Journal of
Chemical Engineering & Process Technology

Abdel-Aal, J Chem Eng Process Technol 2014, 5:6
DOI: 10.4172/2157-7048.1000209

Review Article

Open Access

From Solar Hydrogen to Desert Development: A Challenging Approach

Hussein K Abdel-Aal*

Professor Emeritus of Chemical Engineering / Petroleum Operations, NRC, Cairo, Egypt (Retired)

Abstract

This paper presents a novel approach for desert development, taking the Arab countries a model in our study. Solutions to make the most from the sun to turn our desert into useful and arable land are proposed. Saline water resources from sea or rejects from desalination plants (brines) are chemically processed to produce partially desalted water along with valuable chemical products. Solar hydrogen is a cornerstone in our system to produce ammonia, which has dual functions in the scheme. Ammonia represents a source of nitrogen for plants. It is used together with carbon dioxide in the chemical separation process of saline water.

For the Arab countries with an average solar intensity flux = 700 Watt/m^2, an average sunshine hours of 3000 annually and only 1% of total land area for solar power generation, it is feasible to produce the equivalent of 184 × 106 tons of hydrogen yearly by water electrolysis. Ammonia gas synthesis takes place, using solar hydrogen and atmospheric nitrogen.

Experimental findings are reported by the author and co-workers. Separation of salt brine (from inland sources or from the sea) was carried out in a gas bubbler using a modified Solvay process to study the conversion of sodium chloride into chemical products (namely sodium carbonate and ammonium chloride). The highest conversion achieved of sodium chloride was 82.2%, and the balance makes partially desalted water. Magnesium chloride is obtained as a by-product. The role of hydrogen as a vector coupled with solar energy for desert development is schematically illustrated.

Keywords: Solar hydrogen; Ammonia; Brine salt; Ammonium chloride; Soda ash; Fertile water

Introduction

As the population continues to grow in many parts of the world, the infrastructure that supports that population must be increased as well. Desert development represents a challenging problem that need to be solved. It offers one potential solution to problems of rural unemployment, urban overcrowding, and food security, if pursued in a sustainable means. World hunger is one of the most pressing problems of our time. To overcome it, the three basic economic resources that contribute to agriculture have to be satisfactorily provided. These are:-

- Arable land
- Water and fertilizers
- Energy

It is towards this objective that this study is carried out to harness the sun for desert development into useful and arable land.

Energy security is a challenge that we all face whether this is due to a lack of resources or a dependence on global markets or more recently the prospect of dwindling resources. Hydrogen offers a solution to this in that it can be produced domestically from available renewable sources of energy, in particular solar energy.

You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete. In this paper, we will explore the usage of hydrogen power as an effective means in desert development. A comprehensive and visionary approach that utilizes solar hydrogen, carbon dioxide and saline water resources is presented. Arab countries are taken as a case study to apply our proposed model, where the vast land resources and the abundant solar energy are very much in favour of this study.

The proposed system encompass three main components, as shown in Figure 1

1- Solar Hydrogen Production

2- Ammonia Synthesis

3- Chemical Separation Process of Saline Water Resources.

Solar hydrogen (H_2), once produced by water electrolysis [1-11] is utilized in the synthesis of ammonia (NH_3), a well-established process. Ammonia plays two distinctive roles in the proposed system:-

- As a source of nitrogen-based fertilizers
- As a chemical agent to be used in the separation of minerals salts for saline water resources.

The proposed separation process is carried out for highly-saline water (brine) using a non-conventional partial desalting method [12-14]. The method utilizes a series of chemical reactions involving the conversion of sodium chloride, the major constituent in saline waters, into sodium bicarbonate and ammonium chloride soluble in partially desalted water making what is called "fertile water". It involves the absorption of ammonia gas first, in the brine solution; to make what is called "ammoniated brine". This is followed next, by bubbling carbon dioxide into this brine.

***Corresponding author:** Hussein K. Abdel-Aal, Professor Emeritus of Chemical Engineering / Petroleum Operations, NRC, Cairo, Egypt, Tel: 20237499028; E-mail: habdelaal@link.net

Received July 25, 2014; **Accepted** September 22, 2014; **Published** September 25, 2014

Citation: Abdel-Aal HK (2014) From Solar Hydrogen to Desert Development: A Challenging Approach. J Chem Eng Process Technol 5: 209. doi: 10.4172/2157-7048.1000209

Citation: Abdel-Aal HK (2014) From Solar Hydrogen to Desert Development: A Challenging Approach. J Chem Eng Process Technol 5: 209. doi: 10.4172/2157-7048.1000209

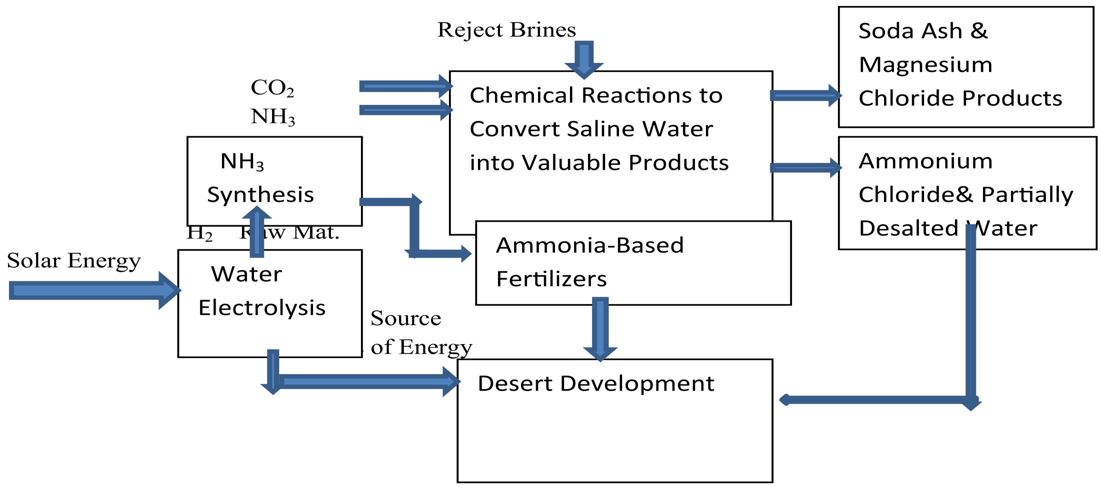

Figure 1: A Demonstration of the Role of Hydrogen Vector Coupled with Solar Energy for Desert Development.

Source of CO_2, Brines and Ammonia

CO_2

Almost all CO_2 emissions (about 96.5%) come from fossil fuels use. When fossil fuels are combusted, the carbon stored in them is emitted almost entirely as CO_2 causing what is known as the green-house effect. While CO_2 could in theory be extracted from the atmosphere, most of the CO_2 collected in processes would be derived from ammonia plants.

Brines

This proposal would be ideal for arid countries that have access to sea shores. Usually because fresh water is scarce, desalination plants are erected near or at sea locations.

It is estimated that the world production of desalination water exceeds 30 million cubic meters per day and the desalination market worldwide is expected to reach $30 billion by 2015 [15]. One of the major economic and environmental challenges to the desalination industry, especially in those countries that depend on desalination for potable water, is the handling of reject brine. Assuming that 50% of the intake sea water to be desalinated, then about 15 million cubic meters/day of rejected brines is produced. The common practice in dealing with these huge amounts of brine is to discharge back into the sea affecting seriously the aquatic life.

Ammonia

Ammonia is a principal raw material for the desalination process of brine along with CO_2 as shown in the diagram. The availability of solar hydrogen makes ammonia synthesis very feasible to produce by the well-established Haber-Bosch process [16].

Role of Solar Energy

Solar energy provides electricity via photovoltaic cells. Sunlight reaching the land surface of our planet can produce the equivalence of 1,600 times the total energy consumption of the world; the amount of solar energy derived from the sun's radiation on just one square kilometer is about 4,000 megawatts. Many of the Arab countries have all practical futuristic possibilities of supplying energy in significant quantity from their vast solar rich deserts, by erecting solar farms on them to generate power which could be used for hydrogen production.

In the wake of the first Gulf War, the US Army assessed Saudi Arabia's solar energy resource potential in a classified effort to determine how oil fires had affected the region. In addition to being a vast petroleum repository, the desert nation was also the heart of the most potentially productive region on the planet for harvesting power from the sun. Sitting in the center of the so-called Sun Belt, the country is part of a vast, rainless region reaching from western edge of North Africa to the eastern edge of Central Asia that boasts the best solar energy resources on Earth [17].

Role of Efficiency in Hydrogen Production

Having solar energy at hand, there is more than one option to generate electricity to be used in the production of hydrogen by water electrolysis.

The following data on efficiencies are cited in order to select the optimum path for hydrogen production [1].

E_1, Solar to EE = 20% (43.5 is the highest)

E_2, Solar to thermal = 80%

$E_{3,}$ Thermal to EE = 40%

$E_{4,}$ Electrolysis = 50-80%, use 70% as an average.

E_5 Hydrogen/EE (Fuel Cell) = >90%

Using these data, let us compare the following options to produce hydrogen from a sustainable energy source (solar energy):-

Option 1: To use E.E produced by PVC for water electrolysis, $E_{overall}$, for Hydrogen production = 0.435×0.7 = 30%

Option 2: To use E.E produced by thermal collector for water electrolysis, $E_{overall} =$ 0.8×0.4×0.7 = 22.4%

Water Electrolysis

The operation of an electrolyser is a trade -off between energy efficiency and productivity [18-21]. There is a minimum theoretical voltage required to split water (about 1.48 volt for the cell to remain thermally neutral), but practically higher voltages are required to overcome inefficiencies in the system. This additional energy is what we call "over-potential".

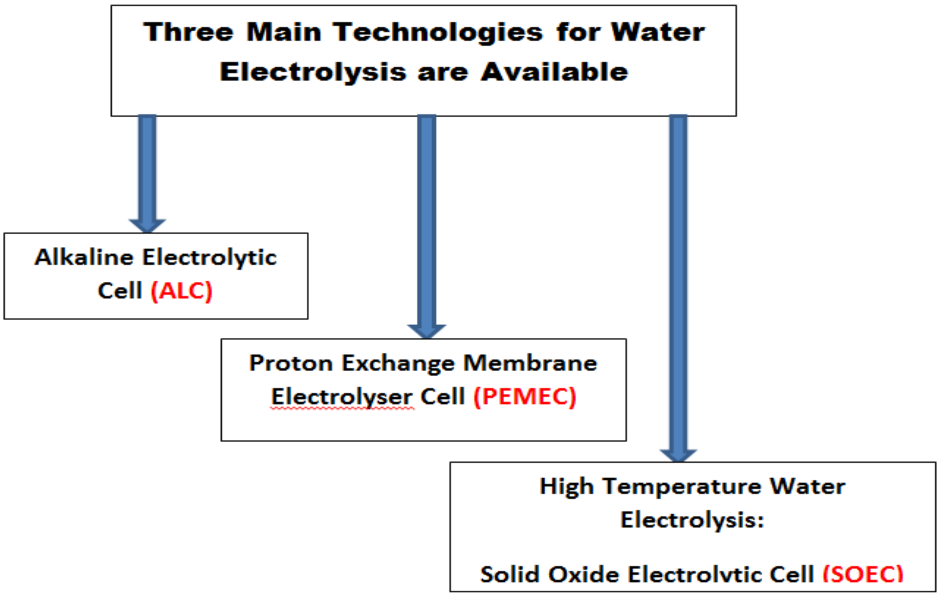

Figure 2: Technology Available for Water Electrolysis.

Type of technology cell	Electrolyte	Operating Temperature °c	Electrode Catalyst
AEC	KOH or NaOH	50-100	Nickel-based
PEMEC	H.P.M	20-100	Platinum/Iridium
SOEC	Ceramic	500-100	Nickel cement

AEC = Alkaline Electrolyte Cell
PEMEC = Proton Exchange Membrane Electrolyser Cell
SOEC = Solid Oxide Electrolytic Cell
H.P.M = Humidified Polymer Membrane

Table1: Technical data for the technology of cells used in water electrolysis

Now, the following scenario applies:-

- As the current density is increased between the electrodes, the over-potential increases. This causes heat to be generated, resulting in loss of efficiency.
- If, however, the current density is reduced, too little gas is produced.

Therefore, a balance has to be established for practical practice in electrolysis. There are a number of ways to reduce over-potential to allow for improved production while maintaining efficiency at the same time. This include:-

- Designing the electrodes in order to maximize the surface (contact area between the electrodes and electrolyte.
- The use of catalytic materials on the electrode surfaces.

Therefore, minimizing the over-potential contributes to lowering the operating costs of an electrolyser, since the cost of electricity represents a substantial element in the running costs. As far as the types of electrolyzers, three main technologies are recognized as shown in Figure 2.

A comparison between the three types of electrolysis cells is presented in Table 1.

High-temperature electrolysis (H.T.E.) or steam electrolysis is a method currently being investigated for water electrolysis with a heat engine. High temperature electrolysis may be preferable to traditional room-temperature electrolysis because some of the energy is supplied as heat, which is cheaper than electricity. Also, electrolysis reaction is more efficient at higher temperatures.

Hydrogen Production

Basis and assumptions

The average solar intensity flux = 700 Watt/m^2

- The average sunshine hours is 3000 annually
- The total land area of the Arab countries considered in the survey for producing non-fossil hydrogen ≈ 11 × 106 Km^2
- Only 1% of total land area is utilized for solar power generation
- The efficiency of solar conversion is taken 10%
- The efficiency of hydrogen production is taken 30%
- One cubic meter of hydrogen produces 3 Kw.hr (thermal)

Calculations

Based on the above, the following calculations are presented:

1st The total annual Kw.hr received by one m^2 = 0.1×0.7Kw × 3000 hr/y = 210 Kw.hr ≈ 200 Kw.hr

2nd The total annual Kw.hr received by land area = 0.01 × 200 ×11× 106 (Km^2) ×106(m^2/Km^2) = 22 × 1012 Kw.hr

3rd The annual hydrogen production = [0.3 × 22 × 1012] /3 = 22 ×1011 m^3 = 22 × 1011 × 83.76 (g/m^3) × 10^{-6}(ton/g)

= 184 × 106 Tons of Hydrogen/year

Ammonia Production

All nitrogen (N_2) fertilizers begin with a source of hydrogen gas (in our case it is the "Solar" hydrogen) and atmospheric nitrogen that are

Citation: Abdel-Aal HK (2014) From Solar Hydrogen to Desert Development: A Challenging Approach. J Chem Eng Process Technol 5: 209. doi: 10.4172/2157-7048.1000209

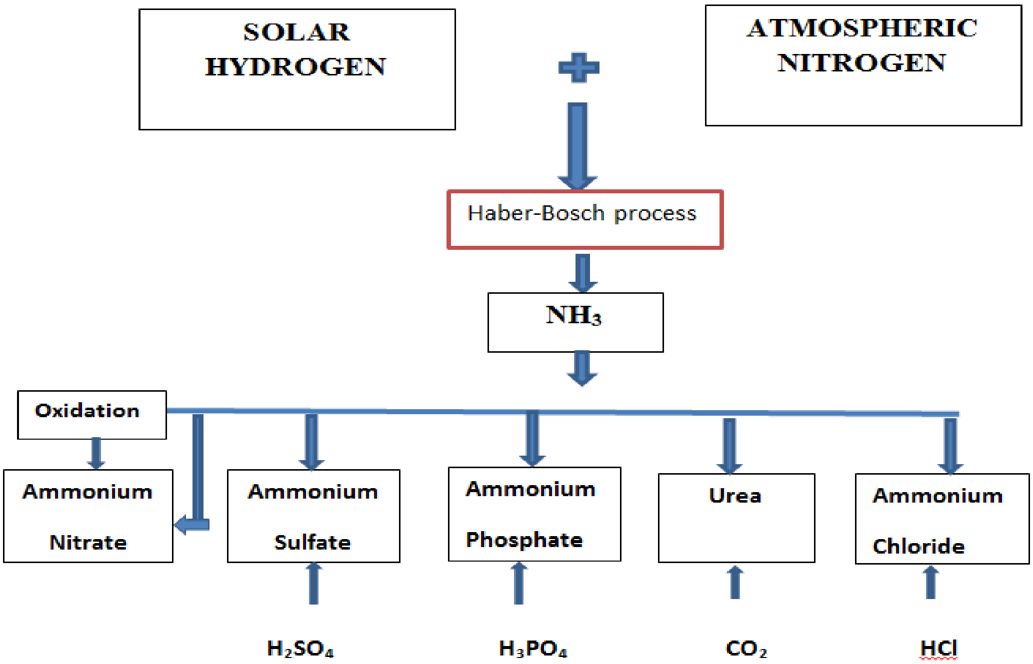

Figure 3: The Chain of Nitrogen Fertilizers produced from Ammonia using Solar hydrogen.

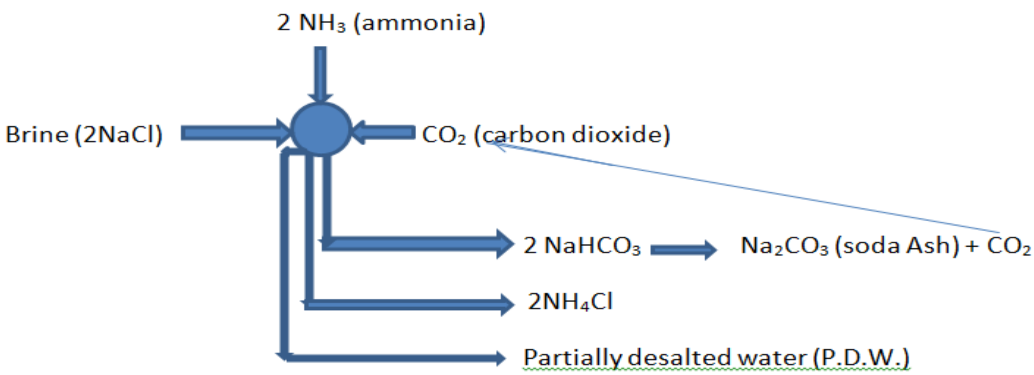

Figure 4: Input and Output for the Chemical Separation Process of Brine.

reacted to form ammonia using the well-known Haber-Bosch process [16].

Nitrogen is essential for many metabolic processes in plants and animals. Perhaps the best-known role of N is in forming amino acids, which are the building blocks for protein. Since the Haber-Bosch process for synthesizing N fertilizer was developed early in the 20th century, its importance in maintaining the global food supply has rapidly grown. It is estimated that half of the food produced now in the world is supported by the use of N_2 fertilizer. After hydrogen and N_2 are combined under conditions of high temperature and pressure to form ammonia, many other important N_2-containing fertilizers can then be made. Urea is the most common N_2 fertilizer, but there are many excellent N_2 fertilizers that can be made from ammonia. For example, some ammonia is oxidized to make nitrate fertilizer. This same conversion of ammonia to nitrate takes place in agricultural soils through the microbial process of nitrification.

Figure 3 represents a diagram for the different types of N_2 obtained from ammonia using solar hydrogen.

Details of the chemical separation process are illustrated in the block diagram, as shown in Figures 4 and 5.

Chemical Separation of Saline Water Resources

The proposed chemical separation process is credited to Abdel-Aal and co-workers [12,13]. The main feed input to this process is highly-saline water resource, which is best represented by the reject brines exit water desalination plants. Ammonia and carbon dioxide are introduced as chemical agents required for executing the underlying reactions, as explained next.

Process outline

As stated earlier, the proposed separation method utilizes a series of chemical reactions involving the conversion of sodium chloride

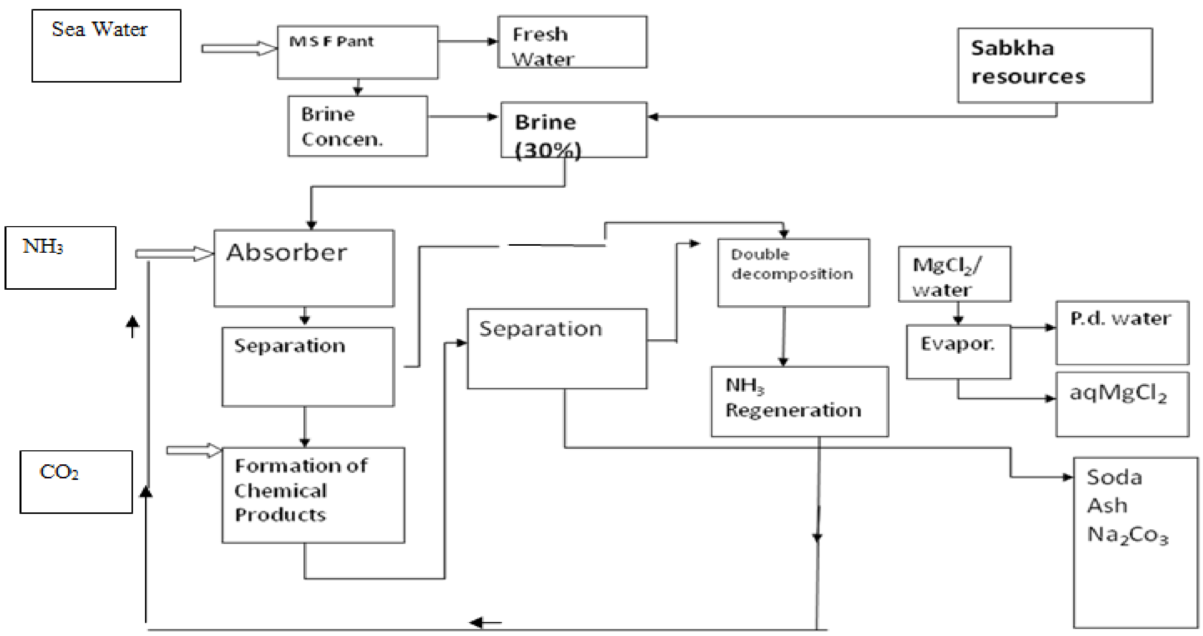

Figure 5: Block Diagram for the Chemical Separation Process.

the major constituent in saline water into sodium bicarbonate and ammonium chloride, by using ammonia and carbon dioxide respectively. The chemical production process involves the following consecutive steps:

1. Treating saturated brine (30 % sodium chloride) with ammonia gas forming what we call "ammoniated brine".
2. Bubbling carbon dioxide gas into the ammoniated brine will trigger a series of chemical reactions. This will lead to the conversion of both sodium cation and chloride anoion respectively into sodium bicarbonate and ammonium chloride.
3. Sodium bicarbonate precipitates under the experimental conditions (slight cooling) and is separated by filtration, leaving ammonium chloride in solution. Soda ash is produced as an end product by the calcination of the bicarbonate.
4. The overall reaction involved could be visualized to take place as follows:-

$NH_4HCO_3^- + NaCl$ à $NaHCO_3 + NH_4Cl$

Partial generation of ammonia gas could be done and recycled back by a double-decomposition chemical reaction with magnesium hydroxide, formed during the ammonia bubbling in the brine.

Ammonia regeneration:

$NH_4Cl + Mg(OH_2)$ à $NH_4OH + MgCl_2$

Reported Experimental Findings

As presented in reference [12,13] the feasibility of the process was investigated experimentally. Some of the results are reported:

a) The Separation of high-salinity synthetic saline water (brines) was carried out in a gas bubbler using a modified Solvay process. The conversion of NaCl in the ammoniated brine into $NaHCO_3$ and NH_4Cl was investigated. The highest conversion of NaCl achieved was 82.2%.

b) The effect of temperature, initial concentrations of NH_3 and NaCl, and the ratio of NH_3/NaCl were studied. An optimum separation temperature of 22°C was found.

c) Indigenous saline resources (such as Sabkha) are abundant in many regions at seashores in countries like Saudi Arabia and Egypt which can make the chemical separation approach very attractive.

Sabkha resources by definition are saline sources containing up to 4-5 mol/L of NaCl. When these resources are subjected to the proposed separation process, partially desalted water is obtained along with other valuable chemical products.

Conclusions

With desert covering a large part of its surface, Arab countries have to develop solutions and propose new strategies to overcome the lack of arable land and potable water. The proposed project begins with a vision of capturing solar energy to produce hydrogen and using it in an innovative way for desert development. The study makes the most from the sun to turn the desert into useful and arable land. Along with solar energy, access to sea water (salt brine) is required; both are abundant for many desert locations.

In the proposed scheme, producing solar hydrogen is considered the cornerstone of our process. Solar energy is used to generate electric power first, for water electrolysis. Once produced, hydrogen is combined with atmospheric nitrogen for the synthesis of ammonia gas. This represents a key source for nitrogen fertilizers.

Ammonia, along with carbon dioxide, assumes an important role to provide what is called "fertile water", in the chemical conversion of highly saline water and brines. Fertile water is defined, in this context as partially-desalted water containing ammonium chloride salt.

Saline-water resources are made available by utilizing rejects from water desalination plants, or using indigenous saline resources (Sabkha).

Solar energy is used to boost salinity of brine to a concentration of about 30% NaCl.

On the other side, other valuable mineral salts are recovered as well. Magnesium chloride, a raw material for the strategic element of magnesium metal, could be recovered.

In the proposed scheme, ammonia is consumed in producing ammonium chloride, as a fertilizer. However, provision could be made to recycle, at least part of the ammonia by regeneration as shown before.

Two options exist, either to have fertile water rich in ammonium chloride; or partially desalted water, ammonium-free to be used for irrigation.

References

1. Ohta T (1979) Solar-Hydrogen Energy Systems. Pergamon Press Ltd.
2. Abdel-Aal HK, Fahim MA, Gashgari MA (1974) Utilization of ConcentratedSolar Energy as a Source of Heat in the Production of Hydrogen.
3. Abdel-Aal GK, Peattie EG (1974) Hydrogen Opportunities in Saudi Arabia, Hydrogen Energy. Part A, Plenum Publishing Corporation, New York, USA 345-369.
4. Abdel-Aal HK (1976) Non-Conventional Energy Trends to Supplement Our Petroleum Reserves. Energy Communications.
5. Abdel-Aal HK, Al-Somait F (1978) Solar Energy Prospects in Saudi Arabia. Energy Communications 4: 271-291.
6. Abdel-Aal HK (1984) From Solar Hydrogen to Ammonium Fertilizers: An Assessment of Large-Scale Production in Saudi Arabia. Hydrogen Energy Progress V, Proceedings of the 5th World Hydrogen Energy Conference, Toronto, Canada 1803-1817.
7. Abdel-Aal HK (1986) Solar Hydrogen Energy Systems: Present State of the Art. Solar Energy Prospects in the Arab World, Pergamon Press 348-353.
8. Abdel-Aal HK, Mohammed MA (1989) Storage of Solar Energy in the Form of Hydrogen: A Pioneering Experiment in Egypt. Energy Sources 11: 95-103.
9. Abdel-Aal HK, Hussein AI (1992) Electrolysis of Saline Water Under Simulated Conditions of P.V. Solar Cell. Volume 1, 9th WHEC, Paris 439-442.
10. Abdel-Aal HK (1992) Storage and Transport of Solar Energy on a Massive Scale:The Hydrogen Option. Int J Hydrogen Energy 17: 875-882.
11. Abdel-Aal HK, Al-Naafa MA (1998) Prospects of Solar Hydrogen for Desert Development in the Arab Countries. Int J Hydrogen Energy 23: 83-88.
12. Abdel-Aal HK, Ibrahim AA, Shalabi MA, Al-Harbi DK (1996) Chemical Separation Process for Highly Saline Water: 1. Parametric Experimental Investigation. I&EC Research 35: 799-804.
13. Abdel-Aal HK, Ibrahim AA, Shalabi MA, Al-Harbi DK (1996) Chemical Separation Process for Highly Saline Water: 2. Systems Analysis and Modeling. I&EC Research 35: 805-810.
14. Hussein Abdel-Aal, Zohdy KM, Maha Abdelkreem, Abdelhamid SM, Bassyouni M (2013) A novel Application in Green Chemical Processing Using Reject Brines and Carbon Dioxide as Raw Materials. Engineering 5: 154-156.
15. Schorr M (2011) Desalination, Trends and Technologies. Corrosion Engineering, Science and Technology 46: 315-316.
16. Shreve NR (1967) Chemical Process industries. McGraw-Hill Company.
17. Middle East at a Glance: Includes Middle Eastern countries and Arab countries of North Africa.
18. Abdel-Aal HK, Hussein IA (1993) Parametric Study for Saline WaterElectrolysis-Part I: Hydrogen Production. Int J Hydrogen Energy 18: 485-489.
19. Abdel-Aal HK, Sultana SM, Hussein IA (1993) Parametric Study for Saline Water Electrolysis - Part II: Chlorine Evolution, Selectivity & Determination. Int J Hydrogen Energy 18: 545-551 (1993).
20. Abdel-Aal HK, Hussein IA (1993) Parametric Study for Saline Water Electrolysis - Part III: Precipitate Formation and Recovery of Magnesium Salts. Int J Hydrogen Energy 18: 553-556.
21. Abdel-Aal HK, Hussein IA (1992) Electrolysis of Saline Water Under Simulated Conditions of P.V. Solar Cell, 9th WHEC, Paris 1: 439-442.

Citation: Abdel-Aal HK (2014) From Solar Hydrogen to Desert Development: A Challenging Approach. J Chem Eng Process Technol 5: 209. doi: 10.4172/2157-7048.1000209