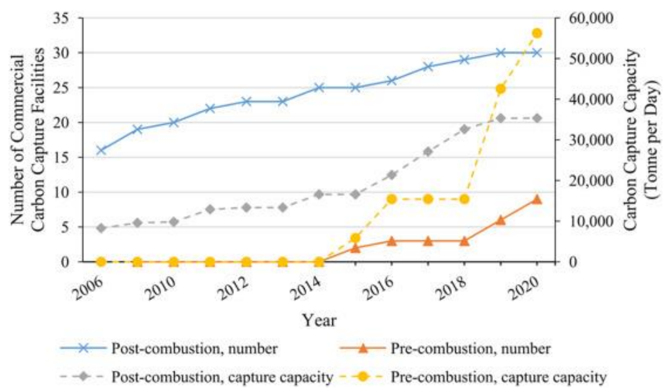

Figure 3 [3]
Carbon Capture from 2008 to 2016 around the world

While CCS is increasing and predicted to continue to do so, this is not occurring on a large enough scale to combat global warming. This is because the methods for traditional CCS are not very productive. This further reinforces how important CarbFix can be, since it is the most effective method of carbon capture and storage. This project has the potential to be implemented on a large scale and drastically increase the CO_2 eliminated in the future with CCS technology.

The world has taken note of the need for this technology. The Paris Agreement- a United Nations agreement dealing with climate change- shows how pressing this issue is: "… [the goal of the Paris Agreement] is to keep global temperature rise 'well below 2° C' compared to pre-industrial levels" [2]. It seems almost counterproductive to use industrial processes to reverse the harmful effects that industrial processes have caused. Some may argue that simply planting more trees and other natural carbon dioxide absorption wildlife seems like a better solution. However, the modern world is beyond this solution. Overpopulation and industrialization prevent enough space to grow new natural sources of CO_2 absorption. Furthermore, natural sources would have to be planted on a very large scale to have the impact that a CCS process, like Carbfix, could have. Therefore, carbon capture and storage processes are predicted to be the key components in achieving the goals of the Paris Agreement [2]. However, with global warming being such a large issue, it draws the question: will this be enough?

Jem Bendell, professor or Sustainability Leadership at the University of Cumbria UK, would say no [10]. Bendell writes about how he believes that social collapse due to climate change is unavoidable. While scientists cannot be sure how serious climate change is, Bendell argues that they often underestimate the effects of global warming. He explains how climate change is no longer proceeding at a linear rate. Instead, as a population we need to be aware that "non-linear changes are of central importance to understanding climate change, as they suggest both that impacts will be far more rapid and severe than predictions based on linear projections and that the changes no longer correlate with the rate of anthropogenic carbon emissions" [10]. This shows that the environment has changed rapidly in recent years. Climate change no longer follows the linear progression it used to follow. Instead, the global temperature is increasing much faster, and this is having irreversible effects on the planet.

When it comes to current world issues, people tend to push global warming to the backburner. However, this issue is very pressing, and will have direct effects on everyone. Mast describes some of these effects: "The consequences of surpassing a 2-degree Celsius increase in global temperature isn't just widespread crop failures, record-setting heat and rising seas. An August PNAS study says it could also tip the planet into new, irreversible climate patterns" [9]. These predictions are not meant to be taken lightly. Crop failure adds to the already serious and widespread issue of lack of food supply. Climate change has reduced crop yield by 1-2 percent every decade for the last century, and this reduction costs the agriculture industry billions of dollars per year [10]; with the population continuing to grow, this issue will get worse. More people to feed, more greenhouse gases emitted from this growing population, and less food due to crop failure from random climate patterns.

Furthermore, the increased heat and rising sea level have many negative consequences as well. Increased average temperature in the artic has caused the polar ice caps to melt. Research shows that they have reduced by 13.2% every decade since 1980 [10]. However, this melting has become more rapid in recent years (following the nonlinear trend of climate change described by Bendell). Satellite research published in July 2018 shows that two glaciers in East Antarctica have lost a very significant amount of ice recently- within the last 15 years [9]. Mast explains why this is so significant since "these two glaciers — only a portion of the eastern ice sheet — hold enough ice to cause 16 feet in sea level rise" [9]. Rising sea levels not only have a negative impact on marine ecosystems (and in turn the amount of seafood available to the population), but also will directly affect many coastal cities. In the United States, some states are already seeing consequences due to this increased pace of sea level rise; Louisiana being one that most citizens are familiar with. As this trend continues, more flooding and loss of viable land will continue to occur. Once again, with rising population and more mouths to feed, this will add to overcrowding and starvation.

While rising sea levels due to the polar ice caps melting is clearly a concern, it is not even what scientists are most concerned about when it comes to global warming. One of the main ways glaciers help keep artic temperatures low is by reflecting the sun's rays (white ice reflects UV rays) [10]. Without this reflection, the artic would warm substantially- much more than any amount of greenhouse gas destruction of the ozone has caused. According to Bendell, "Writing in 2014, scientists calculated this change is already equivalent to 25% of the direct forcing of temperature increase from CO_2 during the past 30 years" [10]. This means that even if we reduce CO_2 emissions by a quarter, it would already be outweighed by the melting of the polar ice caps that we caused from rapid rising temperatures.

Carbon not only affects the ocean by increasing sea level, it also negatively impacts it through a process called ocean acidification. Most of the carbon dioxide released into the atmosphere by the burning of fossil fuels is absorbed by the ocean. Hodaka Kawahata, professor in the Atmosphere and Ocean Research Institute at the university of Tokyo, and colleagues, explain why this is such a problem: "By the end of twenty-first century, the surface waters of the ocean could be more acidic, resulting in an undersaturation condition with respect to carbonate minerals in some areas of high latitude. Ocean acidification (OA) will induce severe stress in calcifiers, some of which are sensitive to environmental changes at global and local levels." [11]. Calcifiers are marine life that significantly contribute to the global carbon burial rate. This means that, a higher pH in the ocean could actually cause even less CO_2 to be absorbed. Furthermore, this could be detrimental to many marine ecosystems. No one can be sure exactly what will happen by disturbing the acidity of these underwater ecosystem, but most scientists predict negative consequences for most ecosystems, including the already endangered coral reefs.

These statistics clearly exemplify why we need to reduce carbon emissions and slow down global warming. While some scientists like Bendell would say it's too late, they still would argue for drastic changes to minimize further human induced climate change. The hope for the human race relies on finding ways to carry out life without releasing large amounts of greenhouse gases into the atmosphere. CarbFix can help achieve this goal.

APPLICATION AND SUMMARY

An idea that developed from a talk between the President of Iceland and some scientists has become a reality. The CarbFix Project has come a long way since it was founded in 2006. The pilot phase that took place in 2010 may have had a few setbacks, but it led to the discovery of many important things. After discovering that the carbon dioxide was able to form stable carbonate materials, the project had a viable way to go about permanently storing CO_2 in the subsurface. The first test runs showed scientists what was working and what was not. After further research, changes, and setbacks, the full industrial scale project was able to be run in 2014. This was a major accomplishment for the CarbFix team, and for the future of this project.

Throughout this paper, we have highlighted why Carbfix is such an important innovation. As described in the previous section, the earth's future could depend on CCS technology success, like CarbFix. The CarbFix project has faced some challenges, but has overcome these to achieve great steps toward productive carbon capture and storage. While the process is not yet perfected, the outlook for this project looks promising. CarbFix is very relevant due to the growing seriousness of global warming. That being said, it is in the best interest of the population to support the success of CarbFix.

In order for this project to continue to progress, CarbFix needs more widespread support, testing, and use. The CarbFix process can be used at plants or factories that produce large amounts of carbon dioxide. Of course, the original CarbFix project at the Hellisheidi geothermal power plant was ideal since there is an abundance of basaltic rock there. This pilot program shows how effective the CarbFix method is, currently capturing "34% of CO_2 emissions and 68% of H_2S emissions from Hellisheidi power plant" [6]. While this is not all of the harmful gases produced, it still is a step in the right direction. Also, this plant is leading by example, setting high goals for the future. Leaders have said, "The vision of Reykjavík Energy calls for zero emission of the power plant as soon as possible" [1]. Furthermore, the CO_2 is able to be quickly converted to stable carbonate materials, only taking around 6-12 months to solidify [6]. Factories have an incentive (other than saving the planet) to implement this process as well. According to Oelkers, "Reykjavík Energy has estimated the monetary value of savings from being able to use the CarbFix method as a way to reduce H_2S emissions from Hellisheidi power plant compared to conventional industrial sulphur removal methods was over 100 million euros through March 2018" [6]. This shows that CarbFix not only is crucial for reducing climate change, but can also help reduce costs for dealing with harmful gas production. Industrial sites should be eager to take part in such a program. Clearly, the world could largely benefit from implementing this process on a large scale.

More funding is needed to allow more research to be done and this process to become widespread. Obviously, factories that are not near basaltic rock would have to have some method to transfer the gases to an injection site. However, factories near the ocean may not have to. The CarbFix2 project, funded by the EU as mentioned earlier, will work on injecting CO_2 into basalt below the ocean floor. This allows for safe storage, and the use of seawater (which is much cheaper to use than fresh water). Furthermore, this project will explore capturing carbon dioxide directly from the air, not just as a byproduct of industry [6]. By doing so, this project would not just be stopping new greenhouse gases from entering the environment, but also filtering out carbon dioxide that is already in the air. This is a big step for CCS technologies that could greatly reduce climate change if successful and implemented across the globe.

Prospects for further research and funding are hopeful. As stated earlier, the world has taken note of serious consequences due to climate change: "Research activities in CCS have surged up over the last decades in the US due to government plan for providing 2.4 billion dollars to support CCS projects and investigation" [8]. Hopefully, other countries will follow suit and provide funding to further CCS technology like CarbFix. This is especially important now with how rapidly global warming is increasing.

CarbFix will only become more relevant as the population grows. A larger population requires more land for human settlement. This in turn leaves less room for natural carbon dioxide absorption from trees and other plants. Also, more people require more food. Climate change directly impacts this food supply because agricultural output is reduced by recent climate patterns. This reduction is costing the agricultural industry billions of dollars every year. The most obvious impact of increased population is even more carbon dioxide production. Industrialized society members produce greenhouse gases in almost every task of everyday life: driving to work, heating their homes, electricity usage, and many other things. Because of this, CO_2 waste is being produced at rates faster than the earth's atmosphere can handle, ruining environment sustainability.

Environment sustainability is only one of the three components that make up the sustainability of a product. For a product to be sustainable it must uphold the perfect balance between the multiple components of sustainability: social, financial, and environmental. CarbFix upholds its sustainability in the social aspect by keeping open communications with the public and considering all ethical dilemmas raised into question, as we discussed earlier in our paper. For example, leakage and natural disaster concerns. Nonetheless, CarbFix has made themselves cognizant of these concerns and has provided their research/answers to these questions. This is important because if a project is not socially accepted, it cannot be sustainable since it will never be approved/supported. As mentioned earlier, public support is important for funding and research.

As to the financial aspect, CarbFix is continually improving its efficiency and cutting back unnecessary costs. A product cannot be sustainable if it is unaffordable. Anything too expensive will never be accepted and used, preventing any sustainability. According to Muhammad Anwar, Professor in the Sustainable Development Study Center, at the Government College University, Lahore, Pakistan, and colleagues, CarbFix is the most affordable method of CCS [12]. Anwar explains "The cost of industrial scale CarbFix operations at Hellisheidi are $24.8/ton. That is significantly cheaper than other known methods for carbon or sulfur capture and sequestration" [12]. This shows that CarbFix is the most financially sustainable solution to excess carbon dioxide in the environment.

In the last aspect of the environment, CarbFix was created "with an ambition to significantly reduce the CO_2 emissions in order to combat global warming and achieve environmental sustainability" [12]. CarbFix's sole purpose is to help reduce our carbon footprint on the earth and attempt to improve the quality of life for ourselves and for future generations. Environment sustainability is achieved when the rates of waste generation do not exceed the environment's capacity. As of now, humans are producing more carbon dioxide than earth's environment can handle. The consequences of this, as mentioned above, are rising ocean pH levels, melting of the polar ice caps, and rising global temperatures. CarbFix was created to help combat this and is a solution towards achieving environment sustainability.

CarbFix is a sustainable innovation that dissolves CO_2 emissions in water and then injects that water into basaltic bedrock. In the rock, the water reacts with minerals forming solid carbonates where the CO_2 will be stable for thousands of years. CarbFix's longevity can provide the solutions we need to save our planet. With more than 10% of earth's crust being basaltic, the human carbon footprint can be significantly reduced in ways no other innovation/process could possibly achieve. CarbFix is worth everyone's investment of time, support, and money: engineers, politicians, business owners, and the general public.

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