Tunisia’s Current Electrical Energy Tripled By Hypersalinity Osmotic Power Generation

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This title may sound to some as a commercial hype or a publicity stunt to promote a consumable product. Energy professionals may denounce such claim and declare the writer’s incompetency. The fact is, Tunisia offers natural renewable unconventional energy potential that is unknown to most intellectuals in the energy field.

MIK Technology strongly believes Tunisia’s barren endorheic salt lakes that are commonly known as Chotts (shores in Arabic) could generate safe and sustainable osmotic power that would at least double Tunisia’s current power demand and possibly triple if all the major Chotts are dedicated for power generation.

In this paper, Tunisia’s current power generation and demand will be reviewed, as well as introducing MIK Technology’s concept of “Hypersaline Osmotic Power Generation”, known as the “ISO Power Potential[1]”. Two power generation schemes will be offered to generate power from Chott el-Jerid or el-Djerid (Arabic: شط الجريد) and Chott el-Fajaj or el-Fedjadj (Arabic: شط الفجاج). One concept is proposed for straight power generation of 3.0 Gigawatts and the other for dual purpose power generation of 2.5 Gigawatts in addition to a 1000 km^2 inland marine life aquatic habitat.

Tunisia Chotts lie in what is called the Zone of Chotts, which is a region of the pre-Saharan Tunisia that is situated in a series of tectonically controlled depressions that lie between the Atlas Mountains and the Saharan Platform, along a structural line, the so-called Sillon Tunisien or Tunisian trough, linking the Tripolitania trough of Libya to the Chott Merouane (Arabic: شط مروان) at Chott Melrhir (Arabic: شط ملغيغ) of Algeria [2].

The generation of osmotic power that employs large natural hypersaline water domains is a mega size world-class development project that would mandate both national and international collaboration and support. Such a prospect would, however; have far reaching impact on the future development plans of Tunisia and the enormous future prosperity for its people and their eastern and western neighbors.

I. Tunisia’s Chotts:

Tunisia (Figs. 1, 2) is a North African country covers 164,150 km^2 with population of 10,589,025 (July 2010), and it is bounded by Algeria on the west, Libya on the southeast, and the Mediterranean Sea to the east and north. It has a coastline of 1314 km long excluding the islands of Jerba, Gharbi and Chergui. Tunisia is divided into two parts of about equal size with three basic salt

Chotts (Fig. 3) that extend from the Gulf of Gabes (Arabic: خليج قابس) of the Mediterranean Sea to the Tunisia/Algeria boarder.

Fig. 1: Tunisia geographical location

Fig. 2: Tunisia physical map

The largest Chott is known as Chott el Jerid (Arabic**:** شط الجريد). It is a large endorheic salt lake in southern Tunisia (Fig. 4). Chott el-Jerid is 15-31 meter above sea level. The northern extension of Chott el-Jerid is another salt pan known as Chott el Fajaj (Fig. 5). These two Chotts are continuous, stretching 193 km from east to west, within 21 km from the Mediterranean Sea. The floor of the two Chotts has a minimum altitude of 15 meter above sea level and comprises barren clay and salt encrusted with some halophtyic vegetation.

Those Chotts have an estimated total surface area of about 5,500 km², which will be used as a conservative preliminary design criterion in this proposal. However, some claims that the surface area is much larger and could exceed 7,000 km². Therefore, an accurate survey of the domain must be conducted to validate final design parameters due its significance on the Chotts osmotic power potential, which could contribute an additional 750 MW of power.

Chott el-Gharsah (Arabic: شط الغرسة) is another salt pan located just north-west (Fig. 6) of Chott el-Jerid and extends slightly across the Tunisia boarder into Algeria. Chott el-Gharsah is the lowest point in Tunisia at 23 meters below sea level. Chott el-Gharsah incorporates additional three smaller Chotts including Chott el-Chtihatt Srhat, Chott el-Rahim (Arabic: شط الرحيم) and Chott Mejez Sfa.

Due to the extreme climate with annual rainfall of only 100 mm and temperatures reaching 50° C, Chott el-Jerid is almost entirely dried up in the summer. The average potential evaporation over the Chotts is 2,500 mm or greater. Direct precipitation on the Chotts has a limited effect in moistening their surface.

In our proposal for Tunisia's osmotic power generation scheme, only Chott el-Jerid and Chott el-Fajaj system is being considered. Chott el-Gharsah could be incorporated at a later date to maximize power generation potential of that group of Chotts.

Conversely, it will be of a greater significance if a new osmotic power generation system is formed comprising both the Tunisian Chott el-Gharsah and the Algerian Chott Melrhir to form a massive water domain of about 7000 km^2. These two Chotts are below sea level and could be directly fed from the sea without the need for excessive pumping.

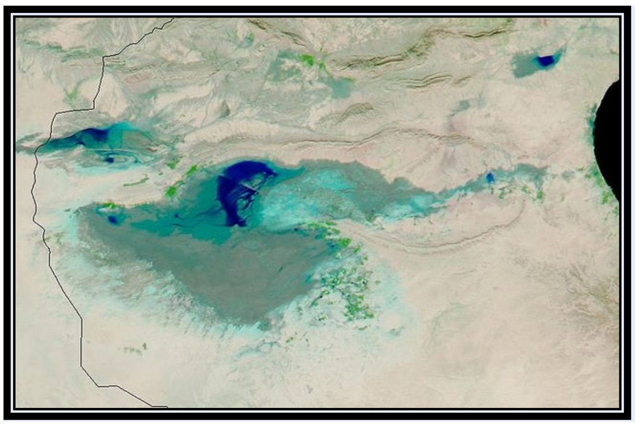

Fig. 3: Sattelite view of Tunisia chotts

Fig. 4: Chott el-Jerid, by Residence Sultana

Fig. 5: Chott el-Fajaj

Fig. 6: Chott el-Gharsah, by Nachoua

II. Tunisia's Energy:

Proven natural gas and petroleum reserves are limited. Tunisia has moderate uranium resources mainly in phosphate mineral. The main sources of energy used in Tunisia, are mainly oil products and natural gas. Few rivers could be exploited for hydroelectricity production. But despite these limitations water resources have been fully used in Tunisia. Wind resource for electricity supply is also available and is currently being exploited with an increasing share. To meet its energy requirements, Tunisia has to import gas and oil products.

Electrical power production capacity and consumption in table 1 has been extracted from the Tunisian National Observatory of Energy report [3]. Average annual growth rate from 2000 to 2007 is 2.3%

Capacity of Electrical Plants (MW)	**1980**	**1990**	**2000**	**2005**	**2007**
Thermal	832	1265	2313	3170	3232
Hydro	28	64	61.2	62	62
Nuclear	0	0	0	0	0
Wind	0	0	10.6	19	19
Geothermal	0	0	0	0	0
other renewable	0	0	0	0	0
Total	861	1329	2385	3251	3313

Electricity Production (GWh)	**1980**	**1990**	**2000**	**2005**	**2007**
Thermal	2406	4854	10008	12857	13054
Hydro	23.5	43.6	64.4	145.2	49
Nuclear	0	0	0	0	0
Wind	0	0	23.1	42.4	43
Geothermal	0	0	0	0	0
other renewable	0	0	0	0	0
Total (including transmission loss)	2430	4898	10095	13044	13146
Electricity ratio/total energy %	3.4	7.7	12.9	16.4	14.9

Electricity Consumption	**1980**	**1990**	**2000**	**2005**	**2007**
Total Electricity consumption (GWh)	2250	4400	8979	11244	12071
Electricity consumption (MWh/capita)	0.352	0.545	0.939	1.121	1.177

TABLE 1: Tunisia Electricity Production and Consumption

Average power per capita (watt per person) in Tunisia is 126, in comparison with 1540 Watts in Kuwait, and 8.6 watts in Mauritania. Tunisia has enjoyed a favorable energy situation characterized by a largely surplus energy balance until the middle of the Eighties.

Currently, the favorable situation has started to deteriorate due to the joint effect of two major factors which are: The stagnation of the national hydrocarbon resources and the sharp increase of energy demand, notably electricity, as induced by economic and social growth.

Oil and natural gas are the most important source of energy covering more than 95% of the total energy supply. Oil products are mostly utilized for transport and industry and as heavy fuel in thermal power plants. Imported gas comes mainly as royalties from the 370 km long section of the TransMed gas pipeline, which ensures the Algerian gas delivery to Italy. The quota of Tunisia was scheduled to increase from 6 to 7 billion cubic meters in 2010.

To ensure a consistent and sustainable energy policy, Tunisia established a state-owned energy company also known as Société Tunisienne de l'Electricité et du Gaz, (STEG) and defined energy plans to fully integrate electricity within the global energy system. Tunisia undertook a preliminary strategic study on the development of renewable energies. According to this study, which was completed in April 2004, Tunisia has a considerable potential of renewable sources of energy especially wind. As a southern Mediterranean country, Tunisia has a good solar potential and biomass one. It led to drawing up an action plan for developing the whole range of sectors at horizon 2011. Due to the Tunisian revolution in December 2010, current plan might be interrupted.

III. Osmotic Power

Osmosis is nature's gift to life. It is the vehicle that transports fluids in all living cells and without it, all biological functions and all forms of life cease to exist! Osmosis is the spontaneous movement of water, through a semi-permeable membrane that is permeable to water but impermeable to solute. Water moves from a solution in which solute is less concentrated to a solution in which solute is more concentrated.

The driving force of the flow movement is the difference in the chemical potential on the two sides of the semi-permeable membrane, with the solvent moving from a region of higher potential (generally of a lower solute concentration) to the region of lower potential (generally of a higher solute concentration).

The term "Chemical Potential" at times can be ambiguous and elusive. In fact, it is one of the most important partial molal quantities. It is the energy source associated with the activity of the ions of an ionizable substance. It is equal to the rate of change in free energy of a system containing a number of moles of such substance.

Chemical potential can be viewed as another form of energy like electrical, gravitational, momentum, magnetic, surface tension, etc. Thermodynamically, this energy is expressed in terms of what is conventionally known as Gibbs free energy.

The osmosis process for salinity power generation is rather simple and requires few basic units of operation; semi-permeable membrane modules, solution pumping means, turbine generators and means of flow control. This process can be simulated with a simple example. Considering a freshwater-brine osmotic scenario, where 1m^3/s brine with 7% salt content is pumped with a given pressure on one side of a semi-permeable membrane. Simultaneously, freshwater is allowed to permeate osmotically across the other side of this membrane with the same flow rate. As a result, the flow leaving the brine side is now doubled (2 m^3/s) and still at the same pumping pressure, but at half of the original concentration or 3% .This excess in flow at the brine original pumping pressure is the hydraulic potential that can be used to generate what is called osmotic power.

MIK Technology ISO [1] osmotic salinity power is unlike any other technology [4, 5], a patent pending technology that promotes the concept of Large Scale Renewable Energy (LSRE) from hyper saline waters. Scientifically, MIK Technology invention introduces a unique process concept employing a series of hydraulic cycles, operating in symbiotic mode within a concentration potential field to exploit the chemical potential dissimilarity of solutions. The proposed isothermal osmotic energy cycle approaches reversibility and is analogous, in its thermodynamic concept, to the Carnot Cycle. We named it the "ISO Cycle", also the "Reversible Liquid Power Cycle".

The subject technology targets world natural basins(6) such as the Great Salt Lake-U.S., Lake Natron-Tanzania, Lake Assal- Djibouti, Lake Urmia- Iran, Lake Baskunchak-Russia, the Dead Sea-Israel/Jordan, Lake Eyre North- Australia, Lake Van-Turkey and many others. This technology is also well adapted to many of the dry salt lakes such as the Aral Sea- Kazakhstan, Badwater basin-U.S. Death Valley, Qattara Depression- Egypt, Chott el- Jerid-Tunisia, Chott Melrhir- Algeria, salt domes, manmade salt ponds and formulated inexpensive concentrated brines.

IV. Tunisia's Osmotic Power Potential

Osmotic power potential is attainable anywhere natural or manmade physical domain or ecological topography allows for cycling of waters of dissimilar salt concentration, preferably via evaporation-accumulation by solar energy. Seawater-fresh water is uneconomical power source (7).

Tunisia dry salt pans are in close proximity to the sea and sharing very dry climate, which offer a unique opportunity for osmotic energy generation. Here nature has provided for massive barren salt beds and dry lakes with less than 25 kilometers from the Mediterranean Sea with a ratio of evaporation to precipitation of about 25 times.

In fact, northern Africa in general has several such mid-Saharan land formations that has promoted MIK Technology to present a paper (8) to the Fourteenth International Middle East Power Systems Conference Cairo, Egypt, December, 19-21, 2010 proposing the transformation of the mid-Saharan Qattara Depression region into a completely self-sustainable and habitable community for 3-5 million people, relying on MIK Technology ISO Power Generation Concept to generate 3-4 Gigawatts of power to promote agricultural and industrial developments, and create the largest inland manmade aquatic habitat and world class resort.

For Tunisia, two power generation schemes will be offered to generate power from Chott el-Jerid (شط الجريد) and Chott el-Fajaj (شط الفجاج). One concept is proposed for straight power generation of 3.0 Gigawatts and the other for dual purpose for power generation of 2.5 Gigawatts in addition to a 1000 km^2 inland marine life aquatic habitat.

The proposed concepts are preliminary and all design parameters for final design must be verified and analyzed by the Tunisian authority and/or its affiliates. In this proposal, the following preliminary design parameters are adopted:

1) Evaporation rate of 2,000 mm (2.0 meter) per year was considered. Literatures indicate that the precipitation rate in the Chotts zone is about 100 mm/year and evaporation rate could exceed 2,500 mm/year, but those limits will change upon filling the Chotts with water so a lower evaporation rate is being used in this evaluation.

2) The Chotts' area that has been simulated is 5,500 km^2. There are many conflicting information, or lack thereof, about Chotts area, depth, elevation, water capacity, water seepage, ground water, etc. This information must be verified and a complete survey of these water

domains has to be prepared. All these parameters would have significant impact on power potential and the mode of operating the proposed power plant.

3) In both proposals for power generation scenarios, route P16 (Fig. 8, 9) connecting the city of Kebili (Arabic: مدينة قبلي) with city of Tozeur (Arabic: **مدينة توزر**) will be used to partition the two Chotts into two isolated water bodies, except for a narrow opining at its western end, where a traffic bridge would be provided. As a result, this road has to be elevated and properly enforced to avoid encroachment and mixing of water between the Chotts upon filling them.

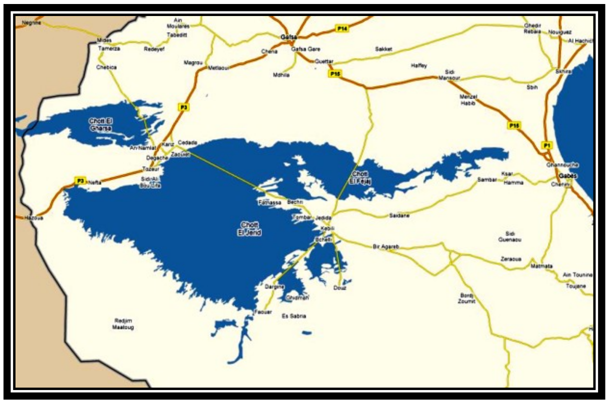

Fig. 8: acess routes


Fig. 9: Route 16 crossing Chott el-Jerid

4) Based on the proposed concept, water has to flow in a relatively narrow long path to insure uniformity of the required salt concentration (30-32%) at the end of this path. Since Chott el-Jerid has a semi-rectangular shape, it would be necessary to construct earthen berms to direct water in a zigzag pattern to control flow movement and maximize its salinity.

5) The proposed system is intended to operate continuously regardless of daily availability of solar energy. This is a great advantage of this technology. In fact, the large capacity of the stored brine and availability of steady seawater flow act as a massive battery that allows the system to run day and night continuously regardless of weather and solar energy interruptions.

6) To insure true renewable source of energy while maximizing domains' power potential, accumulation of salt in the Chotts has to be greatly reduced or preferably eliminated. Salt gathering would be done in dedicated salt ponds that could be provided at the end of each flow path, where water salinity is at its maximum.

7) In case of the 3.0 GW straight power generation concept (Fig. 10), the power plant will be located close to the sea around the city of Gabes (Arabic **مدينة قابس**). Brine discharge from the power plant will be fed to Chott el-Jerid at the city of Kebili (Arabic: مدينة قبلي) in an open canal to enhance water evaporation. While the returning brine through the Chott el-Fajaj will be directed to the plant for power generation and then released to the sea. A short by pass line from this released flow will be mixed with Chott el-Jerid feed for salinity control. Water depth in the Chotts should be kept at the maximum allowed by the Chotts' perimeters to insure enough brine inventories to run the system during inclement weather.

8) In the case of a dual purpose scheme (Fig. 11) for power generation of 2.5 Gigawatts and a large fishery, water will flow in an opposite direction to the straight power concept of item 7.

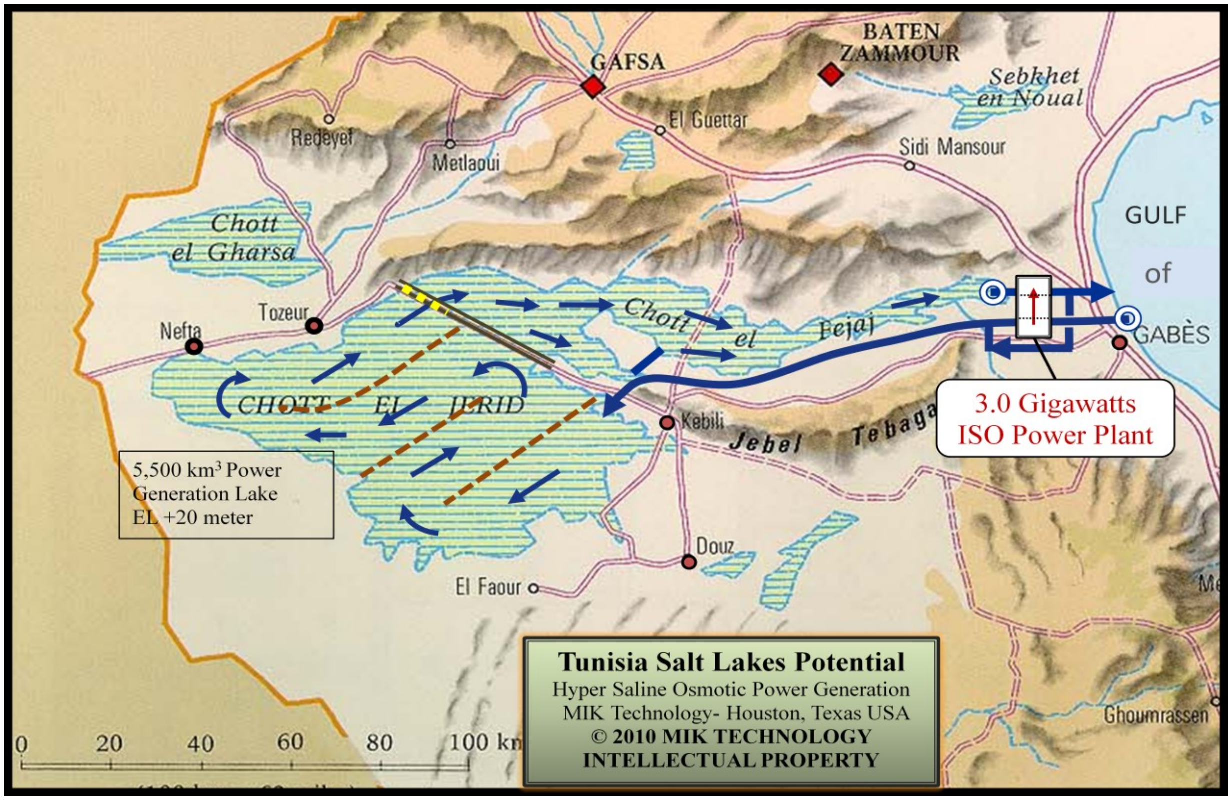

FIG. 10: Tunisia scheme for straight osmotic power generation of 3.0 Gigawatts

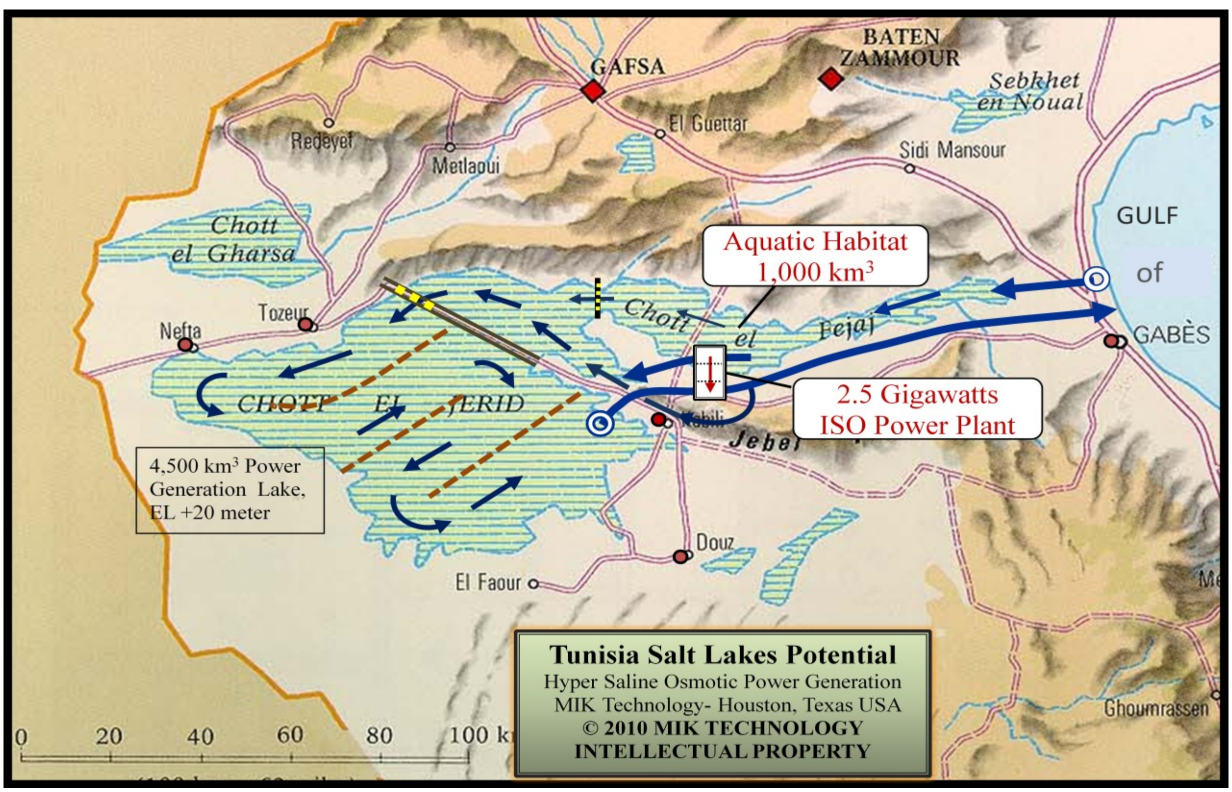

FIG. 11: Tunisia dual purpose scheme for osmotic power / marine life aquatic habitat

Here seawater will enter the Chotts at the eastern end of Chott el-Fajaj and brine leaves from the eastern end of Chott el-Jerid. In this case, the water domain northeast of route P16, which is composed of Chott el-Fajaj and a section of Chott el-Jerid, will be partially used for a fishery.

Water salinity in Chott el-Fajaj has to be carefully managed to a point that will not endanger marine live in this habitat. 4.5-5% salinity is adequate for many marine lives, as experienced in the Gulf of Aqaba and in the Persian Gulf. However, marine biologists need to study, research and recommend marine life species that can survive successfully in warm high salinity water.

For this arrangement, the power plant will be installed in the vicinity of city of Kebili to allow for constructing a short bypass canal to recycle some of discharged brine from the power plant to Chott el-Fajaj at point downstream from the space allowed for marine life. This bypass is important tool to control water salinity to the power plant point of use. As in the case first scenario (item 7), sea water pumping station will be placed at City of Gabes.

9) Surface evaporation rate over the Chotts was reported to be 2,500 mm/year, but we suggested the use of a lower value of 2,000 mm/ year anticipating the change of this rate upon filling the Chotts with water. At 2,000 mm/yr, the estimated amount of evaporated water is about 350 m^3/s.

This is a massive amount of water vapor and in the presence of southerly or south easterly wind; this moisture will not only improve atmospheric temperature but will more likely results in rain. This will encourage agricultural development south of the Chotts, particularly if some of the generated power is used to desalinate underground brackish water to enhance agricultural land development and support future rural and urban growth in mid and south Tunisia.

V. Tunisia's Proposed Osmotic Power Plant

Salinity power generation is an emerging field in the quest for renewable energy. The science behind this field of technology is based on exploiting the osmotic pressure difference between waters of dissimilar salt concentration to drive a hydroelectric generator. As indicated, our technology promotes the concept of Large Scale Renewable Energy (LSRE) from natural and manmade hyper saline water domains.

The technology is adaptable to small closed system application for the range of 1-2 megawatt, particularly where solar or waste energy is abundant. On the other side, natural domain projects are normally of the mega size type, generating massive amount of clean renewable energy and will greatly enhance the welfare of millions. However, such development requires major infrastructure development and massive amount of membrane material and miscellaneous equipment.

The cost of an osmotic power generation of a large water domain is immense and in most cases would not be attainable without the support of international organizations and large venture capital. Our initial estimate of cost is about 5 billion dollars per Gigawatts of generated power. This may seem high cost in comparison with carbon based energy. However, if we consider LSRE osmotic power exceptional potentials in developing self-sustainable new communities, there is no other green energy technology that can match osmotic power.

For example, wind and solar cost are limited by their daily availability. Realized cost per 1.0 GW of land-based wind farm is $4.6 billion [(9)] and realized solar energy costs is about $9 Billion per

GW[10]. The cost of a sustainable, state of the art, nuclear power station after Japan's March, 2011 nuclear calamity is now pegged at $ 10 million per megawatt of capacity[11], or $10 Billion/GW.

All of these alternative technologies offer one common feature, which is power generation. On the other hand, osmotic power technology offers clean and sustainable power more efficiently, makes advantage of barren land, enhances weather condition, allows agricultural development and supports major marine life industry, which all results in developing prosperous new communities.

Fig. 12 depicts the flow dynamics involved in generating 3 Gigawatts of power from Tunisia major Chotts as well as the large facilities and equipment to achieve this endeavor. Sea water intake is 600 m^3/s per at an average evaporation rate of 349 m^3/s, while the rejected brines stream is about 262 m^3/s. This brine could be used to recover about 80 MW of additional energy. The rate of filling the 5,500 km^2 Chotts with water is about 1.0 meter of depth per year. This evaluation assumes that the floors of both Chotts are at the same elevation, otherwise flow pattern and system design may change accordingly. A brine recycle stream is provided to maximize water salinity at point of use.

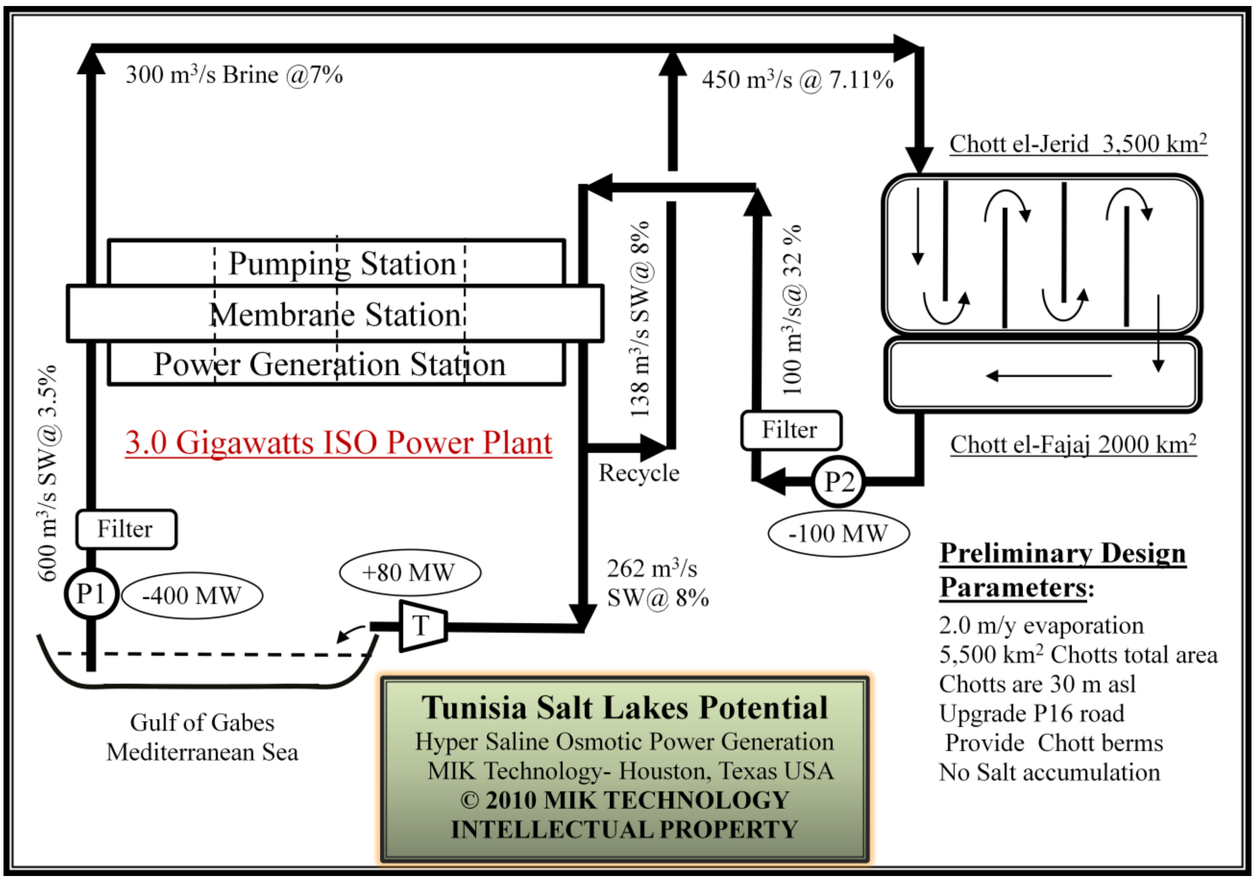

FIG. 12: Schematic of 3.0 Gigawatts Chott el-Jerid Osmotic Power Plant

Table 2 depicts the mass and energy balance of a full operating osmotic power plant. The plant will be constructed, in phases, of several trains of about 100-500 MW each with redundancy to allow for maintenance shutdowns and in meeting peak demand. The Chotts must be filled with water within 1-2 years ahead of the power plant to achieve the water depth and salinity to generate power; therefore standby/temporary power will be required to run the pumping system.

Chott el-Jerid & Chott el- Fajaj Osmotic Power Plant	
Energy Estimation	**Total**
Potential energy generation @85% efficiency	7,240 MJ
Sum of pumping energy @75% efficiency	-3,640 MJ
Membrane Log Mean Concentration Difference (LMCD)	3 (Est.)
Water feed, brine and miscellaneous of offsite pumping	-600 MJ
Net energy generation (Energy generation- pumping energy)	3,000 MJ
System Efficiency (net energy / potential energy)	41.4 %
Required Seawater Flow m^3/second	600

Table 2: Tunisia Osmotic Power Plant Energy Balance

VI. Tunisia's Osmotic Power Project Plan

Implementation plan comprises at least three phases

Phase 1: Each domain has its own peculiarities and each power generation system is custom tailored to meet water domain requirements. Water quality and condition vary from one domain to another. Therefore, it is essential to construct a Salinity Power Laboratory to house a 10 KW fully functional, automated and computer controlled prototype to support testing and defining the final design parameters. Such parameters include water chemical composition, biological forms in water, area topography, water availability, environmental conditions, flow pattern, longevity of osmosis membranes, sustainability and control of the system, etc.

This proposed salinity power laboratory and research work would costs $15-20 millions and expected to take three years. Simulated seawater and high salinity brine will be formulated using seawater electrolyte salts. The proposed facility will be also required for training plant operators and technicians, as well as promoting a hand-on cadre of intellectuals and specialists to manage the development of a large scale commercial osmotic power plant in Tunisia.

In this phase, collaboration and support of the Tunisian Government, technical, engineering, academic institutions and environmental specialists in providing relevant studies and research regarding all matters dealing with domain evaluation and project construction and operation are vital step towards initiating phase 2.

Phase 2: The second phase will construct a 10 MW power generation pilot plant in Tunisia at the gulf of Gabes, potentially in the vicinity of City of Gabes. The estimated cost of such facility is 50-70 million Dollars. The pilot plant will be supplied by 1.0 m^3/s of saline water that could be made available in the eastern edge of Chott el-Fajaj and the sea water would be transferred directly from the gulf at a rate 6.0 m^3/s.

Means for pumping and water treatment of the incoming flows will be provided to maintain operation stability of this system. A source of electrical power will be required to construct and commission such facility. Power could be extended from the City of Gabes or from a hydrocarbon electrical generator that would be provided as a standby to start the facility as needed.

Phase 3: The success in achieving phase 2 more likely will lead to design and build a commercial plant to harness the lake osmotic potential. This plant will be built of several trains of 100-500 MW each, with adequate redundancy to sustain continuous operation. The project will also provide a grid for power distribution and construct the necessary infrastructure modification to achieve the required flow pattern in the Chotts and maximize the Chotts energy potential.

Due to the initial large infrastructure development to support such project; site preparation, water canals, Chotts partition, berms, primary pumping station, etc., the initial cost will be relatively high. All the field civil work and main seawater pumping station has to be completed and commissioned at least two years before installing the first train to allow enough time to fill these large basins with water and reach the desired salt saturation. This work will also contribute to the high cost of startup.

We hope that the Tunisian Government would adopt and support this project since the state is the primary beneficiary of the project. We would also appreciate the support of the technical community in promoting this technology, which we believe will be a major advancement in the field of renewable energy and will have major impact on the prosperity of the people of Tunisia.

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