Producing Green Energy from Renewable Sources and Wastewater Treatment Plants

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الخلاصة:

تُعد التقنيات المتجددة مصادر نظيفة للطاقة، حيث يساهم الاستخدام الأمثل لهذه الموارد في تقليل التأثيرات البيئية إلى أدنى حد، ويقلل من إنتاج النفايات الثانوية، ويضمن استدامة هذه الموارد بما يتماشى مع الاحتياجات الاقتصادية والاجتماعية الحالية والمستقبلية. ستلعب مصادر الطاقة المتجددة دورًا محوريًا في مستقبل الطاقة على مستوى العالم. تنقسم موارد الطاقة إلى ثلاث فئات رئيسية: الوقود الأحفوري، الموارد المتجددة، والموارد النووية. تُعتبر مصادر الطاقة المتجددة تلك الموارد التي يمكن استخدامها مرارًا وتكرارًا لإنتاج الطاقة، مثل الطاقة الشمسية، وطاقة الرياح، والطاقة الحيوية، والطاقة الحرارية الجوفية، وتُعرف أيضًا باسم مصادر الطاقة البديلة.

تستعرض هذه الورقة نتائج البحث العلمي الذي أُجري بهدف تطوير مصادر للطاقة المتجددة يمكن تطبيقها في ليبيا. تم التحقيق في عدة مصادر للطاقة، منها إنتاج الهيدروجين الأخضر من مياه الصرف الصحي المعالجة باستخدام خلايا التحليل الكهربائي. كما تم دراسة إنتاج الغاز الحيوي (الميثان وثاني أكسيد الكربون) من خلال الهضم اللاهوائي للكتلة الحيوية (الحمأة) الناتجة من محطات معالجة مياه الصرف. بالإضافة إلى ذلك، تم فحص نوعين آخرين من مصادر الطاقة المتجددة المباشرة، وهما الطاقة الشمسية وطاقة الرياح. تم إجراء حسابات التصميم وحلول النماذج لكل مصدر من مصادر الطاقة المذكورة. أظهرت النتائج أن تقنيات الطاقة المتجددة توفر فرصة كبيرة لتطبيقها في ليبيا نظرًا لتكلفتها المنخفضة، وتأثيرها الإيجابي على البيئة، وقدرتها على أن تحل محل تقنيات إنتاج الطاقة التقليدية الحالية.

تم تصميم أجهزة الهضم لتسهيل إنتاج الغاز الحيوي، بحجم مدخلات للحمأة يقدر بحوالي 164 مترًا مكعبًا يوميًا، مما يؤدي إلى إنتاج حوالي 30,600 متر مكعب من الغاز الحيوي يوميًا. أظهرت دراسات المحاكاة باستخدام برنامج Aspen Hysis أن مدخلات المياه بلغت 8,557 كجم/ساعة، في حين بلغ إنتاج الهيدروجين

748.2 كجم/ساعة، وإنتاج الأكسجين 5,987 كجم/ساعة باستخدام تقنية PEMEC. تطلبت تقنية SOEC حوالي 21.27 كيلوواط ساعي لكل كيلوغرام من الهيدروجين. أما محطة الطاقة الشمسية، فقد تم تجهيزها بـ 45,042 لوحة شمسية، وهي قادرة على توليد 12.6 ميغاواط ساعة من الكهرباء، مدعومة بـ 12,492 بطارية لضمان تزويد مستمر بالطاقة. بالإضافة إلى ذلك، استُخدمت 21 توربينة رياح في محطة طاقة الرياح، التي تم تقدير إنتاجها بـ 12.6 ميغاواط ساعة من الكهرباء، مدعومة بـ 984 بطارية لضمان إمداد الكهرباء على مدار السنة. قُدرت التكلفة الإجمالية لإنتاج الطاقة من المصادر الأربعة للطاقة المتجددة التي تم بحثها بحوالي 615 مليون دولار أمريكي لكل محطة.

Abstract
Renewable technologies are considered as clean sources of energy and optimal use of these resources minimize environmental impacts, produce minimum secondary wastes and are sustainable based on current and future economic and social societal needs. Renewable energy resources will play an important role in the world's future. The energy resources have been split into three categories: fossil fuels, renewable resources and nuclear resources. Renewable energy sources are those resources which can be used to produce energy again and again, e.g. solar energy, wind energy, biomass energy, geothermal energy, etc. and are also often called alternative sources of energy.

This paper outlines the results of research work conducted towards producing renewable energy sources that could be established in Libya. One of the energy sources investigated is the production of green hydrogen from the abundant treated domestic wastewater by the electrolysis cells. Another energy source is the production of biogas (CH_4 and CO_2) through the anaerobic digestion of biomass (sludge) generated also from wastewater treatment plants. Two other direct forms of renewable energy sources were investigated in this research work namely the solar energy and wind energy. Design calculations and model simulations were conducted on each energy source mentioned above. Results revealed that renewable energy technologies provide excellent opportunity to be established in Libya because at a minimum cost, and provide a clean environment without any adverse effect, and can be a substitute to the current conventional energy production technologies that depend on fossil fuel.

Anaerobic digesters have been designed to facilitate biogas production as a source of renewable energy, with an estimated sludge input volume of 164 cubic meters per

day, leading to a biogas generation rate of 30,600 cubic meters per day. Model simulation studies using Aspen Hysis indicated water input to the electrolysis cells should be 8,557 kg/h. Green hydrogen output was found to be 748.2 kg/h, and oxygen output was found to be 5,987 kg/h for PEMEC. The SOEC required 21.27 kWh per kilogram of hydrogen. The solar power plant, must be equipped with 45,042 solar panels in order to generate 12.6 MWh of electricity supported by 12,492 batteries for continuous power supply. The wind power plant must utilize 21 wind turbines in order to generate 12.6 MWh of power, supported by 984 batteries for a year-round electricity supply. The total estimated cost of producing energy from the above four sources of renewable energy under investigation, was estimated to be $615 million US dollars per station.

Key words: Renewable energy, Solar energy, wind energy, green hydrogen, wastewater, sewage water, activated sludge, anaerobic digestion, biogas

1) Introduction

Renewable energy is energy derived from natural sources that are replenished at a higher rate than they are consumed. Sunlight and wind, for example, are such sources that are constantly being replenished. Renewable energy sources are plentiful and all around us. Fossil fuels - coal, oil and gas - on the other hand, are non-renewable resources that take hundreds of millions of years to form. Fossil fuels, when burned to produce energy, cause harmful greenhouse gas emissions, such as carbon dioxide **[1].** Generating renewable energy creates far lower emissions than burning fossil fuels **[2]**. Transitioning from fossil fuels, which currently account for more emissions, to renewable energy is key to addressing the climate crisis [**3,4].** Renewables are now cheaper in most countries, and generate three times more jobs than fossil fuels **[5].**

2) Common sources of renewable energy:

2.1) Solar Energy

Solar energy is the most abundant of all energy resources and can even be harnessed in cloudy weather. The rate at which solar energy is intercepted by the Earth is than the rate of its consumption. Solar technologies can provide heat, cooling, natural lighting, electricity, and fuels for most applications. Solar technologies convert sunlight into electrical energy either through photovoltaic panels or through mirrors that concentrate solar radiation **[6]**. Although not all countries are equally endowed with solar energy, a significant contribution to the energy mix from direct solar energy is possible for every country. The cost of manufacturing solar panels has plummeted dramatically in the last decade, making them not only affordable but often the cheapest form of electricity **[7].** Solar panels are expected to last around 30 years, and can be manufactured in variety of shades depending on the type of material used in its manufacturing.

2.2) Wind Energy

Wind energy harnesses the kinetic energy of moving air by using large wind turbines located on land (onshore) or in sea- or freshwater (off-shore) **[8].** Wind energy has been used for millennia, but onshore and offshore wind energy technologies have evolved over the last few years to maximize the electricity produced - with taller turbines and larger rotor diameters. Though average wind speeds vary considerably by location, the world's technical potential for wind energy exceeds global electricity production, and ample potential exists in most regions of the world to enable significant wind energy deployment **[9].** Many parts of the world have strong wind speeds, but the best locations for generating wind power are sometimes remote ones. Off-shore wind power offers tremendous potential **[10].**

2.3) Biogas-Energy

Bioenergy is produced from a variety of organic materials, called biomass, such as wood, charcoal, dung and other manures for heat and power production, and agricultural crops for liquid biofuels. Most biomass is used in rural areas for cooking, lighting and space heating, generally by poorer populations in developing countries **[11].** Modern biomass systems include dedicated crops or trees, residues from agriculture and forestry, and various organic waste streams. Energy created by burning biomass creates greenhouse gas emissions, but at lower levels than burning fossil fuels like coal, oil or gas **[12].** However, bioenergy should only be used in limited applications, given potential negative environmental impacts related to large-scale increases in forest and bioenergy plantations, and resulting deforestation and land-use change [13]. Most notably, bioenergy is expected to play a major role in the substitution of fossil energy necessary to meet global climate targets [14].

3) The main objectives of this research work

The primary goal of this research work is to address the global challenge of increasing high energy demand in electric power in our country Libya and introduce or adopt any renewable energy source that can minimize any adverse impact to the surrounding local environment. This research work will also attempt also, to select any renewable technology that will use the available source of renewable energy in such a way it will be highly efficient, cheap, and environmentally friendly.

4) Approach

In order to achieve the ultimate goal of this research work, these renewable energy sources in Libya were targeted for this research, namely solar energy because of vast area available for the sun energy all the year, and renewable energy generated from the wind in several areas in the country of Libya, and finally the renewable energy of hydrogen produced from an electrolysis process of treated wastewater., and finally biogas (CH_4 and CO_2) (biogas is formed from the anaerobic treatment of the activated sludge produced from the wastewater treatment plants). The steps required to achieve these goals are summarized below:

a) Conduct material and energy balance calculations on each renewable technology selected in this investigation.

b) Mathematical model simulations of Hysis software will be used for each renewable technology in order to determine the amount of energy generated as well as the efficiency of each technology.

c) Design a wastewater treatment plant that can serve a hypothetical city located in Tripoli area. The population of this city was assumed to be **2402100** people, with a moderate strength and typical composition of untreated raw domestic wastewater. The amount of treated wastewater and the activated sludge generated will be estimated and used as a feedstock for the green hydrogen and the biogas production.

d) The activated sludge generated will be further treated through anaerobic digesters to produce the biogas (CH_4 and CO_2) that will be used as a renewable energy for power plants. The amount of biogas will be estimated.

e) Design an electric cell unit that will be used to electrolyze the treated wastewater in order to produce green hydrogen and oxygen.

f) Estimate the amount of solar energy generated using predesigned solar energy system. Using this estimated solar energy value an equivalent electric power in MWh will be quantified.

g) Estimate the amount of wind energy generated using predesigned specific wind turbines. Using this estimated wind energy value an equivalent electric power in MWh will be quantified.

5) The expected outcome of this research work

It is highly expected that after completion of this research, the following facts will take place:

a) Preserving the integrity of the environment: by reducing the environmental pollution and hence improving the air and the water qualities.

b) Integrated infrastructure: The project envisions the establishment of joint infrastructure for water treatment and clean alternative energy generation.

c) Producing the green hydrogen from the treated wastewater, green hydrogen is a promising source of clean and sustainable renewable energy that can be used for electric power generation plants.

d) Producing green hydrogen will reduce the amount of treated wastewater disposed to the sea and become a source of a renewable energy generation.

e) Producing green hydrogen, solar and wind renewable energies as well as the production biogas from the anaerobic digestion of activated sludge will reduce the cost of electric power in this country.

g) Job creation and economic development: The project has the potential to create new job opportunities in the alternative energy and water sectors, which stimulates economic growth and benefits the local economy.

h) Technological innovation: By promoting the development and adoption of new technologies in green hydrogen production and wastewater treatment, the project enhances Libya's technological and innovative capacity in these areas.

6) Producing clean energy from wastewater treatment plants

Industrial or sewage wastewater treatment facilities are built to handle wastewater before it is released into the environment. If industrial or domestic wastewater is not cleaned, it can include dangerous pollutants and chemicals and may have a negative impact on the environment and the general public's health **[15].** In order to remove impurities and pollutants from wastewater, industrial or sewage treatment plants involve a number of physical, chemical, and biological processes. Depending on the type of industry and the types of contaminants present in the wastewater, the treatment method may change accordingly [16]. The importance of sewage treatment plant cannot be overstated, as it plays a vital role in protecting the environment, public health, and the economy. Unprocessed effluent discharged into the environment can result in pollution, aquatic life harm, and water source contamination, which can negatively impact public health by exposing people to harmful pathogens, toxins, and chemicals **[17].** Moreover, untreated sewage treatment plant effluent can also harm the economy by reducing the availability and quality of water resources, increasing healthcare costs associated with waterborne diseases, and negatively affecting industries that rely on clean water **[18].** Therefore, an effective industrial sewage treatment plant is essential to ensure that effluent is adequately treated, and that the treated water meets the required quality standards before it is released. This, in turn, helps to safeguard the environment, public health, and the economy by reducing pollution, preventing the spread of disease, and ensuring the availability of clean water resources.

7) Components of an Effective Industrial or Sewage Treatment Plants

An industrial or sewage treatment plant is a facility designed to treat wastewater generated from industries before it is discharged into the environment. An effective industrial sewage treatment plant should consist of five key components, which are **pretreatmen**t, **biological treatment**, **chemical treatment**, **filtration**, and

disinfection. These components of a sewage treatment plant work together to ensure that the wastewater is treated adequately and meets the required quality standards before it is discharged. Wastewater treatment or sewage treatment is a process to improve the water quality, removing some or all of the contaminants, making it suitable for reuse or discharge back to the environment. Generally, untreated wastewater contains high levels of organic material, numerous pathogenic microorganisms, as well as nutrients and toxic compounds that can be harmful to human health, environment and waterways, hence effective treatment of wastewater is very much essential [19]. The major goal of wastewater treatment plants is to eventually produce a treated water that can be reused for various purposes or disposed of in such a way that will not cause an adverse impact to the surrounding environment [20]. These goals listed below:

a. To improve quality of wastewater.
b. Elimination of pollutants, toxicants and many such.
c. Preservation of water quality of natural water resources.
d. To make wastewater usable for other purposes.
e. Prevention of harmful diseases.

Wastewater treatment technologies or advanced waste water treatment methods can be broadly classified into three sub divisions and are as follows:

1) Physical treatment method: It involves removal of pollutants/contaminants by physical forces.
2) Chemical treatment method: Removal of impurities or toxic wastes through chemical reactions.
3) Biological treatment method: Ejection of pollutants by biological activities.

8. Domestic Waste Water Treatment Stages

Wastewater derived from human activities in households such as bath, laundry, dish washing, garbage disposal, toilets is called as domestic wastewater which usually contains relatively small amounts of contaminants but even small amounts of pollutants can make a big impact on environment **[21].** Hence, a properly installed and maintained residential sewage treatment system for treating and disposing of household wastewater will minimize the impact on ground water and surface water. Domestic waste water treatment plays an important role in nowadays. Domestic wastewater treatment ensures that all household sewage is properly treated to make it safe, clean and suitable for releasing back into the environment, land, or sea. Home sewage systems are designed to treat all of the liquid waste generated from a residence. Possible contaminants in household wastewater include diseasecausing bacteria, infectious viruses, household chemicals, and excess nutrients such as nitrate **[22].** Domestic wastewater consists of two main fluxes: one is grey water which is from kitchen sinks, wash basins, laundry washing, showers, baths etc., and second one is black water which is from toilets and urinals. Domestic wastewater consists of two main fluxes: one is grey water which is from kitchen sinks, wash basins, laundry washing, showers, baths etc., and second one is black water which is from toilets and urinals. Household sewage treatment plant breaks down domestic wastes via three major stages **[23].**

8.1. Preliminary treatment stage:

Pretreatment is an essential component of an industrial sewage treatment plant, as it is the first stage of the treatment process. During this stage, the wastewater is screened to remove large solid materials, such as plastics, rocks, and rags, which may cause blockages or damage downstream equipment. This stage also involves the removal of grit and sand, which may cause wear and tear on pumps and other equipment. Pretreatment is necessary to protect downstream equipment and ensure that the wastewater is treated effectively.

8.2) Primary Stage: Preliminary or pretreatment, is the first stage of wastewater treatment and is used to prepare water for purification during the following phases. Thus, it consists of removing objects that could damage the plant or the equipment that will be used during the purification process **[24].** Aftert this Preliminary or pretreatment or first stage of wastewater treatment, the settleable organic and inorganic solids were removed by sedimentation and the materials that will float (scum) were removed by skimming through the primary stage **[25].** The objective of this primary stage is to remove part of the suspended solids flowing with the wastewater. To this end, water is retained for one to two hours in decanter centrifuges where gravity helps to separate these particles. Other benefits of this primary stage include flow homogenization and the removal of organic matter linked to the suspended solids **[26].**

The primary stage also, involves physical and /or chemical operations for treatment of wastewater, it is expected that this stage about 40-60% of the suspended solids are removed. Primary clarifier or settling/sedimentation tank in this stage removes sinking and floating contaminants. Sludge that settles to the bottom of the clarifier is called as primary sludge and it is collected for further treatment process called sludge treatment. Through the primary clarifier about 50-70% of suspended solids, and 35% of BOD will get removed with very few toxic chemicals. The partially treated wastewater from the primary clarifier or primary settling tank then flows directly to the secondary treatment stage where biological treatment will take place **[27].**

8.3) Secondary Stage:

Secondary treatment of sewage is called biological treatment because it involves living organisms such as aerobic or anaerobic microbes to digest the organic waste **[28].** This stage is designed to remove organic matter from the water, as well as nutrients such as nitrogen and phosphorus. This is the stage where the biological (aerobic/anaerobic) treatment of wastewater from the primary stage begins, it is expected to remove up to 90% of the organic matter. It uses activated sludge process which use dissolved oxygen to promote growth of biological floc that substantially removes organic matter **[29]**. As a result of this, BOD gets significantly reduced. The effluent is then passed to a secondary settling tank where flocs settle down to produce activated sludge. Part of this activated sludge is recycled to the aeration tank to promote further treatment. The other part of the activated sludge is pumped to an anaerobic sludge digester to digest the bacteria and fungi in the sludge **[**30]. The action involved in the secondary treatment stage are summarized below:

a) Bacteria-containing “activated sludge” is continually re-circulated back to the aeration tank to 0increase the rate of organic decomposition.
b) Bacteria attack the dissolved and finely divided suspended solids, which are not removed by primary sedimentation.
c) The water is then taken to settling tanks where the sludge again settles, leaving the water 90 to 95 % free of pollutants.

8.4) Tertiary Stage:

Tertiary treatment (sometimes called “effluent polishing”) is used to further clean water when it is being discharged into a sensitive ecosystem. Several methods can be used to further disinfect sewage beyond primary and secondary treatment. Sand filtration, where water is passed through a sand filter, can be used to remove particulate matter **[31].** During tertiary or chemical treatment, the final quality of water is increased then the water can be returned to the environment (sea, rivers, lakes and other hydrographic basins) and, in some cases, used for human activity. To achieve this, a series of processes are carried out to eliminate pathogenic agents, such as fecal bacteria **[32].** Tertiary or Advanced Treatment stage of Wastewater is considered to be the final treatment stage of wastewater processing and its main objective is the removal of specific wastewater constituents which cannot be removed in previous stages and thereby increase the quality of the effluent to higher degree **[33].** Throughout, this tertiary or advanced treatment stage the following actions may take place:

a) When the effluent from secondary treatment is unacceptable, a third level of treatment called tertiary or advanced treatment, can be employed.
b) Through this final treatment stage, the effluent water quality is increased to the desired level.
c) Through this stage, some form of filtration to remove higher level of suspended solids which was not possible through primary and secondary screening and sedimentation. Nutrients, heavy metals, specific toxic chemicals and other pollutants/contaminants are removed during this process.
d) This stage can remove more than 99% of all the impurities from sewage, producing an effluent of almost drinking-water quality.
e) This stage involves disinfection which can be attained by means of physical disinfectants like UV light and chemical disinfectants like chlorine. This stage is also called as disinfection stage and either UV or chlorine, or ozone is used as an ideal disinfectant for wastewater since it does not alter the water quality.
f) During this process significant percentage of pathogenic organisms are killed or controlled
The water at this stage is almost free from harmful substances and chemicals and which can be reused, recycled or released back into the environment.

9. Methods of Biological Treatment of Wastewater

Biological wastewater treatment is an important and integral step of wastewater treatment system and it treats wastewater coming from either residential buildings or industries **[34] .** It is often called as Secondary Treatment process which is used to remove any contaminants that left over after primary treatment. Chemical treatment of waste water makes use of chemicals to react with pollutants present in the wastewater and whereas biological treatment uses microorganisms to degrade wastewater contaminants **[35].** \This treatment relies on bacteria, nematodes, algae, fungi, protozoa, rotifers to break down unstable organic wastes using normal cellular processes to stable inorganic forms. Based on the process, biological treatment of waste water methods is majorly classified into two types namely:
biological aerobic treatment (in presence of oxygen), and biological anaerobic treatment (in absence of oxygen). **[36].**

9.1. Biological Aerobic Treatment:

Aerobic wastewater treatment is a biological process that takes place in the of oxygen. It is the rapid and the most efficient biological waste treatment which remove up to 98% of organic contaminants **[37].** This process causes effective breakdown of organic pollutants and yields a cleaner water effluent than anaerobic treatment. Aerobic biological treatment processes include many processes such as activated sludge process, trickling filter, aerated lagoons and oxidation ponds **[38].** Activated sludge process is the most widely used process for domestic and industrial wastewater. Aerobic biological treatment will remain efficient and stable in all conditions. Biological aerobic treatment is the second stage of the sewage treatment process and involves the use of microorganisms such as bacteria, fungi, and protozoa to break down organic matter in the wastewater. This process takes place in large tanks known as bioreactors, where the microorganisms consume the organic matter in the wastewater, converting it into carbon dioxide, water, and other by-products. Biological treatment is essential because it significantly reduces the amount of organic matter in the wastewater, making it easier to treat in subsequent stages.

9.2. Activated Sludge Process:

The activated sludge process is the most widely used biological waste treatment in secondary stage of wastewater treatment. An activated sludge process refers to a multi-chamber reactor unit that makes use of highly concentrated microorganisms to degrade organics and remove nutrients from wastewater to produce a high-quality effluent. In this method, the sewage containing organic matter with the microorganisms is aerated (by a mechanical aerator) in an aeration tank **[39].** This process speeds up waste decomposition. Aeration in an activated sludge process is based on pumping air into a tank, which promotes the microbial growth in the wastewater **[40].** The effluent from the aeration tank containing the flocculent microbial mass, known as sludge, is separated in a settling tank, sometimes called a secondary settler or a clarifier. The activated sludge process is a very compact, low-cost and an efficient biological treatment system for sewage/waste water treatment. Conventional flow diagram for Activated Sludge Process is shown below in figure (3).

9.3.Biological Anaerobic Treatment:

This treatment process is effectively utilized to treat high strength waste water and it employs organisms that function in the absence of oxygen and it will typically treat high-strength waste water to a level that will permit discharge to a municipal sewer system **[41].** Here, the amount of sludge produced is very small when we compared to aerobic treatment. Anaerobic treatment is a slow process and it occurs in many different stages. Anaerobic digestion is biological process which is used in wastewater treatment plants for sludge degradation and stabilization **[42].** Once the process is completed, the wastewater can undergo many additional treatments. This process is accepted because it is able to stabilize the water with little biomass production. Biogas is produced as the bacteria feed off the biodegradable material in the anaerobic process **[43].** Overall, the process converts about 40% to 60% of the organic solids to methane (CH_4) and carbon dioxide (CO_2) **[44].** Finally, the type of biological treatments selected whether aerobic or anaerobic depends on many factors such as type of waste and concentration of organic matter as well as the treatment objectives **[45].** .

9.4.Chemical treatment

Chemical treatment is the third stage of the sewage treatment process, and it involves the use of chemicals to remove any remaining organic matter and nutrients such as nitrogen and phosphorus **[46,47].** This stage typically involves the use of coagulants and flocculants to remove suspended solids, and disinfectants to kill bacteria and other pathogens **[48].** Chemical treatment is necessary to ensure that the wastewater meets the required quality standards before it is discharged into the environment.

9.5.Filtration

Filtration is the fourth stage of the sewage treatment process and involves the removal of any remaining suspended solids and other contaminants **[49].** This stage typically involves the use of sand, gravel, and other materials to filter out these materials. Filtration is essential because it removes any remaining contaminants, making the water clear and free of suspended solids before it undergoes the final stage of treatment **[50,51].**

9.5.Disinfection

Disinfection is the final stage of the sewage treatment process and involves the removal of any remaining bacteria and other pathogens that may be present in the treated wastewater **[52].** This stage typically involves the use of chemicals such as chlorine, ozone, or ultraviolet light to kill any remaining pathogens **[53].** Disinfection is essential to ensure that the wastewater is safe for the environment and public health before it is discharged **[54,55].** Figure (1& 2) shows a process flow diagram of a conventional wastewater treatment plant including the above mentioned five stages. The effluent treated water stream will be sent to electric ionization cells where the water ionized to its main ions' hydrogen and oxygen. Hydrogen gas will be handled under specified operating conditions and stored into specially design storage tanks until used in the electric power generation plants.

10. Municipal wastewater characterization

Development of an effective treatment method for untreated municipal wastewater before discharge into urban areas and the natural environment is essential **[56].** In order to design a proper wastewater treatment plant and to enable the selection of the most efficient treatment methodology, the need for familiarity with wastewater characterizations is urged **[57,58].** Accordingly, properties and characteristics of general municipal wastewater are represented in Table 2.

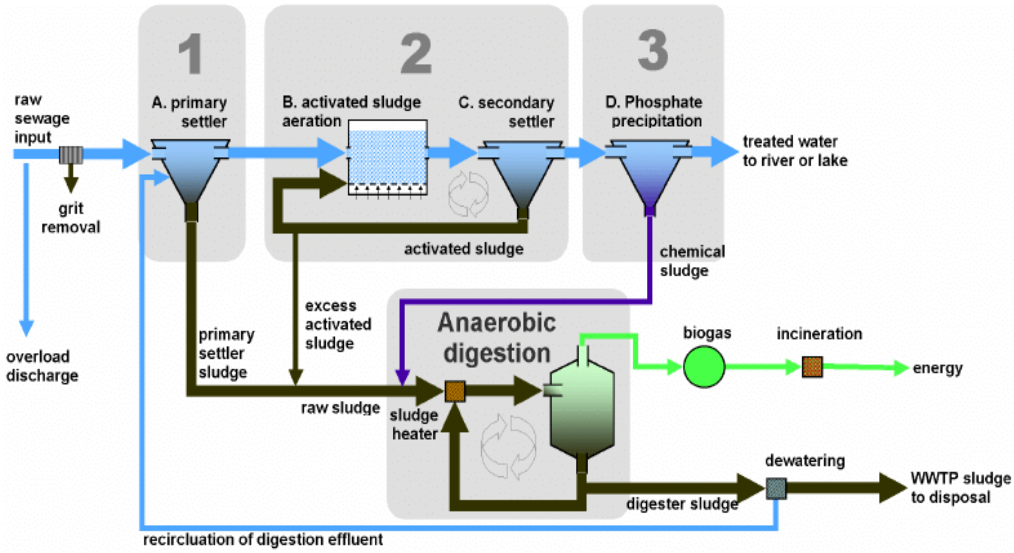

Figure (1) Wastewater treatment plant with biogas exit [28]

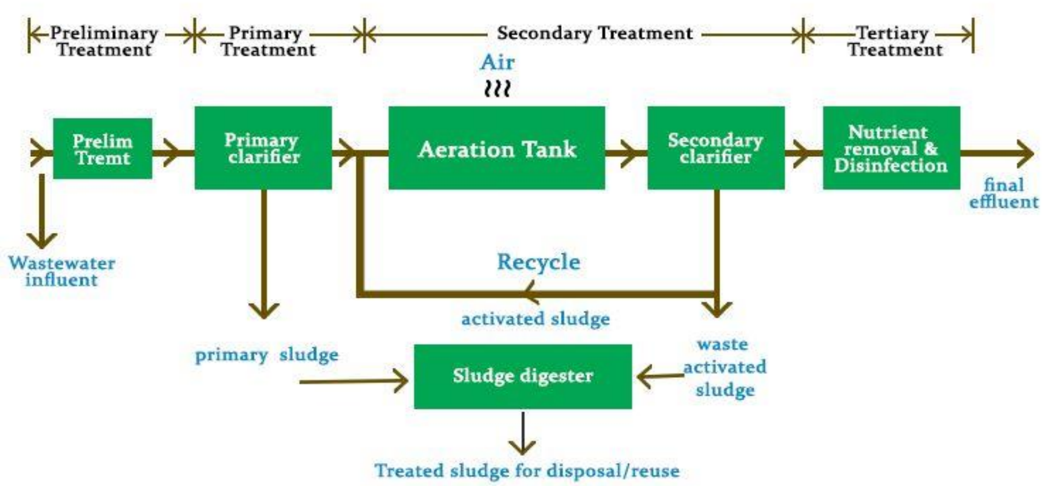

Figure (2) Conventional flow diagram for Activated Sludge Process [28, 29]

11. Activated sludge design equations

Several design equations pertaining to the complete mixed activated sludge design were derived based on material balance principles applied to biochemical oxygen demand (BOD) and total suspended solids (TSS) within the process **[59,60].** The remaining design equations can be found in several references **[61,62**]. In order to obtain the design equations in this research work, material balance on substrate BOD) and biomass (solids) were conducted on the completely mixed activated sludge bio-reactor system shown in figure (3).

Biomass balance:

$$QX_o + V\left\{\frac{\mu_{max}SX}{K_s + S} - k_dX\right\} = (Q - Q_w)X_e + Q_wX_w \quad ---------- \quad (1)$$

Substrate mass balance:

$$QS_o - V\left[\frac{\mu_{max}SX}{(K_s + S)}\right] = (Q - Q_w)S_e + Q_wS_w \quad ------------ \quad (2)$$

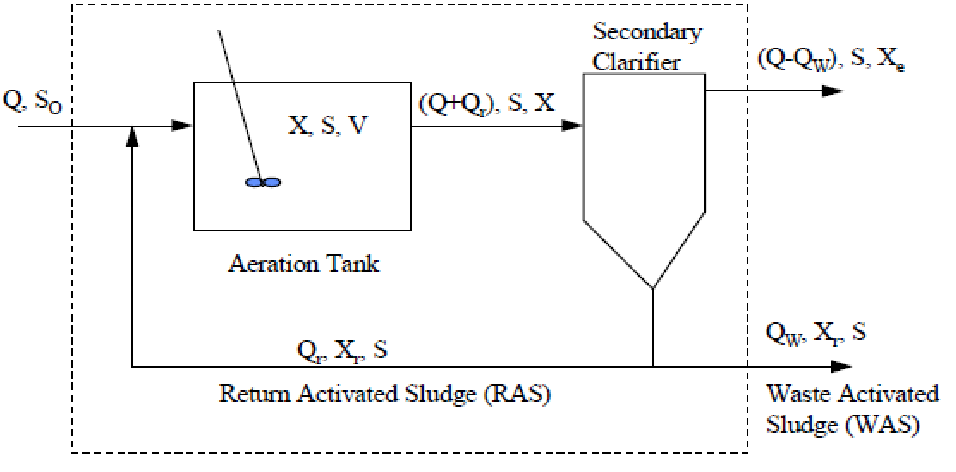

Figure (3) Completely mixed activated sludge bio-reactor system [30]

Where: Q, Q_w = influent flow and waste flow, respectively, m^3/d
V = volume of aeration basin , m^3
μ_{max} = maximum specific growth rate coefficient, h^{-1}
K_s = half saturation constant, mg/L k_d = decay coefficient , h^{-1}

X_o, X, X_e, X_w = biomass in influent, bioreactor, effluent, and waste, mg/L as MLVSS

S = soluble substrate in bioreactor mg/L as BOD or COD

S_o = influent substrate concentration mg/L as BOD or COD

Y = biomass yield, mg biomass formed per mg substrate utilized (mg VSS/*mg BOD*)

The general ranges of magnitude of the kinetic parameters for completely mixed activated sludge process treating municipal wastewater at approximate temperature of 20 °C, are tabulated in Table (1).

Table (1) Kinetic parameters for completely mixed activated sludge process [20, 21, 22]

Kinetic constant	**Unit**	**Range**
Y, biomass yield coefficient	**(mg VSS/mg of BOD_5)**	**(0.4 – 0.8)**
Y, biomass yield coefficient	**(mg VSS/mg of COD)**	**(0.3 – 0.4)**
k_d , microbial decay coefficient	**d^{-1}**	**(0.01 – 0.08)**
K_S, Saturation constant	**mg/L of BOD_5**	**(25 – 100)**
K_S, Saturation constant	**mg/L of COD**	**(25 – 100)**
K, maximum substrate utilization rate	**d^{-1}**	**(4 – 8)**

Assumptions:

- Aeration basin is a continuous stirred tank reactor (CSTR), S=Se=S_w
- All reactions occur in the aeration basin.
- Effluent substrate and biomass concentration are negligible.

$$\text{Average detention time } (\theta) = \frac{V}{Q} = \frac{\text{volume aeration basin}}{\text{flow rate}} \quad -------- \quad (3)$$

$$\text{Mean cell residence time } (\theta_C) = \frac{VX}{Q_w X_w} \quad -------------- \quad (4)$$

$$S = \frac{K_S(1 + k_d\theta_C)}{\theta_C(\mu_{max} - k_d) - 1} \quad ---------------- \quad (5)$$

$$\theta_C = \frac{K_S + S}{S(\mu_{max} - k_d) - K_S k_d} \quad ------------ \quad (6)$$

$$X = \frac{\theta_C Y(S_O - S)}{\theta(1 + k_d \theta_C)} \quad ------------ -- \quad (7)$$

12) Steps for treating wastewater for activated sludge design process

1) Establish effluent soluble BOD5 allowable to meet BOD5, and suspended solids effluent limits.
2) Determine the MCRT (θ_C) required to meet the effluent soluble BOD_5 allowable.
3) Solve for mixed liquor volatile suspended solids, MLVSS, concentration at a given particular hydraulic residence time (θ), or solve for (θ) given a particular MLVSS.
4) Calculate the return activated sludge (RAS) flow, (Q_r), and concentration (X_r).

$$X'_r Q_r = X'(Q_r + Q) \quad ; X'_r = \frac{10^6}{SVI} \quad ------ \quad (8)$$

Where: $X' = MLSS, mg/L$ (X' typically is approximately 1.2 X
$X'_r = RAS\ concentration, mg/L$, $Q_r = RAS\ flow\ rate, m^3/sec$

5) Sludge production can be estimated as follows:

$$P_X = Y_{OBS} Q(S_O - S)\ kg/1000\ g \quad --------- \quad (9)$$

Where: $P_X = sludge\ production, kg/d$, $Q = influent\ flow, m^3/d$, $S_O = influent\ BOD5$, $S = effluent\ BOD5$, $Y_{OBS} = observed\ growth\ yield, mg\ biomass\ formed\ VSS/mg\ BOD5\ utilized$, $Y_{OBS} = Y/(1 + k_d \theta_c)$

6) Oxygen requirement for carbonaceous BOD removal can be calculated as:

$$O_2\ required = \left\{ \frac{Q(S_O - S)}{f} . kg/1000\ g \right\} - 1.42 P_X \quad -------- \quad (10)$$

$$f = conv.\ from\ BOD5\ to\ BODL = (0.45 - 0.68)$$

When nitrification is occurring the oxygen requirement can be calculated as:

$$O_2\ required = \left\{\frac{Q(S_O - S)}{f}\ .kg/1000\ g\right\} - 1.42P_X + 4.57\ Q(N_O - N)\ .kg/1000\ g \quad (11)$$

Where N_O and N are the influent and effluent NH_4-N concentrations respectively.

Table (2) Typical characteristics of untreated municipal wastewater [21,22]

Contaminants	Unit	Weak	Medium	Strong
Total solid (TS)	mg/L	350	720	1200
Total dissolved solid (TDS)	mg/L	250	500	850
Suspended solid	mg/L	100	220	350
Settle able solid	mg/L	5	10	20
Biochemical Oxygen Demand BOD_5)	mg/L	110	220	400
Total Organic Carbon (TOC)	mg/L	80	160	290
Chemical Oxygen Demand (COD)	mg/L	250	500	1000
Nitrogen (N)	mg/L	20	40	85
Phosphorus (P)	mg/L	4	8	15
Chlorides	mg/L	30	50	100
Sulfates	mg/L	20	30	50
pH	dim	5–7	7–9	9–12
Alkalinity	mg/L	50	100	200
Grease	mg/L	50	100	150
Total coliforms	No/100 ml	10^6–10^7	10^7–10^8	10^7–10^9
Volatile organic components	µg/L	<100	100–400	>400

Table (3) Raw sewage wastewater data and influent plant flow rate estimated

Number of sewage plant	3	Plants
Population of one station	800700	people
Population of Tripoli 2023	2402100	people
Sewage plant estimated design period	25	Years
Population growth rate in Tripoli	%1.66	%
Population served per station	1,132,991	people
Water Consumption per person	340	L/day
Influent flow rate to the plant on a (Wet Weather)	385,216.77	m^3/Day
Biochemical Oxygen Demand (BOD_5) (dry Weather)	295	mg/l
Total Suspended Solids (dry Weather)	315	mg/l

Biochemical Oxygen Demand (BOD_5) (Wet Weather)	196	mg/l
Total Suspended Solids (wet Weather)	125	mg/l

Table (4) Aeration tank design data

flow inlet	48895	m^3/day
Total Suspended Solids (TSS) Inlet	7991	kg/day
Biochemical Oxygen Demand (BOD_5) at Inlet	10359	kg/day
Number of Aeration Tanks	8	dim
Number of chambers	32	dim
MCRT based on solids in the aeration basin, θ_C	10	days
Water depth	5	m
Length	68	m
Width	34	m
Oxygen Requirements	10233.12	kg/d
Check (F: M) ratio	0.314	per day
Maximum flow to each aeration basin	40126.75	m^3/sec

Table (5) Secondary Sedimentation data

Number of secondary sedimentations	8	
Diameter of the secondary clarifier	37.547	m
Total depth of clarifier	4.483	m
Hopper Depth	5.5	m
flow effluent treated water	48129.38	m3/day
Total Suspended Solids (TSS) in effluent	10	mg/l
BODs exerted by the solids in the effluent*	6.276	mg/l
Efficiency of biological treatment based on soluble BODs in the effluent	%97.14	dim
Overall treatment efficiency of the plant including primary treatment	%96.61	dim
Total solids wasted from the MLSS collection box below the aeration basin	1507.37	kg/day
Sludge wasting rate from the MLSS collection box	482.36	m3/day
Volume of waste activated sludge	766.74	m3/day
Total Suspended Solids (TSS) in waste activated sludge	2396.05	kg/day
Biochemical Oxygen Demand in waste activated sludge	1503.86	kg/day

13) Anaerobic digestion (AD) process for the production of CH_4 and CO_2

Sewage sludge scraped off the bottom of the settling tank during primary treatment is treated separately from wastewater. Sludge can be disposed of in several ways. First, it can be digested using bacteria; bacterial digestion can sometimes produce methane biogas, which can be used to generate electricity. Sludge can also be incinerated, or condensed, heated to disinfect it, and reused as fertilizer **[63,64].** The digestion process takes place in an air tight container at room temperature and this produces a product called "Biogas"**[65].** This biogas composed of 50-70% methane (cooking gas) CH_4, 30-40% carbon dioxide (CO) (fire extinguisher), 0-3/% Hydrogen sulphide HS and traces of other gases CO, NH3, N_2, H_2 and water vapor **[66]**. The Composition of the biogas produced can vary depending on the Substrates (organic materials) used **[67].** Anaerobic digestion process (AD) is characterized according to the following:

1) Anaerobic digestion (AD) comprises of a series of biological processes in which microorganisms break down biodegradable material (organic matter in the sludge or wastewater) in the absence of oxygen.
2) Anaerobic digestion (AD) is one of the oldest processes used for the stabilization of sludge obtained from Activated Sludge Process (ASP).
3) Anaerobic digestion (AD) process is capable of treating solid or liquid waste.
4) Anaerobic digestion (AD) process is widely used in the production of biogas (CH_4 and CO_2) as a source of renewable energy fuel for electric power generation.
5) Two groups of microorganisms are involved in the anaerobic digestion (AD) namely methane forming bacteria and archaea bacteria.
6) Gas production is one of the important parameters for measuring the performance of the digester. Typically, gas production ranges from 810 to 1120 L of digester gas per kg of volatile solids (13 to 18 ft^3 gas/lb VS) destroyed.
7) Gas produced from a properly operated digester contains approximately 65% to 69% methane and 31% to 35% carbon dioxide. If more than 35% of gas is carbon dioxide, the digester system is not well operated. The quantity of methane produced can be computed from the equation of (McCarty, 1964), equation (11) **[67,68].**
8) Anaerobic digestion process is carried out in either single stage or two stage system. Figure (4) shows a typical two stage system where can easily separate the digested sludge from the supernatant water layer and the bigas. Through this two-stage anaerobic digestion system, the digestion factors are closely monitored and controlled. These factors need to be monitored and controlled for efficient performance include type of bacteria, type of food needed for the anaerobic bacteria, loading rate of thickened activated sludge, contact time, degree of mixing and temperature inside the digester **[68,69].**

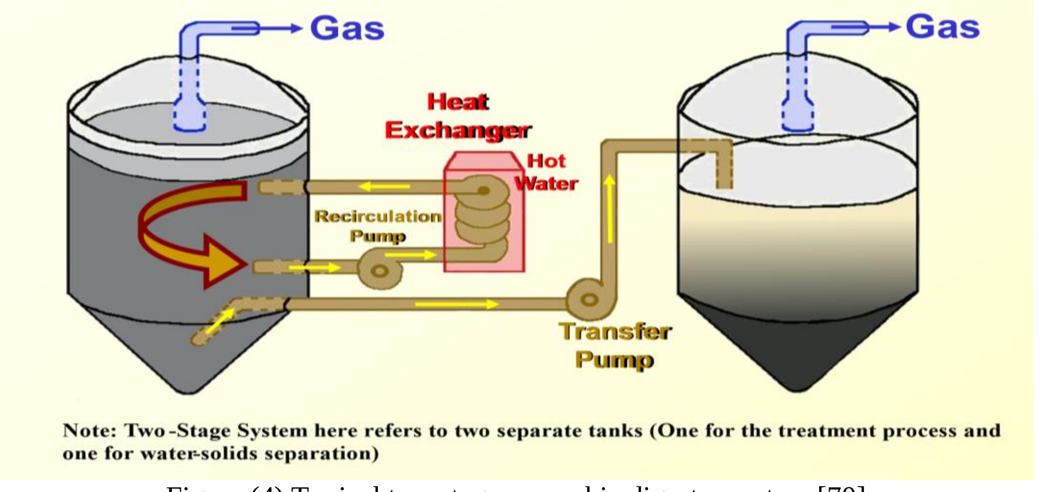

Figure (4) Typical two stage anaerobic digester system [70]

14) Steps for Anaerobic digestion process (AD) design

The digestion of solid waste (Activated Sludge) is divided into four different steps:

1) **Liquefaction process** which is a process that generates liquid waste form a solid waste.
2) **Acidification process** in which the breakdown of the complex organic matter present in the liquid waste take place. The bacteria responsible for this break down is the acidogenic (fermentative) bacteria.
3) **Acetification process** where simple molecules are created through the acidogenic phase. These simple molecules are further digested by acetogens to produce acetic acid as well as CO_2 and H_2,
4) **Methanation process** which is the terminal stage of anaerobic digestion. In this step the intermediate products of the preceding steps are converted to CH_4, CO_2 and water.

The quantity of methane produced from the Anaerobic Digestion Process can be calculated according to the following formula **[68,69,70]**:

$$V_{CH4} = (0.35\ m^3/kg)\left[\frac{f\ Q\ S_O}{1000\ kg} - 1.42\ P_X\right] - - - - - - - - - - - - - (12)$$

Where: V_{CH4} = volume of methane gas produced, m^3/d
f = efficiency of waste utilization , range (0.6 − 0.9)
1.42 = net mass of cell tissue produced per kg
0.35
= theoritical conv. factor for the CH4 prod from the conv. of 1 kg BOD
Amount pf sludge produced in the digester (P_X)

$$P_X(\frac{kg}{d}) = \frac{YQ\,f\,S_O}{(1+\mu_d\,\theta_C)1000} ---------------------- (13)$$

Where: Y = yeild coefficient, μ_d = endogenous coefficient, d^{-1}, θ_C = MCRT (days)

The efficiency of the anaerobic digestor is measured by the percent reduction in volatile solids:

%Volatile Solids in Raw Sludge= V_{RS} and %Volatile Solids in Digested Sludge= V_{DS}

$$\% \text{ Reduction in Volatile Solids} = \frac{(V_{RS}-V_{DS})}{V_{RS}-(V_{RS}\times V_{DS})}\times 100\% ----------- (14)$$

The summary of the Anaerobic Digestion System Results was tabulated below tables (6 & 9)

Table (6) Digester design parameters

Number of Digester	**6**	**dim**
Diameter	**22**	**m**
Height	**10**	**m**
Estimating the flow rate of thickened sludge (Q_s)	**228.28**	**m^3/day**
Total Suspended Solids (TSS) of thickened sludge	**14097.9**	**kg/day**
Supernatant flow rate	**60.68**	**m^3/day**
Total Suspended Solids (TSS) in the supernatant	**242.66**	**kg/day**
BOD5 in the supernatant	**151.7**	**kg/day**
Flow of digested sludge (Q_{ds})	**158.48**	**m^3/day**
Total Suspended Solids (TSS) to the dewatering facility	**8005.65**	**kg/day**

Table (7) Preliminary data required for complete digestion system design

Digester capacity at an average flow using 15 days of digestion	**25**	**day**
Average flow to the digester	**228.28**	**m^3/day**
Total Suspended Solids (TSS)	**14097.93**	**kg/day**
Digestion period at average flow	**17.68**	**Day**
Average flow to the digester high flow	**482**	**m^3/day**
Digestion period at extreme high flow	**8.375**	**Day**
Average flow to the digester low flow	**160**	**m^3/day**
Digestion period at extreme low flow	**25.23**	**Day**
Assuming methane gas is 68 % of the digester gases produced	**68 %**	**%**
Gas produced	**30656.86**	**m^3/day**

15) Producing H_2 as a renewable energy from treated wastewater by electrolysis

There are currently, several technologies based on the direct water separation; concentrated solar power, direct solar desalination, or photocatalysis remain less advanced **[71].** Green hydrogen from water electrolysis is considered to be the most mature technology **[72].** The efficiency of the electrolyzer is a critical parameter in hydrogen production systems, as the total cost of the process is closely related to the desired efficiency **[73].** Alkaline water electrolysis, which is the earliest, the simplest and the most mature technology, has an efficiency in the range of 50–70% making it the most available commercial water electrolysis method in the market **[74].** However, theoretically and according to Eq. (1), the production of 1 kg of hydrogen by water electrolysis requires about 9 kg of fresh water **[75].** In principle, the production of hydrogen from water electrolysis is based on the following equation:

$$H_2O + \text{Electricity}\ (232.2\ \text{kJ/mol}) = H_2 + 0.5O_2 + \text{Heat}(48.6\ \text{kJ/mol}) \quad ----(14)$$

15.1) Electrolysis cell

In this unit, a Solid Oxide Electrolysis (SOE) cell is used to convert treated wastewater into hydrogen and oxygen. The state-owned electrolysis cell operates at a high temperature (about 800°C) and uses steam rather than liquid water as raw materials **[76].** This cell has many advantages, such as reducing electricity consumption, increasing the efficiency of electrolysis, avoiding the need for water pre-treatment, and facilitating the separation of hydrogen and oxygen **[77].** A detailed schematic diagram of the electrolysis cell can be seen in Figure (4). An electrolytic cell is established within the industrial complex to utilize treated wastewater for hydrogen production. Hydrogen is considered a promising and innovative energy source globally and plays a significant role in environmental preservation when produced cleanly. Various methods exist for hydrogen production, with electrolysis being the most environmentally friendly method **[78].** This paper focuses on the use of electrolysis, which significantly reduces carbon dioxide emissions, a major contributor to global warming. Integrating a hydrogen production unit within a wastewater treatment facility is a novel and innovative approach in this field. This integration not only reduces pollution but also leverages shared infrastructure for water treatment and hydrogen production. In this research work two types of electrolysis cells are investigated.

Table (8) Summary of calculated design parameters for the digestion system

Area of each digester	**364.83**
Diameter of each digester	**21.541**
Because floating covers come in 1.5-m diameter increments, provide digesters	**22.0**
Revised side water depth	**10.641**
Provide two digesters each	**22.0**
the bottom cone depth of 3 m adds additional volume	**3.0**
digester is sloped at 3 horizontals	**3.0**
digester is sloped at 1 vertical	**1.0**
Active digester volume (m^3)	**4036.52**
Active volume of 6 digesters	**24219.16**
Total volume of 6 digesters	**26562.92**
Active volume ratio including cone	**0.912**
Estimating the Solids Retention Time (SRT) or (MCRT), and Solids Loading Rate (SLR)	
Average flow to the digester high flow (m^3/day)	**482.0**
Average flow to the digester low flow (m^3/day)	**160.0**
1. Calculating the actual digestion period at average, low, and high flow rates	
Digestion period at average flow (days)	**7.116**
Extreme high flow assuming volatile solids fraction before digestion =0.70	**70%**
Average flow volatile solids fraction before digestion =0.75	**75%**
Extreme low flow volatile solids fraction before digestion = 0.80	**80%**
Extreme low Flow sludge production, (kg/day)	**5879.0**

Extreme high flow sludge production, (kg/day)	**7699.0**
Active depth of cylindrical portion = side water depth (8.35 m) - scum blanket (0.6 m) - space below floating cover (0.6 m)	**9.8418**
Digestion period at extreme high flow	**8.3745**
Digestion period at extreme low flow	**25.2282**
2. Calculating the actual solids loadings at average, low, and high conditions	
Solids loading at average loading condition	**1.0848**
Solids loading at extreme minimum loading condition	**0.1941**
Solids loading at extreme high loading condition	**0.222**
Estimating the gas production rate from several relationships.	
Average quantity of sludge reaching the digester, (kg/day)	**35031.86**
Average volume of sludge reaching the digester, (m^3/day)	**567.25**
Concentration of solids (mg/L)	**61,757.87**

Table (9) Estimating (TVS) reduction and gas production rate for the digestion system

Assume 65 percent solids are biodegradable	**65**	**%**
1 g of biodegradable solids	**1.42**	
Yield coefficient (Y)	**0.05**	
Endogenous respiration or decay constant (K_d)	**0.03**	**d^{-1}**
% Efficiency of the waste sludge utilization (% f)	**80**	**%**
BOD_L in the sludge	**57002.51**	**mg/L**
Sludge production rate (P_X)	**1065.84**	**kg/day**
Sludge volume production rate (V*)	**8523.91**	**m^3/day**
Assuming methane gas is about 68 % in the digester gases,	**68%**	**%**
Digester gas production	**12,535.16**	**m^3/day**
Volatile solids loading using (TVS)	**0.75**	
Total solids and gas production rate	**0.5**	**m^3/kg VS**
Gas produced	**13,136.95**	**m^3/day**
Estimating the Total Volatile Solids (TVS) reduction		
Assume average percentage Volatile Solids (TVS) reduction	**52%**	**%**
Volume of gas produced per kg of (TVS) reduced	**0.94**	**m^3/kg TVS**
Total Volatile Solids (TVS) reduced	**13662.42**	**kg/day**
Gas produced	**12842.68**	**m^3/day**
Estimating gas production per capita		
Total population served	**1,132,990.5**	**people**
Use gas production rate per capita	**0.032**	**(m^3/capita)**
Total Biogas produced from sludge digestion	**36,255.70**	**m^3/day**

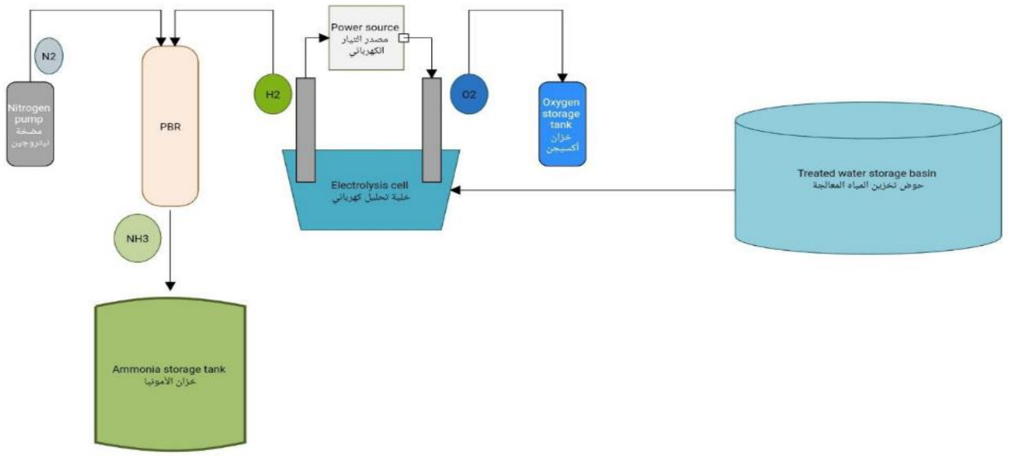

Figure (4) Schematic diagram for the electrolysis cell used for H_2 production from treated wastewater [87]

15.2) Types of electrolysis cells:

1) Proton Exchange Membrane Electrolysis Cell (PEMEC): This is an advanced type of electrolysis cell that uses a membrane to transfer protons between the electrodes **[79].**

2) Solid Oxide Electrolysis Cell (SOEC): This type of electrolysis cell operates at high temperatures and uses solid oxides as the electrolyte material.

15.3) Common components of electrolyzes cells

Both types of cells share several common components as follows:

a) **Electrodes: - Anode:** The positive electrode where oxidation reactions occur. Water is split into oxygen and hydrogen ions (protons) at this electrode. - Cathode: The negative electrode where reduction reactions take place. Protons combine with electrons at the cathode to form hydrogen.

b) **Power Supply:** - Provides the necessary electrical voltage to conduct the electrolysis process. This is typically a direct current (DC) source.

c) **Cell Container:** - The vessel that houses the electrodes and membrane or electrolyte. It must be corrosion resistant and designed to withstand the pressure generated by the electrolysis reactions.

d) **Tubes and Connectors:** - Used to transport the gases produced (hydrogen and oxygen) from the electrodes to storage or utilization points.

e) **Gas Management System:** - Includes devices for measuring and storing the gases produced during electrolysis, such as tanks for hydrogen and oxygen storage.

15.4) Differences between the two types of cells (PEMEC and SOEC):

a) **PEMEC Specific Components**: Proton Exchange Membrane (PEM): - A polymeric membrane that conducts protons but not electrons, separating the anode from the cathode. Protons produced at the anode migrate through the membrane to the cathode, where they combine with electrons to form hydrogen. **SOEC Specific Components:** - Solid Electrolyte: - Made from solid oxides that conduct ions, such as yttria-stabilized zirconia (YSZ). This electrolyte allows oxide ions (O^{-2}) to transfer between the anode and cathode at high temperatures **[80,81].**

b) **Heating System:** - Since SOEC operates at high temperatures (typically between 700 and 1000°C), a heating system is required to maintain the necessary temperature for the process **[82],**

The calculated results associated with hydrogen production for each type of cells are tabulated through tables (10) and (11).

Table (10) Photon exchange membrane electrolyzer cell (PEMEC) design parameters

Property	**Value**
Cell Operating Volts	**1.9 Volts**
Electrical charge	**95719246 coulombs**
Current consumed per liter of wastewater	**26588.6 Amp/L**
Electrical capacity per liter of wastewater	**50.52 K-watt/hour**
Electrical capacity	**37.8 M-watt/hour**
Incoming wastewater	**8557.0 Kg/hour**
Untreated water leaving electrolyzer cell	**913.0 Kg/hour**
Amount of Hydrogen generated	**784.2.0 Kg/hour**
Amount of Oxygen generated	**5987.0 Kg/hour**

Table (11) Solid Oxide electrolyzer cell (SOEC) design parameters

Property	**Value**
Cell Operating Volts	**0.8 Volts**
Electrical charge	**95719246 coulombs**
Current consumed per liter of wastewater	**26588.6 Amp/L**
Electrical capacity per liter of wastewater	**21.27 K-watt/hour**
Electrical capacity	**37.8 M-watt/hour**
Incoming wastewater	**20333.0 Kg/hour**
Untreated water leaving electrolyzes cell	**4049.0 Kg/hour**
Amount of Hydrogen generated	1915.0 Kg/hour
Amount of Oxygen generated	19881.0 Kg/hour

16) Combined Renewable Energy Generation Unit

Three renewable energy sources are used to generate the electricity needed to operate the electrolysis cell. These sources are solar panel plant, wind power plant and biogas plant. A solar panel station uses solar panels to convert solar energy into electrical energy. A wind power plant uses wind turbines to convert wind energy into electrical energy **[83]..** The biogas plant uses biogas from the secondary wastewater treatment process to generate electricity using gas generators. These sources contribute to reducing the energy cost of this project and improving its efficiency and sustainability **[84,85].** The application of the so-called hybrid systems that adopt three renewable energy sources was investigated by several researchers **[86,87**]. In the hybrid system, the system's performance as a function of different users and locations, energy tariffs, and policies still need to be investigated. They will also need to conduct a thorough, rigorous optimization to determine the impact of the design and economic parameters on performance. In particular, carrying out studies on hybrid systems of solar thermal energy and biomass energy can be investigated. A detailed schematic diagram of multiple renewable energies generation unit is shown in figure (5).

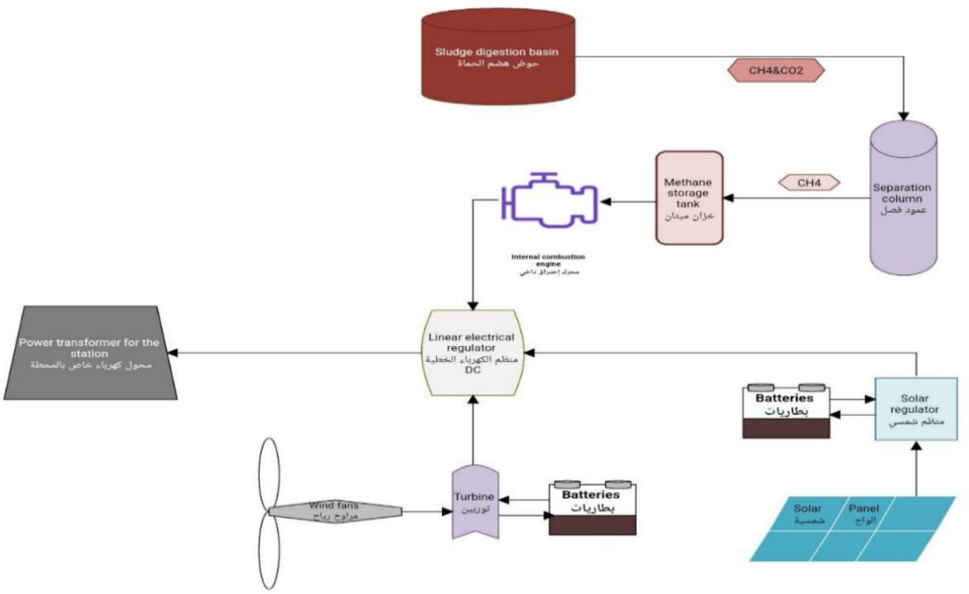

Figure (5) Combined renewable energy generation from solar. wind and biogas sources [87]

17) Solar Energy

Solar energy technologies and power plants do not produce air pollution or greenhouse gases when under operation. Using solar energy can have a positive, indirect effect on the environment when solar energy replaces or reduces the use of other energy sources that have larger effects on the environment **[88].** However, producing and using solar energy technologies may have some environmental effects. From reducing greenhouse gases, improving our air quality and conserving our precious water, solar energy can help to reduce our reliance on fossil fuels and lower energy prices for years to come **[89].** The release of toxic gases into the atmosphere, such as carbon dioxide, methane and nitrous oxide, doesn't just contribute to air pollution **[90].** Electricity generation from fossil fuels can generate harmful carbon dioxide and methane gases that lower the quality of the air we breathe. Application of solar energy technology will contribute to better air quality and pollution free environment **[91]. In this research work,** it is attempted to design a solar photovoltaic system that will convert sunlight to electrical energy **[92].**

17.1) Design Solar PV System:

Solar photovoltaic system or **Solar power system** is one of **renewable energy system** which uses PV modules to convert sunlight into electricity. The electricity generated can be either stored or used directly, fed back into grid line or combined with one or more other electricity generators or more renewable energy source. Solar PV system is very reliable and clean source of electricity that can suit a wide range of applications such as residence, industry, agriculture, livestock **[93].**

17.2) Major system components

Solar PV system includes different components that should be selected according to your system type, site location and applications **[94].** The major components for solar PV system are listed below:

a) **PV module** : It will convert the sunlight into DC electricity.
b) **Solar charge controller** :It regulates the voltage and current coming from the PV panels going to battery and prevents battery overcharging and prolongs the battery life.
c) **Inverter** : It converts DC output of PV panels or wind turbine into a clean AC current for AC appliances or fed back into grid line.
d) **Battery:** It stores energy for supplying to electrical appliances when there is a demand.
e) **Load**: It is electrical appliances that connected to solar PV system such as lights, radio, TV, computer, refrigerator, etc.

f) Auxiliary energy sources: It is diesel generator or other renewable energy sources.

17.3) Solar PV system sizing

Step (1): Determine power consumption demands

The first step in designing a solar PV system is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system as follows:

a) Calculate total Watt-hours per day for each appliance used. Add the Watt-hours needed for all appliances together to get the total Watt-hours per day which must be delivered to the appliances.

b) Calculate total Watt-hours per day needed from the PV modules.
Multiply the total appliances Watt-hours per day times 1.3 (the energy lost in the system) to get the total Watt-hours per day which must be provided by the panels.

Step (2): Size the PV modules

Different size of PV modules will produce different amount of power. To find out the sizing of PV module, the total peak watt produced needs. The peak watt (Wp) produced depends on size of the PV module and climate of site location **[94].** We have to consider a panel generation factor which is different in each site location. An approximate value of the panel generation factor is 3.43. To determine the sizing of PV modules, calculate the following:

a) Calculate the total Watt-peak rating needed for PV modules Divide the total Watt-hours per day needed from the PV modules (from item 1.2) by 3.43 to get the total Watt-peak rating needed for the PV panels needed to operate the appliances.

b) Calculate the number of PV panels for the system Divide the answer obtained in item 2.1 by the rated output Watt-peak of the PV modules available to you. Increase any fractional part of result to the next highest full number and that will be the number of PV modules required.

If more PV modules are installed, the system, it will perform better and battery life will be improved. If fewer PV modules are used, the system may not work at all during cloudy periods and battery life will be shortened**. [95].**

17.4) Inverter sizing

An inverter is used in the system where AC power output is needed. The input rating of the inverter should never be lower than the total watt of appliances. The inverter must have the same nominal voltage as your battery. For stand-alone systems, the inverter must be large enough to handle the total amount of watts you will be using at one time. The inverter size should be 25-30% bigger than total Watts of appliances. In case of appliance type is motor or compressor then inverter size should be minimum 3 times the capacity of those appliances and must be added to the inverter capacity to handle surge current during starting. For grid tie systems or grid connected systems, the input rating of the inverter should be same as PV array rating to allow for safe and efficient operation. **[95].**

17.5) Battery sizing

The battery type recommended for using in solar PV system is deep cycle battery. Deep cycle battery is specifically designed for to be discharged to low energy level and rapid recharged or cycle charged and discharged day after day for years **[96].** The battery should be large enough to store sufficient energy to operate the appliances at night and cloudy days. To find out the size of battery, calculate as follows:

1) Calculate total watt-hours per day used by appliances.
2) Divide the total watt-hours per day used by 0.85 for battery loss.
3) Divide the answer obtained in item 4.2 by 0.6 for depth of discharge.
4) Divide the answer obtained in item 4.3 by the nominal battery voltage.
5) Multiply the answer obtained in item 4.4 with days of autonomy (the number of days that you need the system to operate when there is no power produced by PV panels) to get the required capacity of deep-cycle battery.

$$\text{Battery Capacity } (Amp - hour) = \frac{(\text{Total Watt} - \text{hours per day used by appliances x Days of autonomy})}{(0.85 \text{ x } 0.6 \text{ x nominal battery voltage})}$$

−17.6) Solar charge controller sizing

The solar charge controller is typically rated against Amperage and Voltage capacities. Select the solar charge controller to match the voltage of PV array and batteries and then identify which type of solar charge controller is right for your application. Make sure that solar charge controller has enough capacity to handle the current from PV array. For the series charge controller type, the sizing of controller depends on the total PV input current which is delivered to the controller and also depends on PV panel configuration (series or parallel configuration)**[97].** According to standard practice, the sizing of solar charge controller is to take the short circuit current (Isc) of the PV array, and multiply it by 1.3

$$\text{Solar charge controller rating} = \text{Total short circuit current of PV array x } 1.3 - - - - - (16)$$

The summary of the solar energy calculations are tabulated tables (12, 13, and 14)

Table (12) Summary of Solar Energy plant design and calculations based on Tripoli Area

Property	Symbol	Value	Unit
Energy to be generated	E(generated)	12.60	M-watt/hour
Intensity of solar radiation	I(solar Rad)	2093.0	(K-watt)/(hr-m^2)
Sunshine time period	Sun(time)	9.5	Hours/day
Constant of energy loss during installation	En(Lost)	1.30	dim

Table (13) Solar Panel specification and system requirements

Property	Symbol	Value	Unit
Maximum Power	P(max)	0.70	K-watt/hour
Solar Cell Area	A (cell)	3.10	m^2
Total Cell Area	A (tot cell)	504,751	m^2
Number of Solar Cell Panels	N (cell pan)	45,042	solar
Linear Power Warranty	W(a)	30.0	Year
Solar Regulator Size	S(z)	790,492	Amp

Table (14) Battery specification and system requirements

Property	Symbol	Value	Unit
Nominal Voltage	V	51.2	Volt
Useable Energy	Eu	4.0	K-watt/hour
Expected Service life	LS	15.0	Year
Number of Batteries	N(batteries)	12492	battery
Required Battery Capacity	B(cap)	811992	Amp/hour

18) Wind energy:

Wind energy has emerged as a sustainable and eco-friendly source of power generation, contributing significantly to the global shift towards cleaner energy alternatives. Wind energy is derived from the kinetic energy of moving air masses, which is a result of the sun's uneven heating of the Earth's surface. As air warms, it rises, creating areas of high and low pressure. Wind flows from high-pressure areas to low-pressure areas, generating the motion that can be harnessed to generate electricity **[98]. Wind energy** has become a significant player in the renewable energy landscape, offering a clean and sustainable source of power generation. The fundamental formulas presented in this research provide the foundation for understanding how wind energy is harnessed and quantified. Optimum design of wind turbines, and wind power will play an increasingly vital role in reducing the reliance on fossil fuels and mitigating climate change [**99].** Wind turbines are the primary technology used to convert wind energy into electricity. These devices consist of three main components: the rotor, generator, and tower. The rotor contains the blades, which capture the kinetic energy of the wind, while the generator converts this mechanical energy into electrical power. The tower supports the rotor and elevates it to a certain height where the wind speeds are more consistent **[100,101].** Understanding the science behind wind energy and the formulas that govern its generation, is essential for harnessing its full potential. The following are the necessary equations needed for wind energy calculations **[102]:**

18.1) Wind energy equations

1) Wind Power Formula: The fundamental formula for calculating the power available in the wind is:

$$p = \frac{1}{2} A \rho V^3 C_P ----------------- (17)$$

Where: P = represents the power available in the wind (in watts, W).
A = is the swept area of the wind turbine blades (in square meters, m^2).
ρ = denotes the air density in kg per cubic meter (kg/m^3).
V = represents the wind speed (in meters per second, m/s).
Cp = stands for the power coefficient, which represents the efficiency of the wind turbine.

2) Wind Energy Output Formula: The formula for calculating the actual electrical energy
output of a wind turbine is:

$$E = P.t ------------- (18)$$

Where: E = represents the electrical energy output (in Watt-hours, watt-h or kilowatt-hours, kWatt-h).

P = is the power available in the wind, as calculated using the previous formula (in watts, W).

t = is the time the wind turbine operates (in hours, h).

3) **The swept area (A) Formula**: is a crucial parameter in the wind energy formula. It represents the total area covered by the rotating blades of the wind turbine. The larger the swept area, the more wind the turbine can capture. It is calculated as:

$$, \quad A = \text{Swept Area. } (m^2) = \pi R^2 \quad ------------- (19)$$

Where: A = is the swept area (in square meters, m²). R = is the radius of the rotor (in meters, m).

4) **Air Density (ρ) Formula: (ρ)** Air density (\rho) varies with altitude and temperature. Standard air density at sea level and 15°C is approximately 1.225 kg/m³. However, for more accurate calculations, you can use the following formula to calculate air density at different conditions:

$$\rho = \frac{P}{R_g \, T} -------------- (20)$$

Where: ρ= is air density (in kg/m³). P =is the air pressure (in pascals, Pa). R_g =is the specific gas
constant for dry air (approximately 287 J/(kg·K)). T =is the absolute temperature in (K).

5) **Wind Speed (V) Formula:** Wind speed (V) is a crucial factor influencing wind energy generation. It is typically measured at the hub height of the wind turbine, where the rotor is located. Wind speed can be measured directly with an anemometer. Different wind speed measurement heights and time intervals can be used depending on the application **[103].**

6) **Power Coefficient (Cp) Formula:** The power coefficient (**Cp**) is a dimensionless parameter representing the efficiency of a wind turbine in capturing the wind's kinetic energy. It is influenced by the design of the turbine blades and the rotor's shape. The theoretical maximum power coefficient for a wind turbine is known as the Betz limit, which is approximately (**C_P=0.593**).

7) Ratio of wind speed at turbine shaft height to wind speed at reference height

$$\frac{V(Z)}{V(Zr)} = \frac{\ln\left(\frac{Z}{Zo}\right)}{\ln\left(\frac{Z}{Zo}\right)} -----------(21)$$

$V(z) =$ Wind speed at turbine shaft height, m/s, $V(Zr) =$ Wind speed at reference height m/s

$Z =$ Turbine shaft height (m),

$Zo =$ Turbine blade length (m), $Zr =$ reference height (m)

$$V^{-}(Z) = \frac{\Sigma V(Z)i}{n} ----------- (22)$$

$V^{-}(Z) =$ average wind speed at turbine shaft height m/s, , $n =$ number of the monthes.

$V\,(Z)\,i =$ Wind speed at turbine shaft height (m/s)

8) Number of batteries (n(b))

$$n(b) = \frac{P}{Eu} ----------- (23)$$

$n(b) =$ Number of batteries. $Eu =$ Usable Energy. kwatt/hr,

18.2) <u>Factors Affecting Wind Energy Generation</u>

a) Wind Variability: Wind energy generation is highly dependent on wind variability. Wind speeds can fluctuate throughout the day, seasonally, and annually, affecting the reliability of wind power. To address this, wind farms often have multiple turbines with varying hub heights to capture wind at different speeds and heights **[104].**

b) Turbine Efficiency

The power coefficient (Cp) mentioned earlier is a crucial factor in determining how efficiently a wind turbine converts wind energy into electrical power. Turbine design, blade shape, and materials all play a role in maximizing Cp **[105,106].**

c) Site Selection

The location of a wind farm plays a vital role in its energy output. Wind farms are typically sited in areas with consistent and strong winds. Wind resource assessment, conducted through measurements and analysis, helps determine suitable locations **[107,108].**

The summary of the wind energy calculations are tabulated tables (15, 16, and 17)

Table (15) Wind Speed Analysis and Data for Tripoli Wind Farm.

Property	Symbol	Value	Unit
The energy to be produced	P	12.6	M-watt/hour
Reference height	Zr	10	m
Average Wind speed at reference height	v(zr)	4.2	m/s
Turbine shaft height	Z	105	m
Average wind speed at turbine shaft height	$v(\overline{z})$	6.4	m/s

Table (16) Wind Turbine Specifications and Performance.

Property	Symbol	Value	Unit
Turbine shaft height	Z	105	m
Turbine diameter	D	90	m
Swept Area	A	6359	m^2
The energy produced at average wind speed	EZ	600	K-watt/hour
The energy produced at average wind speed	EZ	14.4	M-watt/hour
Number of turbines	N	21	turbine
Life span of wind turbines	Ls	30	years

Table (17) Battery Specifications and Requirements for Continuous Energy Availability.

Energy that can be stored in batteries	Eb	3	M-watt/hour
Required battery capacity	Cr	63984	Amp/hour
Constant of energy loss during installation	L	1.3	dim
Usable Energy	Eu	4	K-watt/hour
Number of batteries	n(b)	984	battery
Expected service life	LS	15	year

19. Cost of generating the four types of renewable energies

The total cost of installation of any renewable energy facility is the sum of capital cost, operational and maintenance cost, cost of external factors, Energy Storage and Grid Integration, and cost of any future-proofing and scalability **[109].** The breakdown of each type of cost is shown and listed below:

1) <u>Capital Costs</u>

Equipment Costs:

- **Solar**: Photovoltaic (PV) panels, inverters, mounting structures, batteries (if off-grid or hybrid system).
- **Wind**: Turbines, towers, blades, control systems.
- **Biogas**: Digesters, gas storage tanks, gas purification units, generators.
- **Hydrogen**: electrolyzer, storage tanks, compressors, fuel cells.

Installation Costs:

- Labor costs for installing equipment.
- Transportation and logistics costs for delivering components to the site.
- Site preparation (e.g., land clearing, foundations, electrical connections).

Infrastructure Costs:

- **Grid Connection**: Costs associated with connecting the system to the local grid, including wiring, transformers, and protection systems.
- **Storage Systems**: Batteries or other storage systems to manage energy supply and demand.
- **Cooling Systems**: For large installations, especially hydrogen production, cooling systems might be required.

Land Acquisition:

- Costs related to acquiring or leasing land suitable for the installation. Land costs vary significantly depending on location and size

2) <u>Operational Costs</u>

Maintenance Costs:

- Regular maintenance of equipment to ensure optimal performance and longevity.
- Replacement of parts, such as inverters (solar) or blades (wind), which have a limited lifespan.

Operational Labor:

- Costs associated with hiring technicians and operators to run and maintain the system.

Energy Consumption:

- Internal energy use for systems like pumps (biogas) or compressors (hydrogen).

Monitoring and Control Systems:

- Costs for remote monitoring systems and control software to optimize performance.

3) External Factors:

Government Incentives and Subsidies:

- Availability of tax credits, rebates, and subsidies can significantly reduce the overall cost.
- Feed-in tariffs or renewable energy certificates can provide additional revenue streams.

Regulatory Compliance:

- Costs associated with obtaining permits, adhering to local regulations, and environmental assessments.

Financing Costs:

- Interest rates on loans, insurance, and other financial costs associated with raising capital for the project.

Currency Exchange Rates:

- For international projects, fluctuations in exchange rates can impact the cost of imported equipment.

Location and Climate:

- Solar: Geographic location affects solar irradiance levels.
- Wind: Wind speed and consistency vary by location.
- Biogas: Availability of feedstock (e.g., agricultural waste).
- Hydrogen: Proximity to water sources (for electrolysis) or renewable energy sources.

Scale of the Project:

- Larger installations may benefit from economies of scale, reducing the per-unit cost of energy production.

Technology Maturity and Availability:

- Costs can vary depending on the maturity of the technology being installed. For example, hydrogen technology is still evolving, and costs can be higher due to limited suppliers and expertise.

Supply Chain Factors:

- Availability of materials and components, as well as global supply chain stability, can impact costs.

4) Energy Storage and Grid Integration

- **Battery Costs**: For solar and wind, energy storage systems (ESS) are often required to manage the intermittent nature of these energy sources.

- **Grid Integration Costs**: Depending on the existing grid infrastructure, additional costs might be needed to ensure that the renewable energy can be reliably integrated into the grid.

5) **Future-Proofing and Scalability**

- **Design Flexibility**: Systems designed with future expansion in mind might have higher upfront costs but lower long-term costs.
- **Technology Upgrades**: Costs associated with future upgrades to more efficient technology

20. Key parameters significantly affect the cost of generating renewable energy

Several key parameters significantly affect the cost of generating renewable energy, and understanding these factors is essential for optimizing cost efficiency **[110,111].** These parameters include:

a) **Technology Type and Maturity**: Different renewable energy technologies (solar, wind, hydro, etc.) have varying levels of maturity and cost structures. More established technologies like onshore wind and solar photovoltaic (PV) have seen significant cost reductions due to technological advancements and economies of scale, whereas emerging technologies like tidal or offshore wind are still more expensive.

b) **Geographic Location**: The effectiveness and cost of renewable energy generation are highly dependent on location. For instance, solar PV installations in regions with higher solar irradiance (like deserts) produce electricity at a lower cost. Similarly, wind turbines are more cost-effective in areas with consistent, strong winds.

c) **Resource Availability**: The availability of natural resources such as sunlight, wind, and water greatly influence the efficiency and cost of energy production. A higher resource availability typically translates to lower generation costs because it increases the energy output per unit of installed capacity.

d) **Infrastructure and Grid Integration**: The existing energy infrastructure and the ability to integrate renewable energy into the grid also play critical roles. Regions with outdated or inadequate grid infrastructure may face higher costs in integrating renewable sources, particularly if large-scale storage or grid upgrades are needed to manage variability and ensure stability.

e) **Policy and Regulatory Environment**: Government policies, subsidies, and incentives can dramatically influence the cost of renewable energy. Supportive policies can lower costs by reducing financial risks and encouraging investment, while a lack of regulatory support can increase costs due to higher financing risks and uncertainties.

f) **Economies of Scale**: Larger installations benefit from economies of scale, reducing the per-unit cost of energy generation. As the deployment of renewable energy expands, these cost advantages become more pronounced.

g) **Operation and Maintenance Costs**: Ongoing operation and maintenance costs, which can vary depending on technology and location, also affect the overall cost of energy generation. These costs are generally lower for renewable energy sources compared to fossil fuels but still vary across different technologies.

An estimate of the total cost in US$/MWh of producing renewable energy was collected from several references in the past five years starting year 2018 up to this year 2024 **[112,113].** Table (18) shows a comparison of the collected data which is plotted on figure (6) to see how the total cost of solar, wind, biogas, and green hydrogen energy change in the last five years.

Table (18) Cost comparison of electrical energy Produced from different renewal able

Year	Solar	Wind	Biogas	Green H_2
2018	43	41	55	120
2019	40	40	54	115
2020	37	39	53	100
2021	36	38	52	90
2022	35	37	50	85
2023	33	36	48	80
2024	30	35	47	70

Sources for past five years in $/MWh [113,114]

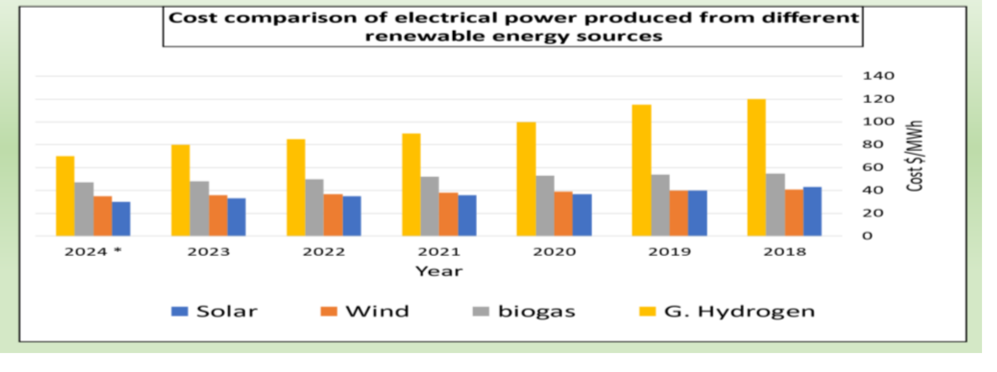

Figure (6). shows a comparison of the collected data

The cost comparison between the four renewable energies reveals the following points need to be considered when planning to install future renewable energy facility for electric power production.

1) Solar energy has seen a consistent decline in costs, making it increasingly competitive and accessible globally.
2) Wind power, particularly onshore, is highly competitive, while offshore wind is rapidly catching up due to technological improvements.
3) While biogas is a steady and improving source of renewable energy, hydrogen shows promise but still needs significant cost reductions to compete with other renewables.
4) While biogas is a steady and improving source of renewable energy, hydrogen shows promise but still needs significant cost reductions to compete with other renewables.

21. General decussation of the results

Treated wastewater is an excellent source of green hydrogen production, that can be used in the generation of electrical power. Most wastewater treatment plants generate effluents contain large amounts of treated wastewater and untreated activated sludge. Disposal of these effluents in a safe manner that will not impact the environment adversely, is costly. Converting treated wastewater through electrolysis to hydrogen, and converting activated sludge to biogas (CH_4 and CO_2) are the best alternative as shown in this research work. However, it should be mentioned that the characteristics of the raw wastewater has a great impact on the treatment process. The concentration of each component present in the wastewater such as Biochemical Demand (BOD) and the Total Suspended Solids (TSS), Total Nitrogen (N), Total Phosphorus contents of the raw wastewater, and the kinetic parameters (μ_i, K_S, K_d, k) that represent the rate of growth and metabolism of the bacteria all of these parameters need to be determined experimentally and verified because they are significant in the design of wastewater process.

In this research work, electrolysis calculations of treated wastewater using two types of cells (PEMEC and SOEC), were performed and all parameters were determined including the amount of hydrogen generated. This electrolysis technique is the most promising in terms of cleanliness and energy consumption, however, the main concern is related to its low hydrogen production rate and hydrogen purity as compared with other research work may be due to wastewater characteristics has impact on electrolysis process.

Anaerobic digestion (AD) is a natural biochemical process that converts organic materials into combustible biogas. Some groups of bacteria involved in the digestion process cannot survive in the presence of oxygen. Therefore, an anaerobic (oxygen-free) environment is necessary for the process. The AD process typically occurs in a closed vessel. Produced biogas flows out to temporary storage and later on to the end-use applications. The main commercial applications of biogas are heat and electricity generation. After AD, the vessel will contain residual solids and organic matter known as digestate. Digestate can be separated into liquid and solid streams. Both streams contain valuable plant nutrients and can substitute as fertilizer in agricultural applications. In this research work, the calculations of the anaerobic digestion of activated sludge, were performed for the purpose reducing the amount of sludge and producing the biogas (CH_4, and CO_2). The anaerobic digestion process is very sensitive it has to be closely monitored for these parameters: Organic Loading Rate (OLR), the Hydraulic Retention Time (HRT), Carbon Nitrogen ratio (C/N) needed for anaerobic bacteria growth and metabolism, PH, and the digestive temperature usually (55 – 60) °C.

In this research work, a complete solar photovoltaic system that will convert sunlight to electrical energy was designed according to the procedure published in the literature. The amount of solar energy collected by the solar cells that are exposed to depends upon: the orientation and tilt of your installation, whether there are shadows cast over your cells, the number of daylight hours, the intensity of the sunlight , the number of hours of full sun vs cloudy days. The total solar energy generated and converted to electrical energy was found to be 12.6 MW/hr. Design calculations were performed based on the weather conditions of the city of Tripoli-Libya and some of parameters were provided by the Solar Energy Research Center.

Wind energy calculations were performed according to the procedure and calculations mentioned above. Estimate numbers of wind turbines (21wind turbines), number of batteries required (984 batteries) and the wind energy generated at average wind speed (14.4 MW/hr) were determined. These values might change according to several factors such **location** of the wind mills either on-shore or off-shore, **wind speed**, **altitude**, **wind park** effect, **environmental impacts**, and effects on **boron power grid**. In this research work, these impacts were not investigated but assumptions were made that each of these factors were kept constant and one location near Tripoli was select at an average wind speed during the entire year.

22. Conclusion

- The project highlights the crucial role of clean and renewable energy in addressing environmental concerns, reducing reliance on fossil fuels, and promoting sustainable development.
- The project on clean energy production has shed light on the importance of renewable energy sources and the need for clean energy in Libya. It has explored the possibility of using treated sewage water as a valuable resource and addressed the issue of air pollution caused by carbon dioxide emissions in the country.
- Hydrogen is recognized as the new energy carrier due to its advantages in terms of energy density and environmental friendliness, especially when it is produced from a green and clean source such as wastewater-based and solar-based sources.
- The topic of hydrogen production as an alternative to clean energy was addressed. The exceptional characteristics of hydrogen as an energy source were highlighted, and fuel cells were compared to batteries. Various processes for hydrogen production were explored, particularly electrolysis of water, including different types such as alkaline water electrolysis, proton exchange membrane electrolysis, and solid oxide electrolysis.
- The biogas process is highly affected by the hydraulic retention time HRT, the organic loading rate OLR, the pH and the temperature of the reactor. Therefore, several research works is needed on the optimization of these parameters for the simultaneous high biogas production and organics degradation.
- The potentials of renewable energy sources such as biogas, solar energy, and wind energy were explored. Their background, availability in Libya, and their role in achieving a sustainable energy future were discussed. Our methodology and findings provided valuable insights into the feasibility and efficiency of harnessing these renewable energy sources.

- Finally, an economic analysis of hydrogen production from wastewater was conducted, evaluating the effectiveness of wastewater treatment plants, biogas production, solar panels, and wind turbines in terms of cost. The economic analysis revealed that the cost of electric generation of 12.6 M-watt/hr biogas production approximately 19 million $, and solar panels approximately 41 million $, and wind turbines approximately 42 M $.

Recommendations for Future work:

- Adapting integration between wastewater treatment industry and the hydrogen production technology. By leveraging the by-products of electrolysis, such as oxygen, hydrogen peroxide, and ozone, the efficiency of WWTPs can be improved, contributing to economic and environmental sustainability. The use of by-products like hydrogen peroxide for disinfection in WWTPs could potentially be realized by adapting electrolyzer technology.
- Implement on-site of wastewater treatment plants coupled with hydrogen electrolysis. Colocation can minimize water transportation, enhance energy and heat recovery, and capitalize on the economic benefits of local renewable hydrogen markets, propelling both sectors towards greater sustainability and economic efficiency.
- Coupling: surplus electricity for hydrogen generation, where the oxygen byproduct can be utilized to improve wastewater treatment processes. This approach promotes the use of renewable energy within the WWTPs and could create additional revenue streams from hydrogen sales.
- Comparative studies of renewable energy sources for cell operation and hydrogen production should be conducted from an economic and environmental perspective. More research work should be conducted to develop new electrolyzes cells for hydrogen production at higher rate using treated wastewater at minimum cost.
- Adopt the idea of building projects for sustainable energy production, especially the ww project, with the aim of covering maintenance, operation, and infrastructure development costs, and transforming the area into a green zone that provides clean water, pure air, and electricity.
- Future work includes implementing a pilot project that involves creating a small-scale version of the proposed infrastructure to treat wastewater, produce hydrogen, and store ammonia. The pilot project will help verify the feasibility and performance of the system in a real environment and provide valuable data for further improvement.
- Encourage the application of the combined renewable energy projects at one site where solar, wind, green hydrogen and bioenergy are generated at the same time. This will lead to a clean environment and improve the economy.
- It is essential for decision-makers to take bold steps in this field to enhance Libya's capabilities in renewable energy, enabling the innovation of solutions and the development of technologies to secure a secure and sustainable energy in the future.

❖ The results presented in this research work can serve as a basis for further research and implementation of clean energy initiatives in Libya. By embracing clean energy production and adopting environmentally friendly practices, and more sustainable future for our nation.

References

[1] United nation .organization www.un.org/en/climatechange/what-is-renewable-energy

[2] What is renewable energy? United Nations

[3] Lori Bird, Jaquelin Cochran, and Xi Wang Wind and Solar Energy Curtailment: Experience and Practices in the United States Technical Report. NREL/TP-6A20-60983. March 2014 .

[4]What-is-renewable-energy https://www.un.org/en/climatechange /

[5]Icddrb.orgcch.icddrb.org/renewable-energy-sources

[6]www.ren21.net/wp-content/uploads/2019/05/GSR2014_Key-Findings_English.pdf

[7]RENEWABLES 2014 GLOBAL STATUS REPORT - REN21

[8]Medium.commedium.com/@zuhairnadia3/solar-energy-a1ca4e13c6ba, Jul 27, 2023

[9]Carboncredits.comcarboncredits.com/what-is-renewable-energy-benefits-sources-and-top-companies/,Jul 17, 2023.

[10]Kiwienergy.uskiwienergy.us/blog/differences-between-onshore-offshore-wind-energy/ Feb 23, 2024.

[11]Repsol.comwww.repsol.com/en/energy-and-the-future/future-of-the-world/wind-energy/index.cshtml

[12]Irena.orgwww.irena.org/Energy-Transition/Technology/Wind-energy Jul 11, 2024.

[13]Thermasis.comthermasis.com/what-is-bioenergy/

[14]Eesi.orgwww.eesi.org/topics/bioenergy-biofuels-biomass/description.

[15]Beeliners.combeeliners.com/blog/what-is-bio-energy/ Feb 27, 2024.

[16]Bumsuk Seo, Calum Brown, Heera Lee and Mark Rounsevell "Bioenergy in Europe is unlikely to make a timely contribution to climate change targets" Environmental Research letters, Volume 19, Number 4 Published 8 March 2024.

[17]Bikram Jit Singh , Ayon Chakraborty , Rippin Sehgal "A systematic review of industrial wastewater management: Evaluating challenges and enablers" Journal of Environmental Management Volume 348, 15 December 2023, 119230

[18]Afreen Nishat a, Mohammad Yusuf b, Abdul Qadir 'Wastewater treatment: A short assessment on available techniques' Alexandria Engineering Journal Volume 76, 1 August 2023, Page 505

[19]Fahad ALDOSARI, Hazem S. KASSEM, Mirza Barjees BAIG, Muhammad MUDDASSIR, Muhammad MUBUSHAR "Impact of Sewage on Health, Economic and Social Life of Rural People in Al-Hair - Kingdom of Saudi Arabia" Agriculture and Forestry Journal, Vol. 1, Issue 1, pp. 10-17, June, 2017 .

[20]Halder J.N., and Islam M.N., 2015. Water pollution and its impact on the human health. Journal of Environment and Human. 1(2): 36-46.

[21]Domestic Waste Water Treatment - Akruthi Enviro Solutions Pvt. Ltd neoakruthi.com/blog/domestic-wastewater-treatment.html.

[22] Viessmann and Hammer "Water Supply and Pollution Control", fourth edition.(1985)

[23]Metcalf, and Eddy, Inc. _2003_. Wastewater engineering, treatment and reuse, 4th Ed., McGraw Hill, New York

[24] Vesilind, P. A (1968). “Discussion of “Evaluation of activated sludge thickening theories,” by R. I. Dick and B. B. Ewin, J. Sanit. Engineering. Div., 94AS1, 185–190.

[25] Shin Dar Lin, C. Lee “Water and wastewater treatment Calculation manual” , 2nd Ed. McGraw Hill professional .(2007)

[26] Chemtech-us.comchemtech-us.com/ preliminary-treatment-of-wastewater/ Preliminary Treatment of Wastewater - Chemtech International Feb 23, 2022.

[27]IDRICA, Idrica.com www.idrica.com/blog/stages-of-wastewater-treatment-plants/ “The four stages of wastewater treatment plants” Aug 3, 2022

[28] Larry W. Moore, Ph.D., P.E “Preliminary Wastewater Treatment NPDES Operator Webinar Series”., WEF Fellow July 25, 2023.

[29] J. Paul Guyer, P.E., R.A., Fellow ASCE, Fellow AEI “AN INTRODUCTION TO PRELIMINARY WASTEWATER TREATMENT” Continuing Education and Development, Inc(2011) .

[30]Tchobanoglous, George; Burton, Franklin L.; Stensel, H. David (2003). Metcalf & Eddy Wastewater Engineering: Treatment and Reuse (4th ed.). McGraw-Hill. ISBN 978-0-07-112250-4.

[31] Metcalf & Eddy, Inc. (2014). Wastewater Engineering: Treatment and Resource Recovery (5th ed.). McGraw-Hill Education.

[32] Grady Jr., C. P. L., Daigger, G. T., Love, N. G., & Filipe, C. D. M. (2011). Biological Wastewater Treatment (3rd ed.). CRC Press.

[33] Henze, M., van Loosdrecht, M. C. M., Ekama, G. A., & Brdjanovic, D. (2008). Biological Wastewater Treatment: Principles, Modelling and Design. IWA Publishing.

[34] Rittmann, B. E., & McCarty, P. L. (2001). Environmental Biotechnology: Principles and Applications. McGraw-Hill.

[35] Wang, X., Wen, X., Yan, H., Zhang, Y., & Qian, Y. (2004). Microbial community dynamics in a pilot scale anaerobic/anoxic/aerobic process treating domestic wastewater. Environmental Microbiology, 6(4), 326-334.

[36] Levine, A. D., & Asano, T. (2004). Recovering sustainable water from wastewater. Environmental Science & Technology, 38(11), 201A-208A.

[37] Rodriguez-Narvaez, O. M., Peralta-Hernandez, J. M., Goonetilleke, A., & Bandala, E. R. (2017). Treatment technologies for emerging contaminants in water: A review. Chemical Engineering Journal, 323, 361-380.

[38] Oller, I., Malato, S., & Sánchez-Pérez, J. A. (2011). Combination of advanced oxidation processes and biological treatments for wastewater decontamination—a review. Science of the Total Environment, 409(20), 4141-4166.

[39]Pavoni, J. L., Paquin, P. R., & Demarco, J. (1972). Water Quality Management Planning for Toxic Chemicals. Journal of the Water Pollution Control Federation, 44(5), 786-801.

[40] Henze, M., Gujer, W., Mino, T., & van Loosdrecht, M. C. M. (2000). Activated Sludge Models ASM1, ASM2, ASM2d and ASM3. IWA Publishing.

[41] Liu, Y., & Tay, J. H. (2001). Metabolic response of activated sludge to toxicants. Water Research, 35(8), 1981-1988.

[42] Wagner, J., & da Costa, R. H. R. (2013). Aeration control in activated sludge systems: A review. Water Research, 47(7), 2379-2391.

[43] Khan, S. J., & Ongerth, J. E. (2004). Estimation of pharmaceutical residues in primary and secondary sewage sludge based on quantities of use and fugacity modeling. Water Science and Technology, 49(3), 213-222.

[44] Anaerobic digestion of wastewater sludge in a two-phase pilot-scale system." (2014). Environmental Technology, 35(20), 2537-2544.

[45] Appels, L., Baeyens, J., Degrève, J., & Dewil, R. (2008). "Principles and potential of the anaerobic digestion of waste-activated sludge." Progress in Energy and Combustion Science, 34(6), 755-781.

[46] Weiland, P. (2010). "Biogas production: current state and perspectives." Applied Microbiology and Biotechnology, 85, 849-860.

[47] Batstone, D. J., Hülsen, T., Mehta, C. M., & Keller, J. (2015). "Anaerobic digestion of wastewater sludge: Operational strategies for improved product recovery." Bioresource Technology, 196, 223-231.

[48] Droste, R. L., & Gehr, R. L. "Theory and Practice of Water and Wastewater Treatment." John Wiley & Sons, 3rd Edition, 2018.

[49] Sundaram, S., Kannan, S., & Sundaram, M. (2008). "Coagulation performance evaluation of aluminum sulfate and poly-aluminum chloride for the treatment of domestic wastewater." Desalination, 223(1-3), 282-292.

[50] Wang, S., & Wang, J. (2019). "Chemical oxidation of organic pollutants in domestic wastewater: A review." Chemical Engineering Journal, 354, 161-170.

[51] Lowe, H. J., & Watson, S. W. (1991). "Filtration in domestic wastewater treatment: An overview." Environmental Technology, 12(10), 849-859.

[52] "The role of filtration in domestic wastewater treatment: An assessment of current practices and future challenges." (2020). Journal of Water Process Engineering, 37, 101438.

[53] Fane, A. G., Wang, R., & Hu, M. X. (2015). "Membrane technology: Past, present, and future." AIChE Journal, 61(7), 2232-2246.

[54] Crittenden, J. C., Trussell, R. R., Hand, D. W., Howe, K. J., & Tchobanoglous, G. (2012). "MWH's Water Treatment: Principles and Design." John Wiley & Sons.

[55] Koivunen, J., & Heinonen-Tanski, H. (2005). "Peracetic acid (PAA) disinfection of primary, secondary and tertiary treated municipal wastewaters." Water Research, 39(18), 4445-4453.

[56] Murray, J. P., & Laband, S. J. (1979). "Ozonation and chlorination of domestic wastewater: Comparative disinfection efficiency and effects on effluent quality." Environmental Science & Technology, 13(4), 423-429.

[57] "Disinfection of municipal wastewater: Efficacy and mechanisms of various treatment technologies." (2020). Journal of Environmental Management, 256, 109963.

[58] Li, W., Zhang, L., Wu, Y., & Tian, Y. (2015). "Characteristics of domestic wastewater and its impacts on the selection of wastewater treatment technologies." Environmental Science and Pollution Research, 22(1), 7285-7297.

[59] Cecchi, F., Traverso, P. G., & Pavan, P. (1991). "Characterization of the organic matter in domestic sewage." Water Science and Technology, 23(7-9), 957-965.

[60] Characterization of domestic wastewater: Parameters, variability, and treatment implications." (2020). Journal of Environmental Management, 256, 109963.

[61] Eckenfelder, W. W., & Davis, L. L. (1977). "Activated Sludge Process Design and Control: Theory and Practice." Journal of the Environmental Engineering Division, 103(4), 715-729.

[62] Henze, M., & Comeau, Y. (2008). "Wastewater Characterization in Activated Sludge Modeling." Water Science and Technology, 37(3), 89-97.

[63] Ekama, G. A., & Marais, G. v. R. (1984). "Mathematical Modeling of the Activated Sludge Process." Water Research, 18(3), 227-237.

[64] Henze, M., Grady Jr., C. P. L., Gujer, W., Marais, G. v. R., & Matsuo, T. "Activated Sludge Model No. 1." IAWPRC Scientific and Technical Reports, No. 1..(1987)

[65] Speece, R. E. "Anaerobic Biotechnology for Industrial Wastewaters." Archaea Press, 1996.

[66] Gerardi, M. H. "The Microbiology of Anaerobic Digesters." John Wiley & Sons, 2003.

[67] Ahring, B. K "Bio-methanation I." Springer, this book is part of the Advances in Biochemical Engineering/Biotechnology series, Volume 81 . .(2003)

[68] Batstone, D. J., Keller, J., Angelidaki, I., Kalyuzhnyi, S. V., Pavlostathis, S. G., Rozzi, A., Sanders, W. T., Siegrist, H., & Vavilin, V. A. (2002). "The IWA Anaerobic Digestion Model No. 1 (ADM1)." Water Science and Technology, 45(10), 65-73.

[69] "Effects of mixing on the result of anaerobic digestion: Review." Renewable and Sustainable Energy Reviews, 40, 1030-1047

[70] Perry L. McCarty "Anaerobic Waste Treatment Fundamentals Part Three: Toxic Materials and Their Control" Journal of Public Works Volume: 95 Pages: 91–94 Year: 1964 Publisher: Public Works Journal Corporation.

[71] " Design and Optimization of Anaerobic Digesters for Methane Production." (2020). Journal of Environmental Management, 254, 109899.

[72] Michigan Department of Environmental Quality Operator Training Unit, PPT1 SlideShare "Anaerobic digestion process " April 2023

[73] Aydin, M.I.; Dincer, I. "An assessment study on various clean hydrogen production methods". Energy (2022), 245, 123090.

[74] Ji, M.; Wang, J. “Review and comparison of various hydrogen production methods based on costs and life cycle impact assessment indicators” Int. J. Hydrogen Energy 2021, 46, 38612–38635.

[75] Bhandari, R.; Trudewind, C.A.; Zapp, P. Life cycle assessment of hydrogen production via electrolysis—A review. J. Clean. Prod. 2014, 85, 151–163.

[76] Buttler, A., Spliethoff, H. “Current status of water electrolysis for energy storage, grid balancing and sector coupling via power-togas and power-to-liquids: A review” Renew. Sustain. Energy Rev. 2018, 82, 2440–2454

[77] Shin, J.-E. “Hydrogen Technology Development and Policy Status by Value Chain in South Korea. Energies” (2022), 15, 8983

[78] Carmo, M.; Fritz, D.L.; Mergel, J.; Stolten, D. “A comprehensive review on PEM water electrolysis”. Int. J. Hydrogen Energy 2013, 38, 4901–4934

[79] Mostafa El-Shafie, Shinji Kambara, Yukio Hayakawa" Hydrogen Production Technologies Overview Environmental and Renewable Energy Systems Division, Gifu University, Gifu City, Japan Journal of Power and Energy Engineering Vol.7 No.1, January 2019

[80] Ernesto Amores, Mónica Sánchez, Nuria Rojas, Margarita Sánchez-Molina “Renewable hydrogen production by water electrolysis” Sustainable Fuel Technologies Handbook (2021), Pages 271-313

[81] Grigoriev, S.A., Porembsky, V.I. and Fateev, V.N. “Pure Hydrogen Production by PEM Electrolysis for Hydrogen Energy”. International Journal of Hydrogen Energy, (2006) 31, 171-175.

https://doi.org/10.1016/j.ijhydene.2005.04.038

[82] Pettersson, J., Ramsey, B. and Harrison, D. “A Review of the Latest Developments in Electrodes for Unitized Regenerative Polymer Electrolyte Fuel Cells” Journal of Power Sources, (2006) 157, 28-34. https://doi.org/10.1016/j.jpowsour.2006.01.059

[83] Mohamed Benghanem, Adel Mellit, Hamad Almohamadi, Sofiane Haddad, Nedjwa Chettibi Abdulaziz M. Alanazi, Drigos Dasalla and Ahmed Alzahrani "Hydrogen Production Methods Based on Solar and Wind Energy: A Review" Energies 2023, 16.(2)

[84] Jun Chi, and Hongmei Yu "Water electrolysis based on renewable energy for hydrogen production

[85] Chinese Journal of Catalysis Volume 39, Issue 3, March 2018, Pages 390-394

[86] Turner, J., Sverdrup, G., Mann, M.K., Maness, P.-C., Kroposki, B., Ghirardi, M., Evans, R.J. and Blake, D. "Renewable Hydrogen Production". International Journal of Hydrogen Energy, (2008) 32, 379-407.

[87] Temitayo Ikuerowo Shree Om Bade a, Akinwale Akinmoladun, Babalola Aisosa Oni "The integration of wind and solar power to water electrolyzer for green hydrogen production

[88] International Journal of Hydrogen Energy Volume 76, 26 July 2024, Pages 75-96

[89] Yuchen Gao Jianguo Jiang , Yuan Meng , Feng Yan , Aikelaimu Aihemaiti A review of recent developments in hydrogen production via biogas dry reforming Energy Conversion and Management Volume 171, 1 September 2018, Pages 133-155

[90] Bing Zhang et al. "Progress and prospects of hydrogen production: Opportunities and challenges" Journal of Electronic Science and Technology https://doi.org/10.1016/j.jnlest.2021.100080

[91] Somtochukwu Godfrey et al, A Comparative Analysis of Different Hydrogen Production Methods and Their Environmental Impact Clean Technol. 2023, 5(4), 1344- 1380.

[92] John A. Duffie and William A. Beckman “Solar Engineering of Thermal Processes” Publisher: Wiley 4th edition published on April 25, 2013. ISBN: 978-0470873663

[93] Frank Kreith, and Jan F. Kreider “Principles of Solar Engineering" by D. Yogi Goswami, CRC Press Publication Date: The 3rd edition was published on September 5, 2007 .

[94] Roger Messenger and Jerry Ventre “Photovoltaic Systems Engineering" CRC Press 3rd edition was published on August 3, 2010.ISBN: 978-1439802938.

[95] L. Ashok Kumar and S. Albert Alexander "Design and Analysis of Solar Energy Systems: Thermal and Photovoltaic” CRC Press Publication Date: October 15, 2020ISBN: 978-0367253422

[96] Wael Charfi, Monia Chaabane , Hatem Mhiri , Philippe Bournot “Performance evaluation of a photovoltaic solar system for electricity generation" Source: International Journal of Renewable Energy Research, Energy Reports Volume 4, November 2018, Pages 400-406

[97] Modupe Ola Dada & Patricia Popoola “ Reviews Recent advances in solar photovoltaic materials and systems for energy storage applications: a review ” Journal: Renewable and Sustainable Energy Beni-Suef University Journal of Basic and Applied Sciences volume 12, Article number: 66 (2023)

[98] Angèle Reinders, Pierre Verlinden, Wilfried van Sark, and Alexandre Freundlich Photovoltaic Solar Energy: From Fundamentals to Applications" Wiley Publication Date: August 26, (2017) ISBN: 978-1118927495

[99] Roger Messenger and Jerry Ventre “Photovoltaic Systems Engineering" by CRC Press Publication Date: August 3, (2010), ISBN: 978-439802938

[100] M. Aghaei et al. “Review of degradation and failure phenomena in photovoltaic modules” Renewable and Sustainable Energy Reviews Volume 159, May 2022, 112160

[101] Rami Alamoudi Osman, Taylan Mehmet, Azmi Aktacir, and Enrique Herrera-Viedma "Designing a Solar Photovoltaic System for Generating Renewable Energy of a Hospital: Performance Analysis and Adjustment Based on RSM and ANFIS Approaches" Mathematics 2021, 9(22), 2929.

[102] James F. Manwell, Jon G. McGowan, and Anthony L. Rogers "Wind Energy Explained: Theory, Design and Application" Publisher: Wiley Publication Date: 2009 (2nd Edition).

[103] Dutton Institute "Wind Energy and Power Calculations" EM SC 470 psu.edu.e-education psu.edu/emsc297/node/649..

[104] Paul Gipe "Wind Power: Renewable Energy for Home, Farm, and Business" Publisher: Chelsea Green Publishing Publication Date: 2004 ISBN: 978-1931498142.

[105] Nick Jenkins, and Ervin Bossinyi "Wind Energy Handbook" by Tony Burton, David Sharpe, Publisher: Wiley Publication Date: 2011 (2nd Edition) ISBN: 978-0470699751

[106] Aldo Vieira da Rosa "Fundamentals of Renewable Energy Processes" Stanford University Publisher: Elsevier Academic Press Publication Date: 2005 (Second Edition) Elsevier Academic Press ISBN 13: 978-0-12-088510-7

[107] Subhashish Banerjee, Md. Nor. Musa, Dato' IR Abu. Bakar Jaafar and Azrin Arriin "Application on Solar, Wind and Hydrogen Energy - A Feasibility Review for an Optimised Hybrid Renewable Energy System" Department of Renewable Energy, University Technology Malaysia

[108] Darwish, A.S.; Al-Dabbagh, R. Wind energy state of the art: Present and future technology advancements. Renew. Energy Environ. Sustain. Volume 5, article 7.(2020)

[109] Wang, S.; Wang, S. Impacts of wind energy on environment: A review. Renew. Sustain. Energy Rev. (2015), volume 49, pages 437–443.

[110] Liebe, U.; Bartczak, A.; Meyerhoff, J. A turbine is not only a turbine: The role of social context and fairness characteristics for the local acceptance of wind power. Energy Policy (2017), volume (107), pages 300–308 .

[111] Renewable energy in Europe: markets, trends, and technologies / European Renewable Energy Council (EREC). First published by Earthscan in the UK and USA in (2010) ISBN 978-1-84407-875-2

[112] Ju Feng, Wen Zhong Shen "Design optimization of offshore wind farms with multiple types of wind turbines" Applied Energy Volume 205, November 2017, Pages 1283-1297

[113] Bortoluzzi, F., Pang, Y., Karunathilake, H., & Rani, K. (2022). "Cost, environmental impact, and resilience of renewable energy under a changing climate: a review." Published in Environmental Chemistry Letters.

[114] Haviv, M., Bouchiba, A., & Kaddouri, A. (2023). "Maximizing the cost-effectiveness of electric power generation through the integration of distributed generators: wind, hydro, and solar power." Published in Bulletin of the National Research Centre.

[115] Can Şener, Ş.E., Sharp, J.L., & Anctil, A. (2018). "Factors impacting diverging paths of renewable energy: a review." Renewable and Sustainable Energy Reviews, 81: 2335-2342.

[116] Dogan, E., Inglesi-Lotz, R., & Altinoz, B. (2021). "Examining the determinants of renewable energy deployment: does the choice of indicator matter?" International Journal of Energy Research, 45: 1–14.

[117] IRENA. Renewable Energy Prospects for the European Union. Available online: www.irena.org/-/media/Files/IRENA/agency/Publication/2018/Feb/IRENA_REmap_EU_2018.pdf (accessed on 23 February (2023).

[118] Renewable power generation costs in 2022, International Renewable Energy Agency, Abu Dhabi. ISBN 978-92-9260-544-5.