STEM School For Boys
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جمهورية مصر العربية
وزارة التربية والتعليم

Group 109

Project Portfolio Report

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I. Chapter 1: Definition and Justifying the Problem and Solution Requirements

This chapter goes through the definition of the problem and a review on the current circumstances concerning the proposed solution, with a brief illustration of its structure and properties.

A. Grand Challenges

Introduction

Being a country means facing several challenges that it hopes to overcome. Egypt is no exception for that; as it endures lots of challenges and goals that can be summarized in the following list:

- Reduce urban congestion
- Improve use of arid areas
- Deal with the exponential population growth
- Increase opportunities for Egyptians to stay and work in Egypt
- Reduce pollution
- Recycle and retain garbage for recycling
- Work to eradicate public health issues/diseases
- Improve sources of clean water
- Increase the industrial base for Egypt
- Improve the use of alternative energies

In the following, the subject that the proposed solution is concerned with is going to be discussed thoroughly.

1. Overpopulation

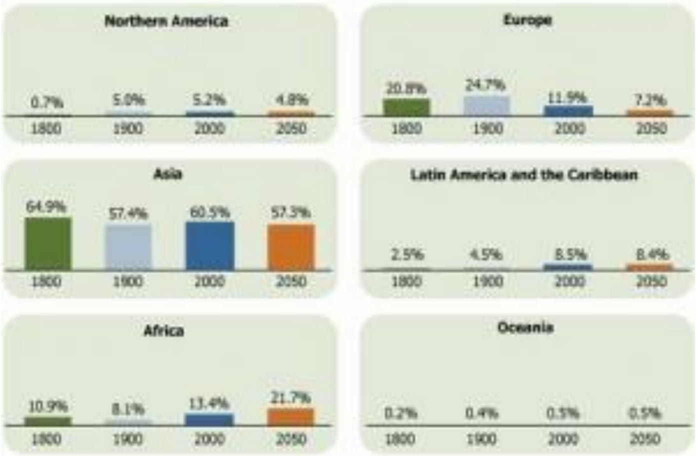
One of the most harming problems that Egypt is still suffering from is overpopulation (illustrated in Figure I.1). A couple of decades ago, Egypt had a good family planning, but now the situation is completely different. Starting from the 1980s, the fertility rate was about 3.2 child per woman, increasing to about 3.8 in rural areas and 2.9 in urban areas 2014. (Zanty, 2014, pp. 39-40) This is an obstacle that threats our progress and development to future. In addition, it leads to other challenges including increased pollution and, consequently, the need to recycle materials.

Figure I.1 An overcrowded street

a) Causes

(1) *The technological revolutions*

Looking throughout history, technological revolutions have resulted in a population expansion. (Ehrlich & Ehrlich, 1990) The three major evolutions (the tool-making revolution, the agricultural revolution and the industrial revolution) have allowed more access to food, resulting in a more life expectancy of a person, especially for children. Industrial revolution is a revolution that took place



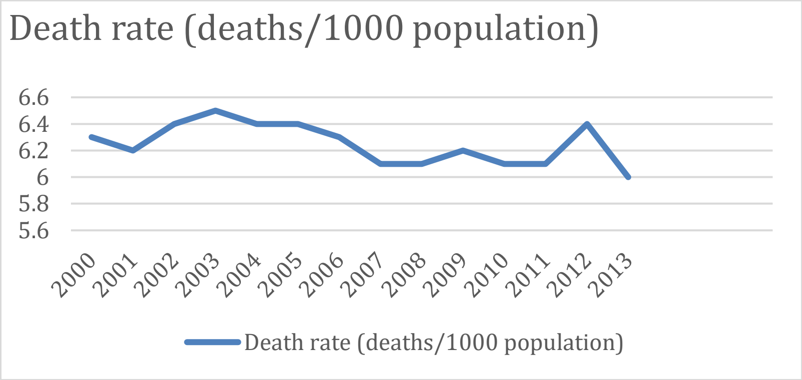
Graph I.1 shows the raising in population number in the six continents in Europe in the middle of 18th century. Industrial revolution changes our behaviors from dependence on primitive resources of energy to new resources, such as coal. Industrial revolution has many bad effects on rising population on the earth. Figure I.2 shows overpopulation due to the industrial revolution. At the dawn of industrial revolution, the number of people grew by 57% to reach about 700 million and was estimated to be 1 billion in 1800. But everything changed when this revolution started. The birth of the industrial revolution altered medicine and living standard resulting in the great population explosion after that. During the 20th century, the population number increased by exponential proportions to 6 billion. About 400% increase of population in one single century. The industrial revolution shows us how far the development or the use of new resources effects on our life badly when used wrongly.

Figure I.2 Overpopulation due to the industrial revolution

There is another reason that encouraged the huge raise in population number, it is the tool-making revolution. The use of tools, such as the bow and arrow allowed the primitive hunters a greater access to a high-energy food, as it was the only way to hunt and to get enough food. Likewise, the transition from hunting to farming later greatly increased the overall food supply, which was used to support more people, and abruptly, for the first time they found excess food which encouraged people to bring children expecting that future is safe and secure. On the other hand, a father farmer needed sons to help him in his farming chores, instead of renting other men. This also was a main reason for the overpopulation in the farming age. The food industry further increased as the machinery, fertilizers and pesticides were used to increase the land under cultivation.

(2) *Decline in death rates*

At the root of overpopulation is the difference between the overall birth rate and death rate in population. If the number of children born every year equal to deaths the ratio will be stabilize, like what happened in developed countries in 2010, for example, Germany experienced a ratio of population growth being -0.19%.



Graph I.2 The decline in death rates in Egypt

As shown in Graph I.2, there is a decline in the death rate happening in Egypt. (Zanty, 2014, p. 24)

b) Consequences

(1) *Depletion of natural resources*

It is logical to say that if the population number raises, the demands on daily resources increase, so there is a strong relation between wealth and over population of country and energy consumption. The more the population the more energy used and the faster depletion of natural resources happens.

Figure I.3 Petroleum; a natural resource

Many troubles such as water shortage and lack of petroleum (depicted in Figure I.3) didn't appear until the growth of population started to raise dramatically. Population grew from 1.49 billion in 1890 through 2.5 billion in 1950 to 5.32 billion in 1990, energy consumption grew even faster, from 1 terawatt in 1890 through 3.3 terawatts in 1950 to 13.7 terawatts in 1990. Energy consumption grows not only as population grows but also as poor people become richer. People in the developing world each use 0.28 kilowatts a year, while those in the developed world use 3.2 kilowatts and people in the United States 9 kilowatts.

The overuse of non-renewable resources and overpopulation will result in depletion of natural resources. This will lead us eventually to wars between countries because of the need of these resources. It can be passed by depending on recycling or renewable clean resources. For example, instead of throwing rubbish in the streets, and with the right instruments, it is possible to be turned into energy to derive replacement fuel instead of oil, so the crisis of oil nowadays can be overcome by recycling. This will produce new forms of energy such as what is needed to substitute oil.

(2) Conflicts and wars

As a result of the reduction of natural resources, people start to fight so that to gain as much resources as possible. For example, conflicts over water may lead to tension between countries, which could result in wars. Starvation is also a huge matter facing the world and the mortality of rate of the children is affected by it.

(3) Rise in unemployment

When the population raises uncontrollably in a country, the amount of available jobs for youth does not rise proportionally with it, as depicted in Figure I.4. As a result, only a group of people are with jobs available to them and other groups aren't.

Figure I.4 Unemployment

(4) *High cost of living*

As difference between demand and supply continues to expand, the prices of various supplies (including food, shelter and healthcare) are raised. This means that people must pay more in order to survive and feed their families.

(5) *More pollution and increased need for recycling and energy*

The rise in the population has caused more people to throw rubbish and pollutants to the environment increasing the need for recycling those wasteful materials into useful resources, most importantly energy.

2. Pollution

Pollution, which is also called "environmental pollution", is the addition of any harmful substance (solid, liquid, gas) or any form of energy, such as (heat, sound, radioactivity) to the environment at a rate faster than it can be dispersed, diluted, decomposed, recycled, or stored in some harmless form.

Figure I.5 Air pollution

There are many kinds of pollution usually classified by environment according to their severity, they are classified into:

1. Air pollution (illustrated in Figure I.5)
2. Water pollution
3. Land pollution

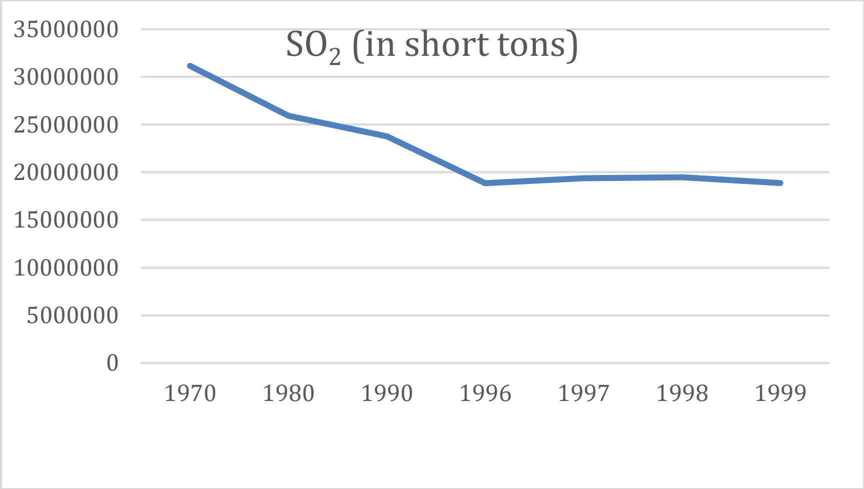
a) Air pollution

The air is approximately the most important thing that our life depends on, air consists of many gases which are all important to us, our life depend mainly on oxygen gas and CO_2 gas, as there is an exchange between O_2 and CO_2 during photosynthesis process.

The benefit of air isn't limited for O_2 and CO_2 only, but there are many useful gases in air.

(1) *Causes*

(a) Burning fossil fuel



Graph I.3 shows the emission of Sulphur dioxide in tons

The burning of fossil fuel plays an important role in polluting the environment, especially air pollution. The combustion of fossil fuels like coal, petroleum, and other factory combustibles emits Sulphur dioxide (SO_2), which is a noticeable component in the atmosphere. Sulphur dioxide has major significant impacts upon human health. The emission rate is shown in Graph I.3. Inhaling Sulphur dioxide is associated with increased symptoms and diseases related to the respiratory system such as difficulty in breath, Children, the elderly, and those who suffer from asthma are especially sensitive to effects of SO_2. To plants and trees, Sulphur oxides can damage their foliage and decrease their chemistry; fog and clouds in forests; killing of fish and other aquatic animals living near or in surface water; and other associated effects. (Bakhshipour, Asadi, Huat, Sridharan, & Kawasaki, 2016) Carbon dioxide and methane are also released during the burning process. These gases are greenhouse gases, that cause global warming which is a very delicate problem. This problem can be solved by turning from using fossil fuel which is the main cause of the problem to alternative fuels such as biodiesel, biogas, hydrogen, non-fossil methane or chemically stored electricity.

(b) Agricultural Activities

Figure I.6 Agricultural pollution

Ammonia is a very common by product from agriculture related gases (emissions illustrated in Figure I.6), and is one of the most dangerous gases in the atmosphere, that causes severe air pollution.

(c) Exhaust from factories and industries

Manufacturing industries emit large amount of carbon monoxide (CO), hydrocarbons, organic compounds, and chemicals into the air.

(2) *Consequences*

The effects of Air pollution can be summarized in Figure I.7.

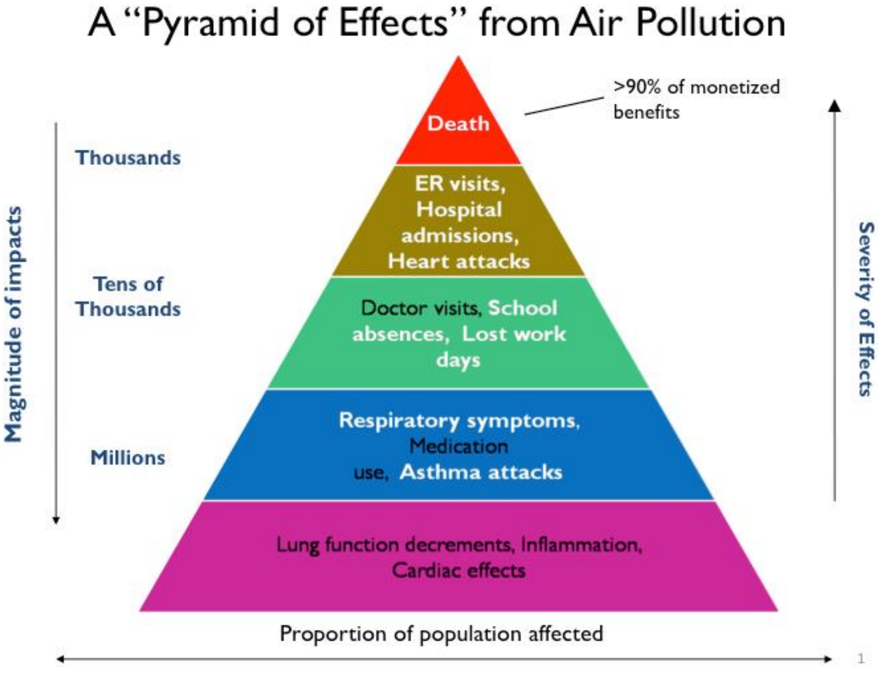


Figure I.7 A figure summarizing the effects of air pollution

(a) Respiratory and heart problems

Air pollution is known to create several respiratory and heart conditions, along with lung cancer, among other threats to the body.

(b) Global warming

Another direct effect is the immediate alternations of weather that the world is witnessing due to global warming.

(c) Acidic rain

Harmful gases like nitrogen oxides and Sulphur oxides are released into the atmosphere during burning of fossil fuels which cause acidic rains. Figure I.8 shows the effect of such rains.

Figure I.8 Effects of acidic rain

(3) *How cities around the world are tackling air pollution*

- **Paris:** cars are banned in many historic central districts at weekends, which imposes streets to be fresh-aired.
- **Delhi:** the reports which the pollution levels in Delhi matched those in Beijing spurred the city to ban all new large diesel cars and SUVs with engines of more than 2,000CC, and to face this, the city has experimented with alternately banning cars with odd and even number plates.
- **Netherlands:** politicians want to ban the sale of all petrol and diesel cars from 2025, allowing only electric or hydrogen vehicles.

b) Water pollution

Figure I.9 Polluting natural water

Water pollution, demonstrated in Figure I.9, can be defined in many ways. It usually means one or more substances have built up in water to such an extent that they cause problems for animals or people. Oceans, lakes, rivers, and other inland waters can naturally clean up a certain amount of pollution by dispersing it harmlessly. If you poured a cup of black ink into a river, the ink would quickly scatter into the river's much larger volume of clean water. The ink would still be there in the river, but in such a low concentration that you would not be able to see it.

(1) *Causes*

(a) Sewage disposal

Sewage from local households, factories and commercial buildings can prove to be problematic. Sewage that is treated in water treatment plants is often disposed into the sea. It can be more challening when people flush chemicals and pharmaceutical substances down the toilet.

(b) Dumbing solid wastes

Figure I.10 A picture demonstrating solid wastes

Dumbing wastes and littering (shown in Figure I.10) by humans in rivers, lakes and oceans can be a cause of the spreading of many diseases like Hepatitis A, and others.

(c) Industrial waste from factories

These wastes, which use freshwater to carry plant waste into rivers, contaminate waters with pollutants such as asbestos, lead, mercury and petrochemicals.

(2) *Consequences*

(a) Groundwater contamination

Groundwater contamination due to pesticides causes reproductive damage within wildlife in ecosystems.

(b) The depletion of oxygen

Sewage, fertilizer, and agricultural run-off contain organic materials that when discharged into waters, increase the growth of algae, which causes the depletion of oxygen.

(c) Health problems

Swimming in and drinking from contaminated water causes skin rashes and health problems like cancer, reproductive problems, typhoid fever and stomach sickness in humans.

(d) Fish contamination

Industrial chemicals and agricultural pesticides that end up in aquatic environments can accumulate in fish that are later eaten by humans. Also, the death of fish is caused which can be viewed in Figure I.11.

Figure I.11 Dead fish because of contamination

3. Recycling

Figure I.12 Assembling of waste materials

Recycling is the reclamation and remanufacturing of discarded used materials to be reused for new products. The well-known stages in recycling are the assemblage of waste materials as in Figure I.12, their processing or manufacture into new products, and the purchase of those products, which may then themselves be recycled over and over again. Usual materials that are recycled include steel fragments and iron, glass bottles, plastics, wood, paper and aluminum cans. The materials recycled are considered as replacements for raw materials obtained from such extremely rare natural resources as natural gas, mineral ores, petroleum, trees and coal. Recycling can help decrease the amounts of solid waste dumped in junkyard, which have become increasingly expensive. Recycling also reduces the air, water, and land pollution resulting from waste disposal, as the wastes piling up the area, they can help in spreading diseases and harming the environment.

Stages of Recycling

- Collection of Recyclable materials.
- Separating different materials from each other ex. plastics and paper
- Processing and reprocessing of materials according to their type
- Reshaping materials, making them into the new desired shapes.

Ways to increase recycling rates

- Increase the number of recycling factories.
- Advice people and enrich their knowledge about the importance of recycling.
- Provide the streets with Trash cans as in Figure I.13.

Figure I.13 Recycling Trash Cans

There are two wide-ranging categories of recycling operations: internal and external.

a) Internal recycling

Internal recycling is the reuse in a production process of materials that are a waste product of that process. Internal recycling is mostly-used in the metals industry, for example. Producing copper tubing results in a certain amount of waste in the form of tube ends and trimmings; this material is re-melted and reshaped. Another form of internal recycling is seen in the distilling industry, in which, after the distillation, spent grain mash is dried and processed into an edible foodstuff for cattle.

b) External recycling

External recycling is the retrieving of materials from a product that has been worn out or rendered outdated. An example of external recycling is the collection of timeworn magazines and newspapers for their creation into new paper products. Glass bottles and aluminum cans are other examples from everyday usage. These materials can be collected by any of three main methods: buy-back centers, which purchase waste materials that have been sorted and brought in by consumers; drop-off centers, where consumers can deposit waste materials but are not paid for them; and curbside collection, in which homes and businesses sort their waste materials and deposit them by the curb for collection by a central agency.

Simply, when someone wants to start a recycling business, they should take care of some points. The recycled materials should not be precious or valuable as some kinds of metals, as they might lose their value after recycling. The recycling process shall not cost too much, as the main purpose of recycling is saving costs on new raw materials, or the process will become worthless.

c) Recycling process of different materials

(1) *Paper*

Figure I.14 Paper recycling

Paper makes up over 35% of municipal solid waste collected, more than any other material. The United recycles almost 42.2% of the paper they use. (EPA, 2013) This recovered paper is used to make new paper products, saving trees and other natural resources. Paper recycling (shown in Figure I.14) is widely-accepted and well-known throughout the world. When you go shopping, look for products that are made from recycled paper.

(2) *Batteries*

Figure I.15 Battery Recycling

Dry-Cell Batteries are used in a wide range of electronics and include alkaline and carbon zinc (9-volt, D, C, AA, AAA), mercuric-oxide (button, some cylindrical and rectangular), silver-oxide and zinc-air (button), and lithium (9-volt, C, AA, coin, button, rechargeable) batteries. (Fisher, Wallén, Paul, Collins, & Collins, 2006)

To be able to recycle alkaline batteries, in a specialized “room temperature,” mechanical separation process. The alkaline battery components are divided into three end products. These items are a zinc and manganese concentrate, steel, and paper, plastic and brass fractions. Then it is used in new products to cut down their cost. Collection of batteries can be seen in Figure I.15.

(3) *Plastics*

Figure I.16 Recycling Plastics

Almost 35 million tons of plastics were generated in the United States in 2015, about 13 percent of the waste stream. Only 9.1 percent of plastics were recycled in 2015. (Geyer, Jambeck, & Law, 2017) Some types of plastics are recycled much more than others as in Figure I.16. Most community recycling programs accept some, but not all, types of plastics.

(a) Meaning of symbols on plastic containers

As shown in Figure I.17, these symbols were created by plastic producers to help people identify the kind of plastic used to make the container. This can help you determine if the container can be accepted by your local recycling program. The resin number is contained in a triangle, which looks very similar to the recycling symbol, but this does not indicate if it is recyclable or not in your community. Although some kinds of plastic are not recyclable.

Resin	Resin Indentification Code-Option A	Resin Indentification Code-Option B
Poly(ethylene terephthalate)	1 PETE	01 PET
High density polyethylene	2 HDPE	02 PE-HE
Poly(vinyl chloride)	3 V	03 PVC
Low density polyethylene	4 LDPE	04 PE-LD
Polypropylene	5 PP	05 PP
Polystyrene	6 PS	06 PS
Other resins	7 OTHER	07 O

Figure I.17 (Photo courtesy of ASTM) Meaning of symbols on plastic containers

(4) *Glass*

Figure I.18 Recycling Glass

Glass, especially glass food, cups and bottles, can be recycled over and over again. In the United States in 2015, 11.5 million tons of glass were generated, about 26 percent of which was recovered for recycling. Making new raw glass from recycled glass is way cheaper than using raw materials, although, raw glass is made by burning sand. Most recycling programs accept different glass colors and types mixed together as in Figure I.18, and then glass is sorted at the recovery facility.

d) Recycling wastes into Energy

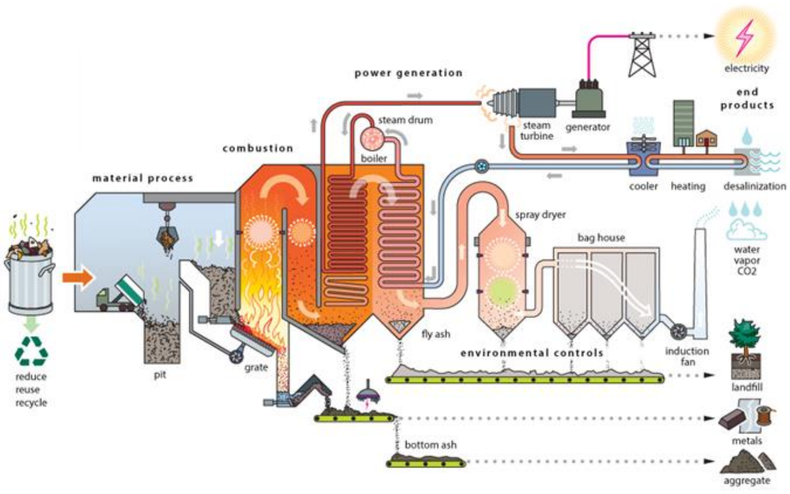


Figure I.19 An example of converting MSW into energy

Recycling saves energy and natural resources; making a product from recycled materials almost always requires less energy than it does to make the product from new materials, as exemplified in Figure I.19. Furthermore, many recycled materials can be used to generate energy. For example, there has been ways that converts unused plastics that are found in landfills to a biogas. One plastics-to-fuel company says that its system can convert 50 tons of plastic waste into 12,600 gallons of oil—per day. The method includes melting then vaporizing of the sorted plastic into gases that are then cooled and condensed into a wide variety of useful products, such as synthetic crude oil, synthetic diesel fuel, kerosene and more. By doing this, 70% of greenhouse gas emissions can be reduced, decreasing pollution and public health problems.

4. Public Health Problems

Figure I.20 A hospital in Egypt

Public health is "the science and art of preventing disease, prolonging life and promoting human health through organized efforts and informed choices of society, organizations, public and private, communities and individuals" (Winslow, 1920). “Public” can be as small as a score of people or as large as to include several continents. “Health” refers to physical, mental and social well-being, and not merely the absence of disease or infirmity.

The Healthcare system in Egypt, which can be exemplified in Figure I.20, is fragmented between the Ministry of Health of Population which delivers 30% of services, the Ministry of Higher Education and Scientific Research delivering 30% of services through University hospitals, the Health Insurance Organization providing 10% of services and independent ministries providing the remainder.

Central Government is responsible for:

- Primary and Emergency healthcare for Egyptian citizens.
- Healthcare Policy and strategy
- Healthcare Public Financing

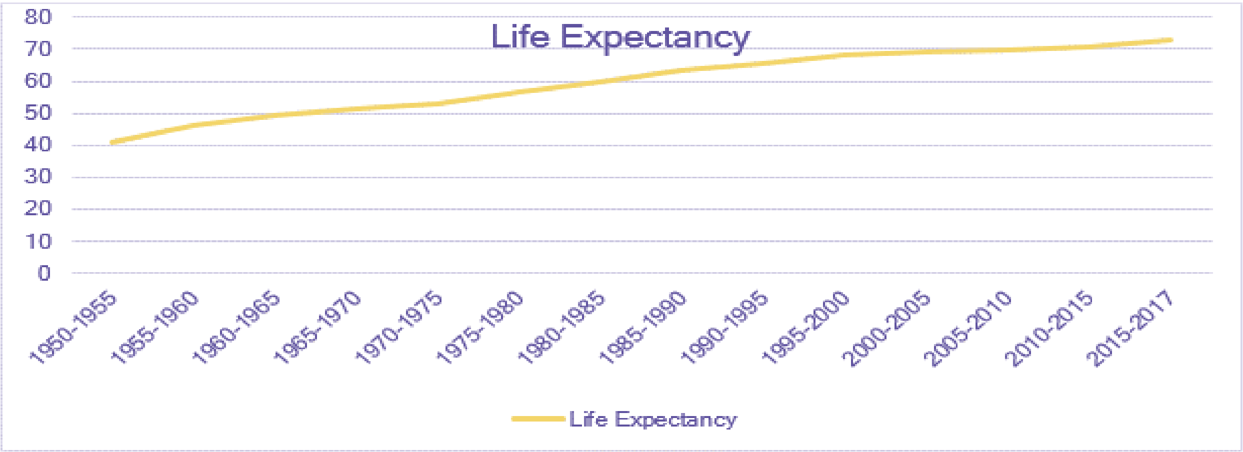
There are governmental campaigns to reform healthcare and also to implement a universal health insurance for every Egyptian by 2030. Nevertheless, there are some problems that Egypt faces concerning public health.

a) Causes

(1) *Low life expectancy*

The life expectancy in Egypt is generally low compared to other countries. According to the CIA Factbook and Egypt DHS 2014, Egypt is the 142th country with life expectancy of 72 years. (Zanty, 2014, p. 24) The below graph (Graph I.4) shows the life expectancy of Egyptians throughout the period between 1950 until now.

> *"OF THE $1 TRILLION IN FEDERAL SPENDING, ONLY 1 PERCENT IS ON PUBLIC HEALTH—AN INFRASTRUCTURE THAT SAVES LIVES." KAREN DESALVO, FORMER NEW ORLEANS HEALTH COMMISSIONER*



Graph I.4 Egypt's life expectancy from 1950 till 2017

(2) *Food safety*

Food safety is a crucial problem that needs to be solved. Food safety is a discipline describing handling, preparation and storage of food in ways that prevent food-borne illness. Food has the ability to transfer pathogens (germs) that can result in the illness or even death of a person and other animals. As such, it’s a very important task to regulate the handling and processing of food by issuing laws and protocols that control the process.

In theory, preventing food poisoning is possible (up to 100%). According to the WHO, there are five key principles of food hygiene, which can be summarized in:

- Prevent food contaminated with pathogens from spreading between people, pets and pests.
- Separate raw and cooked foods to prevent infecting the cooked foods.
- Cook foods for the appropriate duration at the appropriate temperature.
- Store food at the proper temperature.
- Use safe water and safe raw materials.

Locally, there have been and are efforts that are being done to reduce such effects. The most recent one is the signed agreement between the WFP (The World Food Programme) and Egypt’s NFSA (National Food Safety Authority). This five-year agreement is to raise public awareness on food safety and hygiene (the five principles). In addition, it adds to the government’s capacity to ensure access to healthy safe nutritious food.

(3) *Healthcare-associated infections*

Figure I.21 An image showing potential pathogen holders

Health-Care Associated Infections (HAI or HCAI) is an infection that's acquired during a hospital visit or any other health-care facilities. Sources can be viewed in Figure I.21. This type of infection is acquired through many means. Health care staff can spread infection, for example. Other means are contaminated equipment, bed linens and air droplets. The source of infection varies also; it can be due to another patient infected, one of the staff or in some cases it cannot be determined.

In Egypt, limited data are available because most hospital lack surveillance systems for health care-associated infections. Nonetheless, there was a study done in Cairo University Hospitals (CHU) in the period between 1 September 2014 till 31 March 2016. (Elkholy, Gaber, & Mostafa, 2016) Surveillance was active prospective and focused on ICU (Intensive Care Unit) patients; this was due to severity of their illness, their high exposure to invasive procedures and devices and their high use of broad spectrum antibiotics. The results were as following: of the 94877 patients, 1272 HAIs has occurred (1.3%). Of these, 224 (18%) are ICU acquired, 111 (9%) ward acquired, 808 (63%) infections present on ICU admission and 129 (10%) SSI (Surgical Site Infection). These results are relatively high putting in mind that the surveillances are only covering one group of hospitals.

Last, implementing a standardized surveillance system in a resource-limited country like Egypt is possible. Having a continuous and sustainable surveillance system is considered a success that leads to many developments in the infrastructure of health care organizations. Also, surveillance is fundamental to have benchmark of infections and to plan for prevention strategies.

Other causes of death in Egypt include: *road traffic accidents, violence, birth trauma, other injuries, drug use,* and *malnutrition.*

b) Energy and decreasing health problems

By finding alternative sources of energy that are less pollutant to the environment (ones that don't include the release of greenhouse gases or nuclear wastes), public health problems that are related to those gases will cease to exist resulting in a healthier society and a more productive one.

5. Improve Use of Alternative Energy

Energy (iconized in Figure I.22) is defined as the ability to do work. It is the cause of so many things around us. While eating, our bodies convert the stored energy in food into the form of energy that is usable to them. While walking, running or performing any other task, our bodies burn the stored energy in our bodies in order to complete those tasks. This concept is broadened into any other object/entity. It converts energy from one form into another form of energy in order to complete a task. A car burns fuel in order to move, a television uses electric energy in order to draw pictures, and so on.

Figure I.22 Wind turbines, a form of alternative energy

a) Sources of energy

There are mainly two types of energy: Renewable energy and non-renewable energy. Renewable energy is the energy that is collected from renewable resources and has longer age than human beings. From the examples of renewable energy: Solar energy, wind energy, hydroelectric energy, geothermal energy, etc. Non-renewable energy is the energy that comes from sources that will run out soon such as: Oil, natural gas, coal, petroleum, etc.

Figure I.23 Pollutant gas emissions

(1) *Non-renewable resources*

Non-renewable resources do not replenish and are not renewed, rather it takes thousands of years of time for non-renewables to re-exist and reemerge. Moreover, using non-renewables causes negative environmental impacts, leading to health problems. In the Pollution section, it was touched about how gases like carbon dioxide and methane contribute to the air pollution of Earth. Those gases (shown in Figure I.23) are by-products of burning of fossil fuels. They also affect water and land and cause a lot of damage. So, a movement towards using alternative (renewable) resources has been proposed that may help the environment get better and less polluted.

(2) *Renewable resources*

Figure I.24 Renewable energy resources examples

Renewable resources (exemplified in Figure I.24) are the resources that are continuously used by man but also renewed by nature constantly. These resources are endless because they cannot be exhausted permanently. They are definitely more eco-friendly than non-renewable resources and they are also cheaper.

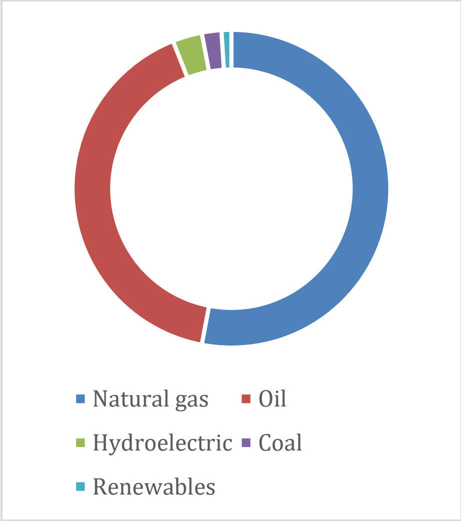
b) Alternative energy sources

Alternative energy sources are generalization over renewable resources. They are defined as any energy source that doesn't use any fossil-fuel-based energy sources and processes. They are the ones which don't cause any harmful impacts to the environment, renewable and free Alternative energy sources can be used for houses, for cars, factories and any other facility.

Alternative energy sources are used widely among all countries because of many factors including the availability of the used material for producing energy, the relatively low cost of it, in addition to being clean (green) and not0 harming the environment. If the alternative energy sources become the only sources which people rely on, the carbon dioxide emission from the conventional energy sources will be reduced and the problem of global warming will be solved in few years.

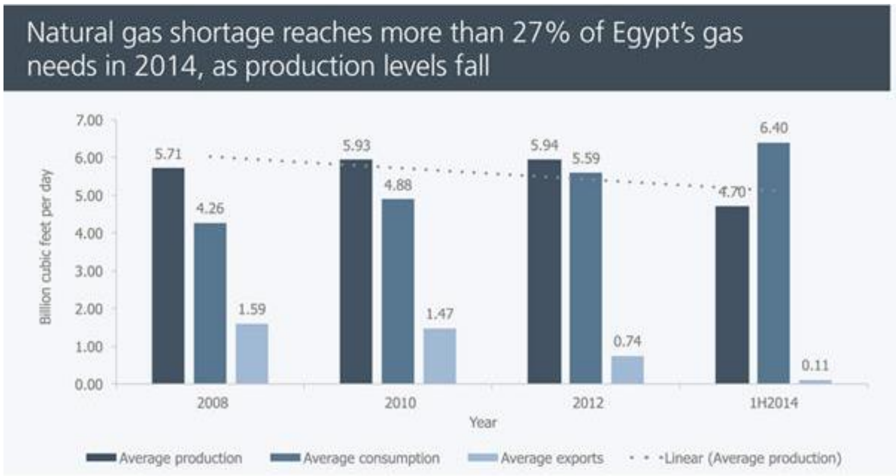
c) Energy in Egypt

Egypt, as well as many countries, faces a lot of problems and grand challenges. One of these big, major problems is the shortage of energy resources. As shown in Graph I.5, this problem is existent because Egypt is known to mainly depend in all processes on three major sources: natural gas, oil and hydroelectric power produced from the high dam in Aswan. On the other side, Egypt has many natural resources that if exploited well, the energy problem would be solved totally.



Graph I.5 Usage of main energy sources in Egypt

(1) *Crisis*

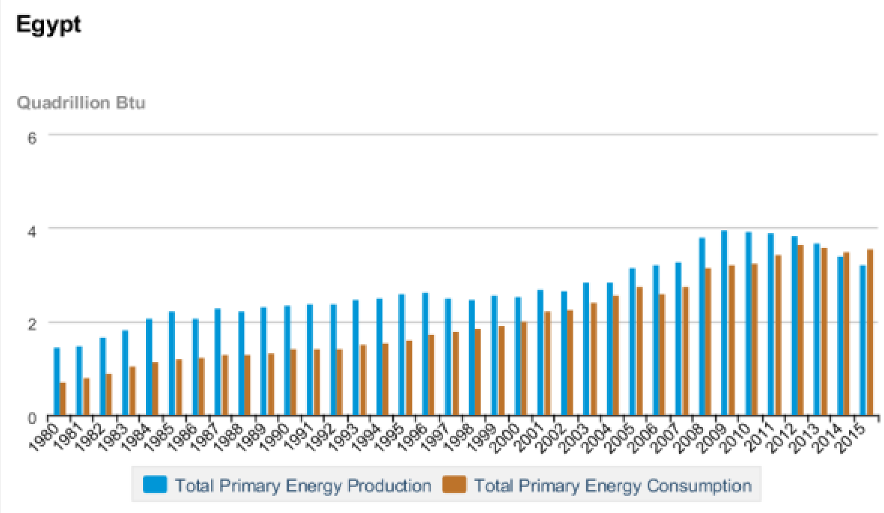


Graph I.6 A graph showing the shortage of he natural gas

Egypt is experiencing one of its most serious energy crises for decades due to the rise of consumption and declining production. As Graph I.6 shows, even the main sources of energy which Egypt depends on are being running out.

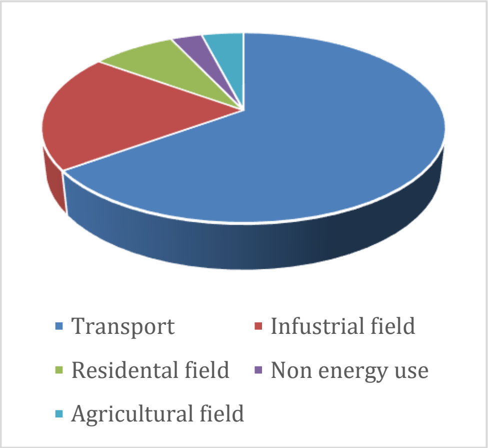
Energy shortage is a critical problem that faces a lot of countries all over the world. Energy shortage, or what is called the Energy crisis, is caused by the increased consumption of non-renewable resources of energy and this certainly would result in a disaster one day, because as the non-renewable sources refer to, they are not renewed and one day they will run out and there wouldn't be any sources of energy rather than renewable sources. The non-renewable sources of energy are just a time bomb that will destroy our life sooner or later.

The energy shortage or energy crisis in Egypt is mainly caused by overconsumption, as shown in Graph I.7, for the first time in 2015, the consumption rate of energy becomes larger than the production rate.



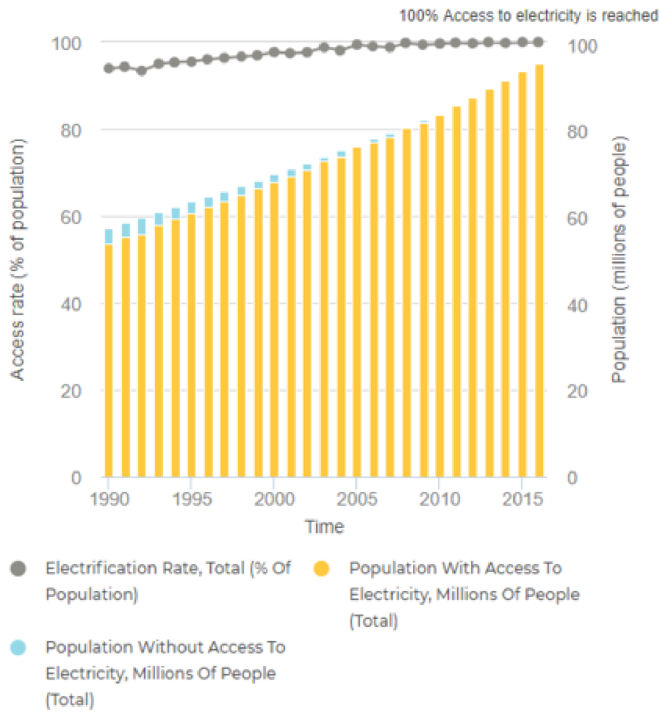
Graph I.7 energy production & consumption in Egypt

There are many factors affecting the energy shortage or crisis in Egypt. One of them is that lately, Egypt's dependence on the industrial and transportation field increased widely, as shown in Graph I.8, the industrial and transportation field participate much larger than other fields. The energy crisis in Egypt is affected by that, because most fields of work depend on energy sources, the transport and industrial fields depend mainly on energy sources and by increasing the number of industries and means of transportation, energy will be exploited faster.



Graph I.8 Various fields of work

Another fact that affect the energy crisis in Egypt is the overpopulation, as it was touched about in the Overpopulation section, whereas the number of residents increase, the demand to various energy sources also increases. Graph I.9 shows the relationship between the energy crisis and overpopulation.



Graph I.9 The relationship between energy and overpopulation

B. Problems to Be Solved

1. Wasted Materials

Figure I.25 Wasted materials

Worldwide, increasing population density along with population migration from rural to urban areas and industrial expansion lead to extreme amounts of waste generation (depicted in Figure I.25) resulting in socio-economic and environmental issues. Overall, managing municipal solid waste (abbreviated MSW) is a challenge rather than a chance to gain other products such as heat, energy or recycling materials. Nowadays, the economy of world is driven by consumer-based lifestyles, where waste production is the most obvious and negative resource-intensive by-product. MSW is classified into organic, such as food scraps, fruit, and vegetables, and inorganic, such as paper, plastic, and metals. MSW varies from a country to another depending on several factors, including economic development, climate culture, and energy sources. Furthermore, low-income countries have the highest fraction of organic waste. On the other side, high-income nations' waste is mainly composed of inorganic materials. The world bank has released a report estimating that currently 1.3 billion tons of waste is produced annually worldwide. It also reports that by 2025 the amount of waste will increase to 2.2 billion tons annually. These data indicate an urgent need for plans and strategies to decrease the rate of MSW around the world. Nonetheless, although in developed countries waste is used as a resource to gain energy, heat, and fuel, compost, collection, transport, and disposal of waste are the current issues in developing countries.

a) MSW in Egypt

The amount of MSW generated in Egypt is estimated to be 55 tons per day by the year 2011 (according to estimates), with an annual amount of waste generated to be 20 million tons. Table I.1 shows the amount of waste generated in Egypt.

Province	Daily MSW in tons	Annual MSW in million tons
Cairo	15000	5.47
Alexandria	4000	1.46
Giza	4500	1.64
Qalyubia	3500	1.27
Gharbia	3500	1.27
Beheira	3500	1.27
Sharqia	1800	0.65
Luxor	250	0.09
Aswan	650	0.23
Mersa Matruh	250	0.09
Suez	400	0.14
Red Sea	450	0.16
New Valley	100	0.03

Table I.1 Waste generation in Egypt

Figure I.26 and Figure I.27 show the decreasing of the Collection process and increasing of disposal sites, which shows the lack of waste management in Egypt. (Fahim, Gazzar, & Gomaa, 2014, pp. 3-4) There are many countries that recycle their wastes in order to produce energy and use the benefits of organic wastes in fertilization. MSW in Egypt contain materials that are 100% recyclable, where high-end garbage in Cairo is composed of 15% paper, 65% organic material which is leftover vegetables, fruit

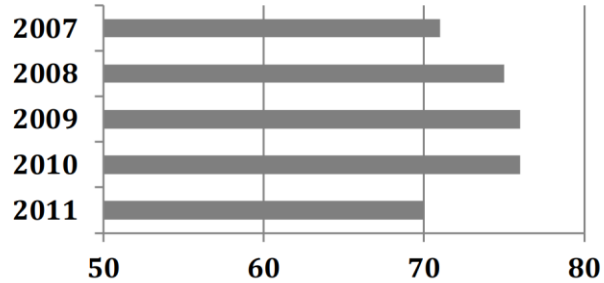


Figure I.26 Collected Waste percentage in Egypt

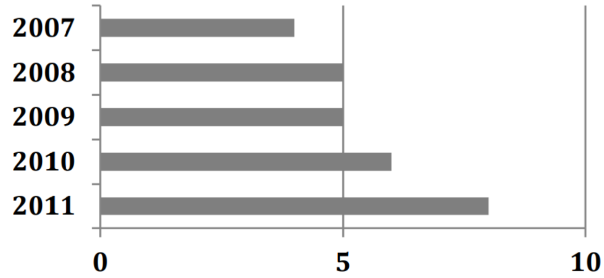


Figure I.27 Number of disposal sites in Egypt and bread and other food scraps and remnants of the kitchen, 3% plastic, 3% glass, 3% cloth, 1% metals, 1% bone, 9% other materials.

The Ministry of Environment reported an increase in the size of garbage year after year dramatically (see Figure I.27), especially with the growing population, and collected half of the garbage leaving a huge section in the streets. The volume of garbage in 2000 was 20 million tons and has reached 30 million tons in 2016.

b) Results and discussion

After conducting an experiment to measure the amount of MSW generated in Al Ma'amoura area, it was found that the rate of solid waste generation at household level was found to be 6 Kg for 5 a family of 5 members, giving a rate of 1.2 Kg/person/day, 1.2 Kg of food products, metal cans, and plastic water bottles. The results are of the experiment are shown in Table I.2. (Fahim et al., 2014, p. 3)

Week Day	Waste for 5 family members	Waste per person
Saturday	6 Kg	1.2 Kg
Sunday	5.7 Kg	1.14 Kg
Monday	5.5 Kg	1.1 Kg
Tuesday	6.5 Kg	1.3 Kg
Wednesday	4.5 Kg	0.9 Kg
Thursday	3.5 Kg	0.7 Kg
Friday	3.5 Kg	0.7 Kg

Table I.2 MSW generated in Al Ma'amoura area

An interview with the chief of waste collection and environmental services in Al Ma'amoura company for reconstruction and tourism development showed that around 12 tons of solid waste are generated daily during wintertime. The waste is gathered twice a day, once at 1:30 PM, then at 7:30 AM. On the other hand, during summertime, wastes range between 20 to 22 tons and are collected 4 times per day, at 7:00 AM, 1:00 PM, 4:00 PM, and 9:00 PM. This shows that the waste generation rate during summertime is nearly doubled if compared with the rate during wintertime. Time of collection is often shifted depending on traffic congestion and the quality of roads. Nahdet Masr for Environmental Services, the company responsible for the collection of waste, is a governmental company managed by Al

Mokawelon Al Arab Company, the same company that is also responsible for collecting waste in Alexandria. The wastes are every day at time mention before from about 150 large garbage boxes, and 100 small boxes dispersed over Al Ma'amoura area. The process is done by huge vehicles with a capacity of 9 tons and then transported to the recycling factories and disposal area. There are two main recycling factories in Alexandria, which are located in Al Amrya and Al Debana site at Al Malhat area. The wastes are sorted by waste pickers who pick metal, paper, and plastic from the garbage boxes, while the rest of the waste is processed in factories in order to produce fertilizers.

c) Pros and Cons of solving the problem

(1) *Pros*

- The decrease in the amount of MSW generated.
- Presence of more job opportunities in the recycling field.
- Improvement of the economy and public health.

(2) *Cons*

- Solving such enduring problem requires concentrated effort, so money will be hindered doing so.
- Treating MSW sites are always unhygienic, dangerous, and unappealing.

2. Wasted Energy

When energy is changed from one form to another, there is some energy loss, as diagramed in Figure I.28. This means that when energy is transformed to a different form, some of the input energy is turned into a highly disordered form of energy, like heat. Functionally, it is very impossible to turn all of the input energy into output energy, unless one is deliberately turning energy into heat (like in a heater). As well, whenever the electricity is transported through power lines, the energy that comes into the power lines is always more than the energy that comes out at the other end. Losing energy prevents processes from ever being 100% efficient.

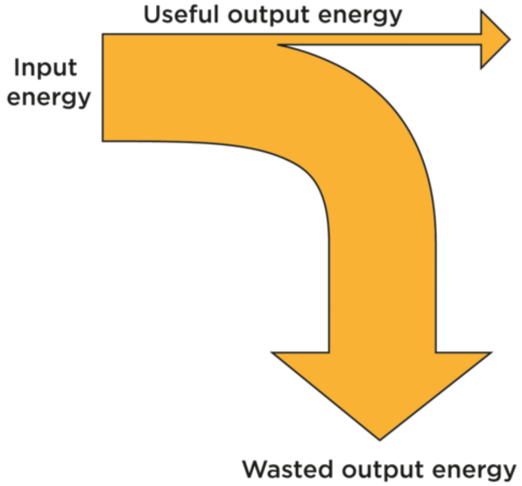


Figure I.28 A diagram illustrating wasted energy

So, alternative ways to generate energy and conserve it are need to be found. Those methods should function in best ways without losing energy through the power lines to make the amount of the wasted output energy less. Ways to convert wasted output energy into useful energy, called "Recovering wasted energy", can be one of the best solutions available.

a) Recovering wasted energy

It is a method or a technique to minimize the input of energy to an overall system by the exchange of energy from one sub-system of the overall system with another. Wasted energy can be recovered to any other form of energy, but the most energy worth recovering is thermal energy, in either sensible or latent form.

In some circumstances using of an enabling technology, either in thermal energy storage or seasonal thermal energy storage, which allows to store heat or cold in the opposite seasons, necessary to make energy recovery practicable by this way. One example is the wasted heat from air conditioning machinery that is stored in a buffer tank to aid in night time heating.

b) Types of energy losses

Energy undergoes many conversions and takes on many different forms when it moves. In every conversion there is a loss of energy. Although this energy doesn't actually disappear, some amount of the initial energy turns into forms that are not usable or the operator does not want to use.

Some examples of the devices with its input and output energy.

(1) *Hairdryer*

The input energy is electrical energy and the types of the output energy are the heat energy and the sound energy. Some of the output energy is useful such as the heat energy because the heat which generated will influence the water to evaporate and dry our hair, and some of the output energy isn't usable, as the sound energy because the sound is generated when the system is switched on and this energy isn't useful. Energy flow in the system is represented in Figure I.29.

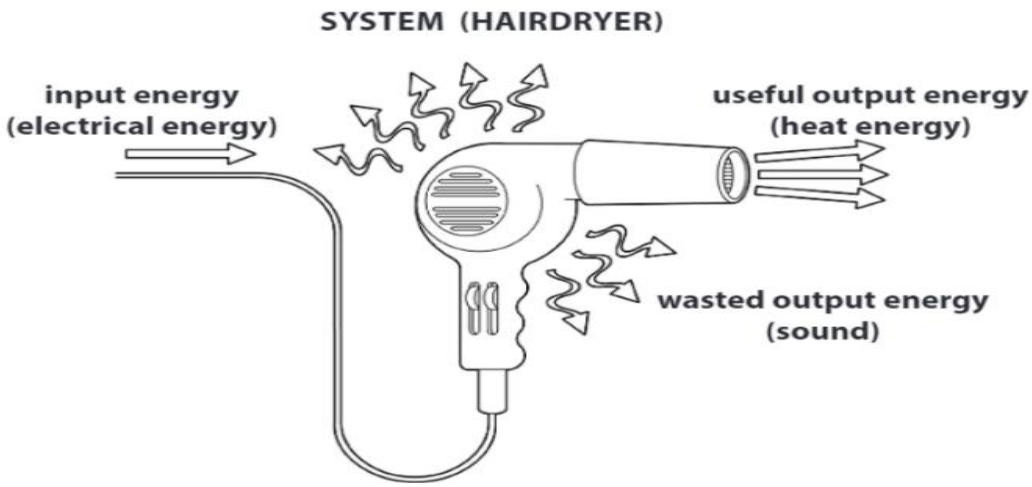


Figure I.29 Diagram of energy flow

(2) *Incandescent light bulb*

The incandescent light bulb is shown in Figure I.31, compared with the compact fluorescent bulb shown in Figure I.30. The input energy of the incandescent light bulb is the electrical energy and the types of the output energy are light energy and heat energy.

In this system, 100J of electric energy is needed every second to make it still glowing, the light energy consumed 5J only per second to be produced while the heat energy consumed 95J per second to be produced. A light bulb is used for light so, only 5J from the input energy (100J of electrical energy) is useful output while the recent 95J is wasted energy (heat energy).

There is the Energy saving light bulbs (or Compact fluorescent light bulbs), in this light bulb the amount of the useful output energy is more than the wasted output energy, this makes these lamps more energy efficient than the Incandescent light bulb. In these two figures shows the Compact fluorescent light bulb and Incandescent light bulb.

Figure I.30 A Compact fluorescent light bulb

Figure I.31 An Incandescent light bulb

(3) *Coal power station*

The input energy is the chemical energy (coal) and the types of the output energy are electrical energy and heat energy. In this system a coal power station burns coal to produce electrical energy but in this process, up to 60% of the output energy is wasted energy in the form of heat energy, this mean that only 40% of the output energy is usable in the form of the electrical energy, this 40% of the output energy moved through power lines to our homes, but the amount of energy that arrive to our houses is less than 40% due to losing of energy in the power lines, Figure I.32 shows represents the energy flow in this system.

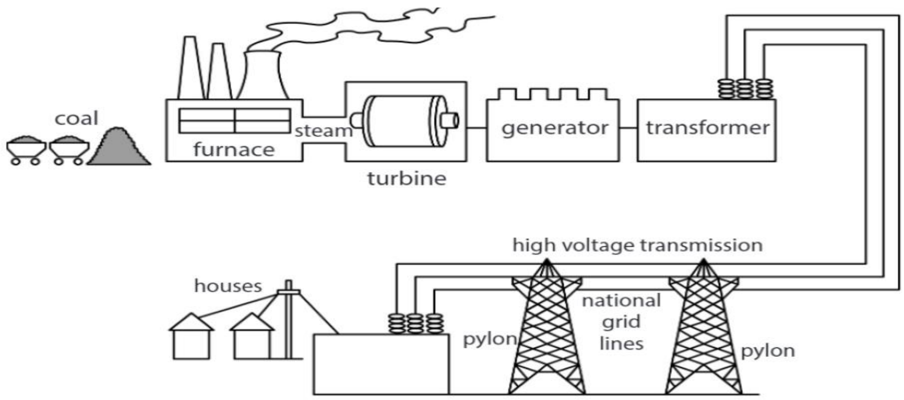


Figure I.32 A diagram showing coal power station

c) Pros and Cons of solving the problem

(1) *Pros*

Energy recovery has many advantages that enables it to be a possible solution for example:

- Solving helps developing countries with unreliable or insufficient power infrastructure flourish.
- It also gives companies a competitive advantage and increased market portion.

- Moreover, it improves overall efficiency of fuel input costs and helps users reduce amount of fuel burned.
- Furthermore, it helps make the environment more ecofriendly.
- Additionally, power density is increased.
- Also, this will result in decreased cost due to generation from wasted heat.

(2) *Cons*

- Increased costs.
- The need to update existing technology can be time consuming.

C. Researches Related to the Problem

1. Impacts of using non-renewable energy sources on the environment

Non-renewable energies are those that do not self-sustain naturally. Examples of non-renewable energies are coal, oil and natural gas. Unlike renewable energy sources like wind, water and sun--most of which are converted to power cleanly--the conversion of fossil fuels to usable energy can result in harmful emissions and its collection can disrupt local wildlife.

a) Atmospheric Effects

Fossil fuels emit harmful greenhouse gases into the air such as: carbon dioxide. Carbon dioxide (CO_2) damages the ozone layer (which protects us from the sun radiation. As well as fossil fuels the air pollution affects the environment also negatively, and affects our respiratory system badly.

(1) *Greenhouse gas emissions*

One of the most well-known impacts of using non-renewable energy sources is the emission of greenhouse gases (as shown in Figure I.33), particularly carbon dioxide, where different of fuels emit different levels of greenhouses, but what is exactly is the greenhouse effect. The greenhouse effect is the process by which radiation from a planet's atmosphere warms the planet's surface to a temperature above what it would be without its atmosphere. For example, coal which is considered as the worst carbon dioxide gas emitter occupied a percentage of 71 in the production of CO_2 gas in USA, while natural gas produced around 28%.

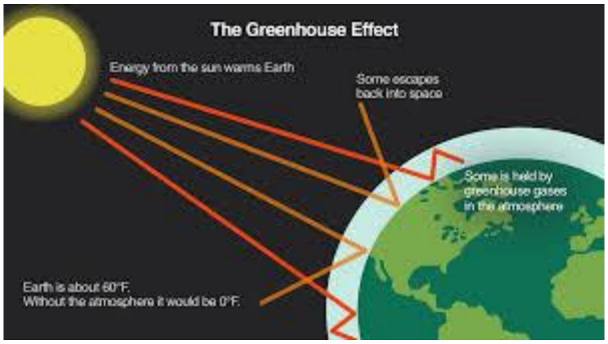


Figure I.33 Greenhouse effect illustration

(2) *Air pollution*

Non-renewable energy sources are not just affecting our Earth's atmosphere by increasing the amount of greenhouse gas emissions, they also emit a variety of pollutants that affect people's health and the environment through air (depicted in Figure I.34), and for example, coal-fired power plants are the single largest source of mercury emissions in the US. When mercury is emitted into the air, it deposits on the ground or in water. This way it can accumulate in organisms of species that inhabit the area (such as fish), passing through the food chain. Other pollutants are emitted due to fossil fuel consumption such as: SIO_2, N_2O_3, and particulate matter.

Figure I.34 Air pollution

(3) *Acid Rain*

Acid rain is created by the emission of sulfur and other chemicals into the atmosphere, often from the conversion of fossil fuels into electricity. It is corrosive to machinery and can disrupt local ecosystems. Figure I.35 illustrates the pathway of acid rain.

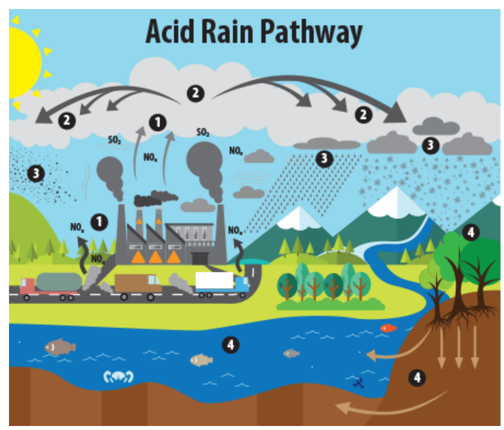


Figure I.35 The pathway of acid rain

b) Other Effects

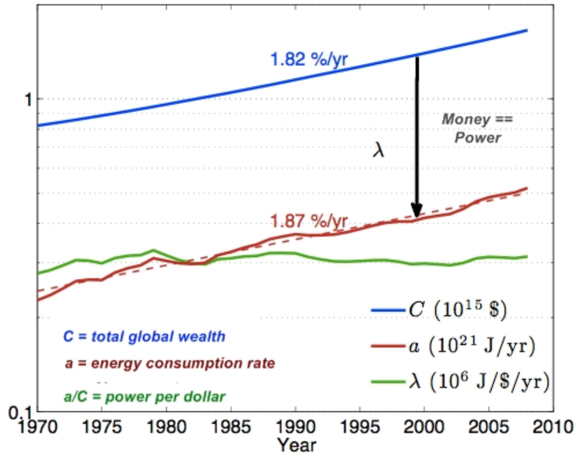
(1) *Oil Spills*

Figure I.36 Oil spills

Oil spills (shown in Figure I.36) often happen because of accidents, when people make mistakes or equipment breaks down. Other causes include natural disasters or deliberate acts. Oil spills have major environmental and economic effects. Oil spills can also affect human health. These effects can rely on what kind of oil was spilled and where (on land, in a river, or in the ocean). Other factors include what kind of exposure and how much exposure there was. People who clean up the spill are more in danger. Problems could include skin and eye irritation, neurologic and breathing problems, and stress. Not much is known about the long-term effects of oil spills.

2. Relation between wealth and energy consumption

Wealth and energy consumption can be considered as inseparable topics. As shown in Graph I.10, the more power and energy a society consumes, the greater society's wealth, the greater its citizens have opportunities to develop their economy. Unfortunately, that may be bad for us. As almost of the energy consumed is from non-renewable resources. In 2005, the world consumed about 14 terawatts of power, almost 90% of it from fossil fuels – oil and coal. These resources will may be one day run out and these societies which completely depend on it will become poorer and poorer. The more society's wealth, the more energy will be consumed due to the existence of energy resources in this country and the less energy consumption, the less society's. However, these resources which consumed may be run out one day if most of resources of energy are non-renewable. Developing and developed countries must search for renewable resources of energy. The sun provides us about 100 000 terawatts of power, enough energy to provide saturation power for about 18 trillion human beings. If only 0.05% of this incident solar energy used, energy can be provided to all people on the planet.



Graph I.10 the relationship between wealth and energy consumption

3. Increasing the costs and the prices of non-renewable energy resources in Egypt

In addition to having environmental effects, using nonrenewable resources of energy has also its economic consequences. Since the value of anything increases by increasing the demand for it then the nonrenewable energy resources are the best example for this. In Egypt, using petrol and natural gas has become a daily habit, the Egyptians use them in nearly all of their activities during the day. And with the growing population comes the continuous demand on these energy resources. And if there were a lack of the local resources (and this what happens in Egypt), the country will have to import these resources from other countries. Moreover, when importing anything from other countries, its price increases by time especially if the currency's value was weak and little in the global market. This began to happen in Egypt when the Oil minister Osama Kamal announced that the country would start importing natural gas by May 2013 in order to meet the growing domestic needs and on December 17, 2012, it became official that Egypt became a gas-importing country. And from this moment, the prices of petrol oil and natural gas have been in continuous increasing. Another cause for increasing the prices and costs is the overconsumption by the Egyptians. A good example for this is an increment in petrol consumption in Egyptian feasts and holidays. Eng. Mohammed Shaaban, president of Misr for Petrol Company, said that the holidays and feasts period has witnessed an increasing consumption by about 20%. He also pointed that his company has pumped about 6 million liters per day from benzene 80 Oct, about 2.2 million liters from benzene 92 Oct, about 60 thousand liters from benzene 95 Oct. This continuous demand and consumption for petrol and natural gas causes the increment in their prices locally. The last increase was on June 29, 2017, when the oil minister Tarek El-Molla announced an increment in prices of fuel means of transport with percentages ranges between 5.5 and 5.6 percent. He also mentioned that the government has raised the price of benzene 92 Oct from 3.5 L. E to 5 L.E with an increment of 43%, and it raised the price of benzene 80 Oct from 2.35 L. E to 3.65 L. E with an increment of 55%, and it raised also the price of benzene 95 Oct from 6.25 L.

E to 6.60 L. E with an increment of 5.6%. There has been also an increment in diesel from 2.35 L. E to 3.65 L. E with an increment of 55%.

D. Researches related to the Solution

1. Energy

As it was touched about in the Grand Challenges section, energy (iconized in Figure I.37) is defined as the ability to do work. It can also be defined as the conserved and quantitative quantity that can be transformed into many forms in order to conserve it. The law of conservation of energy, which was coined by Antoine Lavoisier, says that the energy can be converted into many forms, but it can't be created or destroyed.

Figure I.37 A current distributor, a typical icon for energy

An easy way to well illustrate the law of conservation of energy is the electric bulb in any house, as shown in Figure I.38, electric energy with 400 joules is applied to the bulb and results in light energy with 60 joules and heat energy with 340 joules, so the energy is conserved

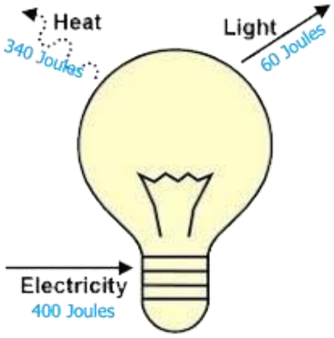


Figure I.38 Illustrating the law of conservation of energy

a) Forms of energy

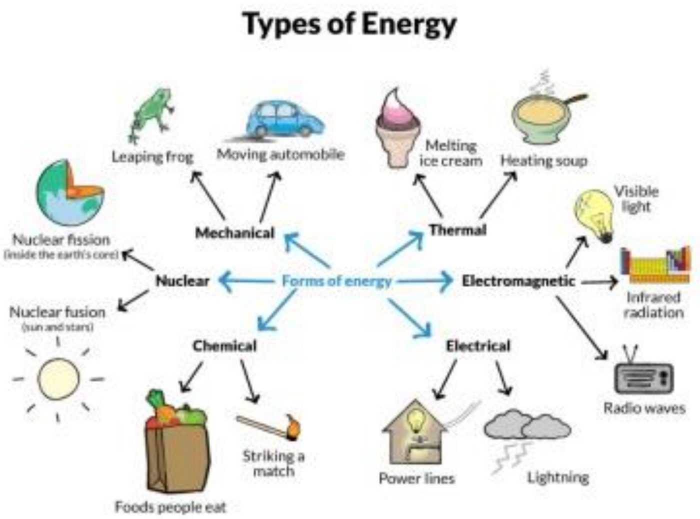


Figure I.39 Energy can be transformed from one form to another in different ways

There are many kinds of energy which are conserved into various other kinds of energy. As shown in Figure I.39, energy exists in many different forms, for example: light energy, heat energy, mechanical energy, gravitational energy, electrical energy, sound energy, chemical energy, nuclear or atomic energy and so on. Each form can be converted or changed into the other forms.

(1) *Chemical energy*

Chemical energy is energy stored in the bonds of chemical compounds (atoms and molecules). Chemical energy is released in a chemical reaction, often in the form of heat. For example, the chemical energy in fuels like wood and coal is used by burning them. As shown in Figure I.40, chemical energy is released when wood is burnt and converted into heat (thermal) and light energy.

Figure I.40 Chemical energy released while burning of wood

(2) *Nuclear energy*

Figure I.41 A nuclear power station

The nuclear energy simply can be known from the two processes: fission and fusion. Fission is the splitting or the division of the nucleus into two or more parts by being hit by a neutron. Fusion is the joining of two or more nucleoli into one. The fission and fusion processes result in a tremendous and huge amount of energy. This amount of energy can be used in various benefits such as: Enormous capacity, Reusable fuel, Greenhouse gas reduction and Economic boost.

The nuclear energy can be produced in nuclear reactors (shown in Figure I.41).

(3) *Heating energy*

Figure I.42 Fire generating heat as it burns

Heating energy (depicted in Figure I.42) is the result of movement of particles in some substance. For example, the resulting energy of bulbs is light energy and heating. The heating is formed from the movement of electrons in bulbs. This energy is usually converted to another type of energy and this process is called energy recovery. In nature, there are some natural resources which emit heating energy. Large quantities of these heat sources are readily available for waste heat recovery and thermal energy harvesting; including e.g. solar radiation energy, geothermal energy, and thermal energy expelled by the processing industry (aluminum melting, glass manufacture, oil and gas, as well as paper and cement production) or the building environment (air conditioning and refrigeration). There are many methods followed to try to convert This wasted heating energy to another type such as electricity. These methods rely on converting heating energy to electricity. The production or the amount of electricity produces depends on the temperature of the sources and the device used to convert energies. For example, if the temperature is less than 230 Celsius will produce less amount of electricity.

(4) *Solar energy*

Solar energy is one of the most promising alternative energy sources. It is simply the radiation emitted from the sun that produces heat resulting in chemical reactions and electricity using photovoltaic cells as shown in Figure I.43. Solar energy has can be used for many purposes and applications, such as solar cars which use the sun as their fuel, space-based solar power were proposed (shown

Figure I.43 Photovoltaic cells used to produce solar energy

Figure I.44 Space-based solar power

in Figure I.44), which is a satellite that rotates in a high Earth orbit and uses microwave power transmission to beam solar power to a very large antenna on Earth where it can be used in place of conventional power sources.

(5) *Hydroelectric Energy*

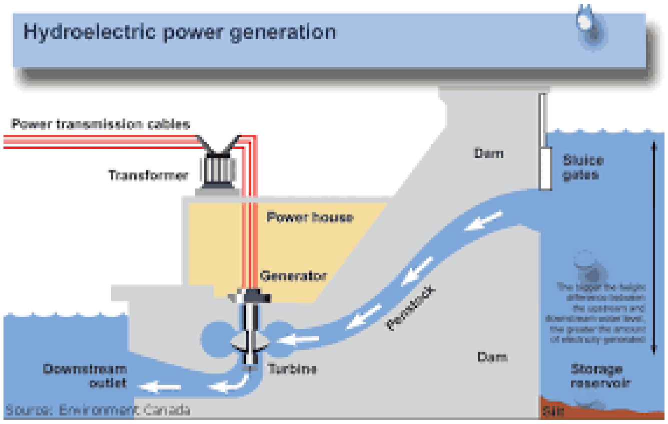


Figure I.45 Basic Idea of a hydroelectric power station

The hydroelectric energy is a form of alternative source of energy which is nearly free. The main idea in the hydroelectric energy is that when the water falls from high surfaces as dams, the potential energy latent in water is changed into mechanical energy, and then the mechanical energy is changed into electric energy by the motor turbines under the surface of water. Figure I.45 illustrates how hydroelectric energy is produced.

(6) *Wind energy*

Figure I.46 Wind mills

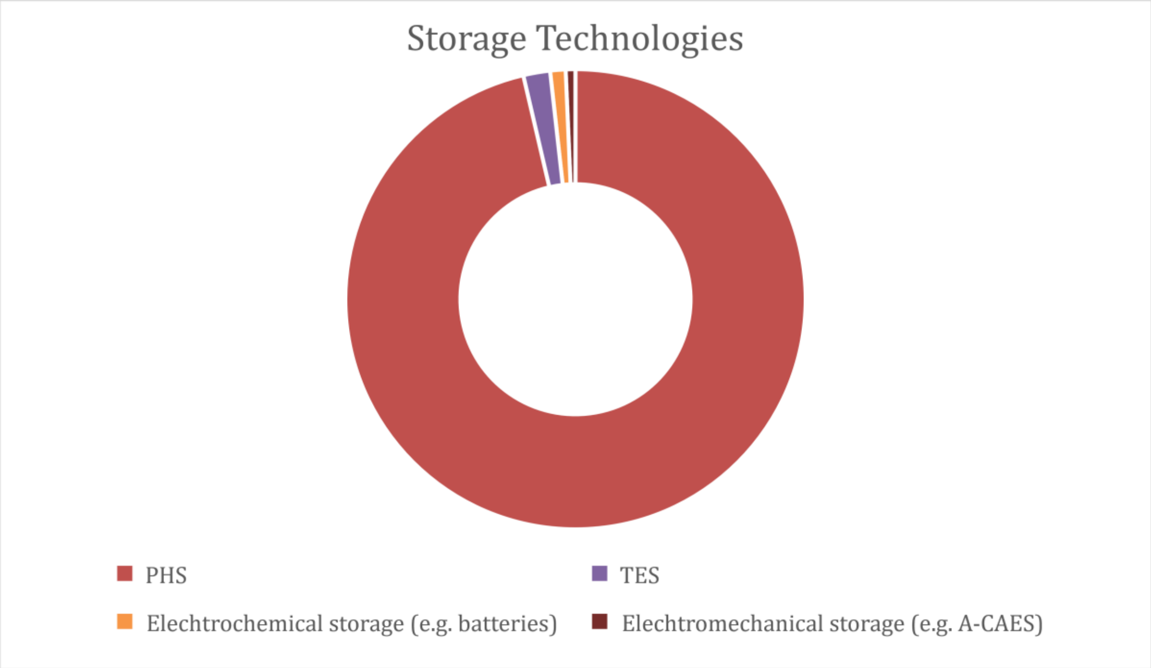
Wind energy is a form of solar energy, it is similar to the hydroelectric energy. Wind energy is a process to generate electricity, where wind turbines – as shown in Figure I.46 - convert the kinetic energy of the wind into mechanical energy, a generator converts the mechanical energy into electric energy.

2. Energy Storage

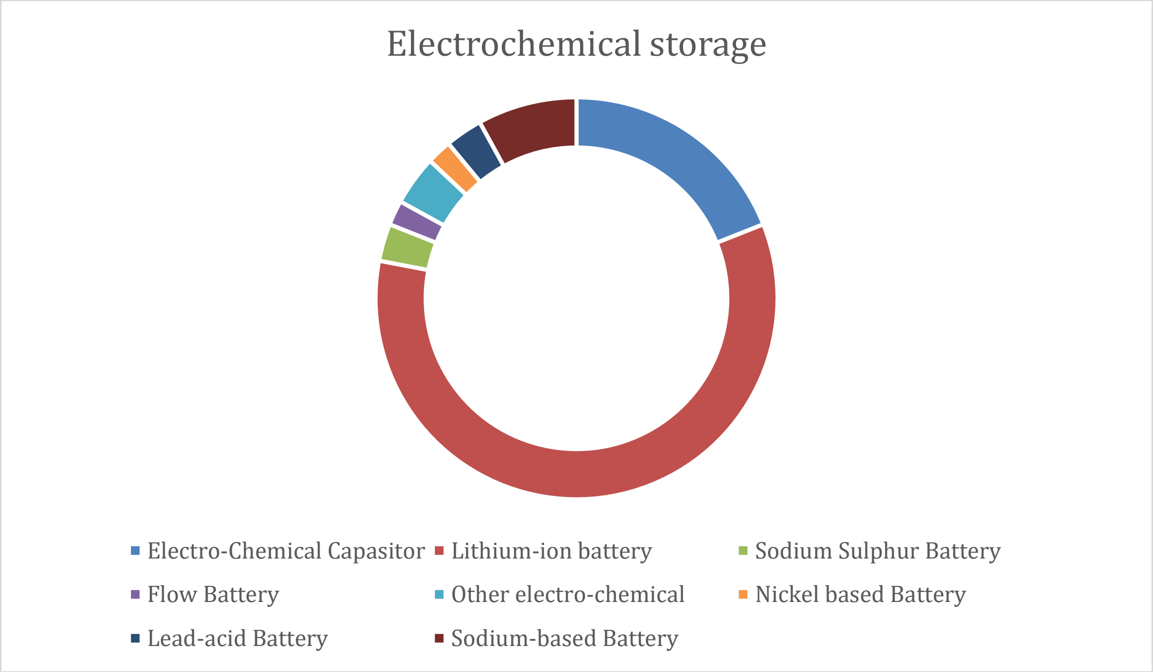
Energy storage systems are the set of methods and technologies used to store various forms of energy. They have many beneficial values for they, for example, have the potential for smoothing out the electricity supply from sources that have variable outputs and ensuring that the supply of generation matches the demand. Furthermore, they are particularly for the development and integration of renewable energy technologies.

a) Storage Technologies

Energy storage is used usually to time-shift energy delivery. (Lund, Lindgren, Mikkola, & Salpakari, 2015) There are many different energy storage systems and technologies. A summary of the current situation is visualized in Graph I.11, Graph I.12



Graph I.11 Total installed capacity of storage technologies



Graph I.12 Total global capacity of electrochemical storage

b) Pumped Hydro Storage (PHS)

PHS, having a long history and large energy capacity, is a technically mature with a 99% share of worldwide storage capacity. Figure I.47 shows a typical PHS plant,

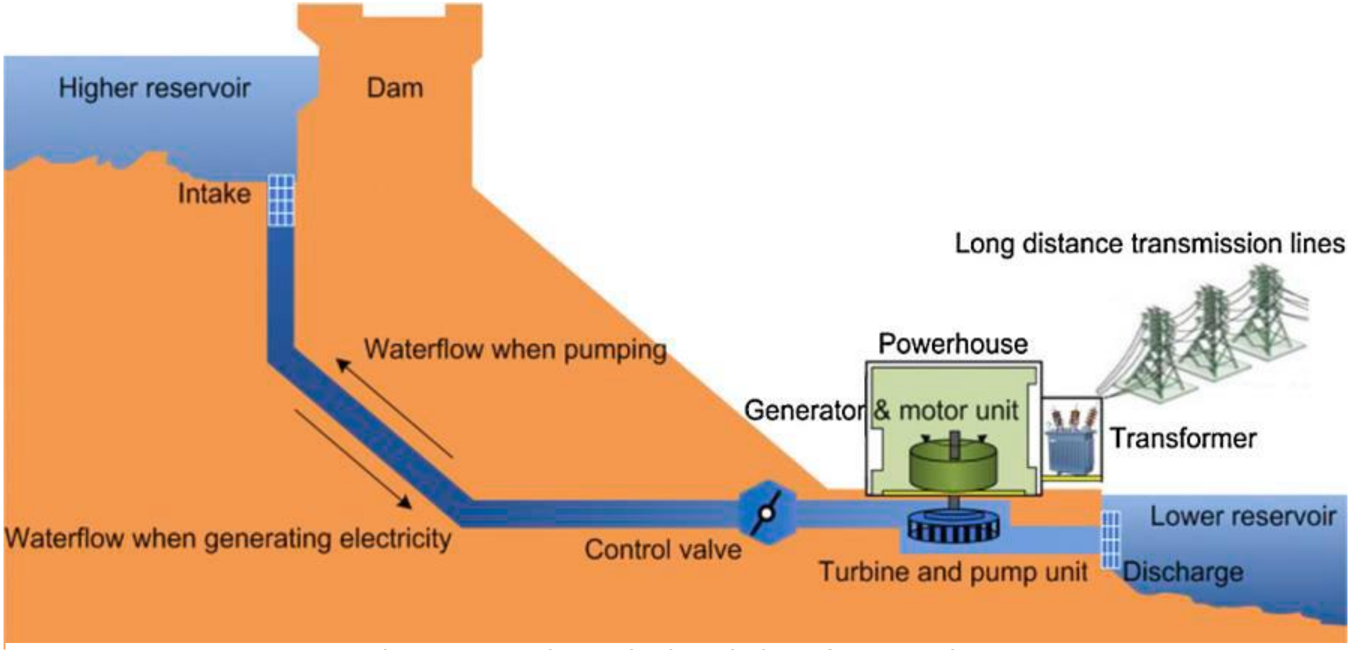


Figure I.47 Schematic description of a PHS plant which uses two water reservoirs. When there is electricity excess, water is pumped into the higher reservoir. On the contrary, when electricity is needed, water can be released back into the lower reservoir, powering water powers turbine units as it moves down in order to generate electricity.

PHS ranks high in availability. The technology is considered very mature and available. PHS is also cost effective. Investment in such projects is definitely going to pay off. (Nonetheless, if a natural disaster occurs, it only takes a crack in the reservoir for all the water to be displaced. Such a situation could result in high repair cost.) PHS system proves to be a selectable candidate to generate 100% ecofriendly renewable energy. Furthermore, as PHS systems depend on water, the negative impact on public health is very low; thus, it has a low probability of health disturbance.

c) Thermal Energy Storage (TES)

TES stores thermal energy using different approaches in insulated reservoirs. As

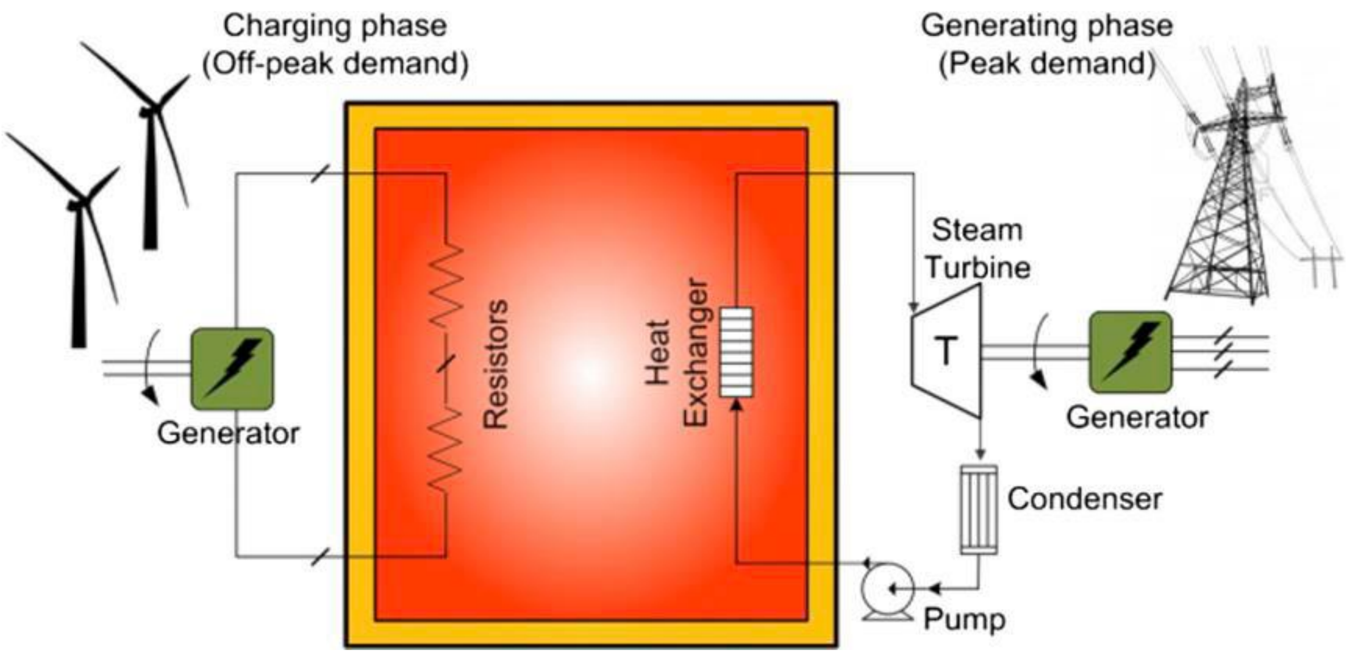


Figure I.48 TES system for excess wind generation

shown in Figure I.48, which is a diagram for a TES system for excess wind generation, the generated electricity is converted into thermal energy and stored. It, then, gets to produce steam vapor. The vapor is used to drive a turbine to generate electricity.

Concerning availability, TES is highly available and can be easily put to use. Furthermore, TES can operate in different locations and temperatures, meaning that it is available, practical and usable by consumers. It is also considered a viable solution with relatively low capital expenditures of approximately (3–60 €/kWh). In addition, it is extremely eco-friendly and doesn't cause any health problems.

d) Batteries

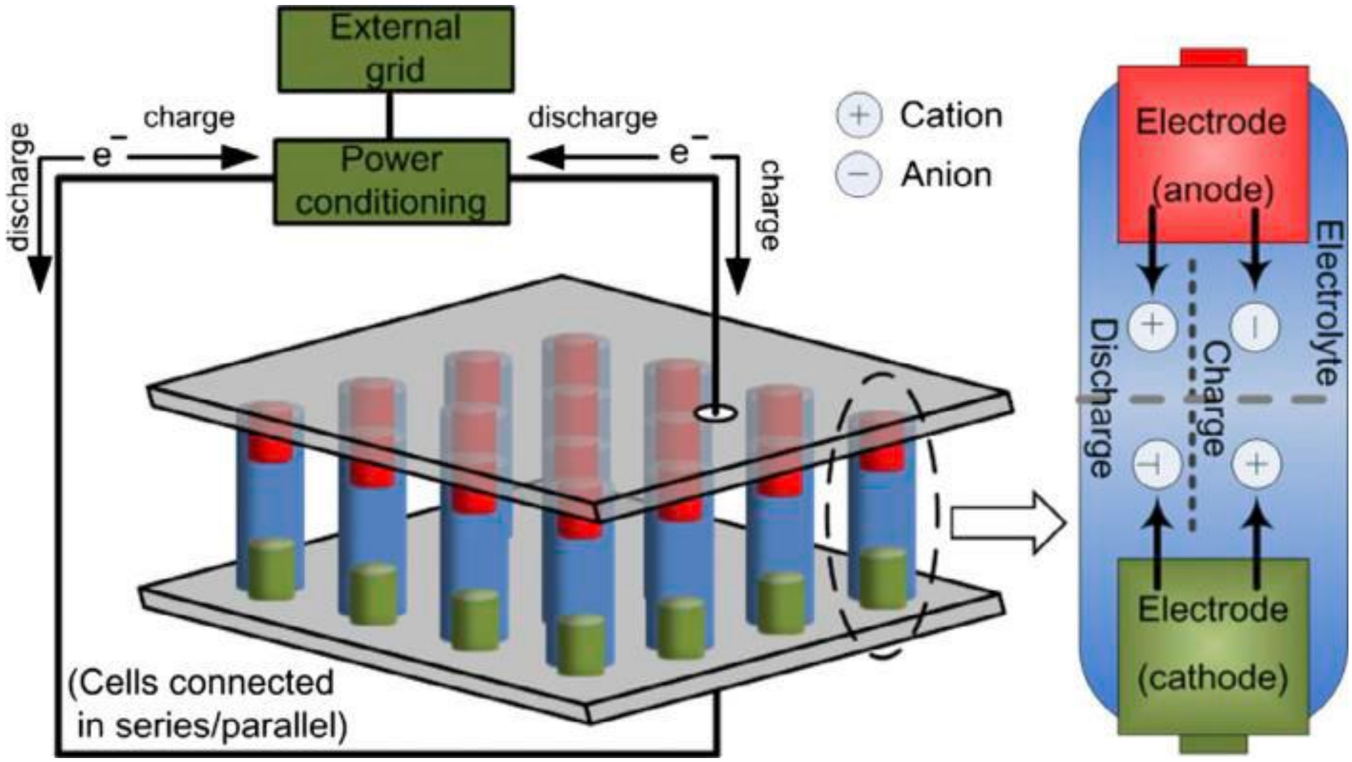


Figure I.49 Battery scheme

Batteries consist of a number of electrochemical cells connected in series or parallel. They produce electricity from an electrochemical reaction. A typical cell consists of two poles (the anode and cathode) with an electrolyte placed between them. The electrolyte can be solid, liquid or viscous. The cell converts chemical energy into electricity, some has the ability to reverse the process of conversion. While discharging, the electrochemical reactions takes place at the anodes and the cathodes simultaneously. To the external circuit, electrons are provided from the anodes and are collected at the cathodes. When charging, the reverse reactions happen and the battery is recharged by converting the electrical energy in the electrodes back into chemical energy. (Many types of batteries cannot be completely discharged due to their lifetime.) These basic operational principles are shown in Figure I.49. The most common battery types are Lithium-ion (Li-ion) batteries, Lead–acid batteries, Sodium–Sulphur (NaS) batteries, Nickel–cadmium (NiCd) batteries, Nickel–metal Hydride (NiMH) battery, Sodium nickel chloride battery (also known as ZEBRA battery).

Availability in batteries score differently depending on the type of the battery being analyzed. Because batteries can be mass produced using a variety of materials, some of these materials, e.g., Sodium, are abundant in the environment and can be obtained easily. However, the most common type of batteries is Li-ion, which is scarce in the environment. With cost, again, it depends from one type to another. Nonetheless, the cost trend clearly indicates a fast cost reduction due to high learning and growth rates.

3. Power

Figure I.50 Distribution towers

Power is the rate of doing work (iconized in Figure I.50), transforming heat or conserving energy to another per time. For example, if two machines do the same work but the first one takes more time to do this work so the power of the second machine is more than the first one. Burning one kilogram of coal releases more energy than what TNT did but the rate or he time TNT did this work is less than coal, so TNT has more power than coal. Power is physical quantity meaning that it has no direction, and its unit is joule per second (J/s). In electrical machines, the power is known as watt. Another definition is horse power which is so used in cars to measure is efficiency. Other units of power include ergs per second (erg/s), metric horsepower (Pferdestärke (PS) or cheval vapeur (CV)), and foot-pounds per minute.

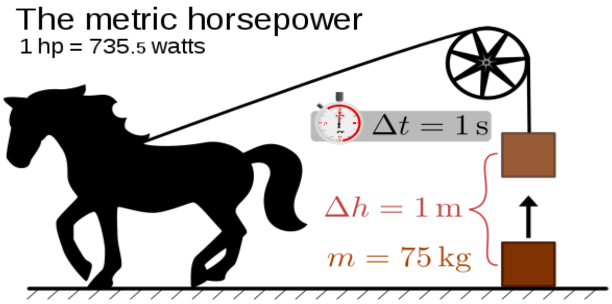


Figure I.51 Shows one metric horse power

Horsepower (illustrated in Figure I.51) is a calculated capacity for performing work with or producing energy from mechanical force, typically torque. Power can be calculated by dividing work by time. Because work also equals force times distance. Power equal also F times distance over area. In mechanics, Horse power or metric horse power is used more than watt in mechanical field. One Horse power is equivalent to 550 ft-lbf/s and 745.7 watts. One metric horse power is the power needed to lift 75 kg one meter in one second by a horse.

Different forms of could be electric power, which is the rate at which electrical energy is transferred by a circuit, human power, and optical power. The electrical power is another type of power. The electrical power is the rate per time at which electricity is transferred through circuit. Electric power is specifically measured by watt. Electrical power can by generated by electric generators or from batteries. Every battery gives different watts. For example, battery of power 50 wats may give the same electricity of that 40 watts but the difference is the 50-watts battery may give this electricity in less time than the other. Electrical power can be calculated by Equation I.1.

$$W = V \ I$$

Equation I.1 Power Equation

where W is the power in watts, V is the potential difference in volts and I is the current in amperes. So, the definition of Watt can be deduced from this equation: One watt is the rate at which work is done when a current of one ampere flows through a network which has an electrical potential difference of one volt. Power can also be calculated by knowing the resistances in the current by Equation I.2.

$$W = V^2 \div R$$

Equation I.2 Calculating power knowing density

For example, if the resistance is 50 ohms and the potential difference is 25 volts, the power would be 12.5 watts.

4. Triboelectric Effect

Also known as triboelectric charging, the triboelectric effect is a type of electrification that happens on contact. This effect causes electrical charging on certain materials after the contact is over. An example of this contact can be rubbing or pressing the materials together. The reason behind this effect is that some materials act as electron donors and others act as electron acceptors. When two of those materials (one a donor and the other an acceptor) come into contact, the electron acceptor hogs the electrons from the electron donor, creating a potential difference. The polarity and strength of this potential difference depends on several factors, including the two materials chosen, surface roughness, temperature, strain, and others.

a) Triboelectric series

Triboelectricity can be largely unpredictable, and only broad rationalizations can be made. One of those attempts to generalize the effect of materials on each other is the triboelectric series (shown in Figure I.52), which is a list of materials showing which have a greater tendency to hog electrons and becomes negative (-) and which have a greater tendency to lose electrons and become positive. This first list was published by Johan Carl Wilcke in a 1757 paper on static charges.

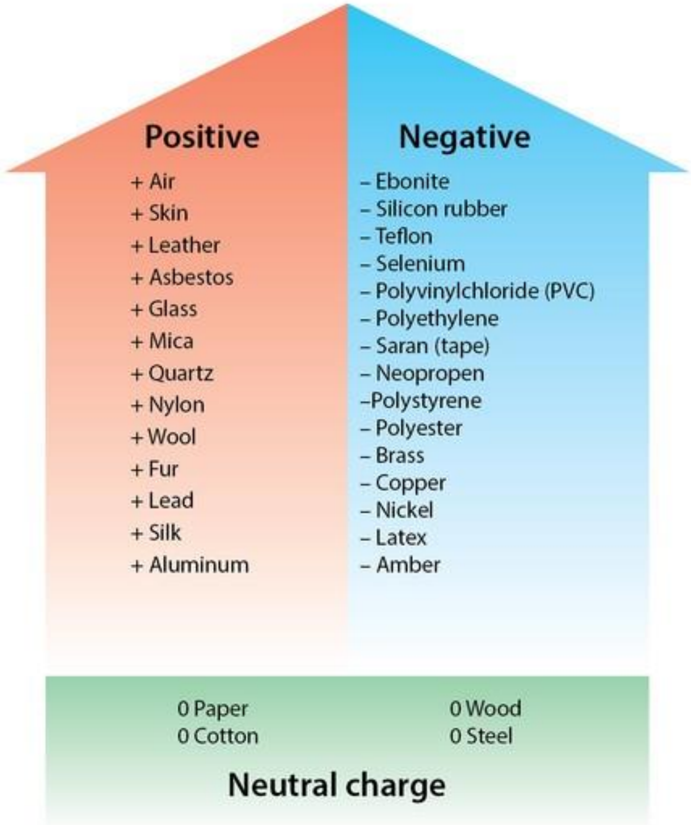


Figure I.52 The triboelectric series

b) Triboelectric Generators

Based on this phenomenon, a new type of electric generators was innovated. This type of generators uses the potential difference created by such materials to derive electric current, making work. They are used as sensors or power generations spots. The mechanism behind such generator is demonstrated in Figure I.53.

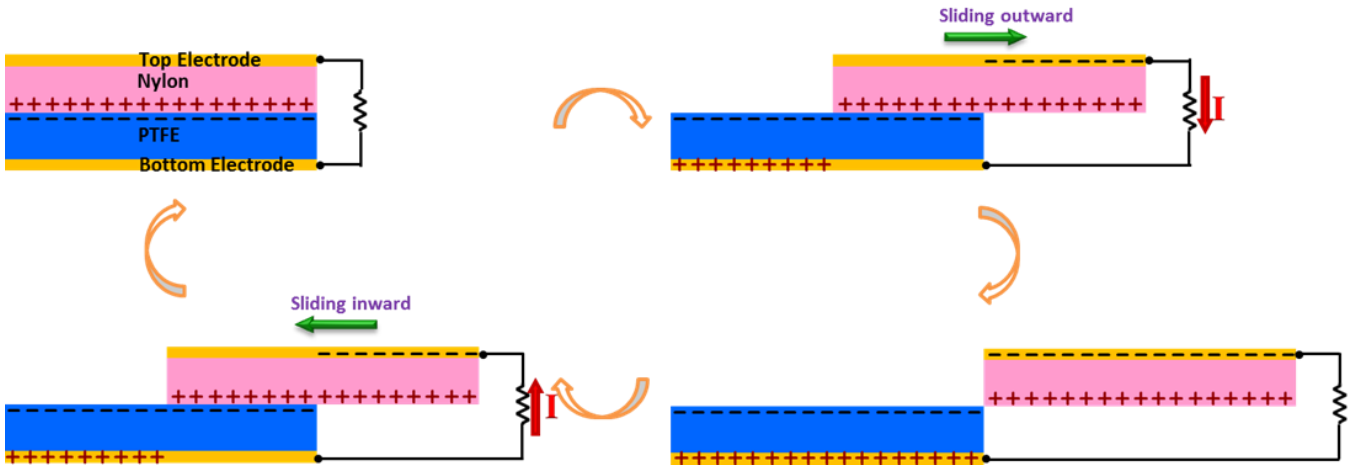


Figure I.53 A nanogenerator employing the triboelectric effect to generate electricity

E. Prior Solutions

1. TEG

TEG is abbreviation for thermal electric generators. (Zabek & Morini, 2019) It is one of the devices or systems that converts heating energy to electricity as shown in Figure I.54. This device is firstly invented by Thomas Seedback. The two semiconductors are put between hot heat source and cold one. Semi-conductors are elements have electrical conductivity less than metals such as copper and not as insulators such as plastic.

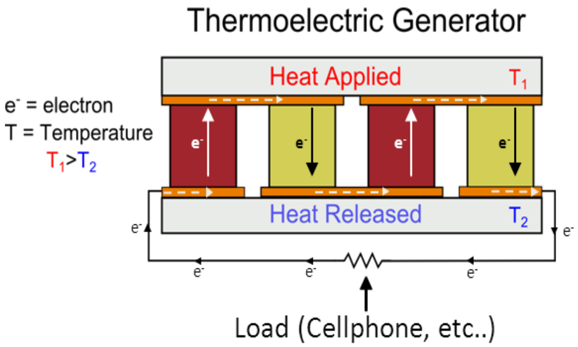
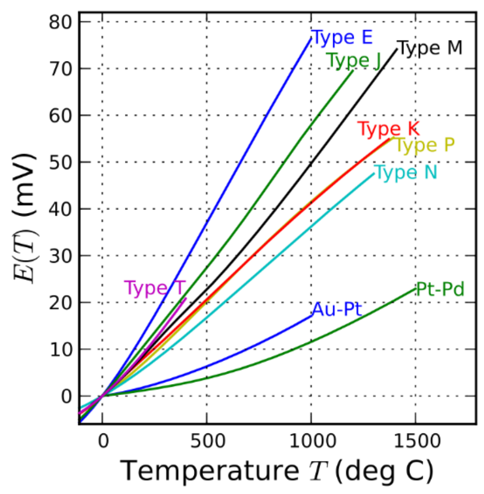


Figure I.54 Thermoelectric generator mechanism

The device consists of three mainly parts thermoelectric materials, thermoelectric modules and thermoelectric systems. The thermoelectric materials (semi-conductors) convert temperature differences into electricity. These materials must have high electrical conductivity and low thermal conductivity. As when one of the minerals or elements(semi-conductors) is hot the other one will stay cold. Thomas seed back said that if tip of part of mineral cold and the other is hot the electrons will flow from the hot side to the cold one creating the voltage difference (electricity). Let's simplify if one of tips of metals is heated the molecules tend to have high kinetic energy. The hotter the molecules, the more kinetic energy they have and they faster move from hot to cold side. The hotter side will be slightly positive and the cold one will be negative creating the voltage difference between them.

The elements or semi-conductors used in his device are considered the most important part in this device and here's some of the most known semi-conductors couples (can be used in the device): chromel–constantan (Type E) (produces 68 µvolt for every degree Celsius), iron-constantan (Type j) (produces 50 micro meter for every degree Celsius), and chromel-alumel (Type K) (produces volt for every degree Celsius). The different thermo-couples are graphed in Graph I.13.



Graph I.13 The voltages produced by different types of semi-conductors couples

Watts or power generated by this device differs by the semi-conductors couples and the temperature. If the temperature is 212 F (100 Celsius) it produces about 3.14 watts. If temperature is 512 F (266.5 Celsius) it produces 19.1 watts.

a) Strength Points

(1) *Size*

The size of TEGs may be reach to 0.14 Ibs. In comparing to the solar panel which its weight is approximately 18 Ibs.

(2) *Area*

Area or size of TEGs can be 5 Square inches. The solar panel's area can be 760 square inches, SO it is easily to deal or put TEGs in for example your home than solar panel.

b) Weakness Points

(1) *Electricity produced*

TEGs produces less watts if comparing with solar panel. AS one TEG can produce 19.1 watts (temperature 266.5 C) comparing to solar panel which produces about 65 watts. 4 TEGs can produce more than one solar panel. (Zabek & Morini, 2019)

(2) *Cost*

	Cost (each) ($)	Cost (4) ($)	Size (each) Area (sq. in)	Size (4) (sq. in)	Weight (lbs	Weight (4) (lbs	Power at 212F Differ. (W)	Power at 518F Differ. (W	Power output (1 solar) (4 TEGs) (W)
TEG	99.75	400	5	20	0.14	0.56	3.54	19.1	76.5
solar panel	250		760		0.18				65

Table I.3 The cost of both solar panels and TEGs (green advantage, red disadvantage)

The cost of one TEG is slightly low. It costs 99.75 Dollars comparing to one solar panel which is about 250 dollars. But one TEG produces less watts than solar panel, so it is better to compare 4 TEGs with solar panel. 4 TEGs cost 400 Dollars. They cost much more than solar panel.

And here’s a comparison between solar panel and TEG.

2. Electric Turbo Compounding (ETC)

It is a technology solution to solve the problem of the wasted energy by improving energy efficiency for the stationary power generation industry. It is predicted to burn the fossil fuel to generate energy to continue for decades, especially in developing economics, this raise the emission in carbon dioxide, which is produced by high percentage be the power sector worldwide. ETC works by making the gas and diesel-powered gensets do its function more effectively and be cleaner, by recovering waste energy from the exhausts to improve energy generation and fuel efficiency.

a) Mechanism

ETC system (shown in Figure I.55) is defined as replacing a turbine by a generator (turbogenerator) which is located in the exhaust gas flow of a reciprocating engine to return waste heat energy which produced from burning fuel and convert it into electrical energy.

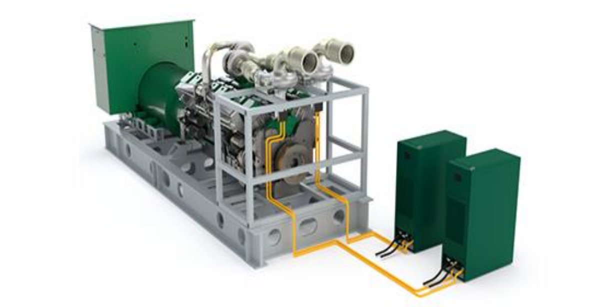


Figure I.55 The ETC

An example on ETC system which replacing turbogenerator down a turbocharger turbine of an Internal Combustion Engine (ICE). The ETC can generate enough power to run local electrical loads, such as engine auxiliaries or to feed an electrical grid.

b) Importance of energy recovery in (ICE)

The operating cost of an ICE is very high, diesel generator set which is continuously operated may have fuel bills which could represent fuel bills more than five time the capital cost of the generator cells.

c) System architecture and working principle of ETC

ETC system is located down the turbocharger of an ICE. The exhaust gases pass with high speed through the turbocharger turbine due to the high pressure before passing through a turbine, then the turbocharger turbine drives a high speed, then the high-speed generator produces more frequency power which can be converted to DC or AC power. in this system, the extra power is added to the primary power that produced from the generator to increase the system efficiency whereas for an automotive application the ETC system would become the primary generator to feed the vehicle's auxiliary systems.

d) Architecture of an ETC system

To aid to know the components of the ETC system (turbogenerator, turbocharger and power electronics)

(1) *Turbogenerator*

It is a generator in ETC system which is coupled to a turbine to achieve the function of converting mechanical energy to electrical energy.

(2) *Power electronics*

Power electronics is the system that controls the turbogenerator operations and convert high frequency of the produced current to DC for auto motive applications or AC for power generation applications.

(3) *Turbocharger turbine*

It is a turbine in ETC system which make its function when air passes through it then it rotates the generator to generate power.

3. The Sludge Treatment Facility

The Sludge Treatment Facility (STF) is held by the Environmental Protection Department of the government of Hong Kong Special Administrative Region as well as the project proponent. (Swann, Downs, & Waye, 2017) STF is a facility committed to treat sewage sludge. It features a state-of-art incineration technology, providing a reasonable sewage sludge treatment solution, with a plan to maximize the reduction on disposal of the sludge to landfill. In consideration of the fading landfill space, the STF is intended to treat 2000 tons per day, therefore reducing the mass of the sludge by 90%.

The STF has another purpose, which is to generate electricity by using the heat resulted from the incineration of waste, resulting in all power being preserved for the daily on-site processes, with the design allowing the export of additional power to the local grid. Furthermore, the facility has a section to produce both processed and portable water in addition to being able to treat all waste water for use on-site. This design makes the facility with no outfall for wastewater and incoming water supply. Figure I.56 shows the layout of the facility.

Figure I.56 Layout of the STF

a) The Sludge Treatment Facility

(1) *Features of the facility*

The layout and location of the facility are shown in Figure I.56 and Figure I.57. The STF is designed to carry two plants, with an administration building in between to house the chimney flues for the four incineration trains.

Each plant is separated into three sectors

- Sludge receiving zone – deodorization and bunker area.
- Incinerator zone – steam production and incineration area.
- Treatment zone – residue handling area and flue gas treatment.

Figure I.57 Location of the STF

Adding to the above three zones, there are two major supporting facilities groups – the power generator and supply system and the water treatment and supply system. Both of these systems are built with the aim for the STF to become a self-sufficient facility. Figure I.58 illustrates the sludge treatment in a simplified diagram. (Swann et al., 2017)

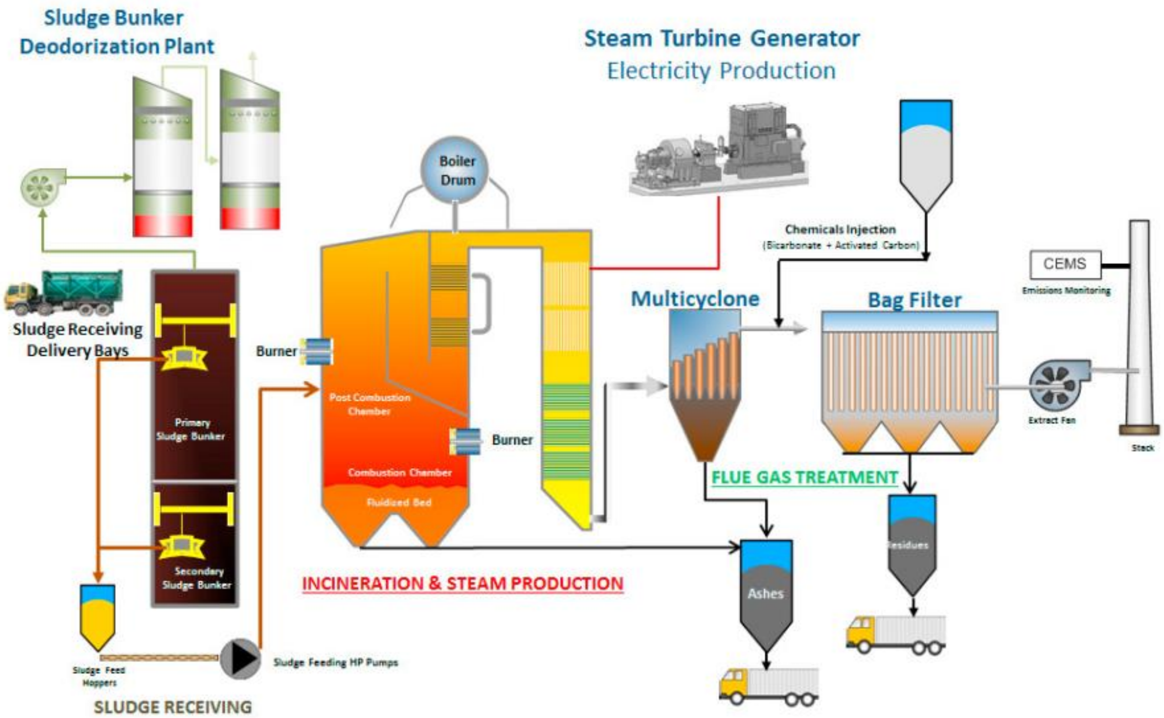


Figure I.58 Simplified Process Diagram of the STF

(2) *Sludge receiving zone*

Over 70% of the sludge is delivered from Stonecutter's Island Sewage Treatment Facility. Sludge is dumped in bunkers and then fed to hoppers that carries it to the incinerator by grab crane. The capacity of treatment of the STF is 2000 tons per day, and the containers are designed to store up to nearly 3000 m^3 per plant providing a barrier. The bunkers are allocated so that primary sludge which represents over 75% of the whole sludge, and approximately 25% which is for biological or digested sludge, bearing on mind that both will be mixed in a particular portion to obtain optimum combustion before delivery to the incinerators. (Swann et al., 2017) Deodorization area then collects and treats the odor generated from sludge receiving zone and bunker area.

(3) *Incinerator zone*

Two incinerators are provided in each plant, it is also provided with a treatment capacity of 550 wet tons of sludge per day, making the STF meet the overall design requirement of having the ability to treat 2000 tons of sludge per day. In view of the sludge characteristics including the high salinity of Hong Kong's sludge, the best solution to facilitate this process was to use fluidized bed incinerators.

The fluidized bed incinerator includes three zones, (inlet and distribution, fluidized bed, and gas exhaust). Sludge is inserted into the system through injection nozzles, it is then distributed evenly in the fluidized bed. The bed encompasses air and sand nozzles located at the bottom of the incinerator, where sand is fluidized as boiling liquid when a proper air velocity is present, heavy turbulences and gas bubbles are then produced which mix with the injected sludge. The bed is heated by injecting diesel fuel. Hot sand's movement appears alike to the boiling liquid, which clarifies the term "fluidized bed". The bubbling sand offers a scrubbing action boosting the combustion process by removing the char layers found around the sludge particles and improving the efficiency of the combustion procedure by creating more surface area. The overall volume of sludge is decreased as a result of this scrubbing action, reducing the sludge's overall mass by approximately 10% of the original one.

The fluidized bed system is an "open bottom" arrangement, thus evading regular shut down of the system in order to clean up material stacked at the bottom of the incinerator. It also performs as a filter, where the coarse material sinks to the bottom hopper and is then removed, while ash is removed to be either recycled into the system as disposed of or bed material.

In addition to that, the incinerator also acts as a boiler, producing steam to run the turbines, where the walls of the incinerator consist of extended water pipes. The hot flue gas experiences numerous phases of heat recovery before entering the flue gas treatment process.

(4) *Treatment zone*

The flue gas treatment system is composed of three stages and treats the combustion gases so that they satisfy the stringent regulation imposed by the environmental impact assessment requirements on emission of pollutants.

Probable pollutants and byproducts extracted by the three stages include:

- Acidic gases
- Ashes and residues
- Furans, heavy metals, and dioxins

First, dust and heavy particles are removed by a multi-cyclone separator, then the flue gas is inserted with different chemicals in the dry reactor, finally, the flue gas moves through a bag filter system where the remaining ash and residues are removed.

No visible plume is generated to eject from chimney stacks during the procedure of the STF. Data from flue gas characteristic and Hong Kong Observatory are reviewed to find any potential plume formation, heated air is then injected into the flue gas to cut down the visibility of plume for certain weather conditions throughout the year.

A continuous emission monitoring system is installed as part of the FGT system to observe the flue gas and guarantee the compliance with the stringent emission requirements.

(5) *Ancillary and supporting facilities*

They are combined with the STF to help with the operation. The two main supporting systems are “water treatment and supply system”, and “power generation and supply system". This makes the STF a self-sustainable facility, since no external water supply or sewage outfall is present and the external provision is for standby only.

(a) Water supply and treatment system

The STF is armed with a desalination plant and a waste water treatment plant, which allows the facility to produce its own water and treat its waste water for recycling.

The desalination plant produces demineralized water for steam production and portable water for consumption. Seawater is thrusted to the desalination plant, where it undergoes two rounds of reverse osmosis. A pre-treatment system is also equipped to account for differences in seawater quality. For drinking water production, remineralization is executed in the plant and the quality fulfills the World Health Organization's requirements for drinking water.

The Contract necessitates that all waste water is recycled on site for non-potable uses, such as landscape irrigation and vehicle cleaning. Treatment of wastewater is done by a bioreactor and UV-treatment. However, due to the zero-discharge policy required by the Environmental Permit, an emergency storage tank was also placed on the Site to ensure the waste water treatment system is robust to changes on site.

(b) Power supply and generator system

The prime source of electricity used for STF daily operations is gained by the two steam turbine generators that are fed with steam retrieved from the incineration of sludge to generate all electricity needed to operate STF. The steam is then condensed back into water through the air-cooled condensers to repeat the process.

In addition to being self-sustaining in power, the STF is also planned to be a waste-to-energy facility by exporting excess power to local electricity grid provided by China Light and Power Hong Kong Ltd (CLP). The steam turbines producing power at STF can also transfer up to 2MWe of electricity power to CLP's grid.

b) Advantages of the system

The STF provides numerous features to be taken for account, it decreases the pollution by disposing sludge, leading to improvements in the public health. It also assists in providing a source of renewable energy for the country, leading to the provision of non-renewable sources of energy, and saving the environment.

4. Actions taken by KSA to face MSW

Millions of worshippers come from across the world in order to perform the religious rituals known as hajj and umrah. Pilgrims visit Medina which is considered one of cities in the world after performing their rituals in Mecca. Most of the municipal solid waste in Medina is disposed of in the landfills after a partial recycling process of metals, papers, and cardboards (ranging between 10% - 20% of total MSW). (Nizami et al., 2017) A new policy of Vision 2030 has been launched by the Saudi government, which outlined the safeguard of local environment through enlarged efficiency of waste recycling and management, pollution avoidance, generating renewable energy from wastes. Presently, the recycling strategies in KSA are implemented by an informal sector through waste scavengers or waste pickers. This has led to the necessity of new, improved strategies to confront MSW and recycle it, especially in Mecca and Medina through a public-private partnership. Enormous amounts of energy can be maintained, that would be used in raw materials extraction, transportation, and manufacturing. Energy reaching to 10000 TJ can be saved in recycling only about 24.21% of MSW in Medina. An estimation was made stating that around 10.2 thousand tons of methane (CH_4) emissions and 254.6 thousand Mt.CO_2 eq. of global warming potential (GWP) can also be saved. Waste recycling does not need high skilled labor or advanced technology; therefore, it can be executed easily in Mecca and Medina to gain environmental benefits.

a) Methodology

The MSW produced in Medina was estimated based on waste generated the population of the city, as well as waste generated during Hajj and Umrah by the pilgrims in 2016. Population of Medina in 2016 was about 1.513 million and 1.4 kg of waste per capita were produced every day. This is equivalent to 773 kg of waste generated by the local population in 2016. 1.8 million pilgrims visited Medina during Hajj time, resulting in increase in waste generation per capita to 2.2 kg for 7 consecutive days. These numbers caused 27.7 thousand tons of waste in Medina in 2016. Similarly, around 6 million pilgrims came to KSA during 2016. It was estimated that each pilgrim stayed in the country for an average of one week, with waste generation of about 2.05 kg per day, which equals to 86.1 thousand tons of waste. It is expected that the number of pilgrims would increase as result of the enhancements and enlargements made in the holy mosque. In addition, Vision 2030's plans are based on that the 8 million pilgrims for Umrah will increase to 30 million per year. The will to the increase in MSW generated in Medina and Mecca.

The savings values of waste recycling in Medina are based on fractions of recyclable materials, including paper (18.6%), metals (1.9%), glass (2.9%), and aluminum (0.81%). Recycling these materials would also generate 444770 MJ per ton. Considering environmental values, methane emissions were handled according to the standard method of Intergovernmental Panel on Climate Change (IPPC). Whereas the global warming potential (GWP) in of Mt.CO_2 eq. was based on GWP of 25 for CH_4. (Nizami et al., 2017)

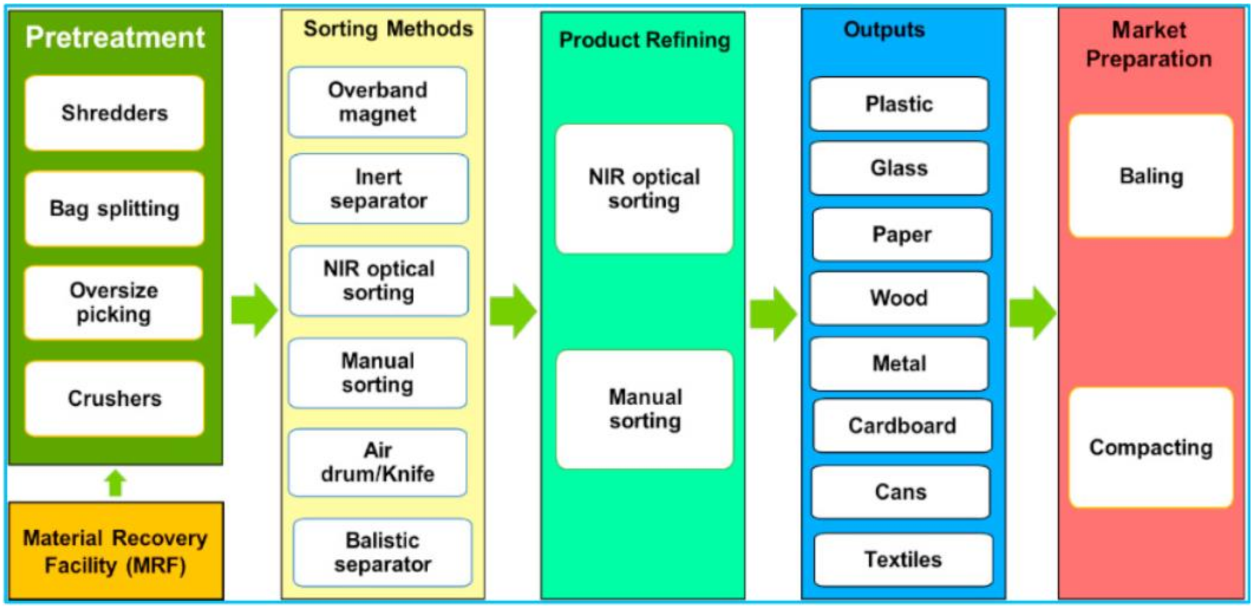


Figure I.59 Material recovery facility in Medina

The recycling scheme of Medina is more successful from energy saving and environmental perspective when integrated in a sustainable way. In order to do this, a material recovery facility (MRF) has been proposed for Medina which will deal with the recyclable materials. Figure I.59 shows the work done by the facility. Currently, aluminum is used in a variety of industries such as electrical energy transmission, construction, electronics, and packaging. Recycling of used aluminum products has been a duty for the global aluminum industry. Furthermore, aluminum has one of the highest energy conservation value compared with other recyclable materials. Therefore, aluminum recycling in Medina is given significant interest during discussion. Same case applies to polyethylene terephthalate (PET) bottles, whose use has been increasing dramatically in Medina. Therefore, recycling PET has also considered during discussion.

b) Results

(1) *Energy and environmental saving values of waste recycling in Medina*

Massive amount of energy would be spent on raw material extraction, transportation, and manufacturing of materials, unless they are conserved through recycling into same materials/use. An estimated 10009 TJ can be saved per year by recycling 24.21% of MSW in Medina, including paper (6368TJ), metals (1081 TJ), glass (142 TJ), and aluminum (2418 TJ). As shown in *Table I.4*.

Recyclable materials	% of MSW	Material heating value (KJ/kg)	Equivalent to fuel energy required (KJ/kg)	Energy saving (KJ/kg)	Total saved energy (TJ)
Glass	2.9	233	106	5517	142
Metal	1.9	889	403	64155	1081
Aluminum	0.81	1163	528	336499	2418
Paper	18.6	16282	7388	38600	6368
Total	24.21				10009

Table I.4 Energy savings by selected recyclable materials

There is enormous environmental benefit for Medina through recycling MSW, it is estimated that about 254600 Mt.CO_2 eq. GWP could be gained with savings of around 10200 tons of CH_4 emissions.

(2) *Development of MRF in Medina*

MRF has an important role in handling combined/mixed waste to maximize the recovery of recyclables from MSW (look at Figure I.59). In addition, MRF has waste sorting, processing, storage, and shipment facilities in its design plan. MRF can handle dirty waste as well as easy waste. Medina's mixed waste might be treated in a dirty MRF as a result of the absence of a large-scale source-separated waste (SSW) collection system executed in any city in KSA (Look at Figure I.59). However, if SSW collection system is carried out in Medina as an exemplary system in KSA, it will save additional power and economic inputs to collect, separate, and sort the recycled materials from the mixed MSW.

(3) *Recycling of waste materials in Medina*

Recycling will get rid of a large fraction of municipal waste from landfill, and as a result, will save land resources in addition to decreasing environmental impacts. Moreover, MSW recycling would provide jobs and supply raw materials to the local industries if the appropriate mechanism is established. The intake of aluminum products is developing quickly in Medina and it is the second most widely used metal after iron. Pilgrims use millions of beverage cans during Hajj and Umrah season, with the majority being end up in the dumpsters. Therefore, the exaggerated market value of aluminum will offer an attracting financial source if recycled in Medina. Furthermore, aluminum can be used in meals packaging. However, with millions of pilgrims travelling to Median per year, it is challenging to evaluate the quantity of aluminum packaging thrown in garbage containers. Similar to cans, aluminum packaging is an absurd source for recycling in Medina. However, it is recommended to separate the aluminum from other packaging materials before recycling. Modern waste sorting/recycling centers use separators to extract aluminum from other packaging.

PET plastic bottles have arisen as a key assignment for waste handling authorities in Medina, making plastics the second largest waste stream section of the MSW. Millions of plastic beverage and water bottles are consumed throughout the year in Medina. Recycling of PET plastic bottles starts with collecting and sorting and delivery to an MRF facility (Figure I.59). in order to recycle and manufacture the same product again, sorting and grinding are insufficient processes for PET bottles and containers, since they might contain contaminants/additives that require surplus pre-treatment and processing.

c) Pros and Cons of MRF

(1) *Pros*

MRF will provide jobs for the population, improve the economy, recycle wasted materials, and save the environment from MSW.

(2) *Cons*

The process of recycling PET will release harmful gases to the atmosphere causing severe damage to the ozone layer.

5. Fuel Cell

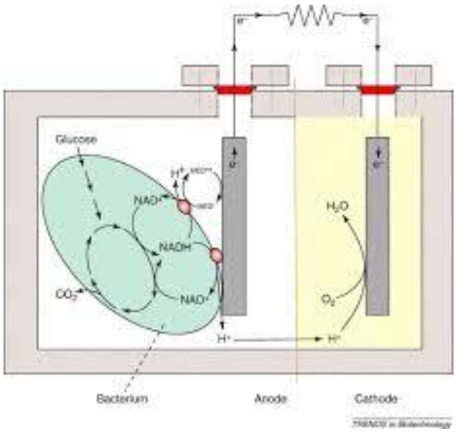


Figure I.60 First fuel cell made

Fuel cell (exemplified in Figure I.60), which was used by NASA, is an electrochemical cell that has the ability to convert chemical energy of a fuel, which is often hydrogen, and an oxidizing agent, which is often oxygen, into electricity. It performs this process through redox reactions. They are different from typical batteries, whereas they require a continuous source of oxygen and fuel to keep the chemical reaction working, while on the other hand, typical batteries use metal and their ions or oxides that are present in the battery to provide them with chemical energy to produce electricity. As long as fuel and oxygen are provided, the fuel cells can generate electricity.

Fuel cells are used in a variety of usage sites and fields. For example, it is used for primary and backup power for commercial, industrial and residential buildings and in remote or inaccessible areas. in addition, it powers fuel cell vehicles, such as forklifts, automobiles, buses, boats, motorcycles, and submarines.

There are various fuel cells, but they all have an anode, a cathode, and an electrolyte in common. The electrolyte allows ions to move between the two sides of the fuel cell. While the fuel undergoes an oxidation reaction by a catalyst, generating ions and electrons. The ions move from the anode to the cathode through the electrolyte. Concurrently, electrons flow from the anode to the cathode through an external circuit, generating direct current electricity. Another catalyst at the cathode causes the electrons, ions, and oxygen to react, producing water and other products. Classification of fuel cells is dependent on the type electrolyte used and the difference in startup time, which range from 1 second to 10 minutes. A fuel cell by itself generate insignificant electrical potentials, which are about 0.7 volts, so cells are connected in series to generate higher potential differences, providing sufficient power for any application’s requirements. Furthermore, fuel cells produce water and heat besides electricity. It may also, depending on the type of fuel cell, generate tiny amount of nitrogen dioxide. The energy efficiency of a cell is ranging between 40%-60%, however, if waste heat is harvested, efficiency can rise up to 85%.

a) Types of Fuel Cells

Fuel cells are found in diverse forms; however, they have the same mechanism. They consist of three parts: the anode, the cathode, and the electrolyte. Redox reaction happens within the three segments. The net result of the reactions is that fuel is consumed, water or carbon dioxide is produced, in addition to the generation of electric current, which is referred to as the load. Figure I.61 illustrates the parts of a typical fuel cell.

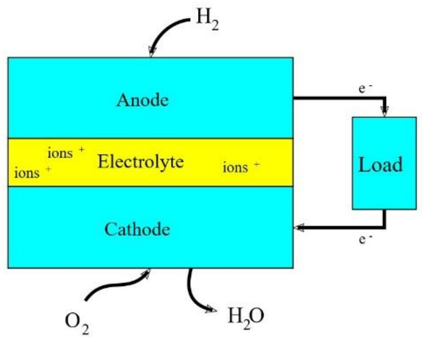


Figure I.61 Block diagram of a fuel cell

A catalyst oxidizes the fuel in the anode, which is usually hydrogen, converting it into positively charged ion and an electron. The electrolyte is a substance that allows the flow of ions only through it. the released electron flows through an electric wire generating electric current. The ions travel through the electrolyte until it reaches the cathode, where it recombines with the electrons and reacts with a catalyst producing water or carbon dioxide.

Characteristics of the fuel cells include:

- The type of electrolyte, which identifies the type of fuel cells.
- The type of fuel used, which is hydrogen the most.
- The anode catalyst, usually fine platinum powder.
- The cathode catalyst, often nickel.
- Gas diffusion layers that are designed to resist oxidization.

A normal fuel cell generate voltage between 0.6 to 0.7 volts, there several factors affecting the potential difference, including:

- Activation loss
- Mass transport loss
- Resistance of cell components to electrons

Fuel cells can be combined in series or parallel connection in order to gain the required energy, where series connection can generate higher voltage, while the parallel connection can produce high current.

(1) *Proton exchange membrane fuel cells (PEMFC)*

PEMFC, also known as polymer electrolyte membrane (PEM), is a type of fuel cells that is being developed for transport applications. Its anode diffuses hydrogen to the anode catalyst, it then dissociates into protons and electrons. The released protons undergo a reaction with oxidants making them change into a multi-facilitated proton membrane. The protons are transferred to the cathode through the exchange membrane, while the electrons are forced to flow through an external circuit, which is the load since the membrane impermeable to electrons. On the other hand, oxygen reacts with incoming protons and electrons producing water in the cathode. The components of PEMFC can be seen in Figure I.62.

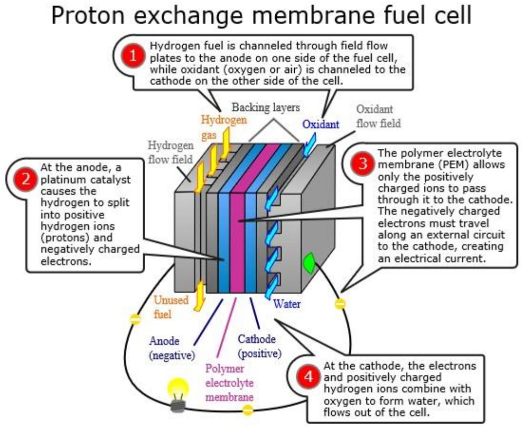


Figure I.62 Components of PEMFC and their functions

There are other types of PEMFC in addition to this pure hydrogen type. Examples are hydrocarbon fuels, such as diesel, methanol, and hydrides. The resulting waste product are summarized in the release of water and carbon dioxide. When hydrogen is used, methane combines with steam in the air releasing CO_2, this process is known as steam methane reforming, producing hydrogen that would be used.

The components of PEMFC are the following:

- Bipolar plates
- Electrodes
- Catalyst
- Membrane
- The necessary hardware such as current collectors and gaskets

According to the type of fuel cell, different materials are used for the components of the fuel cell. For example, the bipolar plates can be made of different materials, including metals, coated metals, graphite, flexible graphite, C-C composite, carbon-polymer composite, etc. The heart of the PEMFC, which is the membrane electrode assembly, is often made of a proton exchange membrane inserted in-between two carbon papers coated with catalysts. Platinum or similar noble metals are usually used as the catalyst for PEMFC. The electrolyte could be a membrane.

(a) Issues with PEMFC

(i) Cost

The Department of Energy an 80-kW automotive fuel cell system could be achieved, costing 67 USD per kilowatt, with assumption that the volume production of automotive fuel cells is 100 thousand per year. The cost could be reduced to 55 USD per kilowatt if the volume production increased to 500 thousand per year.

(ii) Water and air management

This type of fuel cell requires a membrane that must be hydrated, so it requires water to be evaporated at a rate equivalent to the rate of the water produced. If the evaporates in a rate higher than the rate of water produced, this would lead to dehydration of the membrane, causing increased resistance across the membrane, leading to cracks, creating a gas “short circuit” where hydrogen and oxygen combine directly, generating heat damaging the fuel cell. If the water evaporates in a rate slower than the rate of water produced, this would cause the electrodes to flood, averting the reactants from reaching the catalyst and stopping the reaction.

(iii) Temperature management

Temperature must not change during the cell progress to prevent the destruction of the cell through thermal loading. This is difficult to achieve as the $2H_2 + O_2 \rightarrow 2H_2O$ reaction is exothermic, so a large amount of heat is produced from the fuel cell.

(iv) Durability, service life, and special requirements for some type of cells

Applications of stationary fuel cell typically require more than 40 thousand hours of consistent operation at temperatures between -35°C and 40°C, while automotive service life is 2500 hours. Automotive engines have to be able to start reliably at -30 °C and have a high power-to-volume ratio.

(2) *Phosphoric acid fuel cell (PAFC)*

This type of fuel cell (shown in Figure I.63) uses phosphoric acid as its electrolyte to allow the passage of hydrogen ions from the anode to the cathode. These type of cells works in temperatures between 150° to 200° C. heat and energy loss may be caused due to this high temperature, proper use of this heat is recommended. The heat is capable of producing steam for air conditioning systems or any other thermal energy consuming system. Using the resulting heat in cogeneration is advised, where it improves the efficiency of the cell from 40-50% to 80%. The hydrogen ion production rate in the anode is insignificant, so a catalyst made of platinum is used to speed up the ionization rate. The problem with these cells is that they use acidic electrolyte, which might cause the corrosion or oxidation of the components of the fuel cell exposed to the acid.

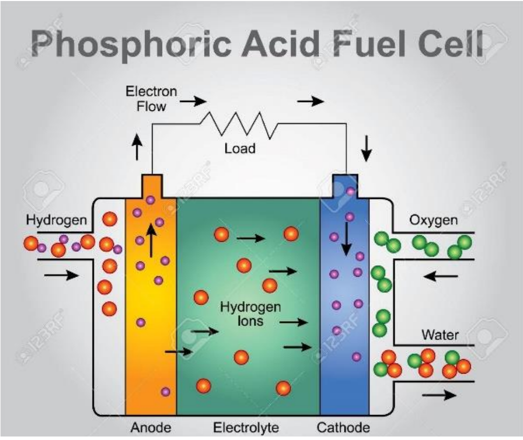


Figure I.63 Structure of phosphoric acid fuel cell

(3) *Solid acid fuel cell (SAFC)*

This type of fuel cell is known for the usage of solid acid material as the electrolyte. The solid acid behaves differently according to the temperature exposed to, at low temperatures, it has an ordered molecular structure as most salts, at higher temperature, the solid acid undergoes a transition in phase becoming highly disordered superprotonic structures, which increases the conductivity by several orders of magnitude. In 2000, cesium hydrogen sulphate ($CsHSO_4$) was used to develop the first proof for the concept of SAFCs. Existing SAFCs systems nowadays use cesium dihydrogen phosphate (CsH_2PO_4) and have showed lifetimes of thousands of hours.

(4) *Alkaline fuel cell (AFC)*

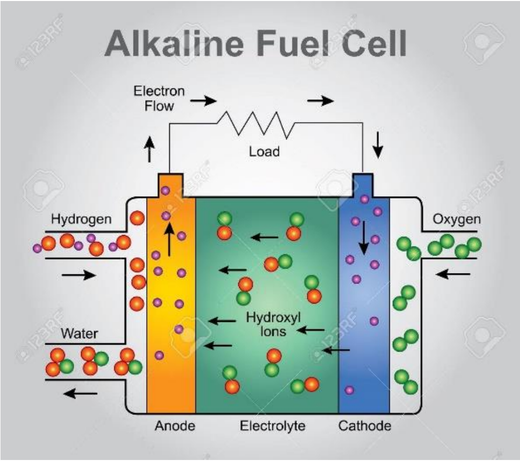


Figure I.64 Components of alkaline fuel cell

The alkaline fuel cell (shown in Figure I.64) or hydrogen-oxygen fuel cell was used to provide electrical energy for the Apollo space program. The fuel cell is made of two porous carbon electrodes impregnated with a suitable catalyst such as Pt, Ag, CoO, etc. The electrodes use a concentrated solution of KOH or $NaOH$ as their electrolyte. H_2 and O_2 gases move through the electrodes passing through the electrolyte. Thus, the overall reaction involves the combination of hydrogen and oxygen gases forming water. The cell can run continuously until the supply of reactants is exhausted. The recommended operating temperature for this type of fuel cell is between 343 K to 413 K, where it could provide a potential difference of 0.9 volts.

(5) *Solid oxide fuel cell (SOFC)*

This type of fuel cell uses a solid material, most commonly a ceramic material called yttria-stabilized zirconia (YSZ) as the electrolyte. Since the materials used to construct SOFC are solid, they are not limited to the flat plane configuration of the other types of fuel cells and are often designed as rolled tubes. They operate at high temperatures ranging between 800° and 1000° C and can run on different kinds of fuels such as natural gas.

SOFCs are different from typical fuel cells, where hydrogen ions flow from the anode to the cathode in typical fuel cells. While on the other hand, oxygen ions flow from the cathode to the anode in SOFC. Oxygen is supplied by the cathode, where it consumes electrons creating oxygen ions. The ions then travel to the anode passing through the electrolyte and react with hydrogen in the anode. Electricity and water are produced as by-products of the reaction. Depending on the fuel, carbon dioxide may also be produced. However, the emissions are less than a fossil fuel combustion plant. The chemical reaction happening in the SOFC are shown in Equation I.3, Equation I.4, and Equation I.5:

$$2H_2 + O_2 \rightarrow 2H_2O$$

Equation I.3 The overall reaction in SOFC

$$2H_2 + 2O^{2-} \rightarrow 2H_2O + \ 4e^-$$

Equation I.4 The reaction happening in the anode

$$O_2 + 4e^- \rightarrow 2O^{2-}$$

Equation I.5 The reaction happening in the cathode

SOFC systems is able to run on a variety of fuels other than hydrogen. However, hydrogen is acquired for the process of the fuel cell as previously mentioned in the reactions. So, the selected fuel must contain hydrogen atoms. For the fuel cell to operate properly, pure hydrogen is recommended for the cell. SOFCs have the ability to reform light hydrocarbons such as methane, propane, and butane. The fuel cells are at an early development stage.

(6) *Molten carbonate fuel cell (MCFC)*

MCFC are similar to SOFC in requiring high temperatures (650° C) to operate. This type of fuel cell uses an electrolyte made of lithium potassium carbonate salt. The salt needs high temperature to be liquified, permitting the flow of ions within the cell. (carbonate ions in this case).

Similar to SOFCs, MCFC are capable of changing fossil fuel to hydrogen-rich gas in the anode, making the need of producing hydrogen unimportant. CO_2 emissions are a result of reforming process. MCFC can run on different fuels, including natural gas, biogas and gas produced from coal. Water, carbon dioxide, electrons, and small of other chemicals are produced as a result of the reaction hydrogen gas and carbonate ions from the electrolyte. The electrons travel in an external circuit generating electricity and return to the cathode, where it reacts with oxygen from the air and carbon dioxide from the anode to form carbonate ions that reload the electrolyte and complete the circuit. The chemical reactions in the MCFC are shown in Equation I.6, Equation I.7, and Equation I.8:

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$$

Equation I.6 The overall reaction happening in the MCFC

$$CO_3^{2-} + H_2 \rightarrow H_2O + CO_2 + 2e^-$$

Equation I.7 The reaction happening in the anode

$$CO_2 + {}^1/_2\,O_2 + 2e^- \rightarrow CO_3^{2-}$$

Equation I.8 The reaction happening in the cathode

(i) Advantage of MCFC

- Resistance to impurities
- It is not prone carbon coking
- Relatively high efficiency (can reach to 50%)

(ii) Disadvantages of MCFC

- Slow start-up times, due to the high operating temperature requirement
- Short life span of the cell
- The high-temperature and carbonate electrolyte lead to corrosion of the anode and cathode.

b) Efficiency of leading fuel cell types

(1) *Theoretical maximum efficiency*

The efficiency of a system generating energy is calculated by the following formula: $\frac{Output\ energy}{Input\ energy}$. In the case of fuel cells, the output energy is considered the electrical energy generated from the cell, while the input energy is considered the chemical energy stored in the fuel. According to the U.S. Department of Energy, the efficiency of fuel cells ranges between 40-60%. This percentage is higher than other systems generating energy such as a typical combustion engine of a car, whose efficiency is about 255. The efficiency of fuel cells can be improved if a combined heat and power system is used to deal with the resulting heat and put it to use. In this case, the efficiency would rise up to 85-90%.

It is nearly impossible to achieve the theoretical maximum efficiency of any type of power generation system in real life application. In addition, other steps in power generation, such as production, transportation, and storage of fuel and conversion of the electricity into mechanical power are neglected by the theoretical maximum efficiency. However, this calculation helps in comparing different types of power generation. The maximum theoretical energy efficiency of a fuel cell is 83%, bearing in mind that it runs at low power density and uses pure hydrogen and oxygen as the reactants. According to the World Energy Council, this compares with a maximum theoretical efficiency of 58% for internal combustion engines.

(2) *In practice*

It is important to consider loses due to fuel production, transportation, and storage. Vehicles depending fuel cells as their power source may have a power efficiency of 22% if the fuel used is compressed hydrogen stored as a high-pressure gas. If the hydrogen is liquified, the efficiency would fall down to 17%. The problem with fuel cells is that they do not have the ability to store energy, but they can store hydrogen. So, some applications such as stand-alone power plants running on discontinuous charges such as solar or wind power implement electrolyzers and storage systems, forming an energy storage system. Hydrogen is mostly used for oil refining, chemicals, and fertilizers production. Therefore, it is generated through steam methane reforming, which releases carbon dioxide. Using pure hydrogen and oxygen can result in an efficiency of 35%:50%.

c) Applications

(1) *Power*

Fuel cells can be used in generating primary and backup power source of commercial, industrial, and residential areas. Fuel cells can also be used in spacecrafts, remote weather stations, large parks, communications centers, rural locations including research stations, and in certain military applications. Figure I.65 shows a German submarine running on fuel cells.

The advantages of fuel cells running on hydrogen are summarized in being compact, lightweight, having no moving parts, and not involving combustion. The reliability of fuel cells can reach up to 99.9999% if they are placed in their ideal conditions.

Figure I.65 Type 212 submarine with fuel cell propulsion of the German Navy in dry dock

Fuel cell electrolyzers rely on external storage systems, since they cannot store fuel in themselves, they can be implemented with large-scale energy storage, to be used in rural areas for example. The power efficiencies vary with the variety of stationary fuel cells, with most having power efficiency ranging between 40% and 60%. However, efficiency can raise to 85% if the fuel cell's heat waste is used. This is significantly more efficient than traditional coal power plants, which are only about one third energy efficient. Fuel cells can save 20-40% on energy costs if used in cogeneration systems, bearing in mind that mass production of stationary fuel cells is applied. Fuel cells are much cleaner than traditional power stations. They produce less pollution than the traditional ones, they also produce 97% less nitrogen oxide than the traditional power station.

(2) *Fuel cell electric vehicles (FCEVs)*

FCEVs are spreading worldwide as of 2017, where about 6500 FCEVs have been sold. Figure I.66 shows the components of a typical FCEV. Three car depending fuel cells have been introduced: the Honda Clarity, Toyota Mirai (shown in Figure I.67), and the Hyundai ix35 FCEV.

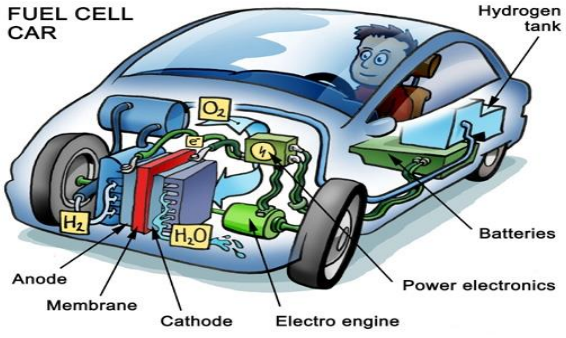


Figure I.66 Configuration of components in a fuel cell car

Figure I.67 Toyota Mirai

Further demonstration FCEVs have been proposed, including Honda FCX Clarity, and Mercedes-Benz F-Cell. As of June 2011, demonstration FCEVs had driven more than 4.8 million km, with more than 27 thousand refueling. Fuel cell electric cells can travel 505 km without the need to be refueled. They are refueled in less than 5 minutes. According to the US department of Energy's Fuel Cell Technology Program, fuel cells reached 53-59% at one-quarter power and 42-53% vehicle efficiency at full power, it also achieved a durability of over 120 thousand km with less than 10% degradation. According to General Motors, a fuel cell electric vehicle using compressed hydrogen produced from natural gas as a power source uses 40% less energy than normal internal combustion vehicle, it also emits 45% less greenhouse gases.

II. Chapter 2: Generating and Defending a Solution

This chapter goes through the description of the prototypes, the solution and design requirements of it, and the test plan the proposed solution is evaluated with.

A. Solution and Design Requirements

1. Solution requirements

a) Cost effectiveness

The cost of the project is an important feature to be considered. The materials of the prototype should be as cheap as possible in order to have the ability of being accessible for the public. Also, while decreasing cost, efficiency must not be affected excessively. As a consequence, the best result to accomplish is having the highest possible efficiency to cost ratio. This can be accomplished in the prototypes, since most of the materials used are left out.

b) Durability

It is the ability of the prototypes to withstand the environmental conditions without being affected significantly. The constructing materials must be resistant to several factors, including fire, acids, and several other environment obstacles. For example, the glass used in the project has to bear high temperatures and not melt easily. It also shouldn’t react with acids if the project is put in any industrial climate or in a coastal area.

c) Eco-friendliness

It is the capability of the prototypes to do its functions without harming the environment. By minimizing the number of harmful byproducts such as carbon dioxide, or recycling as much as possible of these harmful byproducts, so the project will produce much energy with less pollution, and, consequently, can help increase the overall health of people in a specific area. This is achieved in the prototypes since waste is used to operate the prototypes.

d) Availability

It is how available the used materials are. This factor is crucial for the survival of any prototype or system. This is achieved since the materials used are accessible and widespread.

e) Practicality

It is the capability of the prototypes to be applicable in real life and in different environments and conditions. The prototype must have high usage range. This can be accomplished since the used materials are widely available.

f) Usability

It is how easily the prototypes can be used. The processes done by the prototypes must be simple and not complicated. This factor makes solving any problem related to the prototypes easy and quick. This can be achieved in the prototypes since the processes are simple as well as clear.

2. Design Requirement

In order to achieve the required successful prototype, there are some criteria and specifications that should be followed: cost and efficiency. The prototype must be as efficient as possible. Moreover, the cost shouldn't be neglected; it should be as low as possible.

In the chosen prototype, the efficiency is measured by the electric power produced from the prototype. The electric power is mainly the power associated with the transmission and generation of electricity. It is also defined as "the rate at which electricity does work." Generally, to achieve the mandatory effective prototype, power / cost ratio must be obtained, which is mainly the electric power that the electricity in the prototype does (measured in Watt) divided by the cost (in L.E). $\frac{Power\ (Watt)}{Cost\ (L.E.)}$

A high power-cost ratio means that the power output of the prototype should be as high as possible while the cost should be possible as low as, and that's the design requirement of the prototype.

B. Selection of Solution

In order to make the problems to be solved diminish, two solutions are proposed:

1. Recovering Wasted Materials

Recovering the latent energy in chemicals could be a practical way to generate electricity. Several forms of wasted materials represent a good candidate. However, being focused on industrial cities, one of the most abundant forms of wasted materials was aluminum, so it was chosen as a source energy.

2. Harnessing Wasted Energy

Supported by different researches, harnessing the wasted energy proved to be a good way to generate electricity. (Cui et al., 2018; He et al., 2015) Many forms of energy were proposed, but only mechanical and heat energy withstood, being very abundant in industrial cities.

C. Selection of Prototype

1. Descriptions

a) Triboelectric Generator

This prototype was chosen based on the need to retain the energy hindered during the movement of workers in factories. The prototype uses an effect called “The Triboelectric Effect” that uses the difference in the sequence in materials in the triboelectric series (shown in Figure I.52) to generate a potential difference across the two materials, resulting a transfer of electrons. The materials used were the human skin and silicone rubber/PDMS. Silicone rubber/PDMS was made porous using a sheet of sandpaper and then glued (using silicone rubber) over a piece of copper foil. The copper foil acts as an electrode. The generator (silicone rubber/PDMS and copper) was stuck into an elbow bad, enabling to be attached to an elbow of a human hand.

b) Thermoelectric Cooler

This prototype was selected based on the need to retain the energy hindered from machines and devices in factories. The prototype uses the Seebeck effect that occurs in the thermoelectric cooler to generate electricity. One side of the TEC is exposed to the heated machine and the other is run on by water derived from the central watering system in the factory, with an endothermic reaction happening in it (ammonium chloride mixed with water).

c) Aluminum-air fuel cell

This prototype was used based on the abundance of aluminum as a waste in industrial cities. Aluminum was used as an anode in the fuel cell where the reaction happens; it loses its electrons. Those electrons transfer through an external circuit, generating electric current, then finally reach the cathode, in which the electrons react with the electrolyte, which consists of KOH dissolved in water.

2. Test plan

The flow of electric current is tested by an instrument known as a Multimeter, which is used to measure the current intensity and potential difference produced by each prototype, whose measuring units are Ampere and Volt respectively. The resulted numbers are used in a formula (stated in Equation I.1) to calculate the power output of the prototype, whose unit is Watt. The output power is then related to the cost of the prototype to calculated the power-per-unit-cost, whose unit is Watt/L.E.

III. Chapter 3: Constructing and Testing the Prototypes

This chapter goes through how the prototypes were constructed, tested, and also the data collected from these tests.

A. Materials & Methods

1. Materials

Shown below is the materials used in the three prototypes: The triboelectric generator, the thermoelectric generator, and the aluminum-air fuel cell, in the tables: Table III.1, Table III.2, and Table III.3, respectively.

a) Triboelectric Generator

Name	*Description and/or Usage*	*Cost*	*Source*	*Quantity*	*Illustration*
Silicone Rubber / PDMS	An adhesive, biocompatible electron acceptor.	0.31 L.E.	Plumper's shop	5 g	
Sandpaper	A rough surface that is used to make pores in the PDMS film.	0.42 L.E.	Carpenter's shop	(3.5 × 5) cm	

Copper Foil	Used as an electrode.	0.44 L.E.	CopperWorks Corp.	(3.5 × 5) cm	
Elbow Pad	Used to attach the TENG on the elbow.	10 L.E.	A medical store	1 piece	

Table III.1 Triboelectric generator materials

b) Thermoelectric Generator

Name	*Description and/or Usage*	*Cost*	*Source*	*Quantity*	*Illustration*
Thermoelectric Cooler	A device that generates electricity from temperature difference.	80 L.E. each	Ram Electronics	3 pieces	

Ammonium Chloride	Added to water causing an endothermic reaction.	10 L.E.	Medical Science	500 g	
Water Faucet	½ inch water faucet.	7 L.E.	Plumper's shop	1 piece	
T-Connector	1 to ½ inch t-connector.	9 L.E.	Plumper's shop	1 piece	
Pipe	2 1-inch pipes with one with a hole and a ½ inch pipe.	42 L.E.	Plumper's shop	3 ½ meter pieces	

Stainless steel Container	A container with a whole made in one upper side.	Free	Home	1 piece	
Hose	Connects the pipe and the container.	Free	Chemistry Lab	1 piece	
Pipe elbow	½ to ½ water elbow.	10 L.E.	Plumper's shop	1 piece	
Silicone rubber	A heat conducting adhesive.	25 L.E.	Plumper's shop	1 pack	

Table III.2 Thermoelectric generator materials

c) Aluminum-Air Battery

Name	*Description and/or Usage*	*Cost*	*Source*	*Quantity*	*Illustration*

Wasted Aluminum Foil	Collected from junkyards and cleaned.	Free (wasted)	Junkyard	(10 × 12) cm	
Activated Carbon	Used for filtration.	1.8 L.E.	Medical Science	30 g	
Metal Mesh	Net-like metallic wires.	0.012 L.E.	MetalWorks Corp.	(10 × 12) cm	
Epoxy	Super adhesive.	1.7 L.E.	Corner	7 g	

Filtering Paper	Used for filtration.	Free	Home	(10 × 12) cm	
Potassium hydroxide (KOH)	Used as an electrolyte	0.8 L.E.	Medical Science	20 g	

Table III.3 Aluminum-Air fuel cell materials

2. Safety precautions

Before heading towards building any of the prototypes, safety precautions must be put into consideration:

- Safety gloves should be worn to deal with the net-like metallic wires, the copper foil, the epoxy, and the silicon rubber adhesive.
- Apron, and goggles should be worn while the preparation of potassium hydroxide in chemistry lab.
- When dealing with potassium hydroxide, it should be put away from other metals in order not to react with it releasing a pungent gas.

3. Measurement tools

Name	*Purpose of use*	*Illustration*
Digital balance	Used to measure the masses of the materials used in the prototypes.	

Beaker	Used to measure the volume of the electrolyte used in the Aluminum-Air fuel cell	
Digital thermometer	Used to measure the temperature difference between the hot and the cold side of the TECs	
Measuring tape	Used to measure the length of the pipes used in the TECs prototype	
Multimeter	Used to measure the current intensity and the potential difference of the prototypes.	

4. Methods

a) Triboelectric Generator

1. Silicone rubber/PDMS is uniformly casted on sandpaper
2. The PDMS is pressed hard to flatten it
3. The film is left to cure for 4 hours
4. The film is peeled off the sandpaper
5. A cut of dimensions (5 × 3.5) cm is taken from the thin layer
6. An identical cut of copper is made
7. The two are glued together with silicone rubber
8. A wire is attached at the copper electrode

9. The nanogenerator is attached to the elbow pad at above the elbow. Steps are shown in Figure III.1.

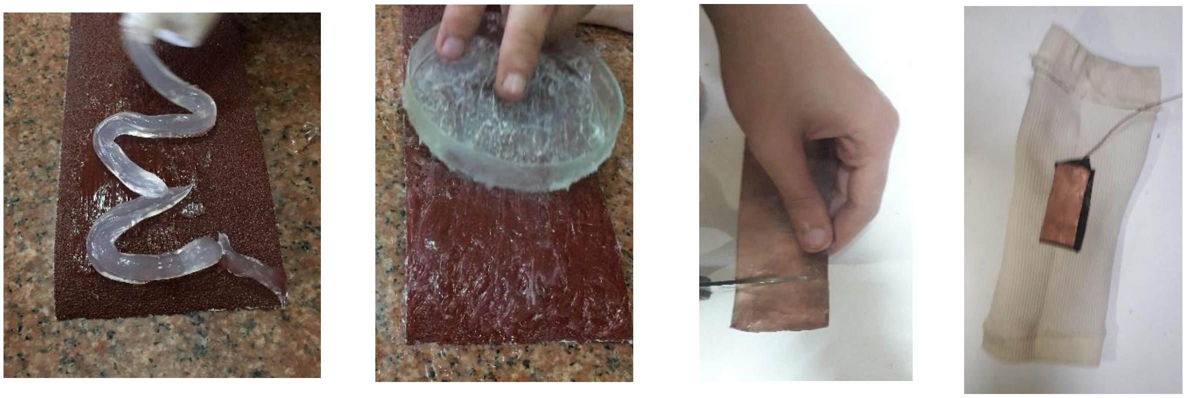


Figure III.1 Steps of the TENG construction

b) Thermoelectric Generator

(1) *Preparing the Container*

Figure III.2 The container used with 3 TECs attached

1. A hole is made in the container
2. The 3 TECs are glued to the lower part of the container using the thermally conductive glue. The container is shown in Figure III.2.

(2) *Preparing the Pipe System*

3. A divergence from a water disposal system is made
4. A water faucet is fixed at the end of the divergent pipe in order to regulate the flow
5. A hole is made in the lower main pipe

(3) *Connecting*

6. Below the faucet, the metallic container is put
7. The container and the lower main pipe are connected using a hose

c) Aluminum-Air Fuel Cell

(1) *Formation of the solution (electrolyte)*

1. About 200 ml of water is poured into a beaker
2. Ten percent of water mass (20 g) is poured as KOH

3. The solution is stirred with glass rod, then it is left until its temperature declines to about 30°C

(2) *Air cathode construction*

4. Epoxy is distributed well above stainless steel, then activated carbon is scattered on the stainless steel

(3) *Assembling*

5. The aluminum foil is sandwiched between two filtering papers and two carbon cathodes on both sides, with the dimensions of each being 10 cm * 12 cm

(4) *Submersion*

6. The assemblage is then submerged in the electrolyte. Steps are shown in Figure III.3.

Figure III.3 Steps of the Aluminum-Air fuel cell construction

B. Test Plan

The prototypes are tested for the sole design requirement, which is achieving the highest efficiency-to-cost possible.

1. Triboelectric Generator

1. The device is worn on the elbow, as shown in Figure III.4.
2. Continuous motion of the elbow is made at a constant rate.
3. Output voltage and ampere is measured, calculating power using the relation $W = V I$, where W is the power in watt, V is the voltage and I is the current intensity.
4. A relation between the rate at which the elbow moves and the output power is made.

Figure III.4 Testing the TENG

2. Thermoelectric Generator

1. With the container containing water, it is put on a heater at a known temperature.
2. Add ammonium chloride to the water.
3. Measure the temperature of the water, calculating the difference.
4. Measure and calculate the output power.
5. A relation between the difference in temperature and the output power is made.

3. Aluminum-air fuel cell

1. Immerse the fuel cell in the electrolyte.
2. Measure and calculate the output power (as shown in Figure III.5).

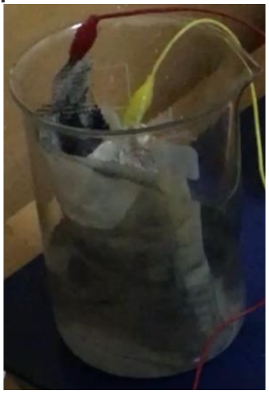


Figure III.5 Testing the Aluminum-Air fuel cell

4. For all prototypes the following is done

Relate the cost of the prototype to the output power.

C. Results

1. Negative

At first the aluminum-air fuel cell behaved unexpectedly when put in the electrolyte. We tried to investigate the reason behind this and we couldn't know the answer. At the end, we found out that the high concentration of KOH solution caused a reaction between the aluminum foil and the solution, which is illustrated in Equation III.1.

$$2Al + 2KOH + 6H_2O = 2K[Al(OH)_4] + 3H_2$$

Equation III.1 Reaction of aluminum with potassium hydroxide

2. Triboelectric Generator

Having performed the test plan on the prototype, the device produced an alternating electrical potential that reached 183 V (shown in Figure III.6), when slapped hard on by hand. With the same method, the current intensity reached 100 μA, producing a power of 18.3 milliwatts. If installed in a factory of 750 workers, the output Furthermore, the cost of the generator is significantly low. The cost of the nanogenerator without the elbow pad is **0.75 L.E.** only, making the power per cost unit 24 milliwatt/L.E.

Figure III.6 The triboelectric generator producing 180 V

Testing using the prototype attached to the elbow pad produced less power (a voltage of 1.5 V). This is because of the less pressure caused by the human hand than caused by slapping.

Storing such power in a power storage system such as a super capacitor could be highly beneficial because of the high alternating of the output. By doing so, one nanogenerator could power small devices or sensors making it advantageous in emergencies.

3. Thermoelectric Cooler

Figure III.7 Each thermoelectric cooler producing 3.93 volts

After the test plan, the test was performed on one TEC, producing a voltage of 3.93 V (shown in Figure III.7) and 0.075 A, with a power output of 294 milliwatts. The conditions of these tests were a cold side of 15°C and a hot side of 105 ° C, with a temperature difference of 90°C. The cost of thermoelectric cooler is **240 L.E**. Knowing that connected in series the voltage adds, the output of the three TECs is 891 milliwatts, making the power per cost unit 3.7 milliwatt/L.E.

4. Aluminum-air fuel cell

Having recorded the results of the test plan, 0.9 V and 0.029 A was generated, making the power output 26 milliwatts. The cost of a single fuel-cell is **2.88 L.E.**, making the power per cost unit 9 milliwatts/L.E.

The different results for the three prototypes are shown in Table III.4.

Prototype	*Voltage (V)*	*Current intensity (I)*	*Power (W)*
Triboelectric generator	180 V ± 10	100 µA ± 2	18.3 mW
Thermoelectric cooler	11.79 V ± 2	75 mA ± 2	884 mW
Aluminum-air fuel cell	0.9 V ± 2	0.029 A ± 2	26 mW

Table III.4 Results of the three prototypes

IV. Chapter 4: Evaluation, Reflection, Recommendations

Evaluation, Reflection, Recommendations

A. Analysis and Discussion

As affirmed in the results section, the project has achieved its design requirement, producing power that is usable and highly helpful in its adoption-site.

1. Triboelectric Nanogenerator

The nanogenerator consists of the electron acceptor (polydimethylsiloxane [PDMS]) and an electrode (copper [Cu]). When the human skin comes into contact with the PDMS, the human skin loses electrons, and the PDMS accepts them, creating a potential difference. This is due to the materials (human skin and PDMS) being far apart in the triboelectric series. The mechanism behind electric generation is as follows: When a pressure force is applied on the device by hand, the PDMS film fully contacts with the surface of skin. The produced triboelectric charges with opposite polarities are fully balanced, so that no electron flows in the external circuit. Once the pressure force is removed, the porous thin film starts to separate from the skin and the interacting surfaces have opposite triboelectric charges. The negative charges on the surface of PDMS film induce positive charges on Cu electrode; thus, free electrons flow from Cu electrode to the ground, which leads to producing an output current signal. When the PDMS film continues to completely separate from the skin, the device will reach a charge equilibrium state. As the PDMS film moves toward human skin again, the electrons start to move back toward Cu electrode, resulting in a reversed output current signal. When the PDMS film and

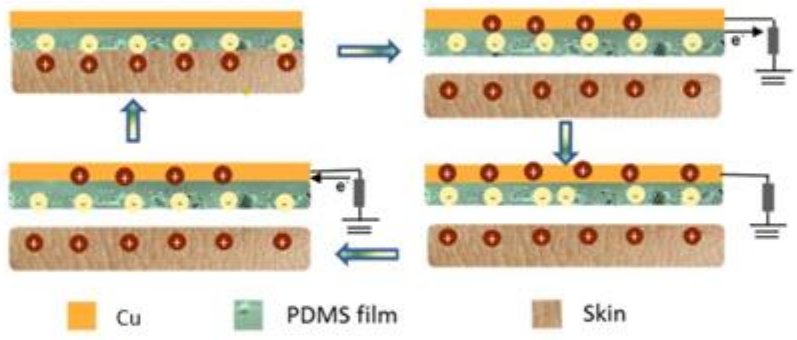


Figure IV.1 Charge Cycle

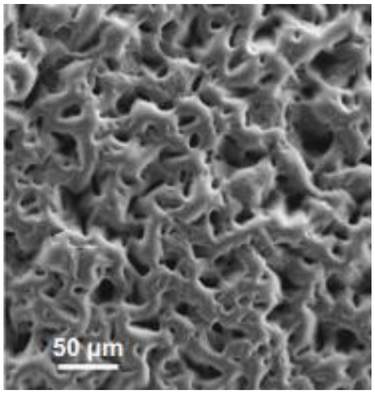


Figure IV.2 An SEM of PDMS film

human skin overlap again, the electric potential will return to the original status. The above cycle is illustrated in Figure IV.1. (Cui et al., 2018)

The reason behind pressing the mixture against the sandpaper is the increasing in roughness, resulting in more friction between the film and the skin. A SEM image is shown in Figure IV.2, revealing its uniform micro-structured rough surface.

This nanogenerator is intended to harness the mechanical energy of workers in factories and other working sites. With a number that reaches 750 worker per factory, the amount of generated electricity could be significantly high reaching 13 watts per factory per movement.

2. Aluminum-Air Fuel Cell

The cell consists of an aluminum anode, an air cathode, and a $KOH_{(aq.)}$ electrolyte. The aluminum anode has an oxidation potential of 1.66. Therefore, it reacts with hydroxide ions, producing aluminum hydroxide and releasing electrons, which flow through an external circuit to the cathode. In the cathode, oxygen and water react receiving the electrons flew, synthesizing hydroxide ions, which return back to the anode through the electrolyte and restart the reaction. Equation IV.1, Equation IV.2, and Equation IV.3 (2 & 3 being the half-reactions) illustrate all the redox chemical reactions occurring in the Al-Air cell, where chemistry (especially electrochemistry) helps in understanding.

$$4Al + 3O_2 + 6H_2O \rightarrow 4Al(OH)_3$$

Equation IV.1 The overall reaction occurring in the cell

$$Al + 3OH^- \rightarrow Al(OH)_3 + 3e^-$$

Equation IV.2 The chemical reaction happening in the anode

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

Equation IV.3 The chemical reaction happening in the cathode

Regarding the components of the fuel cell (shown in Figure IV.3), the first layer, which consists of metal mesh with activated carbon glued on using epoxy. It acts as a current collector and the site of the oxygen-water reaction. The second layer consists of a filtering paper

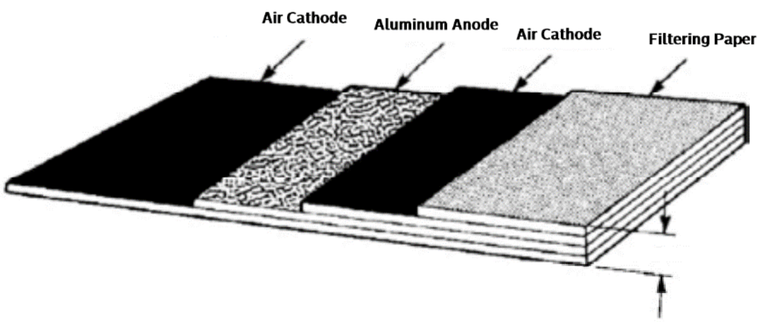


Figure IV.3 Layers of the aluminum-air fuel cell that permits hydroxide ions to move from the cathode to the anode. The third layer consists of aluminum foil that acts as the anode, reacting with hydroxide ions forming aluminum hydroxide and electrons move through an external circuit, with the cycle repeating. The theoretical cell voltage, which was estimated to be 1.2 volts, could not be achieved due to the absence of the standard conditions (which are 1 atm, 25°C, and one molar solution, as we learned in chemistry). Instead, the cell voltage mentioned in the results section was achieved.

3. Thermoelectric Cooler

Thermoelectric cooler (shown in Figure IV.4) is based on converting the difference in temperature) between its two sides into electricity through a phenomenon called Seebeck effect. Seebeck effect states that when heat is applied to one of the two sides, excited electrons (because of heat) flow toward the cooler side. If the pair is connected through an electrical circuit, direct current (DC) flows through that circuit. The device consists of a cool side, a hot side, and a semi-conductor couple (P-N type). An example of a semiconductor couple can be Antimony (N type) and boron (P type) added to silicon (shown in Figure IV.5).

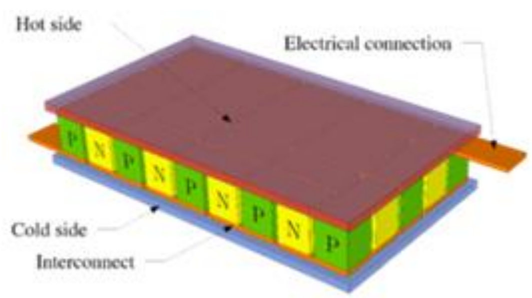


Figure IV.4 The arrangement of the TEC

Since boron has 3 valence electrons in its outermost level, it will form three covalent bonds with silicon leaving a hole (an unmade bond) with a fourth boron atom. Antimony has 5 valence electrons, that are formed four covalent bonds with silicon, leaving one electron. When N and P type are combined it creates what is called PN junction. When heat is applied electrons migrate from N to P type through an external load.

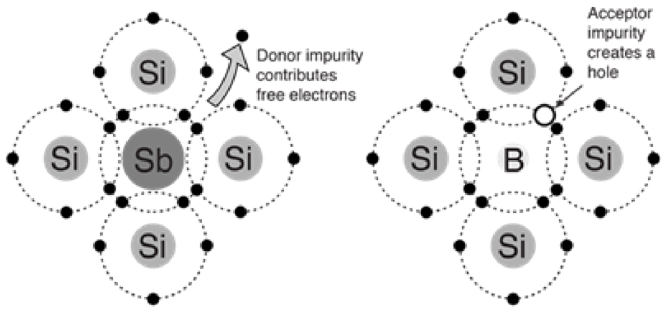


Figure IV.5 Thermo-couple Lewis structure

The more difference in temperature gradient, the more voltage is created. So, inspired by Chemistry, an endothermic reaction that would make a side of TEC cooler was used, which is $NH_4Cl + H_2O \rightarrow NH_4^+ + Cl^- + H_2O$.

The reaction of ammonium chloride with water will occur in a container which is connected to a pipe that fitch water from an external source. TEC is glued to the outer side of the container with heat applied to the hot side. The water is disposed to outside the container through a pipe to a disposal system.

Furthermore, according to the equation studied in Physics through fluids, Bernoulli's equation, when water flows from low level to high level with constant area of pipe its velocity will decrease, so we made the container on a higher level than the pipe make the water take much time to react completely with ammonium chloride.

4. Final Statement

The prototypes clearly show how the design requirement was met, being highly efficient, highly usable, and highly advantageous. With each having a high efficiency as stated in the design requirement, the prototypes help solve the problems to be solved, and thus contribute to the diminishing of the related grand challenges. They also evidently help industrial cities recover several forms of wasted energy (mechanical and heat), in addition to a major wasted material (aluminum).

B. Recommendations

1. Liquid-Metal Electrode

Using a liquid-metal electrode may significantly enhance the stretchability and, consequently, usability of the triboelectric generator (illustrated in Figure IV.6). (Yang et al., 2018) This type of electrode exhibits stretchability that reaches 300%, owing to the flexibility of the liquid metal and silicon rubber. Galinstan, which is an alloy of indium, tin, and gallium, can serve as the electrode (the liquid metal). The obstacle hindering its usage is the scarcity of the component elements in Egypt, resulting in a high price.

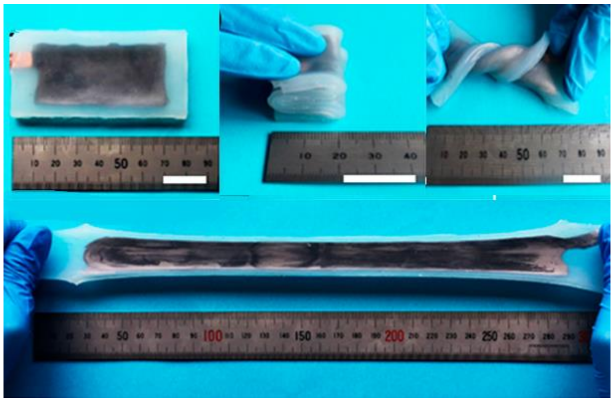


Figure IV.6 Liquid-Metal Electrode stretchability

2. Triboelectric Generators in Car Wheels

Another deployable place for a triboelectric generator is a car wheel, as demonstrated in Figure IV.7. (Mao, Geng, Liang, & Wang, 2015) This usage offers a unique capability for scavenging the otherwise-wasted friction energy between a rolling wheel and the ground. By increasing the number of TENGs on the wheel surface, the number of induced charges can be effectively increased, and thus improve the electric output power.

Figure IV.7 TENGs put on car wheels

3. Thermoelectric Generators

Instead of using TECs, which are directed towards the usage as a peltier (cooler), TEGs (exemplified in Figure IV.8) produce the same effect when a difference in temperature exists on both of its sides (the Seebeck Effect), but TEGs can withstand higher temperature on the hot side. Therefore, using them can in hot places can result in a higher power produced. (He et al., 2015; Jo, Kim, Kim, & Kim, 2012; Leonov, Gyselinckx, & Hoof, 2008)

Figure IV.8 A TEG

4. Porous Na_2CO_3

Mixing PDMS with sodium carbonate and then using an ultrasonic cleaner to break down the sodium carbonate could significantly increase the efficiency of the TENG. (Cui et al., 2018) The reason behind this is that it would make the PDMS film porous so it would hog more electrons, making it transfer more electrons on one push (shown in Figure IV.9). They also make the material more hydrophobic, increasing its usage sites.

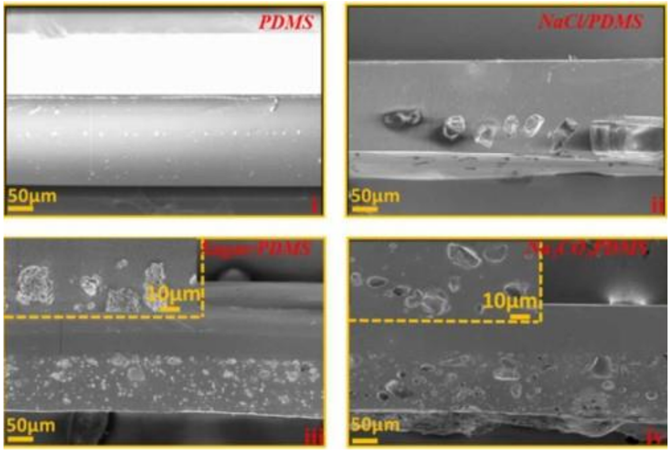


Figure IV.9 A SEM of PDMS, NaCl/PDMS, Sugar/PDMS, and Na2CO3/PDMS.

The downside of implementing such film was the unavailability of the ultrasonic cleaner and other conditions required for its application.

5. Hydrophobic Insulation materials

In order to increase the usability of TENG attached to the skin, a hydrophobic insulating material is in urgent need. Sweat secreted by the skin could hinder the function of the TENG or possibly decrease its efficiency. Figure IV.10 shows an example of a hydrophobic material. This material should also be biocompatible for it will be in constant contact with the human skin. It should not interfere with the function of the PDMS layer (becomes an electrical insulator).

Figure IV.10 A drop of water over a hydrophobic material

C. Learning Outcomes

Not only did the study of the learning outcomes in our curriculum help us in the cracking of the problem that we were assigned to solve, but they also opened to us new viewpoints that from which we looked at the problem from a different angle, helping us understand and comprehend what was the problem's causes, effects, and, also, possible solutions. In Table IV.1, the LOs which helped us the most are mentioned.

L.O. Code	Subject	Description	Concepts	Capstone Connection
CH.1.11	Chemistry	➢ Use basic laboratory techniques (to the accepted tolerance of instruments) to determine the amount, mass, or volume of a substance produced or required in a chemical reaction. ➢ Precision, accuracy, experimental error	➢ Stoichiometry ➢ Mole ➢ Molar mass ➢ Standard temperature and pressure (STP) ➢ Dimensional analysis ➢ Percentage yield ➢ Limiting reagent	➢ Using mole ratio to prepare solutions ➢ Applying limiting reactant method in the used chemical reactions
CH.1.12		➢ Conduct laboratory tests to identify three different gases. ➢ Use chemical reactions to make gases for propulsion. ➢ Investigate different types of chemical reactions involve gases.	➢ Synthesis reaction ➢ Decomposition reaction ➢ Single-replacement reaction ➢ Double-replacement reaction	➢ Gaining Knowledge about Different types of chemical reactions that generate Electricity

CH.1.15		➢ The student can design his own battery	➢ Electrochemical cell ➢ Voltage ➢ Volts ➢ Current load ➢ Ion ➢ Oxidation ➢ Reduction ➢ Half-reactions ➢ Oxidized ➢ Reduced ➢ Oxidation-reduction (redox) reaction ➢ Spectator ions ➢ Galvanic cell	➢ Having the ability to Design Batteries and measure its Voltage ➢ Understanding electrochemical cells' mechanisms and Applying it in prototypes related to them.
CH.1.16		➢ De-termine the relation between the system and environment ➢ Differentiate between thermodynamics and kinetic ➢ Apply the law of conservation of energy in many systems ➢ Compare between endothermic and exothermic system ➢ Find ΔH and calculate it in physical and chemical change ➢ Draw the energy diagram for endothermic and endothermic system	➢ System ➢ Thermodynamic ➢ Kinetics ➢ Energy ➢ Heat ➢ Maximum work ➢ Law of conservation of energy ➢ Endothermic ➢ Exothermic ➢ Heat content ➢ Enthalpy change ➢ Energy diagram ➢ Activation energy ➢ Activated complex ➢ Entropy(S) ➢ Spontaneity ➢ Gibbs free energy ➢ Catalyst	➢ Applying the law of conservation of energy in the designed prototype ➢ Understanding How the surface areas of reacted materials could change chemical reactions

		➢ Determine the activated complex position in energy diagram ➢ Determine the ➢ Gibbs free energy in endothermic and exothermic system ➢ Explain the effect of surface areas and use of a catalyst on reaction rate		
ES.1.08	Earth Science	➢ Identify and discriminate among common Fe-ores (magnetite, hematite, pyrite), common Cu-ores (chalcopyrite, malachite, native Cu), Pb-ores (sphalerite, galena), and precious metals (native Au and native Ag) as well as other important Egyptian ore minerals. ➢ Interpret geologic processes from textural evidence in ore deposit hand samples or outcrops. ➢ Identify and use different tools to measure physical	➢ Different earth materials and ore minerals have different chemical, physical and engineering properties making them suitable for different economic industries. ➢ Common ore minerals include both relatively oxidized (some oxides, hydroxides, carbonates) and relatively reduced (some oxides, sulfides) compounds of metals as well as native	➢ Using different Learning the percentage of occurrence of minerals to know if it can be found in Egypt

		properties of minerals. ➢ Using microscopic scale features to interpret and classify different types of ore minerals. ➢ Use different geologic maps that show occurrences of ore minerals in Egypt.	elements. ➢ Ore minerals must become concentrated by some geologic process to produce an economic mineral deposit. Igneous, sedimentary, and metamorphic processes can all produce ore deposits. ➢ Modern electronics technologies require new materials, such as rare earth elements, that must also be extracted from earth materials, creating new ores and new industries.	

ES.1.09		➢ Use the statistical studies to analyze the data for different energy resources in Egypt and calculate the future needs as a function of the exponential growth of population. ➢ Compare the use of energy resources for electricity generation in Egypt to those used in other countries using different statistical charts and visualization figures. ➢ Students will conduct an analysis of the socioeconomic and environmental impacts of the Aswan High Dam and explore the potential of tidal generation. ➢ Arrange the energy resources according to different factors (current and future availability, current and future	➢ Electrical energy and transportation fuels come from a variety of natural resources.	➢ Understanding the different resources of energy and their occurrences in Egypt ➢ Trying to replace the resources that cause pollution with other eco-friendly ideas

		need, cost of production…., etc.).		
BI.1.10		➢ Investigate the use of solar energy by constructing a solar water heater and determining its maximum energy output. ➢ Investigate the use of wind energy by constructing an anemometer to measure wind speeds and calculating how much power can be generated by wind.	➢ Electrical energy and transportation fuels come from a variety of natural resources. ➢ Directly capturing the sun's energy through solar panels or wind energy through turbines, is a renewable way to provide heat, hot water, and electricity. ➢ Electrical energy could be generated by hydroelectric - from dams or by tidal movement of water.	➢ Exploring different ways to generate electricity ➢ Considering prior solutions

BI.1.11	Biology	➢ Make accurate inferences and conclusions using text materials	➢ Photosynthesis - definition ➢ Cellular respiration - definition ➢ Light ➢ Chloroplasts & chlorophyll ➢ Producers ➢ Mitochondria and cytoplasm ➢ Oxygen-dependent cellular respiration ➢ Photosynthesis - process ➢ Cellular respiration - process ➢ Adenosine triphosphate (ATP)	➢ Discovering energy lost in some biological processes. ➢ Exploiting lost energy in the biological processes
BI.1.12		➢ Use microscopes to make and record observations ➢ Analyze data ➢ Make predictions ➢ Identify and describe trade-offs involved in ecosystem changes ➢ Use case studies to make accurate interpretations, inferences and conclusions from text	➢ Ecological biodiversity ➢ Food as energy source. ➢ Food web diagram ➢ Energy flow and pyramid ➢ Ecosystems diversity, disruption and collapse	➢ Understanding the transformation of energy in an ecosystem and mirroring them in our prototype.

PH.1.09	Physics	➢ Apply Bernoulli's Principle in daily life ➢ Explore alternative energy applications of fluid dynamics such as windmills, hydrological dams,	➢ General properties of Fluids ➢ Continuity equation ➢ Laminar vs Turbulent Flow ➢ Pascal's Principle ➢ pdV = Work ➢ Work-Energy Theorem ➢ Conservation of Energy in fluids ➢ Bernoulli Equation	➢ Understanding the mechanism of fluids to have the ability to adjust the used fluids as required
PH.1.10		➢ Differentiate between temperature, thermal energy and heat ➢ Measure temperature ➢ Solve problem ➢ of general law of thermometer ➢ Describe how temperature changes as a result energy transfer to a system ➢ Convert between different temperature scales (k - f - c) ➢ Describe the natural sources of heat ➢ Explain the idea of solar heat	➢ Temperature ➢ Thermal energy ➢ Heat ➢ Conduction, ➢ Convection, ➢ Radiation ➢ Measuring ➢ Temperature ➢ Temperature scale ➢ Heat capacity ➢ Specific heat ➢ Capacity ➢ Blackbody radiation ➢ Solar heat collector. ➢ Natural sources of heat: sun, geothermal ➢ Latent heat	➢ Understanding the mechanism of Thermometers ➢ Using specific Heat capacity to measure The Emitted or absorbed Energy in the chemical reaction

		collectors. ➢ Identify the uses of solar heat collector in daily life ➢ Calculate temperature change fora given amount of a substance for a given energy transfer, or determine the amount of energy required for a given substance to change temperature by a specific amount.		
EN.1.41	English		➢ Listening & speaking ➢ Reading: ➢ Listening ➢ Key vocabulary ➢ Reading ➢ Articles (Grammar way U 12) ➢ Communication skills ➢ Critical thinking	➢ Being able to write academically. ➢ Having the ability to summarize paragraphs. ➢ Skimming & Scanning

Table IV.1 The LOs which helped us the most

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