SEMESTER 2
2021/2022

THE CARBONIC CELL

Group 113

Made by
Abdelhamid Ahmed
Omar Mohamed
Ziad Aboud
Belal Hassan
Muhammed Emad

Key words:
Redox reaction - Electrical energy – Greenhouse gases – Electrochemical cell

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Introduction

Egypt has overcome many grand challenges in the past and has even more to overcome today. The energy crisis is the one most severe problem that plagues Egypt. Producing energy from unrenewable resources such as fossil fuels cause a decrease in the percentage of it, and Egypt must find renewable resources that have a high efficiency in producing energy to overcome the energy crisis. Another concern related to the energy crisis is that burning fossil fuels causes the percentage of greenhouse gases in the atmosphere to increase, especially carbon, which leads to the harmful effects of greenhouse effect. According to the Intergovernmental Panel on Climate Change (IPCC), emissions from fossil fuels are the primary cause of global warming. In 2018, fossil fuels and industry accounted for 89 percent of global CO2 emissions. So, burning fossil fuels to produce energy not only responsible for climate change, but it also affects the public health, and increase percentage of pollution. So, another way to produce energy must be considered by Egypt. The source of energy must be renewable, eco-friendly, and cost efficient. So, producing energy using greenhouse gases (especially carbon dioxide) will be a solution to both climate change and energy crisis problems. Producing energy from greenhouse gases will decrease the percentage of pollution in air, and give the earth a space to heal from human industrial activities

I. Chapter One

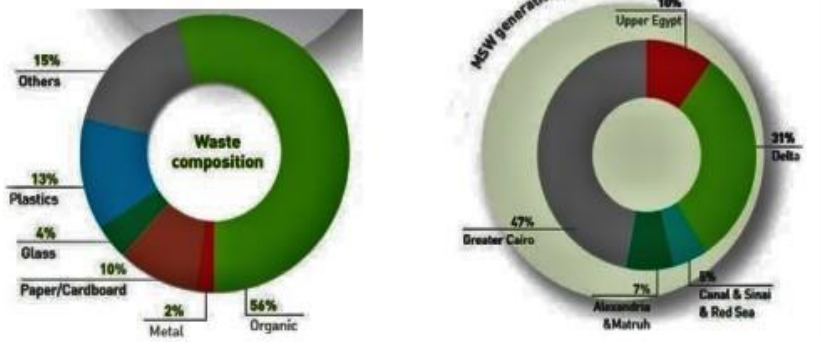
(Present and justify a problem and solution requirements)

Egypt Grand challenges

Recycle garbage and waste for economic and environmental purposes

Solid wastes are unwanted and useless materials that result from the daily use of residential areas. They may be categorized according to their content (organic materials, glass, metal, plastic, paper, etc.) or according to where they came from (domestic, industrial, commercial, agricultural, etc.).

Recycling refers to the removal of items from the waste stream to be used asraw materials in the manufacture of new products. In addition, it has a great economic effect, as it provides raw materials which are reused again. From the perspective of the environment, it reduces the unwanted waste that is dumped in the streets or illegal dumbs. in a report issued in 2009. The report estimated that the annually generated solid waste in Egypt reached nearly 75 million tons, while municipal waste was about 20 million tons. And the most critical situation is in Great Cairo because of the high population. (As shown in graph (1)), Cairo generates 47% of the municipal waste. There are more concerns about the waste management conditions in Egypt.



Graph 1: water composition

- The total annual municipal solid waste generation in Egypt has increasedby more than 36% since 2000.
- More than 80% of the generated municipal solid waste in Egypt is simply dumped, as the overall recovery rate has not exceeded 11.5%.

Recycling is from the effective methods of waste management and the processis grouped into six main phases:

1. Waste Identification.
2. Handling, separation, and storage at the source.
3. Collection.
4. Transfer or transport.
5. Processing and transformation.
6. Disposal.

Causes: -

From causes that increase the number of unused wastes is:

- **Dumping most of the garbage in illegal dumps and streets.**

  Because of a lack of awareness of the dangers of throwing garbage in the street, also due to the increase in the number of illegal garbage collectors that dumb them in illegal garbage dumps. So, 44.8% of garbage in Egypt is dumped in the street.

- **Not having a clear waste management method.**

  According to a recent report published in science magazine, Egypt occupies the 7^{th} position in the list of countries with the most mismanaged plastic waste. The report was based on data collected in 2010. Egypt produces 75 million tons of solid waste without having a clear plan to reuse them.

Impact: -

- **Lack of clear waste management method led to an increase in the amount ofgarbage on the streets.**

Because of bad waste management, the percentage of clean streets decreased remarkably. In Great Cairo, 40% of the garbage is dumped in the streets, where it loses its economic benefits and breaks down the ecosystem.

- **Wastes affect public health and increase pollution.**

Air pollution has been a problem for Egyptians for years. In Greater Cairo, which has the highest percentage of waste, there are levels of PM10 and PM2.5 that pose the greatest risk to people's health and are several times higher than the levels the World Health Organization (WHO) recommends.

- **Increase the amount of greenhouse gases.**

Producing plastic from petroleum generates many greenhouse gases, and these gases trap the heat in the earth, increasing the temperature and affecting the climate; recycling prevents this by reusing these materials rather than dumping them in landfills.

- **Landfills fill up faster.**

When recyclable materials are dumped in landfills rather than recycled, the landfills fill up faster and faster, resulting in increasing the garbage in the streets, increased air pollution, and forcing the government to build new landfills, which hurts the economy.

Increase industrial and agricultural base

Industry and agriculture are the most important pillars for economic development in both leading and developing countries, and they have become a key indicator for measuring economic progress, so Egypt seeks to expand and improve its industrial and agricultural bases throughout the country's governorates.

The industrial sector is the backbone of economic development in Egypt, where industry plays a key role in creating jobs and reducing the employment rate, as well as developing various economic activities, launching new technologies and products to Egypt, reducing importation, and boosting the country's export capabilities.

Major industrial complexes exist in Badr, South Raswa in Port Said, Marghem in Alexandria, Al- Sadat City, Kufr Al-Dawwar, and Mahalla Al-Kobra. The Upper Egyptian governorates are going to be home to nine industrial complexes in Aswan, Sohag, Assiut,
Beni Sweif, Fayoum, and Minya (as shown in figure (1)).

Figure 1: QIZ locations in Egypt

In these industrial zones, Engineering, electrical machinery (renewable energy), food processing, chemicals and pharmaceuticals, textiles, and garments, building materials, furniture, and paper and paperboard have traditionally been the most important industrial sectors in terms of contribution to manufacturing value-added+. In addition to the existing sectors, the strategy proposes a greater focus on the following:

- engineering machinery and equipment (renewable energy)
- labor-intensive consumer electronics
- automotive components
- life sciences

- biotechnology
- ethnic products.

In most developing countries, increasing agricultural production is now widely recognized as a prerequisite for rapid industrial and overall economic growth.

Agriculture is a significant part of the Egyptian economy, accounting for 11.3 percent of the country's GDP. Agriculture employs 28 percent of the workforce, and agriculture employs over 55 percent of the workforce in Upper Egypt. Small farms dominate Egypt's agriculture sector, which uses traditional practices that do not meet international standards. The strategic goals of the agricultural sector include Improving crop yields per unit of land and per liter of water consumed, closing the gap in terms of food security, achieving self-reliance, and increasing agricultural export revenue in foreign currency.

Causes: -

- **The poor technical education.**

  The main reason for the poor technical education in Egypt which is responsible for the labor force in the industry is the rising population, which leads to poor educational quality in both schools and public universities. Because of the large number of students per class and the poor quality of workshops and laboratories. Furthermore, there is a lack of marketing and advertising skills. All this resulted in the decline of the productivity of Egyptian labor.

- **The shortage of energy and natural gas.**

Many production and consumption activities, such as cement, steel, and fertilizers, rely on energy as a basic input, making it a key source of industrial growth. Due to Egypt's dense population, the residential use of energy brings down industrial use. The pressure on these industries has been reflected in headlines and company statements. Samir Naamany, the commercial director of Ezz Steel, the largest producer of iron and steel in the Middle East, said that “the biggest problem we faced in 2015 was the lack of energy, which led to a decline in production and exports in our factories.”

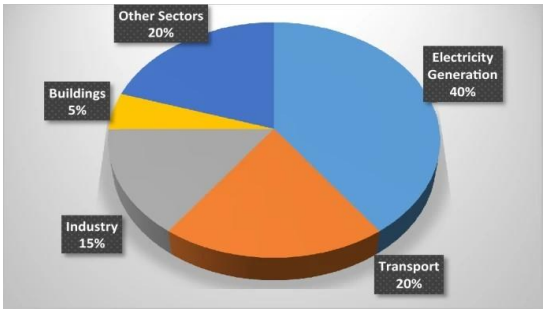
- **The lack of dollars in the Egyptian monetary system, and a deflating Egyptian pound.**

Due to the continuous devaluation in the pound, the exports become more expensive for the industry in Egypt, but on the other hand, inputs, imported and domestic, have become more expensive, and as production has slowed due to decreased energy, companies can produce and export less, further adding to Egypt's foreign currency shortage.

Impacts: -

- **Industrial pollution.**

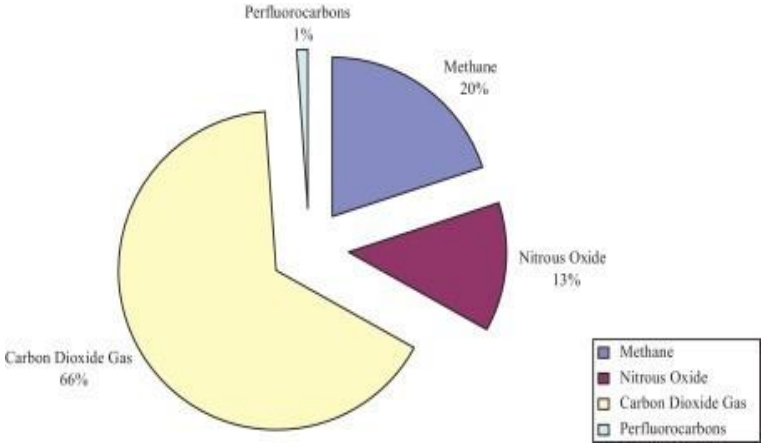
The industrial process emits excessive amounts of organic compounds carbon monoxide, carbon dioxide, hydrocarbons, and chemicals into the air. (As shown in graph (2)) industrial sector in Egypt is responsible for (15%) of CO2 emissions so it causes a greenhouse effect on the air reason for the greenhouse effect in the air.



Graph (2): CO2 emissions by Egypt's sector

- **Climate crisis due to Agriculture activities**

In addition to industry, Agriculture activities often release harmful chemicals like pesticides and fertilizers. Organic matter gradually reduces the water and oxygen in the soil during the flooding of rice fields; as a result, methane is produced by anaerobic decomposition. Globally methane emission is much lower than CO2 emissions annually (as shown in this graph (3)) but it is more effective in global warming.



Graph (3): Methane emissions from agricultural sector

Address and reduce pollution fouling our air, water, and soil

The release of harmful materials into the environment is referred to as pollution. "Pollutants" is the term used for these hazardous substances. Pollutantscan be naturally produced, and they can also be caused by human activities.
Pollution threatens the whole world, and Egypt specifically. There are many types of pollution, including air, water (the Nile in Egypt), soil pollution, and other types ofpollution.

In Egypt, air pollution is caused by greenhouse gases. Greenhouse gases are emitted as an effect of the burning of fossil fuels to produce energy. As a result, it threatens public health and is the main cause of global warming. The pollution of the Nile River is also a problem that is frequently overlooked. It's caused by people throwing garbage into the Nile. Throwing garbage into the Nile may seem ineffective to some, but it's extremely harmful to the environment. Another type of pollution is soil pollution, which is mainly caused by using harmful agricultural pesticides. It affects the soil, which is needed for agriculture. It also causes threatening diseases and leads to water pollution.

Causes: -

Air pollution:

- Fossil-Fuel Emissions.

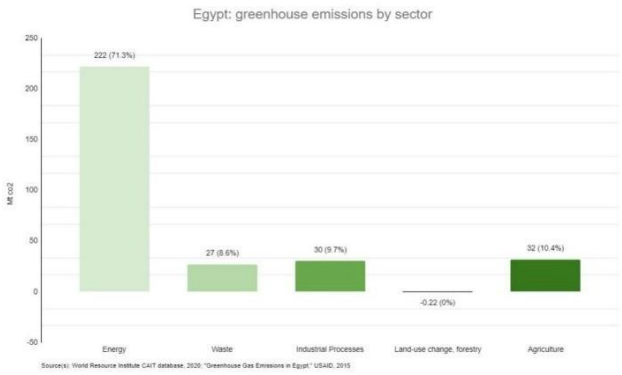
The combustion of fossil fuels like coal, petroleum, and other factory combustibles is the major cause of air pollution in Egypt. These are commonly found in power stations, manufacturing factories, waste incinerators, furnaces, and other fuel-burning heating devices. Egypt is heavily dependent on hydrocarbon-based fossil fuels to produce energy. Burning fossil fuels causes the greatest amount of pollution. (As shown in figure 5).

- greenhouse gas emissions due to agriculture.

It’s the second reason for air pollution, which contributed to 32 Mt CO2, or 10.4% of our total in 2016. (As shown in figure 5).

- **Manufacturing emissions.**

The emissions due to manufacturing are the third main reason for greenhouse gas emissions. In 2016, manufacturing and industrial operations combined emitted 30 Mt CO2, accounting for 9.7% of Egypt's total CO2 emissions (as shown in graph 4). Minerals, chemicals, metals, pulp and paper, food and drinks, halocarbons, aerosols and solvents, electronics, and electrical equipment, as well as the usage of refrigeration and air conditioning, are all major contributors, according to Climate Watch Data.



Graph (4): CO2 emissions sources

Water pollution:

- Industrial pollution.

Egypt's surface and groundwater are rapidly deteriorating because of increased discharges of extremely contaminated domestic and industrial effluents into its waterways.

- Agricultural pollution.

Water pollution is also caused by the overuse of pesticides and fertilizers in agriculture. The leakage of nitrates from nitrogen fertilizer and bacteria from livestock and feed wastes polluted local surface and groundwater in many agricultural areas and the Nile.

- Throwing garbage in marine.

Many Egyptians throw garbage in the Nile and that harms Egyptian agriculture because Egypt mainly depends on the Nile for agriculture.

Soil pollution:

- Agricultural pollution.

Using pesticides excessively leads to soil pollution and this affects the agriculture of Egypt and water pollution.

- Desertification.

Desertification is land degradation in arid, semi-arid, and dry sub-humid areas, collectively known as drylands, resulting from many factors, including human activities and climatic variations which lead.

- Crop intensification.

Due to the difficulty of a horizontal expansion, crop intensification is used as a kind of vertical expansion. This led to continuous depletion of nutrients in the soil, especially nitrogen, requiring the massive use of chemical fertilizers, which have negative effects on crops that cause serious diseases to Man after eating them.

Impacts: -

- **Air pollution.**

  In Egypt, air pollution was involved in 90,559 premature deaths in 2019, accounting for more than 12% of all deaths in 2017. According to the World Health Organization database, heart disease (57.9%), stroke (17.7%), pulmonary and lower respiratory diseases, and cancer (24.4%) were among the air pollution-related disorders that caused premature death in Egypt in 2016. (WHO, 2018).

- **Global warming.**

Global warming is the long-term warming of Earth's climate system that has been observed since the pre-industrial period (between 1850 and 1900) because of human activity, principally fossil fuel combustion, which increases heat-trapping greenhouse gas levels in the atmosphere.

- **Water pollution.**

The marine ecosystem is threatened because of the water pollution that occurred dueto throwing garbage into oceans. Humans' lives are also threatened by water pollution as Egyptians suffer from long-term diseases and require medical care owing to kidney failure, cancer, or the Hepatitis C Virus (10-20% of the population). Renal diseases and kidney failure are at dangerously high and rising rates. For an estimated 72% of patients, drinking polluted water and being exposed to pesticides were identified as some causes of kidney disease by public health researchers.

- **Soil pollution.**

Soil pollution has a variety of negative consequences on ecosystems, as well as human, plant, and animal health. The agriculture of Egypt is badly harmed due to the soil pollution that occurred due to the excess use of pesticides. Air pollution is also a serious threat to public health as it reduces Egyptians' life expectancy by two years on average due to illness and incapacity (Apte et al., 2018). Soil pollution can also cause central nervous system depression, headaches, nausea, fatigue, eye irritation, and itchiness.

Reduce and adapt to the effect of climatic change

Climate change is a long-term change in the environmental conditions that affect weather patterns on earth in several ways and it is caused by certain factors that might be internal or external. Over the past century, Earth's average temperature has increased by approximately 0.6 degrees Celsius. There is no doubt that climatic change is one of the most severe problems worldwide not just in Egypt and it became a global concern in the last few decades.

Egypt is continually trying to reduce the effects of climate change and it has taken various steps which include:

- Introducing electric buses,
- Boosting renewable energy.
- Trying to ban plastic bags.

It has also contributed to the Climate-related Conference "2019 UN Climate Action Summit" which was held in New York on the sidelines of the 74th session of the United Nations meetings in September 2019 which was held to highlight the danger of global warming considering that the greenhouse gases emissions have reached levels that have never been reached before and are continuing to increase.

Causes: -

Natural climate change:

- **Volcanic eruptions.**

During volcanic eruptions, there is a huge amount of ash, aerosol droplets, and volcanic gases, like carbon dioxide, and sulfur dioxide released into the atmosphere. Carbon dioxide is a greenhouse gas, so it can cause global warming, while sulfur dioxide has a cooling effect.

- **Movement of plate tectonics**

The movement of plate tectonics generates heat by changing the ocean's current. The Change in the ocean's currents along with atmospheric circulation caused by the colliding plates redistributes the heat of the earth, which causes the climate to change slowly.

- **Changes in the earth's orbit around the sun.**

Any small change in the earth's orbit around the sun changes the distribution, and the amount of energy received by the earth from the sun, as a result, the Earth gets warmer or cooler.

Anthropogenic climate change:

- **The increase of the percentage of greenhouse gases in the atmosphere.**

Greenhouse gases emissions have reached levels that had never been reached before due to the human activities that emit large amounts of greenhouse gases, which trap the sun's heat in the earth causing global warming. Greenhouse gases include methane, carbon dioxide, nitrous oxide, and fluorinated gases. Their percentage gets higher by a lot of activities which include:

- **Cutting down trees.**

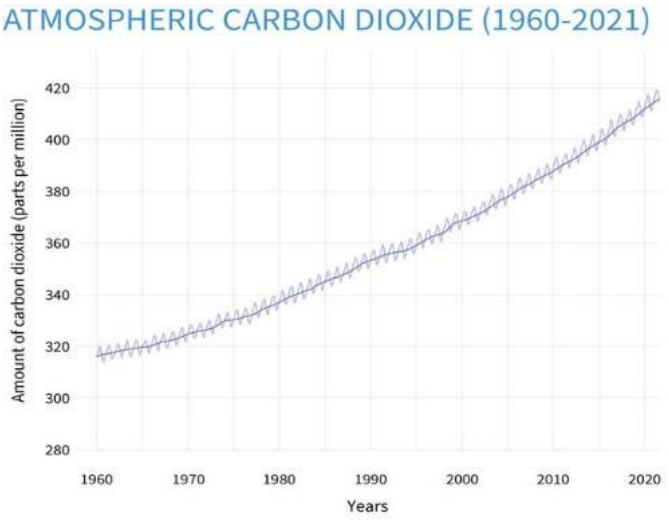
Trees absorb carbon dioxide and produce oxygen. When trees are cut down, the percentage of carbon dioxide in the atmosphere increases.

- **Increasing livestock farming.**

A large amount of methane is produced when cows and sheep digest their food.

- **Burning oil, gas, and coal.**

When burning coal, natural gas, and oil, carbon dioxide, and nitrous oxide are produced. The emission of carbon dioxide by humans is the largest contributor to global warming. In 2020 its concentration in the atmosphere had risen to 48% above its pre-industrial level. graph (5) shows the rapid increase in the quantity of carbon dioxide from 1960 to 2021.



Graph (5): the quantity of carbon dioxide from 1960 to 2021

Impacts: -

- **higher temperature.**

Almost all areas are experiencing more hot days and heatwaves, this is due to global warming. It is easier for the wildfire to start and rapidly spread. 2020 was one of the hottest years ever recorded. The high temperature makes it harder to work and can cause more heat-related illnesses.

- **Severe storms.**

Changes in climate cause changes in rainfall which is a reason for more frequentand severe storms and floods. It can also ruin crops causing hunger.

- **Rising of the ocean.**

The ocean absorbs most of the heat from global warming causing the ice sheets to melt which can cause more floods threatening coastal areas and islands causing displacement and poverty. Weather-related disasters displace around 23 million people a year.

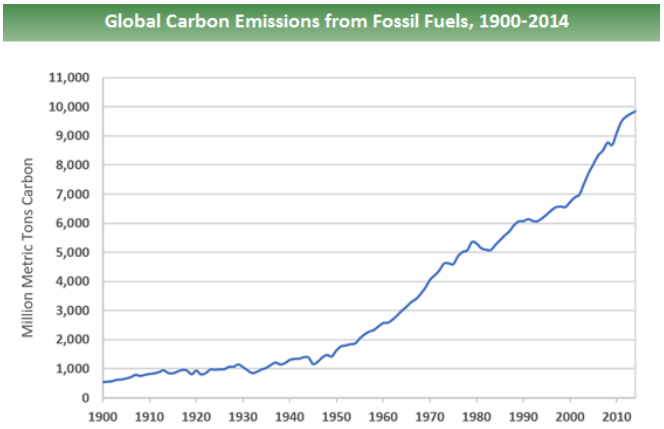
- **Threatening wildlife and marine life.**

The increase in the temperature makes it easier for the wildfire to occur and spread which can be dangerous for the animals living in these areas. Oceans absorb a huge amount of CO2 which makes them more acidic, endangering marines.

Problem to be solved

Generating energy from greenhouse gases

Greenhouse gases are the gases that contribute to global warming because it traps heat in the atmosphere while letting the light escape. And they include:
Water vapor, Carbon dioxide, Methane, Ozone, Nitrous oxide, and Chlorofluorocarbons.
Greenhouse gasses are emitted mainly because of human activities,



graph (6): carbon dioxide gas increasing

(Graph(6) shows the emissions of carbon due to fossil fuels) but sometimes, it is emitted due to natural phenomenon without human intervention. The carbon dioxide emission rate has been rapidly increasing since the beginning of the industrial revolution (1760), and it is still increasing at an excessive rate now. The most available greenhouse gas in the atmosphere is carbon dioxide. Its emission rate is exponentially increasing as shown in figure (2). This extreme increase in greenhouse gases emission led to an uncontrollable change in the climate. Climate change leads to long-term repercussions like ice melting, ocean warming, sea-level rising, and ocean acidification. All of these are critical challenges that must be addressed to protect the earth.

If solved:

- Ice wouldn’t melt anymore.

Heat is trapped in the earth, causing global warming. As a result, the temperature rises, melting the ice at both poles. The temperature will not rise if this problem is handled, and the ice will not melt.

- Ocean won’t get warmer.

Temperatures in the world's oceans are rising as more heat is absorbed—not just at the surface, but also 1,500 feet below. If the problem is resolved, the temperature will fall, allowing the oceans to recover.

- Sea levels won't rise more.

As mentioned earlier, ice is melting at both poles. Causing sea levels to rise. If the problem is solved ice won't melt therefore the sea levels won't rise.

If not solved:

- Ice melting.

If the problem is not solved the temperature would increase and get higher day by day causing the ice to melt at both poles.

- Warming the oceans

If the issue is not resolved, the temperature will rise. Causing the ocean to absorb more heat and thus get warmer.

- Rising sea levels

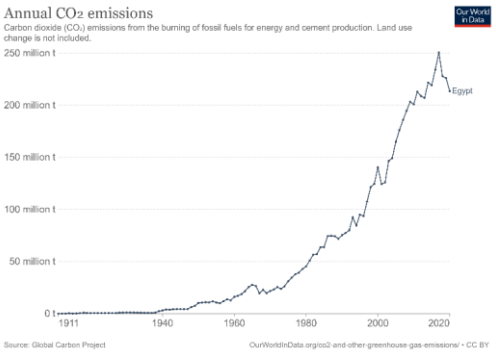
Higher temperature causes the ice to melt at both poles when the ice met water is formed thus the sea levels would rise.

Research

Topics related to the problem

- **The greenhouse effects and Global warming**

The greenhouse effect is caused by the interaction of the sun's light with greenhouse gases such as carbon dioxide, methane, nitrous oxide, and fluorinated gases. graph (7) shows the annual emissions of CO_2 Greenhouse gases are consisting of two or more atoms making them possible for them to trap heat in the atmosphere and prevent releasing them into space causing a rise in the global temperature. The greenhouse effect keeps life on Earth by warming and improving the plant with a suitable amount of heat (15



Graph 7 annual CO_2 emissions

degrees Celsius) and preventing the cooling of Earth and making life possible, but the increase of greenhouse gases lead to overheating and global warming. 30% of the solar energy that reaches the Earth reflects the space while 70% of them are absorbed by lands, ocean, and the atmosphere and heats the planet. This heat is then reflected in form of invisible infrared light to space, 90% of this infrared radiation absorbed by the greenhouse gasses causes global warming. The Intergovernmental Panel on Climate Change (IPCC) predicts a rise in temperature from 2.5 to 10 degrees Fahrenheit over the next century. Global warming has many impacts on the Earth and the human, for Egypt the increase in global warming will lead to:

1. The rise of the Mediterranean Sea level due to the melting of the two poles' ice, poses a threat to five governorates on the northern coast: Port Said, Kufr El-Sheik, Damietta, Behera, and Dakahlia. If the water level rises to more than 100 cm, saltwater will cover a vast area of the northern delta lands, causing soil salinity, and affecting crop quality, productivity, and food scarcity.
2. Increase the risk of droughts, particularly given that 86 percent of Egypt's land is desert, increasing the risk of desertification, drought, and a shortage of water resources, resulting in water poverty.

- **Ocean acidification**

Ocean acidification is one of the repercussions of rising carbon dioxide levels in the atmosphere. Each year, the oceans absorb around 25% of the total carbon dioxide emissions from the atmosphere. Carbon dioxide dissolves in water and forms carbonic acid (H_2CO_3), a weak acid that breaks down into hydrogen ions (H+) and bicarbonate ions (HCO_3^-). The average PH of the seas hit 8.1, which is slightly alkaline, but if the oceans continue to absorb carbon dioxide, the PH will drop, and the oceans will become more acidic.
The rate of increase in ocean acidity has accelerated in recent years, posing a threat to ocean systems' ability to respond to CO2 increases. Ocean warming and deoxygenation are linked to ocean acidification, resulting in climate changes such as heat, acidity, and deoxygenation in the marine environment. The problem of ocean acidification will persist if carbon dioxide levels rise. To avoid this problem, the carbon dioxide concentration in the atmosphere must be reduced to between 320 and 350 parts per million (ppm). Ocean acidification has an impact not just on ocean ecosystems, but also on ocean-related societal benefits such as fishing, food

security, and natural shoreline protection. Increases in seawater acidity have harmed species' development and reproduction, particularly creatures that build hard shells and skeletons by mixing calcium and carbonate from seawater (skeletons and shells can dissolve if the PH drops too low), as well as corals, mollusks, and many phytoplankton and zooplankton species that constitute the foundation of marine food webs. The acidity of seas affects many creatures that play essential roles in food webs, such as the pteropod, a tiny sea snail the size of a little pea. After 45 days in corrosive waters, its shells progressively dissolve.

Topics related to the solution

- **CCUS technology**

Carbon Capture, Utilization, and Storage (CCUS) is a key emissions reduction technology that consists of a set of methods (as shown in figure (2)) that involves capturing CO2 from flue gas and the atmosphere, recycling it for use, and determining safe and long-term storage options.

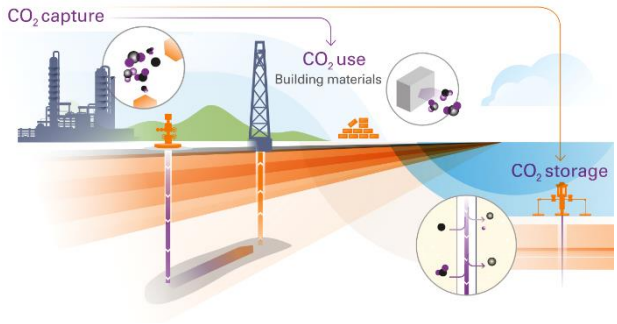


Figure (2): CCUS Technology

CO2 is captured before it reaches the atmosphere in industries such as cement and steel production, hydrogen production from fossil fuels, incineration of waste, and power generation. It is then compressed to over 100 atmospheres and injected into porous rock layers a kilometer or more underground, beneath impermeable rocks that will keep it in place for tens of thousands to millions of years. Alternatively, the CO2 can be incorporated into products such as building materials if they give the same long-term storage.

In most cases, a chemical substance called amine is used to capture a large amount of highly pure CO2 before it reaches the atmosphere in industries such as cement and steel production, hydrogen from fossil fuels, incineration of waste, and power generation. When flue gas meets an amine solution, the amine absorbs CO2. The amine and CO2 are then separated, and the CO2 can be captured by heating this CO2-containing solution to around 120 °C.

CO2 is stored in a "reservoir" that is deeper than the ocean and made of porous rock, such as certain types of sandstone.

800 meters below the surface of the earth. The reservoir must be protected with a "cap rock" made of mudstone, etc. to prevent CO2 leakage. Even long-distance pipelines carrying large amounts of CO2 can have relatively low costs, though some locations will have easier access to storage than others.

For example, in Japan, many potential CO2 storage sites are existed offshore, beneath the
seabed. Furthermore, many large-scale CO2 emission sources, including thermal power plants and other facilities, are in coastal areas. Therefore, CO2 storage below the seabed is considered suitable, and CO2 transportation by ship is deemed a viable option for transporting CO2 offshore from coastal areas.
CCUS will be critical for achieving net-zero emissions fast enough to avoid dangerous climate change and meet sustainable development goals for the world's population.

Carbon utilization has the potential to make CCUS projects more commercially viable in the industrial, steel, cement, and chemical sectors. CO captured can be used as a feedstock to make concrete, methanol, ethanol, carbonates, plastics, chemical products, etc.

- **Electricity generation**

The process of generating electric power from primary energy sources is known as electricity generation. It is the stage before the electric power is delivered (transmission, distribution, etc.) to end-users or stored by utilities in the electric power sector (using, for example, the pumped-storage method).
Because electricity is not found naturally, it must be "produced" (that is, transforming other forms of energy into electricity). Production takes place in power stations (also called "power plants"). Depending on the type of energy, electricity can be generated in a variety of ways.
Coal and natural gas are used to generate electricity by combustion (thermal power), while Uranium is used to generate electricity by nuclear fission (nuclear power), and their heat is used to boil water and rotate a steam turbine.

Sunlight is directly converted into electricity (photovoltaics), wind rotation energy is converted into electricity (wind power), and running water rotates a water wheel to generate electricity (hydro). Magmatic heat boils underground water, causing a steam turbine to spin and generate electricity (geothermal). researchers are continuing to develop technology to convert resource energies or renewable energies into electricity with less loss. Maintenance and operator training are also important for the operation of a power plant.

- **Electrochemistry and electrochemical cells**

Electrochemistry is a branch of physical chemistry concerned with physicochemical phenomena that occur when electrical and chemical energy exchanges, usually in liquid media such as solutions, are generated by electron movements from one element to another in an oxidation-reduction ("redox") reaction. In this sense, electrochemistry mainly deals with systems in which electrical currents flow, such as electrochemical generators or batteries found in a variety of everyday applications such as automobiles, cell phones, and so on.

The electrochemical cell is a device capable of either producing electrical energy from chemical reactions or using electrical energy to stimulate chemical reactions. Voltaic or galvanic cells are types of electrochemical cells that can produce an electric current from spontaneous Oxidation-Reduction reactions.

In the galvanic cells (Voltaic cells), Two electrodes are usually immersed in one or more suitable electrolytes and are connected externally in an electrochemical cell. A chemical reaction takes place. One electrode undergoes oxidation, and the electrons released are used to reduce the other electrode. The anode is the electrode that undergoes oxidation, while the cathode is the electrode that undergoes reduction. Because electrons flow from anode to cathode, electricity flows from cathode to anode. The Daniel Cell is the best example of a galvanic cell made up of a Zn rod dipped in ZnSO4 solution and a Cu rod dipped in CuSO4 solution (as shown in figure (3)).

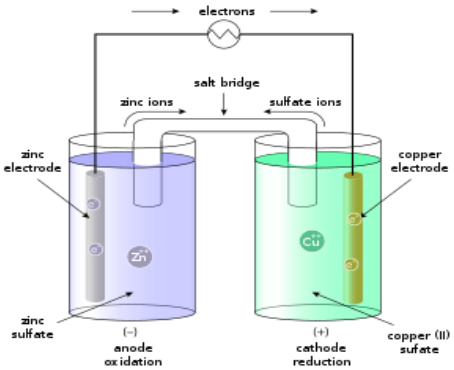


Figure 3 Galvanic Cell

A high level of control and measurement of the cell reaction is possible with an electrochemical cell. The reaction halts if the external circuit is disrupted. We can control the rate of the cell reaction by simply turning a knob if we add variable resistance to the circuit. We can also force the reaction to go through in its non-

spontaneous, or reverse, direction by connecting a battery or other source of current to the two electrodes. We can determine the quantity of electric charge that flows through the wires and, as a result, the number of moles of reactants that are converted into products in the cell reaction by using an ammeter in the external circuit.

Prior solutions

1) Al / CO_2 electrochemical cell: -

Al / CO_2 electrochemical cell is a project founded at Cornell University in the USA. the metal / CO_2 electrochemical cell uses high-energy-density Li, Na, and Mg anodes to capture CO_2 from mixed CO_2/O_2 streams. (As shown in Figure (4)) Despite producing electrical energy, a significant finding from these studies is that the presence of O_2 is required to enable chemical reduction and thus CO_2 capture. These cells are available in two configurations: secondary (rechargeable) or non-rechargeable primary. Al is used because it is less expensive than Li or Na, and it is the third most abundant element in the earth's crust. It also has a high specific energy, which means that its electrochemical conversion by CO_2 can be used to generate large amounts of electrical energy.

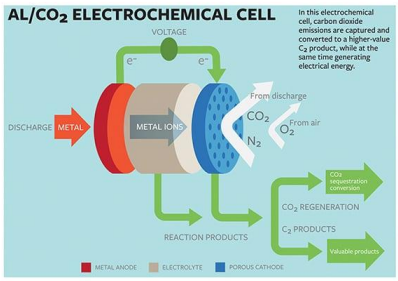
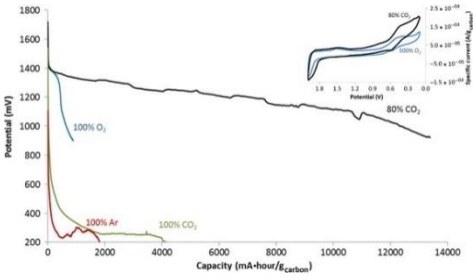


Figure 4 Al/CO2 electrochemical cell.

Mechanism: -

(graph(8))shows from galvanostatic discharges of Al electrochemical cells operated under Ar, O_2, CO_2, and CO_2/O_2 mixes. Discharging the Al cell under pure O_2 (denoted 100 percent O_2) yielded a significant amount of electrical energy (about 890 mAhour/gCarbon) at 1.4 V. When CO_2 was injected at a molar ratio of 80:20 in comparison to O_2, the capacity increased nearly 15-fold (denoted 80 percent CO_2). Discharging Al under pure CO_2 or Ar yielded no/zero electrical energy, with the only noticeable discharge voltage plateau at lower potential of roughly 0.3 V. For Al/100% O_2 and Al/80% CO_2 systems, cyclic voltammetry (CV) (graph (8),inset) indicated a matched decrease peak approximately 1.5V, corresponding to the



Graph (8) voltage profiles

discharge potential.

Points of strengths:-

- **Using Al instead of Li or Na.**

Using Al in the cell gives it a significant advantage because it is less expensive than Li or Na, and it is found all over the world as the third most abundant element in the earth's crust, allowing the project to be both sustainable and cost-effective.

- **Generating O_2 and other valuable products.**

Despite the fact that it generates electrical energy, the Al / CO_2electrochemical cell produces a variety of valuable products, the most important of which is O_2, as well as a variety of other valuable C_2 compounds.

Points of weakness: -

- **Sensitivity to moisture.**

The researchers acknowledge that the cell has one significant disadvantage: it will not work if water is present in the mixture of gases it draws in, which is a situation that would exist in most of the world, so they intend to look for another electrolyte that is less sensitive to moisture to solve the problem.

- **Regenerate of CO_2.**

Despite producing electrical energy and a range of valuable compounds, the researchers admit that the cell has major disadvantage. Al/CO_2 releases an amount of CO_2 after the process.

2) Orca plant

Figure 5 orca plant

Clime works opened the world's first commercial direct air capture (DAC) plant in Hinwil, Switzerland, in 2017(as shown in figure (5)). The plant apparently captures 900 tons of CO_2 per year from the atmosphere and transports it to a nearby greenhouse. The Orca plant captures significantly more carbon dioxide and, rather than using it, converts it for storage via Carbfix's "natural mineralization process. "This involves combining carbon dioxide with water and pumping it deep underground, where it becomes trapped in stone. This effectively removes it from the atmosphere for good. Orca is the world's largest carbon capture plant as well as the world's first climate-positive direct air capture and storage plant. Clime works developed the project, and Orca is the name of the company's direct air capture and storage plant. The plant will go above and beyond previous carbon capture projects by combining direct air capture technology with carbon dioxide storage, enabling industrial-scale direct carbon capture and storage.

Mechanism: -

As shown in figure(6) The plant draws in air with dozens of large fans before filtering it. The CO2 trapped in the filter is then released via heat. Using Carbfix technology, the CO2 extracted is mixed with water and injected into the ground.

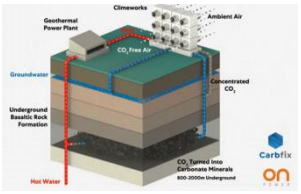


Figure 6 mechanism of orca plant

Points of strengths

- **Using of carbon dioxide in valuable way.**

  Carbon capture could be an effective technique to extract enormous amounts of CO2 out of the atmosphere and enhance the planet's health if technology improves and costs fall. And use it to generate energy and solve the energy crisis.

- **Effective construction**
  Orca's construction began in May 2020 and is built on innovative modular technology, with stackable container-size collecting units. Orca can be

operational in less than 15 months thanks to these powerful and compact machines with a small physical footprint.

Points of weakness

- **The cost**
  There are several significant limitations to the technology. For one thing, it's an expensive process that most businesses can't afford.

- **The effectiveness**
  For another, the amount of CO2 removed from the atmosphere by current facilities is so negligible in comparison to the entire amount that needs to be addressed

3) Petra Nova

Figure 7 Petra nova

The Petra Nova project figure (7) is a coal-energy-sector/clean-energy project that aims to reduce carbon emissions from one of the boilers of a coal-fired power plant in Thompsons, Texas. NRG Energy and JX Nippon Oil have embarked on a multi-million-dollar project to retrofit one of the boilers at their WA Parish Generating Station with a post-combustion carbon capture treatment system to treat a portion of the atmospheric exhaust emissions from the retrofitted boiler. It is first launched in January 2017.

Mechanism: -

The Petra Nova carbon emissions reduction system employs an amine-based absorption system, known as the KM CDR Process (Kansai Mitsubishi Carbon Dioxide Recovery). Mitsubishi and Kansai Electric Power created this process, which employs a high-performance proprietary solvent known as KS-1. A simple absorber-stripper system removes CO_2 from exhaust gas. The gaseous CO_2 is then compressed into a supercritical liquid. The CO_2 that exits the carbon capture plant is over 99 percent pure and is transported 82 miles through 12-inch diameter pipes to the West Ranch oil field, where it is used for enhanced oil recovery. The carbon dioxide from the Petra Nova Initiative will eventually end up in sandstone in the Frio Formation of the West Ranch oil field.

Points of strengths:

- **CO_2 captured at the W.A. Parish plant for enhanced oil recovery (EOR).**
  The CO_2 will be compressed and transported 81 miles (130 kilometers) to the West Ranch oil field in Jackson County, Texas, via a new 12-inch underground pipeline. The compressed CO_2 will be pumped a mile (1.6 kilometers) underground to boost oil production at the site while also sequestering CO_2 in geologic formations.
- **Petra nova uses a high tested carbon capture technology.**
  Petra Nova employs the improved Kansai Mitsubishi Carbon Dioxide Recovery Process (KM CDR Process), an amine-based gas-treating process that Mitsubishi Heavy Industries adapted and scaled (MHI).

Points of weakness:

- **High cost**

The installation of the Petra Nova carbon emission reduction system cost around $1 billion. NRG shut down the project on May 1, 2020, due to pandemic.

4) Fuel Cell

A fuel cell is an electrochemical cell that uses redox reactions to transform the chemical energy of a fuel (typically hydrogen) and an oxidizing agent (commonly oxygen) into electricity. Fuel cells differ from most batteries in that they require a constant supply of fuel and oxygen (usually from air) to sustain the chemical reaction, whereas in a battery, the chemical energy is typically derived from metals and their ions or oxides that are already present in the battery, except for flow batteries. If fuel and oxygen are available, fuel cells can create power indefinitely.

Mechanism: -

There are many different types of fuel cells, but they all have an anode, a cathode, and an electrolyte that permits ions to travel between the two sides of the fuel cell, commonly positively charged hydrogen ions (protons). A catalyst at the anode causes the fuel to undergo oxidation processes, which produce ions (typically positively charged hydrogen ions) and electrons. The electrolyte transports ions from the anode to the cathode. Simultaneously, electrons move from the anode to the cathode via an external circuit, resulting in direct current electricity. Another catalyst causes ions, electrons, and oxygen to react at the cathode, resulting in the formation of water and

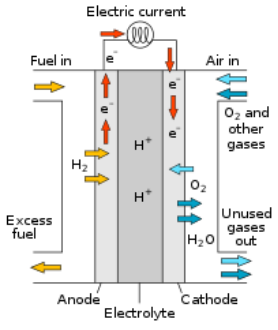


Figure 8 mechanism of fuel cell

perhaps other products. Figure (8) demonstrate the mechanism of fuel cell.

Points of strength: -

- **Environmentally beneficial**
  reduces CO2 and harmful pollutant emissions significantly which leads to a reduction in the percentage of greenhouse gases, thus reducing the harms of the greenhouse effect
- **avoid sound pollution**
  The process of generating energy in fuel cells produces the lowest amount of noise.

Points of weakness: -

- **High cost: -**

Expensive to manufacture due the high cost of catalysts (platinum) also the Hydrogen is expensive to produce and not widely available.

- **Safety: -**

Spilled liquid hydrogen creates enormous gas pressures in enclosed areas with normal temperatures, tearing apart vessels without safety valves. The two primary dangers of fuel cell and hydrogen-powered vehicles are electrical shock and fuel flammability

II. Chapter Two

(Generating and defending a solution)

Solution requirement

Sustainability:
The material used in the prototype should be sustainable which means to be resistant to erosion, have a long-life span resistant to rooting, and available in Egypt to renew if needed, furthermore, it must be strong as well and have enough strength to stand in front of storms or any other emergencies.

Safety:
Safety is one of the most important characteristics that should be ensured in any solution, so we must reflect that on our prototype. For example, it shouldn't emit any poisons or harmful gases and the materials must be incombustible.

Eco-friendly:
Eco-friendly is so highly recommended requirement that must be met by any solution because if the solution doesn't meet this requirement so it solves the problem and on the other hand it causes or boosts another problem which is pollution, so all the materials and processes involved in the solution must be eco-friendly and it also must be nonpolluting to prevent the pollution of water.

Cost-effectiveness:
Low cost is one of the essential requirements that makes any project a successful project and affordable to be placed in all places of Egypt which will have a great result in providing a clean source of energy in all places Egypt. Also, the long-term maintenance costs should be low, so the materials should be low-price and available in Egypt.

Efficiency:

The project should have high efficiency to be applied on the large scale, so first and foremost it should be built at the indusial complexes where the carbo dioxide rate is high due to the emissions that exert from factories by burning fossil fuels. In addition to that, it is required high effective materials to generate the maximum possible output from the same number of inputs.

Design requirement

The goal is to generate not less than 1.5 volts between the anode and cathode, which will be immersed in two solutions with the same ion concentration. As soon as the co2 enters the system, one of these ions, h+, will evolve into pure hydrogen gas due to the flow of electric current in the circuit, and the system should eventually achieve an efficiency of more than 90%.

Selection of solution

To address the issue of a scarcity of energy sources. It is critical to developing a solution that allows Egypt to generate energy while also addressing another issue which is climate change caused by harmful gases such as carbon dioxide in the air. The solution is to develop an electrochemical cell that aims to generate electrical energy from CO2. This solution has many benefits, including reducing the percentage of carbon dioxide gas in the air, which is responsible for many climate change crises, by generating electricity, and this system does not regenerate CO2 during the charging process unlike aprotic metal-CO2 cells, which have similar ideas but regenerate CO2. Also, it generates hydrogen gas which can be used in other applications.

The right place:

As it's known the most source of CO2 is fossil fuels, so the project should be constructed around factories that depend on the burning of fossil fuels as a source of energy. The emissions which these factories exert will enter the Hybrid Mg-CO2 system and then react with water. by depending on electrochemical reactions between an aqueous solution in which the cathode is immersed and an electrolyte solution in which the anode is immersed, the electricity will be generated, and hydrogen gas will evolve but it is important to transfer through a nonporous pipe for safety.

The structure of the solution:

1) **Entry of CO_2:**
   This part is so important to import the carbon dioxide gas (CO2) from the funnel of factories directly to the system.

2) **Two Huge containers:**
   This is representing the main part of the solution as throughout most of the electrochemical reactions will undergo, the anode is immersed in the container and the cathode in the other container while the two containers are connected by a membrane.
3) **Electricity transmission**:
   The electron flow from anode to cathode generates electricity which will transfer by wire to the transformer to step up voltage for transmissions.

Selection of Prototype

Our solution prototype is an electrochemical cell bases on the chemical reactions to produce electricity especially oxidation and reduction. The prototype is composed of two container the first container contains water (H_2O) and copper cathode, another container contains salt solution ($Na^+ Cl^-$) and aluminum anode connected with the copper cathode with a wire, the two containers are connecting with salt bridge, as shown in the fig ().
The process starts with the reaction between the water and carbon dioxide producing hydrogen carbonate

$$H_2O_{(l)} + CO_{2\,(g)} \longrightarrow H_2CO_{3\,(l)}$$

due to the weakness of hydrogen bond in the hydrogen carbonate it will ionized into positive hydrogen ions and negative bicarbonate ions

$$H_2CO_{3\,(l)} \longrightarrow HCO_3^{-}{}_{(l)} + H^+$$

on another container the aluminum sulphate which is an electrolyte will help in the oxidation of aluminum anode which has a high oxidation potential, therefore the aluminum atoms will loss electrons forming aluminum ions

$$Al_{(s)} \longrightarrow Al^{+2} + 2e$$

on the other side the copper cathode will attract the lost electrons by the aluminum creating an electric current and these electrons will attract with the positive hydrogen ions and the hydrogen gas will evolve

$H^+ + e^- \longrightarrow H_{(g)}\uparrow$

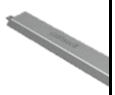
The salt bridge is a U-shaped tube filled with salt solution and clogged with cotton. The role of this salt bridge is keeping the charge of the cells which the oxidation of aluminum sulphate will precipitate many negative aluminum ions and on another side the reduction of hydrogen ions will make a repulsion force between the negative sulphate ions, so the salt bridge will modify the charge by adding negative chloride ions to the aluminum sulphate solution and positive sodium ions to the water solution.

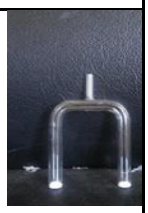
III. Chapter Three

(Constructing and testing a Prototype)

Materials and Methods

The main used materials in the prototype are listed in the table (1):

Item	Quantity	Description	Usage	Cost	Source of purchase	Picture
Container	Two	The 2L container is made of plastic and was used to store water, solutions, cathode, anode, and so on.	Containing the solutions where the chemical reactions take place	60 L. E	Feisal	
Aluminum Anode	One	The anode is a charged positive plate immersed in NaCl solution where the oxidation undergoes.	It is a part of chemical reactions where the oxidation process occurs	30 L. E	Ramses Square	

Copper Cathode	One	It is immersed in distilled water, and the cathode is the electron acceptor where the reduction undergoes.	It is a part of chemical reactions where reduction process occurs		Ramses Square	
Salt bridge	One	It is a U-shaped tube that contains a salt solution.	Balancing the charge of the cell at the two apartments	60 L. E	Feisal	
Distilled water	600 ml.	It is a type of water that is evaporated and condensed to ensure its purity.	It is one of the reactants solutions that reacts with carbon dioxide in a half-	10 L. E	Gas station	

			reaction			
Sodium chloride solution.	500 ml.	It is a solution containing Na+ ions and Cl- ions.	It is one of the used solutions in the second half-cell reaction	1 L. E	Supermarket	

Table (1) the material used

Safety precautions:

- Wearing coats and gloves
- Doing the test plan in open place to prevent the concentration of chemicals and solution odors

Test plan:

Design requirements

1) The project should make a voltage difference of not less than 1.5 volts
2) The project should produce hydrogen gas.
3) The project should achieve an efficiency of more than 90%

Test plan steps:

Testing of prototype followed some steps, represented in:

- First, connect the aluminum anode with the positive part of a multimeter **(AVO Digital Multimeter, DT-9205A)** and the copper cathode with the negative part by using wires.

- Adding 1 liter of vinegar to 50 grams of baking soda in a bottle connected to a hose to produce 0.83 moles of carbon dioxide gas in a try to balance the concentration of the solutions in the two half-cell parts.
- Putting the hose at the bottom of the water container, making the rection between the evolved carbon dioxide and water.
- Recording the volt and ampere measurements as shown in figure 9 to be sure of achieving the design requirement of producing not less than 1.5 volts and to calculate the electrical power of the cell.

Fig (9): calculating measurments

Data collection:

AVO Digital Multimeter, DT-9205A that shown in the figure (10) has been used to measure the cell's potential difference (Volt) with absolute error of 0.04 and the electrical intensity (Ampere) with absolute error of 0.42. The results of the test plan are listed in the table (2):

Figure10: AVO Digital Multimeter, DT-9205A

	Measurement	Absolute Error	Error percentage
Potential difference	1.52 volt	0.04	2.63%
Electric intensity	18.6 microamperes	0.42	2.25%
Work	2.827×10^{-5}	1.37×10^{-6}	4.88%

Table (2) the result

IV. Chapter Four

(Evaluating, Reflection, and Recommendation)

Analysis

To achieve the design requirements and obtain the best result from the electrochemical cell. The material and methods should be depended on a strong scientific base.

Material Analysis:

Starting with the container that is used, the isolation of the container was considered, the container must be a bad conductor of electricity. So plastic container was used because plastic is a good insulator. The insulators have atoms that are tighter to each other than conductors as shown in Figure (11). This prevents the electrons from flowing forming an electric current as electricity is the flow of electrons.

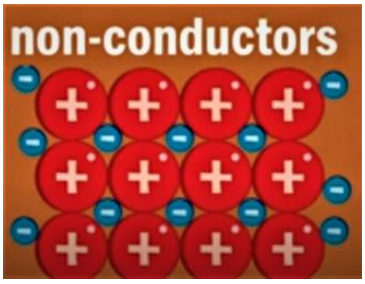


Fig (11): distribution of atoms in insulators

When it comes to the electrolyte in the container, sodium chloride was used because it is a strong electrolyte. Electrolytes are divided into strong, weak, and non-ionization degrees. The ionization degree of NaCl is 100%. This means that NaCl ionizes to positive sodium ions and negatively charged chlorine ions completely in water at Standard temperature and pressure (STP).

The aluminum anode was chosen because of the high oxidation potential of the half-reaction of it as well as its low cost and availability and the oxidation potential is the measure of a material oxidizing or losing electrons. The standard reduction

potential of **($Al_{(S)} \rightarrow Al^{+3} + 3e^-$) = -1.66**.

The continuity equation in fluid dynamics is an equation that describes the flow of some quantity of fluid throw a cross-section area (as shown in Figure (12)). It states that the area of the cross-section multiplied by the velocity of the fluid is constant at any given time. This means that the relation between the cross-section area of the pipe or the hose is inversely proportional to the velocity of the fluid. Based on this equation, the hose which was used as a path to the carbon dioxide has a small diameter, to accelerate the velocity of the gas to the distilled water to obtain faster and more effective results.

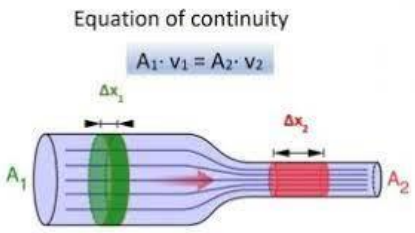


Fig (12): Continuity equation

Moving to the salt bridge, it was used because during the process of flowing the electron from the oxidation site to the reduction site, The percentage of electric charge increased in the reduction site, while the percentage of positive charge increased in the oxidation site. This issue was solved by adding a salt bridge. A salt bridge is a U-shaped tube filled with KCl that has been fully ionized in water to produce both positive and negative ions. That is why it balances the solutions; positive ions are pulled to the concentrated negative charge, while negative ions are pulled to the positive concentered charge. KCl was used because ions have a property known as mobility, and the mobility of an ion depends on its size. Smaller

ions have higher mobility than larger ions. That means that the ideal species for a salt bridge should have a cation and an anion of the same size and charge. Potassium chloride is the ideal species for incorporation into a salt bridge, as K+ and Cl-have the same number of electrons and are approximately the same size.

Chemical reaction analysis:

First, carbon dioxide is prepared by adding vinegar to baking soda which is stated in this balanced equation $\mathbf{NaHCO_3(s) + CH_3COOH(l) \rightarrow CO_2(g) + H_2O(l) + Na^+(a) + CH_3COO^-(aq)}$ (as learnt in CH.1.10). Although Carbon dioxide is polar (has a slight negative charge near the oxygen molecule and a slight positive charge near the carbon molecule), water gets attracted to it, thus, it dissolves in water (as learned in CH.1.12) which is put on the cathode side (Copper side). Coldwater is a better solvent than hot water because the solubility is inversely proportional to the temperature of the solvent (CH.1.08). This reaction between cold water and carbon dioxide produces carbonic acid which is stated in this equation $\mathbf{CO_2 + H_2O \rightarrow H_2CO_3}$. Because of the weakness of the bond between the hydrogen ion and the hydrogen carbonate ion, the hydrogen ion will dissociate from the carbonic acid, producing the two spectator ions separately which is written as $\mathbf{H_2CO_3 \rightarrow H^+ + HCO_3^-}$. On the anode side (Aluminum side), sodium chloride is dissolved in water into spectator ions which could be written as $\mathbf{NaCl + H_2O \rightarrow Na^+(as) + Cl^-(aq) +}$

$H_2O(l)$. As the aluminum anode has high oxidation potential, it undergoes oxidation as stated in this equation **$2Al \rightarrow 2Al^{+3} + 6e^-$**. The aluminum ions precipitate in the container and the electrons are attracted to the hydrogen ions and pass through the wires and the cathode producing Hydrogen gas written in a chemical equation as **$6H^+ + 6e^- \rightarrow 3H_2(g)$** and thus, producing an electric current by passing through wires. The net redox reaction (as learned in CH.1.12) is shown in figure (13). The salt bridge completes the circuit allowing current to flow. The salt used in the salt bridge is KCl Anions (Cl^-) in the salt bridge flow toward the anode (Al) and cations (K^+) in the salt bridge flow toward the cathode (Cu). The movement of these ions completes the circuit and keeps each half-cell electrically neutral.

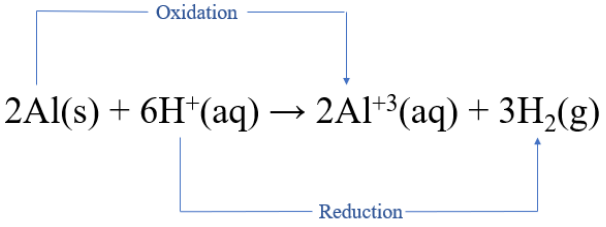


Figure 13: Net Redox equation

Cell Potential, Electrical Work, and Free Energy analysis:

We've only looked at electrochemical cells as that shown in figure (14) from a practical standpoint so far, with little theoretical knowledge. Now consider how the E° cell is related to thermodynamic quantities such as G° (free energy) and K° (equilibrium constant). Chemical energy is

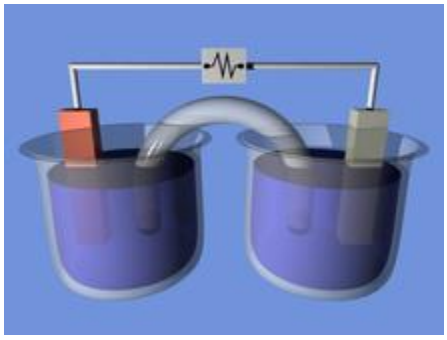


Fig (14): Electrochemical cell

transformed into electric energy in a galvanic cell. The product of the cell potential and the total electric charge (in coulombs) that passes through the cell is the electric energy produced in a galvanic cell:

electric energy = volts × coulombs = joules

The charge on 1 mole of electrons is a constant called the faraday (abbreviated F), which has a value of 96,485 coulombs of charge per mole of electrons. Thus, q equals the number of moles of electrons times the charge per mole of electrons:

$$\boldsymbol{q = nf}$$

Now let's calculate the maximum possible work that this cell can do (the right-hand side's negative sign indicates that the system performs electrical work on the surroundings.):

$$\boldsymbol{w_{max} = w_{electrical} = -qE^{o}_{cell} = -nfE^{o}_{cell}}$$

And (as learned in CH.1.10): The maximum possible useful work obtainable from a process at constant temperature and pressure is equal to the change in free energy: $\boldsymbol{\Delta G^{\circ} = w_{max} = -nFE^{\circ}}$

Thus: $\boldsymbol{\Delta G^{\circ} = -6 \times \left(96485 \frac{C}{mol\, e^{-}}\right) \times \left(1.66 \frac{J}{C}\right) = 960990.6\, J/mol}$

This relationship is significant because it allows for the experimental determination of Delta G for a reaction. It also proves that a galvanic cell will run in the direction that results in a positive cell value; a positive cell value corresponds to a negative Delta G value, which is the condition for spontaneity.

Equilibrium constant (K)

The quantitative relationship between $\Delta G°$ and $E°$ allows for the calculation of redox reaction equilibrium constants. For an equilibrium cell,

$$E°_{cell} = \frac{0.0592V}{n} \log(K)$$

The equilibrium constant can help us understand whether the reaction tends to have a higher concentration of products or reactants at equilibrium.

When it comes to our cell, the equilibrium constant is 1.76×10^{154} which proves that our reactions are spontaneous as when the equilibrium constant is greater than 1 tend to be spontaneous and vice versa. The word spontaneous implies that a reaction happens as soon as the reactants are mixed.

Conclusion

From the research and identification of the problem to the analysis and test plan, there had been a lot of work done. The results of the test plan showed how effective the cell is. It fulfilled the design requirements and solved the problem of both climate change and Energy, making Egypt's reliance on carbon-based fossil

fuels in the industry a benefit rather than a disadvantage, as it will produce electrical energy and hydrogen fuel while also avoiding carbon dioxide emissions from factories.

Recommendation

- It is recommended that if we make our prototype in the real-life, it will be placed at the industrial complexes near the funnels of factories that depend mainly on the fossil fuel that emits carbon dioxide gas as the project will receive the gas through a pipeline and in this way, it will reduce the percentage of factories' contribution to the climate crisis and global warming.
- It is recommended that the lithium anode (as shown in the Figure (15)) be used instead of the aluminum anode because its standard reduction potential is high as ($Li_{(S)} \rightarrow Li^{+} + e^{-}$) is about (-3.05 Volt), meaning that it is a strong reducing agent and thus easily undergoes oxidation, and it is also readily available in Egypt.

Figure (15): Lithium rods

- It is recommended to use multiple lithium anodes in the electrolyte solution to generate more voltage and electric current. Furthermore, lithium superionic conductors (LISICON) (shown in Figure (16)) are preferred over salt bridges because they act as a positive ion membrane, allowing Li ions to flow only to the required side quickly and easily.

Figure (17): LISICON

Figure 16 (LISICON)

- It is recommended that the hydrogen produced by the reactions be transported via pipeline with safety considerations to hydrogen refueling stations and used not only in cars, but also in much heavier trains and ships instead of gasoline to fulfill hydrogen's longstanding potential as a clean energy solution.
- It is recommended to install a lightening protective system figure (17) as the project can conduct electricity by exposure to lightening. Included in the system are rooftop air terminals, also known as lightning rods, but they are only one part of the puzzle. The system includes a lightning conductor network that extends down a building and connects to ground electrodes embedded in the earth outside the structure's foundations, as well as other materials that aim to avoid the danger (as shown in Figure (18)).

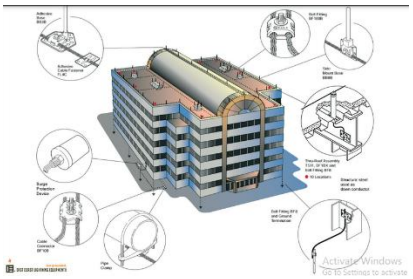


Figure (17): lightening protective system

Benefits of the project

The project returned to us by many benefits:

How did the project help us in the scientific fields?

The project helped us to go deeper in many topics and understand a lot of things, the most prominent is the energy, what it is, the sources of energy, and the mechanisms of generating energy, in addition to it helped in improving or our researching skills.

How did the project help us in the engineering field?

The capstone prototype helped us in learning how to make a 3D model, in addition to it improved our logical thinking in the arrangement of constructing steps.

How did we benefit from the project socially?

The project was having a big social impact due to the dealing with its challenges as searching for the materials and go to many places and dealing with merchants, and of course improved our teamwork skills

Learning Outcome

Table (3) shows learning outcomes that was used during the project.

Learning outcome	Connection
BI.1.10	The **Photosynthesis process** is an example of using carbon dioxide gas by the plants for making energy (Glucose), which is like the project that is also powered with carbon dioxide to make energy (electricity).
CH.1.08	In the concept of **Solution,** learning how to determine the solutions has helped in detecting the type of liquids that have been used either if they are solution, suspension or collide.
CH.1.10	**1.** Learning the concept of **Mole** aided in calculating the amount of used carbon dioxide, which in turn aided in calculating the ratio of used carbon dioxide to produced energy (electricity) **2.** Learning the concept of **yield percentage** helped in calculating the percentage of getting the expected amount of energy by dividing the actual yield by the theoretical yield multiplied

	by 100. In addition, learning about the expected reasons for a decrease in the expected amount of energy during the study of this concept
CH.1.11	learning about different types of chemical reactions in this L.O., which helped in figure out what kind of chemical reactions we deal with
CH.1.12	The concepts of electronegativity and polarity helped in understanding the dissolving of carbon dioxide on water and the attraction of lost electrons by the cathode
CH.1.14	In this LO learning about the electrochemical cell and our solution is a type of electrochemical cell powered with carbon dioxide gas.
CH.1.15	The concept of **redox reaction** helped in understanding the chemical reaction of the electrochemical cell which the anode exposes to oxidation while the cathode exposes to reduction
ES.1.09	This LO helped in collecting more data about general the energy resources, in addition to the energy situation and the different types of energy resources in in Egypt
ES.1.10	Learning about the different types of energy generation and resources as the energy generation form the solar energy.
PH.1.08	Leaning about the buoyant force in the LO helped in choose the suitable carbon dioxide pipe that can overcome the buoyant force on it applied by water

	and keep down in the bottom
PH.1.09	Learning about the fluid dynamics and fluids flow rate in this LO, helped in getting the better way to make the carbon dioxide flows through a pipe reaching the water.

Table (3) learning outcome that was used.

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