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Plasma Technology Contributions to Energy Transition and Environment

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Abstract

A fair and reliable energy transition is needed for the depleted fossil fuel, energy supply and climate concern the world knows now days. Alize climate is adequate for hybrid green hydrogen projects especially with the new innovations and the promising plasma technology solutions for direct seawater hydrogen production. Non thermal plasma with its low temperature and effectiveness of its energetic electrons toward the inert carbon dioxide becomes the new interest for biomass and CO2 conversion to energy. This conversion is in fact a great reduction of CO2 emission that could be considered as another value added. Gas hydrate risk and geohazard could be mitigated to be a value added and one of the various storages for CO2 emission reduction to atmosphere. Plasma technology in waste treatment has advantage on the conventional methods in pollution prevention. Non thermal plasma in water treatment is still in laboratory scale but has shown great progress by its effeteness of its generated reactive species.

Keywords: plasma; electron density number; reactive species; wind speed; irradiance; energy transition; environment.

1. Introduction

The depleted hydrocarbon reservoirs, energy demand and climate change are the main factors for a fair and reliable energy transition. In this study we focus in case study on the major sustainable energy of energy transition, solar and wind energy, and plasma technology contributions to renewable energies and environment for energy transition.

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An estimation of power potential and possible one GW hybrid green hydrogen project has been treated based on respectively climatologic average monthly data for wind speed over 55 years since 1960, and satellites (PVGIS SARAH2) average monthly data for solar irradiance in some regions in Mauritania continental. Direct seawater methods for hydrogen production andt electrodes corrosion mitigation have been discussed. Then the diverse known renewable energies have been reviewed focusing especially on plasma technology contribution to biomass and CO2 conversion and energy storage for energy transition.

Greenhouse gas, CO2 various techniques of storage and emission reduction have been mentioned. Gas hydrates risk and geohazard on environment and the proposed mitigation are clarified. Plasma technology waste treatment and its advantage on the conventional methods in pollution prevention have been indicated. The key industry plasma technology reactive species contaminated water treatment has been explained.

2. Energy transition

2.1Plasma technology contributions

In addition to the known three state of matter, there is another fourth state called plasma which is mainly constituted of electrons, ions and neutral atoms and molecules. Among these constituents there are reactive species that are behind the plasma key industry in technology. The excitation of gas per example by a microwave source in rectangular wave guide generates electrons density number in order to the ions one **Figure.1**. In case of limited plasma, electrons number density is proportional to the wave source frequency and collision one [1].

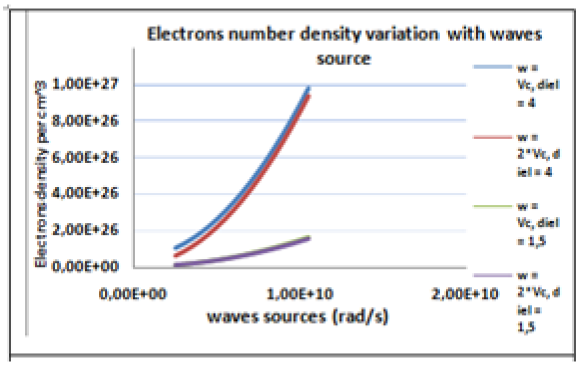

Figure 1: Electron number density for high wave source

These reactive species as we mentioned are the base for today industry and technology. Coating metal or polymer surfaces to change their prosperities or hardness needs to clean these surface first from contamination. Oxygen or hydrogen reactive species for example react strongly with the surface to eliminate these impurities. Thus, chemical bonds and adhesion become stronger for any coating film. They bombard the substrate for etching and deposition in general for all other type of processing [2]. It is used in biomass and carbon dioxide conversion, renewable energy equipments, energy storage, health equipment, air pollution protection, waste and water treatment and environment in general.

In general plasma technology is the main tool for the semiconductors processing. The latter is the foundation for the fabrication of all types of energy devices. Plasma technology has the great part of energy creation and conservation. It would completely control energy transition and environment in the new future. All types of energy and CO2 conversion and energy storage have been dominated by thermal and non thermal plasma. It has shown its great contribution to the concern the world gives today to energy transition and environment.

2.2Wind and solar renewable energy

In addition to the other types of renewable energies, wind and solar energy compared to hydropower sustainable energy is classified as major class of these energies. This renewable able energy is considered one of the leading energy to a fair and reliable energy transition. The depleted fossil fuel reservoirs worldwide constitute big concern in term of energy supply. Decreasing CO2 emission needs sustainable energy replacing these natural depleted reservoirs to secure energy demands and environment issues. The importance of wind and solar energy in green hydrogen storage and electrical energy, makes it essential in securing energy supply over the world. The innovation of super capacitors for this intermittent energy would classify this type of energy as a primary reliable sustainable energy for energy transition. The estimation of the potential of this energy is essentially based on the distribution of wind speed and solar irradiation over the year. We have estimated the power for both renewable, wind and solar energies based on respectively climatologic average monthly data for wind speed over 55 years since 1960, and satellites (PVGIS SARAH2) average monthly data for solar irradiance for this purpose in Mauritania continental. Weibull distribution of wind speed at elevation of 100m for seven regions in the country shows a normal distribution smooth and not skewed. Wind speed varies from 2 to 15m/s in the area. The average speed for example for Nouadhibou is 10,43m/s which is close to the value of median calculated by the distribution, 10,48m/s. **Figure.2.**

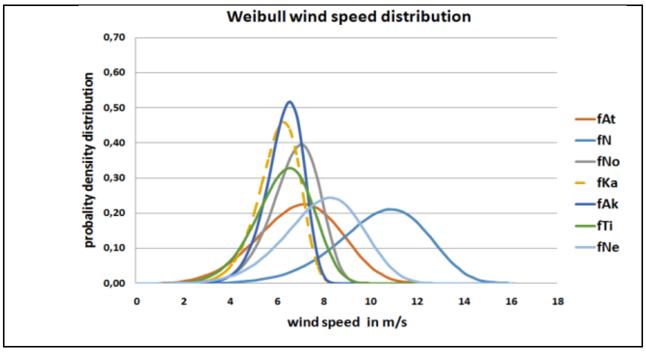

Figure.2: Weibull wind speed distribution for some region in Mauritania continental

Power densities at these regions vary from poor, fairly to good or excellent on the international scale for 50m height. **Table.1**. Over this long period of climatologic data wind speed directions at for example the coastal region of Nouadhibou where the Alyse climate are mainly North-westly of maximum average speed of 9.5m/s and minimum speed of 6m/s at reference height of 10m. They are calculated based on the statistic analyze of Weibull distribution at these regions. Power density for Nouadhibou is of 675.8W/m2, and is considered as good or excellent in this scale.

Table 1: Regions power density on the international scale for 50m height

Nouadhibou	Atar	Nouakchott	Nema	Kayhadi	Akjoujt	Tijikja	R capitals
9.33	6.23	6.06	7.12	5.69	5.66	5.64	Avereag speed (m/s)
675.80	204.86	180.37	285.97	135.12	130.82	134.26	Wind PD (w/m2)

Global irradiance power density has been calculated based on the anisotropic model that takes an account the horizon brightening and circumsolar diffuse in addition to the known isotropic one. The optimum irradiance corresponds to a tilt angle of 10° for almost all the regions (Nouakchott, Atar, Nouadhibou, Nema and Akjoujt). River areas near Kayhadi have a tilt angle of 16° for an optimum irradiance illustrated by the dashed line. **Figure.3.**

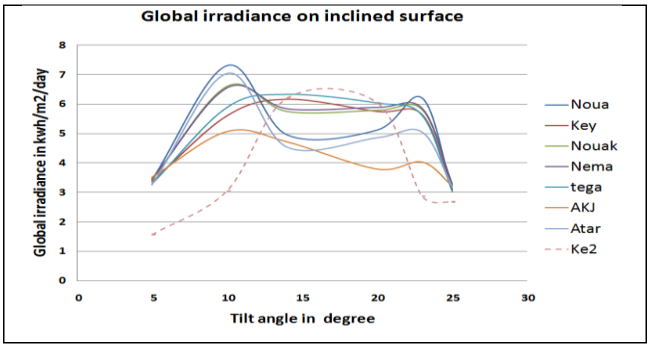

Figure 3: Global irradiance of anisotropic model on inclined surface

The electrical output power densities per kilometer square per example for a PV panel of power 250W and size 1,6m2 at Akjoujt and Atar are between 28.28 to 34.42MW per kilometer square. For Nouadhibou, this density is of 35.64MW per kilometer square with an inclination angle of 10°.**Table.2.**

Table 2: OUTPUT power at the regions for a PV panel of 250W and 1.6m2 of size

Nouadhibou	Atar	Nouakchott	Nema	Kayhadi	Akjoujt	Tijikja	R capitals
10.00	10.00	10.00	10.00	13.00	11.00	14.00	Tilt angle (degree)
304.58	294.17	275.42	275.42	233.33	241.67	264.17	GTI (watt/m2)
35.64	34.42	32.22	32.22	27.30	28.28	30.91	OUTPUT(MW/KM2)

Green hydrogen production from fresh water becomes a debate and issue. By contrast hydrogen production from seawater mitigates the risk of conflict menace on our planet for fresh water shortage. Indirect seawater usage for hydrogen production needs different methods for treatment like desalination, reverse osmosis to protect electrodes from the precipitations that cause essentially corrosion and stop electrolysis operation. Thus, despite the advantages of indirect seawater which offers pure water for humankind, like potable water and agriculture, it is considered cost effective. Electrolysers that need these treatments, for example proton exchange membrane ,PEM constitute the big part of capital and operating expenditure cost of any green hydrogen project. A novel direct seawater electrocatalyst comes with a solution for the problem of corrosion by innovating new technical strategies. More than 50% of seawater ions are chloride ions and they are the principal agents of corrosion to the electrodes [3]. Some studies suggest coating the cathode by a material reach of negative charges to repulse the negative ions [4]. The novel innovation proposes to coat the cathode by double hard films of Lewis acid oxide on transition metal oxide [5]. The alkaline seawater solution in the vicinity of cathode produces hydrogen and hydroxyl ions. The abundant produced OH ions keeps the alkalinity of the solution and alleviate the others precipitations of seawater. Plasma technology in its turns in plasma driven solution electrolysis, PDSE known also by contact glow discharge electrolysis, CGDE has made great effort in green hydrogen production. Instead of metal electrodes, this method focuses on plasma reactive species and energetic electrons generation in the liquid. The solvated or hydrated electrons at interfacial region over the two plasma regions in the gas-vapor envelope create hydroxyl ions, oxygen and hydrogen [6]. In their experiment of plasma electrolysis known now by PDSE, the evolved gas of hydrogen and oxygen at CGDE electrodes are noticed steadily after plasma disappears at 90V [7]. In another study that compares plasma water treatment with conventional electrolysis of NaCl electrolyte, chloride evolved only on the conventional electrolysis [8]. Green hydrogen projects are in its way in this country along the offshore of Atlantic Ocean and North West of the continental. A possible hybrid wind and solar projects are for sure favorable along this coast based on this study. A one GW green hydrogen possible hybrid project based on this sky anisotropic model of PV solar energy and that of wind energy, would take 161 squares kilometer with 235 wind turbines of 3MW of capacity and PV panel power of type 250W and size of 1,6m2. **Table.3.**

Table 3: One GW hybrid green hydrogen project at Nouadhibou

1 GW green hydrogen (possible project) - Nouadhibou				
Renewable	Power MW	Turbines, Panels	Spacing	Area Km2
Wind	700	235.3MW	800m	150.97
Solar	356.4	250W, 1.6m2		10

Off grid projects in vast area like Mauritania, are of great importance. The country is characterized by their known geological sites for mining. It is considered among the major producer of copper and has a trusted deposit of rare earth elements. Critical materials are wanted and appreciated for renewable energy installation and storage equipments. A first order permissive mineral tract for polymetallic Pb-Zn-Cu deposit is considered to include in Rgeibat Shield and Mauritanid belt. **Figure.4.**

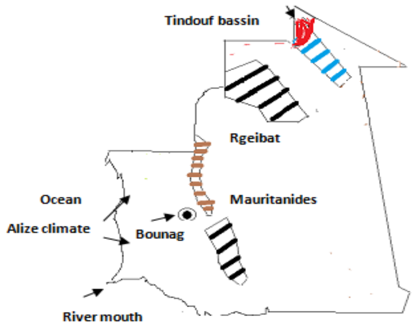

Figure 4: Polymetallic Pb-Zn-Cu deposits at Rgeibat shield and Mauritanides belts

2.3Hydropower energy

Share of hydropower renewable energy in energy transition is high compared to other sustainable energies, especially in location where this energy has the condition characterizing the economic potential source for its extraction.

Some hydroelectric powers can store renewable energy in low demand periods to electricity like in pumped storage by lifting water from low reservoir to high reservoir and used it in high electrical demand periods. In run-of-river facilities, the procedure is to channels a portion of river through a canal at the river decline to generate the electricity by water gravitational forces. In impoundment facility, water stored in, dams turns turbines to generate electricity. It may contain fish-ways for environment concerns [9].

Wave energy is essentially favorable in location of latitude in between 40 and 60 North and South. The mean power of this energy has proportionality to the period and front high of the wave. Tidal energy is created by gravitational forces between moon and earth, and sun and rotation of earth. This energy in coastal regions is considered valuable when tidal length or range has at least 7m [10].

2.4Biomass energy

Today biomass and CO_2 from fossil full and atmosphere can be converted to energy on behalf of energy efficiency and environment. Biomass renewable energy is a focus today that contributes to energy transition. This energy is based on conversion and transformation of this rich carbon material to biofuel. The principle of its transformation is similar to that of hydrocarbon formation in overburden formation. There are gas and oil windows that depend on temperature, pressure and type of accumulation. Biofuel also generation depends on temperature and pressure. The biofuel generated from the first feedstock which is considered as a food competitive, are bioethanol and biodiesel. By conventional treatment for example gasification from the other feedstocks, the biofuel syngas is essentially a mixture of hydrogen gas, carbon monoxide, complex hydrocarbon components (tar), carbon dioxide and methane. In pyrolysis process, the operation is completed without oxygen and the biofuel yield is a vapor which is transformed by condensation to liquid ‘’crude-oil’’ oil [11]]. Plasma technology by both thermal and non thermal one has shown progress in biomass conversion for this purpose. The liquid biofuel can be produced by non thermal plasma in pulsed discharge plasma reactor. The idea is based on the generation of reactive species, O and H in the biomass solution to facilitate the redox reaction. This is the advantage of plasma technology over the conventional methods. It yield high liquefaction rate in shorter time [12]. In study on the conversion of biomass to syngas, carbon dioxide has been used as an oxidizer for the reaction in thermal Arc plasma [13]. In non thermal plasma this oxidative carbon rich gas can be used with biomass in dry treatment and in situ liquid for value-added products and fuel. Biomass powder is treated in the reactors with plasma discharge gas of oxygen, nitrogen, argon, air and dioxide carbon. In liquid treatment, the primary reactive species can be in the gas phase or interphase or oriented inside the biomass solution to generate secondary species. Nitrogen and oxygen primary species generated by electrons impact on O_2 and N_2 collide with other heavy molecule to form NO and this latter in its turn react with hydroxyl, OH to form, HNO_2 another secondary reactive species [14]. In addition to its function as oxidant, dioxide carbon is useful especially with the non rich carbon feedstocks for the reaction of conversation. Plasma technology by means its generated reactive species and electrons in the reactor, could decompose the inert molecule of carbon dioxide for added value products and fuel for energy. In non thermal plasma, the relatively high temperature of energetic electrons to ions, transfer its energy to this molecule to break carbon bonds to oxygen and monoxide carbon in pure CO2 splitting. Thermal plasma, by catalyst co-reactants like CH4, H2 and H2O, converts CO2 gas using both physical and chemical quenching in the operation [15,16].

2.5Salinity gradient, geothermal and electrochemical energy

Salinity gradient sustainable energy is among the diversity of sources of nature donation. It is stored chemical energy located especially at river mouths. Its principle based on the difference of the salinity of high concentrated and low concentrated solution. Reverse electrodialysis membrane, RED method uses the transport of ions from high to low concentrated saline solution to generate electricity in multiple AEMs (anion exchange membranes) and CEMs (cation exchange membranes) in series. Pressure retarded osmotic, PRO membrane method uses pressure as mechanical energy to create electrical energy. CAPMIX is another type of battery based electrodes, which uses renewable energy, salinity gradient for charging and its power density is based on the area of electrodes [17]. The new bio-inspired membrane mimics the asymmetry of the pores in electric eel. This type of membrane can eliminate power dissipation and polarization phenomena. This energy is estimated to reach up to 30 terawatts (TW) [18]. Tidal length or range higher than 1.2m is considered unfavorable [19]. Plasma technology as an example has been used to enhance the mechanical and chemical proprieties of porous polyethylene in the matrix of RED membrane [20]. From this energy electrical energy is yielded through constraints and environmental regulations and could be used per example for the industrial facilities in place.

Geothermal energy is another type of renewable energy that has important contribution to energy transition. Geothermal reservoir is characterized by heat flow of its rock, its permeability and the presence of fluids. As an example in this country of study, some studies based on the variation of heat flow and geothermal gradient across the African palate, reported the high heat flow in Mauritania [21]. Tindouf basin is among the East West geothermal trend that comprises Canary Archipelago and continues until Algerian Sahara Fig. It has a wide geothermal gradient range and heat flow that vary respectively from 25-45C/km and 70-100mW/m2 [22]. The high enthalpy system that has high geothermal fluid temperature which is estimated to be above 150C could generate electricity [23]. Even below this temperature the binary hybrid system in exchanger that uses another fluid with boiling point lower than the fluid of the system, could enhance the geothermal reservoir production for power. The part of Tindouf basin north Mauritania continental could be a favorable site for geothermal power based on these studies.

Thermoelectric energy is obtained from waste heat energy conversion to electrical energy. The principle is based on temperature difference across two metals, which generates the electricity. Thermoelectric devices performance is proportional to electrical conductivity and inversely to thermal one. It has wide application in industrial facilities, automotive, aerospace and others. Plasma synthesis by microwave is used for the preparation of SiGe nanomaterials that have contributed to the enhancement of the performance of these devices [24]. The role of this energy in energy transition, energy conversion and emission reduction is remarkable and appreciable.

2.6Energy storage

The energy transition has no sense if there is no method and robust solution for the conservation of this various and huge energy in the nature. Plasma technology has made a great effort on conservation of energy in form of potential one for energy transition. It remains the eco- friendly tool in fabrication of energy device storage, batteries, super capacitors and electrochemical energy storage in general. Carbon based and noble metals nanomaterials are used in fabrication of energy device storage components. For example carbon porous nanoparticles are favorable for ions transport in electrolyte because of its porosity, structure. Electrodes are made by deposition of various forms of carbon nanomaterials , CNT, CNW graphene and others on metallic foil like Cu for more charges exchange and transport. In thermal plasma, the temperature of energetic electrons is in order of the ions one. Plasma enhanced chemical vapor deposition, PECVD is one of the various thermal plasma applications used to prepare and deposit these nanomaterials in electrode fabrication [25,26]. This technology has the big part contribution in the enhancement of performance and durability of electrochemical device storage for energy efficiency. The benefit of energy storage in electrochemical devices is important factor in energy transition.

3. Environment

3.1Carbon dioxide, CO2 storage

Carbon dioxide storage is known method for reduction of green house gas emission and for oil recovery for fair and reliable energy transition. Geological formations, unmined coal seam and deep saline aquifers are the main targets for injection and storage of CO2. Among the underground geological formations for carbon dioxide sequestration, there are depleted oil reservoir and salt caverns. Another unusual type of CO2 storage is proposed in gas hydrates accumulations. Gas hydrates formation stability is controlled by the prevailing conditions of pressure and temperature. **Figure.5.** Any depression in the stability zone could release for example green house gas, methane from methane hydrates formation to the atmosphere. This depression causes a failure in the slop riser and constitutes serious geohazard and risk for the environment. To mitigate this risk, a method has been suggested to produce methane from methane hydrate in the accumulation by injecting CO2 to replace the gas to strengthen and secure the stability of the formation. Bottom simulation reflector, BSR is the main indicator of this gas.

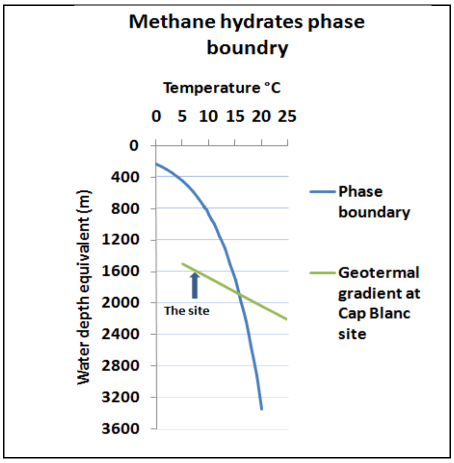

Figure 5: Gas hydrates stability zone at Cap Blanc site

3.2Waste and water treatment and pollution prevention

Plasma technology is eco- friendly. It has a dry treatment in contrast of the wet chemical treatment that is supposed have waste affecting the environment. Plasma technology has great contribution to all different part of the environment. This technology has reduced a big part of CO2 green house emission which represents the great concern of climate change. It could control the essential factor and parameters of CO2 global emission scenario for 2050. Its application in waste and water treatment, air pollution has noticeable advantages over the known traditional conventional ones [27]. Fine particles from thermal power plants, dust, coal, glass and iron powder from conventional incineration and toxic gas like NOx and SOx could be removed by electrostatic precipitator (ESP) as pollution prevention. Thermal plasma using Arc or torch plasma reactor could be completed with high temperature in gasification or without oxygen in pyrolysis processes. Its high temperature and density minimize the exhaust gas and by product, decomposes the harmless dioxins, organic halogens and toxic gases [28]. In water treatment, waste or surface water like river dames or lakes in general, non thermal plasma is a good candidate for this type of treatment. This application for waste water treatment is valuable and efficient toward water contaminants like organic compounds and bacteria. The generated oxidant reactive species at water surface or inside water act to deactivate these impurities. This technology is still in laboratory scale but it is really present in nature. Lightning strike is an example of electric source that produce plasma which is in contact with water of the snows in rain. Plasma created at surface of water is more efficient than that inside water. Collision of energetic electron with water, produce Hydroxyl, OH which is considered a main oxidant among these species. These primary reactive species when it acts with water it generate another secondary species. Peroxide, H2O2 is for example one of these secondary species. Somme of these species have short period life which may take seconds, others take several days [29]. Water treated with plasma is called plasma activated water, PAW that has its intrinsic characteristic of low ph, high electric conductivity and high ORP, oxidation reduction potential. PAW can be controlled based on gas carrier and plasma reactors. The contaminated water by microorganisms could be treated by adjusting the characteristics of PAW to low ph and high ORP for example. Collision of reactive species in contaminated water with microorganisms makes damage to its cells membranes. Oxidative reactive species have strong antibacterial effect.

Hydroxyl is strong oxidant as it has mentioned has an important role in affecting the outer part of the cell membrane. Among the non thermal plasma applications for water treatment, the gliding arc, corona and DBD discharges [30]. Even the installation of this kind of water treatment of plasma technology is cost-effective; the experiment results show that plasma water treatments are beneficial for human health and comfort. The energy transition and the promising renewable energies would contribute to minimize this cost in the near future.

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