THE INTERCONNECTIVITY BETWEEN WATER AND ENERGY:
THE BENEFITS OF HALOPHILIC BIOFUELS

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I. Introduction

Human beings have made an undeniable impact on the world. While the ingenuity and innovation of man has resulted in a lot of beneficial advances, the modernization of civilization has come at the expense of the surrounding environment. Because of the interconnectivity of the ecosystem, a detrimental impact in one area resonates throughout the entire system. If neglected, issues such as climate change, rising sea levels, population increases, and competing resources will result in serious repercussions for the future of the United States.

Among these concerns is the management of finite resources. Two of the most influential resources in the United States are freshwater and energy. While these resources are often taken for granted, the availability of freshwater and energy are the foundation upon which the conveniences of modern day society exist. Water, though seemingly abundant, is primarily present in unusable form. Freshwater is distinct from oceanic water in saline content, a key difference that dictates its function. The limited supply of freshwater is compounded with the fact that water almost always requires treatment prior to consumption. The ability to process and treat water prevents illness and upholds the national standard of water quality. Treatment processes are generally highly water intensive and can place a stress on another key resource: energy.

Energy is produced from an array of different methods, including coal, gas, oil, thermoelectricity, and hydrogen. The production of energy calls for the use of freshwater in a panoply of processes ranging from steam injections, to mining operations, and many other applications. It is clear to see the inextricable relationship between water and energy. Energy is required to generate usable water, and water is required to produce energy. The overlapping
tension caused by the mutual demand of these resources creates an ever present stress on both the environment and the economy.

Having recognized the need to alleviate the tension caused by this competition for resources, the Bush Administration signed the Energy Independence and Security Act. This legislature promotes the production and implementation of biofuels to a further extent than already exists. Despite the good intentions of the plan, the use of most energy crops for fuel is questionable because not only do they compete with the food supply, they create heightened stress for other resources. Increasing biofuel production potential creates a dependency on the crops used to produce fuels.

Agricultural practices in the United States epitomize the inefficient use of water and energy that is present throughout the country. The need to mass produce key crops has championed the use of agricultural practices that are not sustainable and pose a serious threat to the health of the environment. These practices, as they relate to water and energy, influence the viability of biofuel as a feasible option for energy independence.

Currently, the United States produces corn-based ethanol as its primary source of biofuel. While other forms of biofuel are generated within the United States, they are trumped by the production ethanol derived from corn. The implications of this are multifaceted. Not only is the use of corn-based ethanol an inefficient use of freshwater, it competes with the food industry. This further competition of resources adds another dimension of stress to an already precariously balancing economy.

A potential solution is the use of halophilic, or salt tolerant, plants to produce biofuel. Decades of research have resulted in the discovery of biofuel that can be produced using
salicornia, referred to colloquially as “sea asparagus.” The salicornia plant thrives in saline waters and has the potential to generate energy without exploiting the limited freshwater supply. The salicornia crop is able to embrace seawater irrigation; salicornia crops takes advantage of the ocean, one of our most abundant resources.

In order to assess the applicability of halophilic biofuels to a sustainable society, a close examination of current halophyte projects is explored. The Seawater Foundation, and its counterpart the Global Seawater Institute, have implemented Integrated Seawater Farms. These farms capitalize on the use of seawater to irrigate salicornia crop, produce biofuel, and generate a host of other magnificent extraneous benefits. The foundation has done extensive work with this project along the coastal deserts of Mexico and has found much success. Understanding the potential application of halophilic biofuels to countries such as the United States could revolutionize the way energy is produced and consumed.

II. The Role of Energy in the Production of Freshwater

The water supply is deceptively scarce. While 70% of the earth’s surface is covered in water, 97% of that is ocean water and is high in salinity, making it unusable for most conventional purposes. The remaining 3% is fresh water; however, of that, close to 70% is tied up in glaciers and icecaps, leaving merely 1% of the world’s water supply in usable form. The accessible freshwater supply is generally in the form of either surface water or groundwater. Surface water accounts for 0.3% of Earth’s available freshwater; it is by far the most accessible source of freshwater and consists primarily of pristine lakes, swamps, and rivers. Groundwater is less accessible than surface water, but is significantly more abundant. A common misconception about groundwater is that it exists in the form of subsurface rivers and streams. Groundwater is in fact water that has been
drawn from below the earth’s surface through gravitational forces and collected in the form of saturated soil. An aquifer is essentially an area where the soil has acted much like a sponge in absorbing large volumes of water that can be extracted using ground wells. Natural filtration occurs in groundwater as the result of the water passing through the many layers of gravel, sand, silt, and clay on its way to the aquifer. Unlike surface water, which is visible above the surface, one of the challenges of groundwater is that it is difficult to locate and measure (US Geological Survey, 2009).

![Distribution of Earth's Water](image)

(US Geological Survey, 2009)

Given the immense amount of freshwater consumption that occurs on a daily basis, it is daunting to think that only 1% of the world’s water is actually available for modern day consumption. While water consumption is high in magnitude, the earth has natural mechanisms of renewing its resources. As a whole, the planet is a self-contained system. The hydrologic
cycle, as depicted below, tracks the movement of water from the earth up to the sky, through evaporation, and back down to the earth, through precipitation.

![Diagram of the hydrologic cycle](http://www.dnr.state.ne.us/watertaskforce/Resourcematerials/HydrologicCycle.jpg)

This cycle is essential because it replenishes and renews the world’s water sources. The hydrologic cycle has many implications for water usage. Not only does it highlight the conservation of water quantity, it reflects the consequences of water quality as well. The way that water is returned to the cycle affects all subsequent components of the water cycle. For example, water expended on irrigation is directly invested back into the water cycle, while water used on thermoelectric ventures is returned to the system in the form of produced water, which is water that is discharged with different temperature and chemical properties (U.S. Department of Energy, 2006).

While globally, the net water supply is robust enough to sustain the world’s population, the issue of water distribution poses significant challenges. The United States extracts 20% of its renewable water supply; however, freshwater sources are not necessarily spaced according to
demand (Thirlwell, Madramootoo, & Heathcote, 2007). An important note about the hydrologic cycle is that replenishing processes are not immediate; resources require time to renew.

Furthermore, despite the recharge of water sources through precipitation, the water supply is under extreme stress. As populations continue to grow, freshwater is being overexploited and causing water shortages nationwide. The map below, taken from a document released from the U.S. Department of Energy, depicts water shortage across the United States. The water shortage in this case is defined as a ratio between the amount of water withdrawn and the amount of water replenished through the hydrologic cycle. The numbers in the boxes indicate percentage growth of the regional population, which directly implies increasing demand.

(U.S. Department of Energy, 2006)

From the figure, it is clear to see that many of the most water stressed areas are also subject to rapid expansion in population. America is globally the number one consumer of
freshwater, and consumes 345 billion gallons of water per day. As shown in the figure below, 40% is used on agriculture and irrigation needs, while 39% is used on thermoelectric demands. Another 13% is expended on the public supply, 5% on mining, and the remaining 4% is split evenly between mining, domestic, aquiculture, and livestock.

(U.S. Department of Energy, 2006)

The most prominent usages of water are allocated towards energy and irrigation. Energy is a key factor in the usability of ground and surface water. Energy is most commonly used in the extraction and treatment of freshwater sources. It is often used in supplying and transportation of water as well, an expensive endeavor due to the high density of water. According to an article in the Oil and Energy journal, a doubling of the price of electricity would increase the price of water by 25-40% as a result of the transportation costs of water (Snow, 2009). This highlights the role of energy in the distribution of water.
The demand for energy in the production of usable water varies by region and water source. When using groundwater as a water source, energy concerns are concentrated on the extraction of groundwater. The amount of energy required to pump groundwater is directly linked to the depth of the water table. When water table depths are approximately 36.5 meters (120 feet), about 540 kWh per million gallons of water is needed for extraction; when the groundwater is deeper, at approximately 122m (400 ft), about 2000 kWh of energy per million gallons of water extracted is needed. Notice that the energy needed to extract groundwater from deeper depths is much higher, as is generally the case with groundwater extraction. The less robust the aquifer, the greater the necessary energy required to extract from it. Generally, groundwater does not require extensive purification due to the natural filtration mechanisms that take place during aquifer recharge. However, continual extraction of groundwater decreases the integrity of the water, leading to the formation of brackish water; this leads to the need for increased treatment of the brackish water, which is in turn more energy intensive.

Surface water tends to require less energy because it does not require deep extraction and other pumping systems that are common to groundwater extraction procedures. In comparison to groundwater extraction, however, a higher level of service and transport is often associated with surface water extraction. Also, highly polluted surface waters are more common making the treatment costs associated with surface water extraction relatively high (U.S. Department of Energy, 2006).

Freshwater solutions such as desalination and water reclamation are generally restricted by feasibility issues. Desalination, for example, is an entire order of magnitude higher in expenses for crop production (Edwards, 2009). Water reclamation, while a noble concept, does not change consumption enough to alleviate water issues.
III. The Role of Water in the Generation of Energy

The use of water in the production of energy is the flipside to the demand of energy on the generation of freshwater. Energy production in the United States is predominated by fossil fuels. In 2005, 40% of energy was produced by petroleum, 23% by coal, 23% by natural gas, and 14% by nuclear power, hydroelectric dams, and renewable energy combined (U.S. Department of Energy, 2006).

The high water demands of energy production has posed a challenge to further industrialization. A number of expansionary projects have been either rejected or regulated as a result of the strain the added energy demands would place on local resources. For example, the threat to the health of an aquifer system in Arizona led to the rejection of a permit for a proposed power plant in 2002. Likewise, Idaho found itself in a similar situation when it rejected the introduction of two power plants as well. Many other states are finding themselves constricted by the very apparent limited resource of water as it relates to an ever-growing need for energy production (U.S. Department of Energy, 2006).

Certain types of energy are absolutely dependent on water inflow. A clear example of this would be the role of freshwater in hydroelectric plants. The threat of drought or a limited water supply can cause the closing down of hydroelectric plants. Economically, this equates to lost jobs and lost revenue. Furthermore, hydropower plants are most often used to supply energy during peak demand; without a functioning hydroelectric plant, energy demands must be supplemented by natural gas, which is also a constricted resource.
As noted in the figure above, the current demand for water on the production of energy heavily rests on a few main sources: coal, gas, oil, hydrogen, thermoelectric, and biofuels. The water requirements for coal are associated primarily with mining and transportation operations. Mining demands water for the cooling, lubricating, cutting and drilling processes. Often times the coal is washed in order to optimize the production process, increasing the demand for freshwater associated with coal-based energy production. Additionally, water is often used to control ambient air pollution caused by mine tailings and other dust deposit that may result from hauling and transportation of coal. The other main application of water in the production of coal-based energy is for transport. Coal slurry refers to coal suspended in water, creating a sludge that allows it to be transported through pipelines. The coal slurries are sometimes treated, and the water is extracted and used for other parts of the energy production process; while this may conserve water, it further exacerbates the energy demands.
Oil production uses water for a number of purposes including exploring and producing crude oil, refining, and creating unconventional liquids, which include oil shale and liquid coal. The exploration and production of coal requires freshwater for pretreatment of oil and drilling. Much like mining for groundwater, the stability of the extraction source dictates the amount of energy required to successfully extract oil. In drier wells, secondary and tertiary methods are used. Secondary methods employ the use of freshwater for flooding, while tertiary methods use steam and carbon dioxide injections to extract oil. Clearly both of these processes require high amounts of fresh water, but are also quite consumptive of energy.

The entire process generates something called produced water. While the idea of generating water might sound appealing, it is actually quite misleading. Produced water is often much higher in temperature and altered in chemical content; many times produced water has a high salinity content and is not viable for recycled purposes. Furthermore, treatment is requires for this process; so while water might be generated, it is at the expense of a higher energy demand.

The production of unconventional liquids involves operations such as taking coal into a liquid form and producing oil shale. The production of these fuels requires water as an input for the boiler, general processing, and for cooling applications. The process and boiler water are consumptive, while the water used for cooling can be recycled. However, the recycled water is still subject to water losses of approximately 3-5%. Oil shale can undergo retorting, which is aboveground processing, or in-situ, or belowground processing. Retorting uses water to mine, drill and cool the shale during production and for transportation, dust control, fire control, and irrigation of revegetated sites. Approximately two-and-a-half to four barrels of water is needed per barrel of product. The in-situ process uses less water with a demand of one to three barrels.
of water per barrel of product and is used when mining options are not as feasible. The use of water in this process is for hydrofracturing inputs, generating steam, flooding, processing cooling, and rinsing the resulting product. Both methods are highly consumptive in water expected to be more widely used as prices for oil continue to rise.

Refining the crude oil now involves better processing methods which has increased the amount of water needed it is primarily used for cooler and boiler inputs. Roughly 70% of the consumptive water is lost due to evaporation and system inefficiencies.

Gas production uses negligible amounts of water for production; production of gas uses water primarily for cooling purposes, but at a relatively low demand. Pipeline transport of gas uses water primarily for hydrostatic testing. This process involves running high pressure water through the pipe system to track leaks and other potential pipe issues. The resultant water can be recycled, but would demand further energy requirements for this.

Unconventional natural gas production, such as tight sands and gas shale, also consume water. Tight sands use water for hydrofracturing. This process uses freshwater that is treated with a host of chemicals in order to increase gas yield by creating a greater surface area in the tight sand reservoirs. Shale gas production uses a comparative amount of water as seen in tight sand methods. According to a report by Argonne National Laboratory, an affiliate to the United States Department of Energy, the estimated water used by unconventional liquids is relatively low; however, production of unconventional liquids is localized, resulting in the overlap of resource demand (Elcock, 2008).

Hydrogen energy is not predominantly used in the United States, but is on the rise. In 2004, the Bush Administration proposed the Hydrogen Posture Plan, which champions the use of
hydrogen as a viable alternative for energy usage in the transportation sector. By 2030 to 2040, the plan aspires to have developed the technology to implement hydrogen energy commercially and develop the infrastructure necessary to transform the current United States into a “hydrogen economy.” The plan also looks to incorporate hydrogen energy with other renewable sources (US Department of Energy, 2004). These ambitions are noteworthy in terms of the benefits gained by cleaner automobile emissions; however it adds considerable tension on freshwater supplies. Estimates project that hydrogen consumes 18.8 liters of water per kilogram of hydrogen product. This water usage is allocated primarily towards treatment of the gas (reforming and shift factors), steam production, and cooling. While the current consumption of this method is not a significant fraction of the water demands for energy, government plans have primed this to be a highly incorporated and highly consumptive form of energy for the future (Elcock, 2008).

Thermoelectric power generation uses heating and cooling processes to create an electric potential. Consequently, a majority of the water consumption used for this method of energy generation is in cooling processes (Elcock, 2008). Advanced cooling methods pose the opportunity for more efficient water usage in thermoelectric plants; however, these are accompanied by issues such as high costs, scalability, and performance in warm climates.

Production of biofuels is currently the most consumptive use of water in the United States. Bioethanol consumes 62% of total consumption of energy production and is projected to demand as much as 84% in the year 2030. Within that projected biofuel demand for energy, 72% is expected to be attributed to ethanol production. Biofuel currently consumes water for irrigation and processing. The immense impact of biofuel on the demand of water for the production of energy makes it a prime candidate for further investigation. Ethanol is a significant aspect of the
biofuel sector and is generally produced from corn or cellulosic matter, which consists of wood-waste and other related materials. The distribution of ethanol production from these two sources however is heavily skewed.

(Elcock, 2008)

The chart above chart depicts the use of different ethanol sources. Clearly, corn-based ethanol trumps the use of cellulosic ethanol. One of the primary differences between the two is the degree of irrigation required to produce each form of energy. Many of the inefficiencies of biofuel production are linked to agriculture, as it is the starting point for ethanol production.

IV. The Role of Agriculture on the Production of Biofuels

The importance of energy extends to virtually every aspect of life. As the need for innovation in energy production becomes increasingly important, the use of biofuels has become a consideration. Fossil fuels are predominantly used and derive from fossilized organic matter
embedded in the earth’s crust. The combustion of fossil fuels results in cheap and immediate energy; this incomplete combustion is also responsible for the creation of greenhouse gasses and a large portion of air pollution. Unlike fossil fuels which have been formed slowly over hundreds of millions of years, biofuels are created from relatively new organic matter. Common biofuels are based on carbohydrates, such as sugars and starches, to produce alcohol (ethanol) that is then used as a base for fuel. Crops such as corn and soybean are commonly used to produce ethanol in countries such as the United States and Brazil. Other biofuels are made from oil-seed plants and are similar to vegetable oil. Popular oil-seed biofuels includes soybean biodiesel.

The agricultural practices associated with the harvesting of crops for biofuel has a direct influence on the efficiency of biofuel as an alternative energy source. The United States has built itself heavily on the ability to farm and depended almost exclusively on farming prior to the industrial revolution. Around the middle of the 20th century, agriculture moved from its traditional roots and became industrialized. This period, coined “The Green Revolution,” was based on the heavy use of fossil fuels to increase production. In his book, *Crash! The Demise of Fossil Foods and the Rise of Abundance*, Mark Edwards coins the “Green Revolution” as the “Black Revolution,” referring to the fact that most of the advances were based on the unsustainable energy of fossil fuels. During this time, the production of food increased 300% and was followed by a subsequent population increase. During this time, the government employed heavy subsidies and incentives to focus efforts on a select few crops to maximize production. The push to mass produce high yields of certain crops induced the distinguishing point between organic farming and industrialized farming. Farmers began to rely on heavy fertilization of land and increased irrigation technologies. The affect on the land was subtle at
first but has since proved to quite profound. In order to replace nutrients lost from farming mining for nutrients became a standard technology. This led to the self-destructive cycle that characterizes agriculture in the United States today. The high yield of crops is marked by the blatant misuse of natural resources. Industrialized farming has led to the gradual destruction ecosystems and soil integrity; additionally, it has contributed to increased pollution and extreme resource consumption. The benefit of this modernized agriculture was a tripling of the global food supply, allowing for the sustainability of a burgeoning population. The drawback was that in order to sustain this precarious balance in the long term, farmers had to continue these practices. Now, half a century later, farmers are faced with the repercussions of this endless cycle.

The advent of fossil fuels was the impetus behind modern day farming techniques. Suddenly, farm tasks that once took man 200 hours to complete could be accomplished by machine within an hour. Farming changed dramatically because of the introduction of cheap and available fuel that could power machines. Furthermore, farmers quickly learned that fertilizers, pesticides, and herbicides could protect their crops and maximize their yields. With the exception of transportation, the agricultural sector is the top consumer of energy; about a fifth of the energy consumed in the United States is put towards agricultural applications. Beyond the energy inputs necessary for plowing, tilling, aerating, and planting crops, tasks such as food processing, packaging, transporting, and fertilizing crops also requires a heavy energy investment.

This relates back to the same competition of resources that is prevalent in many other areas. Here, we see the need to produce food not only for the purpose of feeding a burgeoning population but also for the secondary application of the production of biofuels. The processes
used to generate the crops are both highly consumptive of freshwater and energy. While the net energy production of biofuels by some calculations is positive, the means of industrialized agriculture are absolutely unsustainable. One of the primary flaws with industrialized agriculture is the inefficiency of irrigation systems and the massive usage of fertilizers that have high associated energy demands (Edwards, 2009).

V. The Current Status of Corn-based Ethanol

Ethanol in the United States has been increasing in popularity. Brazil is known for its widespread use of ethanol as a viable source of fuel and it derives its ethanol from sugarcane. In the United States, ethanol is produced primarily from corn, and more recently from soybeans. The ethanol industry is highly expansive; in 1979, it was reported that 76 million liters, and by 2001, that number had risen to 6.4 billion liters (Dias de Oliveria, Vaughan, & Rykiel Jr., 2005).

Ethanol alone is not generally used as a source of fuel energy; rather, it is mixed with gasoline to form a mixture. E85 is the most commonly used ethanol-based fuel and is composed of 85% ethanol and 15% gasoline. By 2003, ethanol-based gasoline accounted for 10% of United States gas (Dias de Oliveria, Vaughan, & Rykiel Jr., 2005). By 2008, ethanol production has increased to 34 billion liters annually.

Federal mandates under the Energy Independence and Security Act (EISA) require that US production of ethanol increase to 57 billion by the year 2015. Corn ethanol, the leading source of ethanol production, accounts for 95% of bioethanol in the United States. Although ethanol-based gasoline produces a less carbon dioxide emissions when used as fuel for transportation, great oversight has been cast regarding the ecological and environmental impacts associated with actually producing this fuel. The water input for corn-derived ethanol is
approximated to be 263-784 liters of water per liter of bioethanol. As if the magnitude of water required is not striking enough, it is important to note that they generally fail to account for the irrigation of the corn—which is highly water and energy intensive. As mentioned previously, agricultural water usage comprises 40% of water use in the United States, and because of distribution issues, most of that water needs to be irrigated through various mechanisms. Estimates done in the Water Resources Science and Department of Bioproducts and Biosystems Engineering at the University of Minnesota have determined a more accurate range for the input of water, after taking into consideration regional irrigation practices, is 2-2138L of water per liter of ethanol. This study, by Wenchiu et. al, used state statistics on regional irrigation practices for 41 states from the years 2005 to 2008 in order to determine the amount of embodied water, or the water requirement from “field to fuel pump,” needed per liter of bioethanol. The research includes water used for irrigation as well as water used for processing within the refineries; it excludes the water received by corn crops through natural means, such as precipitation. The article assumed that the corn was grown in close proximity to the processing sites; of the 41 states that were examined, they found that one, New Mexico, imported the corn it used for the purpose of ethanol production. Additionally, the values for water investments for the bio-refineries assume dry-mill processing, which is used in 99% of ethanol production. Dry mill processing uses water for slurring, boiling, fermentation, and distillation stages of processing(Wenchiu, Walseth, & Suh, 2009).

Previous estimates of water per liter of ethanol have failed to include irrigation costs into the equation. Because irrigation is a large contributor to the water input of ethanol, it should be taken into consideration when evaluating corn ethanol efficiency. The results of the study conducted at the University of Minnesota found that production of a liter of ethanol required
between five and 2138 liters of water. Clearly this is an overwhelmingly broad range. General
trends from the study indicated that the amount of water needed to produce corn ethanol
increases from East to West across the United States. The study did not include water from
precipitation and other natural water sources as part of the water investment in energy production.
This may account for the stark disparity between the water requirements in different regions of
the country. Also, the availability of water in the various soil types may play a contributing role.
Among the states tested in the study, Ohio had the lowest water requirement, while California had
the highest. Despite the outrageous water inputs required for ethanol production in the
Southwest Region, three ethanol production facilities exist in California, and one is currently
under construction.

(Wenchiu, Walseth, & Suh, 2009)
It is counter-intuitive that the areas that require the most irrigation seem to be expanding corn ethanol production the most. Nationally averaged figures do not reflect this and are basically non-representative because the regions play such a significant role in irrigation needs.

One of the primary concerns of high water requirements in the Southwest is the fragility of the water table. Water consumption for biofuel can seem to have less of an impact because essentially the water is being returned to the earth in agricultural applications. However, it is important to bear in mind that even when water is absorbed by the earth and eventually added to the groundwater table, there is an immense energy cost, and subsequently a freshwater cost, associated with the extraction of water. Also, irrigation processes are costly and require additional energy inputs. Furthermore, the addition of chemicals and pesticides for growing crops for corn ethanol has a direct impact on the quality of water.

The Ogallala Aquifer, also known as the High Plains Aquifer, is an expansive, yet shallow, aquifer that spans eight states: South Dakota, Nebraska, Wyoming, Colorado, Kansas, Oklahoma, New Mexico, and Texas. The Great Plains region is historically significant as the site of the great Dust Bowl of the 1930s (Roberts, Male, & Toombs, 2007). The Ogallala Aquifer supports 27% of irrigation throughout the Great Plains region and 30% of national groundwater-derived irrigation. Additionally, the Ogallala Aquifer is the source of drinking water for 82% of the people in this region; that equates to roughly 2 million citizens. Since irrigation became popular in the 1940s, the High Plains Aquifer has seen a decline of over 100 feet (United States Geological Survey).

A highly depleted area is defined as being within a 50-foot radius of a portion of the groundwater table that has experienced a decline of at least 10 feet since 1980. In 2007, only a
handful of ethanol plants occupied these areas; however, with another nine plants under construction, ethanol capacity is expected to increase from 71.5 million gallons of ethanol per year to 639 million gallons of ethanol per year. This leads to a subsequent 900% increase in ethanol production in areas already facing high water stress. The potential for serious water shortages in these areas is remarkable. Estimates approximate a 2.6 billion annual increase in the demand for water due to ethanol production alone; the water demand for irrigation of those crops has an even further impact on water depletion of the water stressed High Plains region.

According to the statistics for the irrigation water requirements for corn, it is predicted that the irrigation needs for this area will add 59-120 billion gallons per year to support the new and existing ethanol production facilities (Roberts, Male, & Toombs, 2007).

(Wenchiu, Walseth, & Suh, 2009)
Corn, which is dependent on freshwater irrigation, requires 1,000,000 gallons of freshwater irrigation per acre. At an estimated yield of 140 bushels per acre, and 56 pounds per bushel, a single pound of corn consumes 128 gallons of freshwater. One gallon of water weighs 8.4 pounds; at that weight and that volume, the amount of energy and money that is invested in freshwater irrigation is remarkably high (Edwards, 2009).

VI. The Introduction of Halophilic Ethanol:

With the resource constraint of freshwater on the production of biofuels, researchers have explored alternatives to biofuel production. High salt content in soil has been the demise of civilizations. Almost a quarter of the world’s freshwater irrigated land is experiencing salinity issues. Furthermore sodicity, the presence of sodium in a soil, is a serious threat to the health of a soil. When salt, a dispersing agent, is present in soils at high levels, it breaks up the soil restricting drainage. Salt cannot be readily utilized by most plants; consequently, high salt content often leads to a build-up of salts along the root-zone of plants. There are two ways to remedy this issue: soluble salts either need to be leached out of the soil by applying copious amounts of freshwater, or other substances, such as limestone and gypsum, need to be added to replace tightly held sodium ions. Both solutions are temporary and often associated with high costs. With most water containing such high levels of salt, finding a way to incorporate salt into agriculture would be a monumental discovery.

In the past, the innovation of bioengineering has been applied in efforts to create salt-tolerance in domesticated crops such as corn and cotton. These efforts, however, have been largely unsuccessful. Alternatively, the use of halophylic plants poses has proved to be considerably more successful. Halophytes are salt tolerant plants that are commonly found on
coastal areas. These plants have the natural ability to thrive on saline water. Most freshwater plants can tolerate salt content of approximately 15 parts per million; halophytes can tolerate salt content of 30 parts per million, which is the salinity of ocean water. Some coastal halophytes can tolerate saline levels of over 40 parts per million. While these plants are not traditionally used as crops, it is important to bear in mind that all of our currently domesticated crops were once wild, and have been conditioned over the years to meet the demands of a modern society.

After investigating different types of halophytes, researchers have established salicornia bigelovii as a potential candidate for biofuel production. Salicornia, a halophyte, produces succulent seeds that can be used to generate biofuel (Glenn, Brown, & O'Leary, 1998).

(Hodges, Thompson, & Riley, 1993)

The crop used to produce SOS-7, Salicornia Oil Seed: Seventh Generation, produces a biomass of 20 metric tons per hectare, 10% of which is oil seed, which is comprised of 30% oil and 70% protein, a distribution similar to that of other oilseed crops such as soybeans. The salt content of the oil is low, at only 3% composition. Furthermore, the extraction methods currently
used for oilseed extractions apply to Salicornia as well (Hodges, Thompson, & Riley, 1993). The protein from salicornia can be used as a source of meal for livestock. This helps to combat one of the major shortcomings of corn-based ethanol: the effect of the increased demand for corn on other markets.

Corn as a fuel input is inefficient because it is used in so many other applications. Currently, corn is used as a source of ethanol production, but it is also a staple food item for humans and livestock. The use of corn in ethanol production increases its market demand. Consequently, the higher demand for corn increases its price, which not only affects the cost of fuel, but also increases the price of all food containing corn. While salicornia can still be used as a food source, but is not as prevalent as other crops such as corn and soybean.

The salicornia seed produces edible, nutty-flavored oil; it has texture similar to that of olive oil and a chemical composition similar to that of safflower oil. When used as a source of feedstock, salicornia is ideal due to the high levels of protein and digestible carbohydrates. The presence of saponins, a bitter-tasting compound, limits the amount of salicornia meal that can be incorporated into animal feed. Salicornia meal can still be used in moderate amounts in animal feedstock. Studies conducted on the effectiveness of salicornia-based animal feed showed that the feed can easily be ingested, and many animals were actually preferential to the taste of the feed. The quality of the meat that resulted from the livestock fed with experimental fodder was unaffected, and the feed was a good fattening agent. However, the amount of water the animals drank doubled due to the salty nature of the feed. Overall, the net amount of meat per kilogram was less than that of current feed. In addition to consuming the entire seed, the stalk of the plant can be used to rejuvenate top soil, and be used as a wood-like material in building (Hodges, Thompson, & Riley, 1993).
One of the benefits of using salicornia-based biofuel is that it does not require any major re-engineering of any equipment. The primary difference between salt water irrigation versus freshwater irrigation is the amount of water needed to sustain the crops. Traditionally, farmers irrigate crops when the soil is at half of its original field capacity, which is the level of water held by the soil after full drainage has occurred. Halophytes, however, need to be flooded to avoid the build-up of salt. Studies on the salicornia plant show that it can thrive in salinity contents nearly three times that of ocean water; however, the use of the saline water is selective. Consequently, increased irrigation prevents salt build-up along the roots of the plants. Ultimately, the halophytes need 35% more irrigation than the freshwater plants. This number seems relatively minimal when we consider how much more saline water is available in respect to salt water.

There are other disadvantages involved in using halophytes as a crop. The salicornia plant tends to flatten in the field, despite adequate nutrition and watering. Also, in many cases, the salicornia seeds shatter, or release, prior to harvest. This restricts yields, and ultimately the salicornia yields are only 75%, while traditional yields are 90% in other oilseed plants. Additionally, growth of the crop is restricted to subtropical areas that experience cool winters and warm summers.

There are many more benefits associated with salicornia harvesting. As mentioned before, one of the primary issues with salt in soils is the issue of drainage. With the close proximity to the ocean, drainage is much less of an issue. In a ten year pilot project conducted by the Environmental Science Laboratory at the University of Arizona, there were no drainage issues. Another advantage of using coastal deserts is that it poses no threats to the underground aquifer. While the issue of salinity threatens most freshwater aquifers, the aquifers used for
saltwater irrigation are already exposed to high salt levels. Furthermore, the ability to use the untapped lands for agriculture creates the opportunity to capitalize on non-competitive resources. Also, the barren nature of the coastal deserts poses less of a threat to the surrounding ecosystem. As opposed to destroying acres of rainforest to raise crops, barren coastal deserts can be used to gain the same benefits. The highest energy demands associated with freshwater irrigation are from pumping water from aquifers, which can exceed 100 meters in depth. When pumping water for salt water irrigation, the issue of deep aquifers is not an issue, greatly reducing the costs.

VII. Case Study: The Seawater Foundation and Global Seawater Institute

The technology of halophilic biofuel has been implemented through the efforts of the Seawater Foundation and the Global Seawater Institute (an affiliate of The Seawater Foundation). Using the fundamental research that prompted the creation of salicornia-based biofuel, the Seawater Foundation, a non-profit organization, has created sustainable ecosystems based on seawater farms. The purpose of looking at the work of The Seawater Foundation is to understand the potential application of halophilic biofuel in a sustainable ecosystem. Water and energy create the balance upon which the industrialized United States has grown to rest upon; likewise, understanding the role of new technology in a society can allow for its success to translate into our daily lives.

Dr. Carl Hodges, a former professor at the University of Arizona, created The Seawater Foundation. Dr. Hodges was the founding director of the University of Arizona’s Environmental Science Laboratory and was involved with many of the first steps of research on harvesting
salicornia for biofuel. After years of growing The Seawater Foundation, Dr. Hodges has recently founded a for-profit company called the Global Seawater Institute.

The main appeal of The Seawater Foundation is its ability to capitalize on non-competitive resources. After all, it is the competition between water and energy that has catered to the need for an energy revolution in the first place. In an excerpt from his report, *Global Warming: Effect, Solution, Opportunity*, Carl Hodges outlines the goals of The Seawater Foundation. The primary goal of the project is to introduce the use of SeaForest Biofuels, particularly SeaForest BioDiedel-10. This fuel is based on halophilic technology and is a key proponent in the success of the project. Other goals of the project include creating wealth and jobs, increasing freshwater resources, promoting biodiversity, sequestering atmospheric carbon, and curbing the affects of a rising sea level.

The Seawater Foundation has implemented the idea of Integrated Seawater Farms. The concept behind seawater farms is the creation of large, man-made streams and canals created for holding seawater. In these salt rivers, fish and shrimp can be harvested, while mangrove trees and salicornia plants use the stream as a means of irrigation. Because halophilic plants thrive on saline water, the salt rivers are an ideal source of nutrition. The salicoria crop can displace corn in terms of biofuel production by enabling the growth of SeaForest Biordiesel-10. The spillover benefits of this ecosystem extend far beyond the scope of relaxing the tension between water and energy. The many benefits of the Integrated Seawater Farm program are closely related to the interconnectivity between water and energy. The relationships between the spillover benefits of the seawater agriculture are modeled in the following diagram:
SeaForest Biodiesel-10 is based on a mixture of fossil fuel and salicornia oil seed. The name reflects the fact that the fuel is not only part of the SeaForest Biofuel line, but it also reflects its value on the SACB, or System Atmospheric Carbon Benefits. The system responsible
for the production of making the biofuel is capable of sequestering ten times the carbon that results from emissions. SeaForest Biodiesel is one of the few biofuels that can make such claims; it is quite impressive that the system is so sustainable. This implies that if one-tenth of the transportation sector were to adopt SeaForest Biodiesel-10 as their fuel of choice, carbon emissions from transportation would be virtually void. While these expectations sound lofty, they are possible, but would require much more cooperation. To put the SACB of SeaForest Biodiesel into perspective, it can be compared with those of corn-based ethanol and soybean-derived biodiesel. Soybean systems are able to sequester twice the amount of emissions they produce, meriting a SACB score of two. Corn ethanol on the other hand has a maximum SACB value of one, and is often estimated to be a negative value. The incredible feature of carbon sequestration through this project is made possible in part by the addition of mangrove trees and other ornamental halophytes that work in conjunction with the salicornia crop to reabsorb atmospheric carbon. Literature produced from The Seawater Foundation claim that the technology for salicornia-based biofuel has developed to the extent that it is already viable and capable of use for transportation. Further advantages of SeaForest Biodiesel-10 are highlighted by the array of accompanying benefits.

The constraint of freshwater availability for the growing demand for energy was partially the impetus for exploring salt-tolerant plants. In the Integrated Seawater farms, freshwater is not only conserved but also created under the proposed model of The Seawater Foundation. The most obvious benefit pertaining to freshwater comes from excluding the need for freshwater irrigation, which is a highly consumptive process. Using seawater irrigation saves hundreds of billions of gallons of freshwater consumption.
The creation of freshwater is particularly interesting. Water from the inland canals can evaporate into the atmosphere where it is returned to the cycle in the form of freshwater. More interestingly, however, is the creation of a water lens. There is a difference in density between salt and fresh water. Seawater is 1.027 the density of freshwater; this differential creates a water lens that is a source of freshwater that can be pumped and extracted. These areas can be gradually expanded, creating a new source of freshwater for many different operations.

According to Dr. Hodge’s projections, 60 cubic meters per second, or 1.5 million acre-feet per year, can be created in freshwater; furthermore, the entire system can produce more freshwater for irrigation and localized demands than the Central Arizona Project (Hodges, 2007).

The creation of economic growth through the introduction of SeaForest Biodiesel-10 separates the project from other experimental endeavors focused on improving biofuels. The use of the seawater channels as a site for the harvesting of shrimp and fish is ideal. This opens up a new opportunity for aquiculture, which not only creates jobs and wealth, but also increases the biodiversity of the area. Furthermore, the waste produced by the shrimp and fish provide an organic fertilizer for the salicornia and mangrove crops. Every aspect of the seawater farm contributes to the success of the ecosystem.

Another innovative benefit of the integrated seawater farms is the idea of pulling water from the sea inland in an attempt to control the rising sea level. Global warming has been a prominent issue that is gaining even more attention. Factors such as the glacial melt of polar caps and thermal expansion threaten to flood coastal communities, and even national icons such as the Florida Everglades. According to projections by The Seawater Foundation, sea levels are expected to rise as much as 1010 cubic kilometers per year. To combat this The Seawater Foundation proposes an increase to 25 million hectares of integrated seawater farmland to restore
the balance of the earth’s resources. One of the benefits of the Seawater Foundation is that it uses uninhabited coastal deserts. The use of seemingly obsolete land makes access to such large areas more realistic. Furthermore, unlike conventional farmland (such as that used for producing energy crops such as corn), the seawater farms do not disturb the ecosystem to such a drastic extent. Current projects in Bahia Kino Mexico have proven the success of this method. At a projected cost of $2,000 per hectare, the idea of converting coastal deserts into farmland sounds appealing (Hodges, 2007).

VIII. Conclusion:

With time, industrialization has become the metric of progress. Because of the inventions of the modern world, access to resources is seemingly effortless. It is easy to forget the limitations that arise from the laws of scarcity.

The introduction of halophilic biofuel brings with it hope for a more efficient economy. In the past agriculture has been built upon an unstable foundation where the mass production of energy crops, fossil fuels, and synthetic fertilizers contributes to the rapid depletion of precious resources. The idea of developing a society around saline water, one of Earth’s most bountiful resources, indicates a step towards innovation and efficiency that could set a global standard for industrialized and developing countries alike. This becomes especially important as the world continues forward in a global economy, because ignoring the building tension created by competing, finite resources could result in grave consequences.

One of the fears of globalization is that everyone is playing the same game, but by different rules. People fear that incorporating the environment into the bottom line will cripple competition, as global competitors may not adhere to the same rules and regulations. It is a
classic case of the prisoners’ dilemma, where both parties fail to optimize for fear that the other is not playing fair. Transforming resource management into a serious consideration for industries and nations cannot be realized through idealism alone, but through economic growth. By redefining the consumption of natural resources, the stress placed on their allocation will lead to industrialization that expands the economy. Developing countries will have the financial means to satisfy their basic needs, and can then turn their attention to protecting the environment. Already industrialized countries will have the means to continue to provide a national standard of living that is robust and can withstand the natural depletion of resources. Learning to not just compete, but to collaborate on a global scale would allow the world to unify over a central cause, where optimization is realized through growth, not hindered by fear of the competition.
Works Cited


