# Feasibility of Biomass Energy Production to Support Local Water Self-Sufficiency

**Report to the Western Governors Association**

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*California Department of Food and Agriculture*
*Office of Agriculture and Environmental Stewardship*

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**by**
**The California Department of Food and Agriculture**
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## Abstract

A preliminary evaluation was made of the technical feasibility of transferring electricity from biomass as "virtual water" in place of direct water transfers to provide for water needs of coastal urban areas while maintaining productive use of agricultural land. Electricity would be used to desalinate ocean or provide other water treatment to meet urban demand. The study focused primarily on the Imperial Valley of California, with an examination of selected sugar crops to provide ethanol and power. High yields of biomass along with lower energy demands associated with RO desalination approaches may provide conditions under which virtual water transfers prove feasible. These estimates are uncertain, however, and further analysis will be required to determine optimal supply conditions, economic feasibility, and lifecycle environmental performance.

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# Introduction

Water supply and management continues to be one of the most contentious natural resource issues in California. Californians depend on a complex and sophisticated water supply and transport infrastructure, one which is becoming increasingly subject to often competing demands regarding reliability, growth, and environmental impact. The water acquisition, storage and transport infrastructure is also highly dependent on electric power. The linkage between water and power has long been recognized, but until recently has not been examined in depth from both a supply and demand perspective.

Over the last fifteen to twenty years, competition for water supplies has increased dramatically, spurred on by population growth and the rightful recognition of the need to maintain stream and river flows and aquatic and related habitats. Absent additional water supply and transport infrastructure development during this period, urban and environmental water supply increases have been met largely from water reallocations and transfers from agriculture. Reallocation and transfer agreements between municipal and agricultural sectors rely on fallowing and retirement of agricultural land from irrigation to provide the water in order to meet physical or "real" water demands. Fallowing and retirement of often highly productive agricultural land results in a loss of the agricultural resource base and associated loss of economic activity to local agriculturally based rural communities.

As water supply reliability issues heighten at the regional and state levels, a new systems analysis that strengthens the linkage between water supply and renewable energy may provide pathways to systems improvements mutually beneficial to rural and urban areas of California. This study is an initial attempt at defining a new energy-water substitution mechanism to improve and expand flexibility in managing California's vital water and energy resources.

# Background

## Virtual Water

Virtual water is the water embodied in producing a particular good. For example, water is required to produce food - cereals, vegetables, meat and dairy products. To produce one kilogram of wheat requires about 1000 liters of water. Meat production embodies about five to ten times as much water by weight. This accounts for the large share of fresh water used in food production. Globally, agriculture demands 70 percent to 80 percent of fresh water supplies.

Virtual water trade is the trade of goods, especially food. There is a virtual flow of water from commodity exporting countries (food and manufactured goods) to the countries that import those commodities. Instead of producing these goods themselves, the importing country can use local water resources for other purposes that otherwise would have been necessary for the domestic production of the same goods.

It follows that water-rich countries profit from their abundance of water resources by producing water-intensive products for export. Virtual water trade between nations and

even continents is used as an instrument to improve global water use efficiency, to achieve water security in water-poor regions of the world and to alleviate the constraints on the environment by using best-suited production sites.[1]

The concept of virtual water trade might be applied to improve water use efficiency in California by exploring it from a slightly different perspective. Agricultural water supplies (real water) are currently physically transferred at great energy, monetary, and political expense to costal urban areas under various water settlements and transfer agreements, such as the Colorado River Quantification Settlement Agreement (QSA) and the Palo Verde Water Transfer Agreement, that require massive fallowing of highly productive agricultural land. If instead the water were used in its area of origin to produce a bioenergy crop, economic activity associated with agricultural production on the land would be retained. A bioenergy crop such as sugar cane in the right location could produce virtual water in the form of electricity that could be "transferred" to coastal urban communities to enhance local water supply reliability by providing the energy needed for water recycling, reuse, treatment, conjunctive use, reclamation and desalination. This study is an initial exploration of the feasibility of this concept.

## The Water-Energy Nexus

According to the Water Subgroup of the California Climate Action Team, approximately 19% of electricity and 30% of natural gas (non-power plant) consumed in California are used to deliver, treat, and dispose of water. Long-distance water conveyance, such as that from Northern to Southern California, accounts for a significant portion of the energy used to provide water. Water recycling reduces energy use by providing local water more efficiently than importing "new" water from non-local sources. The Subgroup goes on to recommend that renewable energy be expanded to provide the power needed to treat and recycle urban water.

## Water Transfers – The Quantification Settlement Agreement

California is allotted 4.4 million acre-feet of water from the Colorado River. Historically the state had been taking up to 1.1 million acre-feet of "surplus water" allocated to other states. The Quantification Settlement Agreement (QSA) and Related Agreements of 2003 settled certain disputes among the federal government, the State of California, Imperial Irrigation District (IID), Metropolitan Water District (MWD), Coachella Valley Water District (CVWD) and the San Diego County Water Authority (SDCWA) to ramp down California's use to the allotted 4.4 million acre-feet. Provisions of the QSA are in place for 35 to 75 years.

Provisions of the QSA included conserved water transfer agreements between IID and SDCWA, IID and CVWD and IID and MWD. These contracts identify the conserved water volumes and transfer schedules for IID along with the price and payment terms. As specified in the agreements, IID will transfer to SDCWA up to 200,000 acre-feet per year (AFY) and to CVWD and MWD combined up to 103,000 AFY of water conserved from delivery system improvements and on-farm efficiency improvements.[2]

[1] World Water Council. 2004. E-Conference Synthesis: Virtual Water Trade - Conscious Choices, March 2004. http://www.worldwatercouncil.org/index.php?id=866
[2] http://www.iid.com/Water_Index.php?pid=61

A fundamental dispute between the Imperial Irrigation District and the San Diego County Water Authority has emerged over the socioeconomic impacts of fallowing in the Imperial Valley. A Local Entity has been established to determine the magnitude of the socioeconomic impacts and implement a mitigation plan. SDCWA disputes that these impacts exist.[3]

Under the QSA, a 15-year fallowing program was implemented to conserve water for transfer to SDCWA. The program ramps up for the first 10 years and then decreases for the next 5 years as efficiency conservation projects are developed and implemented. Efficiency conservation will replace all fallowing by 2018. Mitigation to provide inflows to the Salton Sea is also a part of the program. Based on the QSA, IID transferred 10,000 acre-feet (AF) to SDCWA in 2003 and another 20,000 AF in 2004, and the amount of water transferred to SDCWA will reach 200,000 AF by the year 2021 while the amount transferred to CVWD will reach 103,000 AF by the year 20264.

The fallowing program provides that willing land owners and/or lessees will contract with the IID to fallow fields to meet the transfer and Salton Sea mitigation water needs for the first 15 years of the IID/SDCWA and QSA Compromise Delivery Schedule. Each year the price for the water to be conserved from fallowing is set by IID and solicitations are sent out asking for voluntary participation to fallow a field in return for payment for the conserved water. Each field is limited to participate in the fallowing program two in every four years. However, this program results is a 15-year net loss of approximately 50,000 to 75,000 acres of highly productive agricultural land and the associated economic activity resulting from that land being in production.[5]

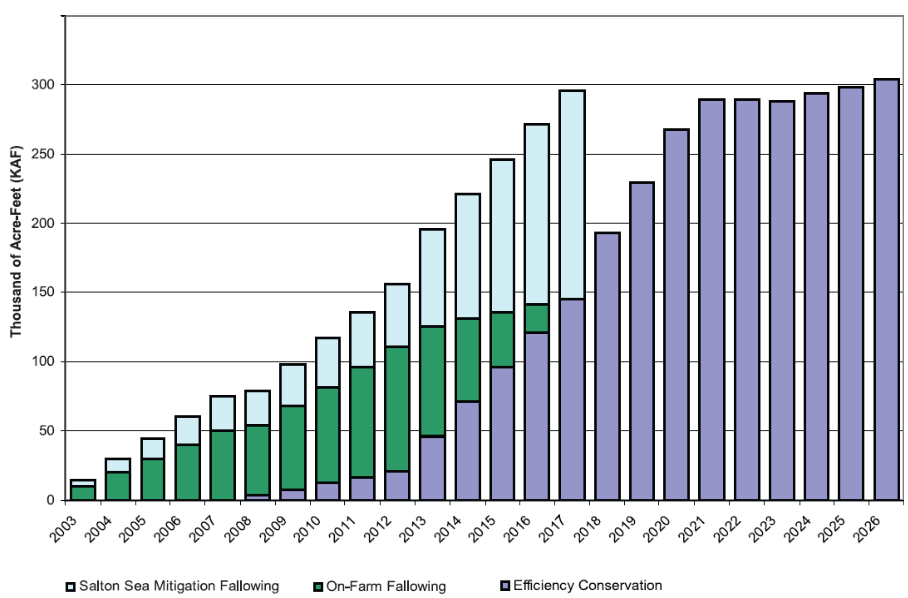


Figure 1. Fallowing and efficiency conservation allocations under the QSA.

[3] http://www.iid.com/Water_Index.php?pid=2227

[4] Quantification Settlement Agreement: Imperial Irrigation District/San Diego County Water Authority, Water Conservation and Transfer Agreement, Annual Implementation Report. 2004.

[5] http://www.iid.com/Water_Index.php?pid=267

Over 80% of California's population lives along the Pacific Coast. At present, many coastal municipalities and utilities are challenged by population growth pressures and new prolonged drought patterns that threaten the long-term sustainability of water supplies. By the year 2030, the state's population is projected to increase from 36.5 to 48 million, which in turn would require over 1,000 million gallons per day (MGD) of new fresh water supplies[6]. Recognizing this water demand is not likely to be met by only relying on traditional sources of water supply and aggressive conservation and reuse, the California Department of Water Resources is investigating seawater and brackish water desalination as a permanent addition to the state's water portfolio. Currently, Southern California imports 50% of its water from two main sources: the Sacramento River-Bay Delta, and the Colorado River. In Northern California, if construction of seawater desalting plants is found viable, the desalination initiative may yield one to three seawater desalination plants with a total production capacity of 20 to 80 MGD.[7] To date, about one dozen existing desalination facilities have been located along the coast, and about 20 are in various stages of planning (Tables 1 and 2).

Table 1. Existing desalination facilities along the California coast.

| Operator/location | Maximum capacity | Technology | Source | Discharge | Status |
|---|---|---|---|---|---|
| Chevron/Gaviota | 410,800 gpd, 460 AF/yr | | Ocean | Ocean | Active |
| City of Morro Bay | 600,000 gpd, 672 AF/yr | | Seawater wells | Not known | |
| City of Santa Barbara | | | Ocean | Not known | Inactive |
| Duke Energy/Morro Bay Power Plant | 430,000 gpd, 482 AF/yr | | Ocean | Blending w/ cooling water | |
| Duke Energy/Morro Landing Power Plant | 480,000 gpd, 537 AF/yr | distillation | Ocean | Blending w/ cooling water | Active |
| Marina Coast Water District | 45,000 gpd, 50 AF/yr | RO | Seawater wells | Injection well (beach) | Active |
| Monterey Bay Aquarium | 40,000 gpd, 45 AF/yr | RO | Ocean | Combined w/ other seawater discharges | Active |
| PG&E, Diablo Canyon/San Luis Obispo County | 576,000 gpd, 645 AF/yr | | Ocean | Blending w/ cooling water | |
| San Simeon/San Luis Obispo County | 10,000 gpd, 11 AF/yr | | Ocean | Not known | Inactive |
| Santa Catalina Island | 132,000 gpd, 148 AF/yr | | Seawater wells | Not known | |
| U.S. Navy/San Nicolas Island | 24,000 gpd, 27 AF/yr | | Seawater wells | Not known | |
| Various offshore oil&gas platforms | 2,000-34,000 gpd, 2-38 AF/yr | | Ocean | Ocean | Active |

[6] Pretreatment Solutions, Winter 2006/2007. American Membrane Technology Association.
[7] Desalination Task Force – Desalination Issues Assessment Report, 2003. California Department of Water Resources.

Table 2. Proposed desalination facilities along the California coast.

| Proponent/location | Maximum capacity | Technology | Source | Discharge | Status |
|---|---|---|---|---|---|
| Cambria Community Service District/San Simeon | 430,000 gpd, 481 AF/yr | RO | Seawater wells | Subsurface exfiltration | Planning |
| Cannery Row Marketplace/Monterey | 5,000 gpd, 6 AF/yr | RO | Ocean | Pipeline to ocean | FEIR certified by City of Monterey |
| Carmel Area Wastewater District | Not Known | | | | |
| City of San Buenaventura | Not known | | | | |
| City of Sand City | 27,000 gpd, 50 AF/yr | RO | Seawater wells | Injection well | Planning |
| City of Santa Cruz/Santa Cruz | 2.5 mgd w/ expansion | RO | Ocean | Blend w/ sewage outfall | Planning |
| East-Wet Ranch/Cambria | | | | | Withdrawn |
| Fort Ord State Park/Monterey County | | | | | Being researched |
| Long Beach/Haynes Generating Station | 300,000 gpd | Two stage NF | Ocean | Seawater reconstituted | Design/Construction |
| Long Beach | 9 mgd, 10,000 AF/yr | Two stage NF | Ocean | | Initial planning |
| LA Department of Water and Power /Playa del Rey | 12 mgd, 11,000 AF/yr | RO | Ocean | Blend w/ cooling water | Planning, 2010 target |
| Metropolitan Water District of Southern California | 5 mgd, 5,600 AF/yr | | Ocean | | |
| Monterey Bay Shores/Monterey County | 20,000 gpd | RO | Seawater wells | Injection well | Not likely, backup plan |
| Monterey Peninsula Water Management District, Carmel River/Sand City | 6-9 mgd | RO | Seawater wells | Injection well | Preliminary work on EIR |
| Municipal Water District of Orange County/Dana Point | 27 mgd, 30,240 AF/yr | RO | Ocean | Pipeline to ocean | Working on DEIR |
| Poseidon Resources/Huntington Beach | 50 mgd | RO | Ocean | Blend w/ cooling water | |
| San Diego County Water Authority & Poseidon Resources/ Carlsbad | 50 mgd, 56,000 AF/yr | RO | Ocean | Blend w/ cooling water | |
| Sterling Hotel/Sand City | 20 AF/yr | | Seawater wells | | |
| | | | | | |

Table 2 (continued). Proposed desalination facilities along the California coast.

| | | | | | |
|---|---|---|---|---|---|
| Santa Cruz County Sanitation District | 3-14 mgd | | | | Planning |
| U.S. Navy, North Island Naval Air Station/San Diego | 700,000 gpd | | Seawater wells | | |
| West Basin Municipal Water District/El Segundo | 20 mgd, 22,400 AF/yr | RO w/ MF | Ocean | Blend w/ cooling water | Pilot plant on-line, 2008 target |

# Bioenergy Alternatives to Conventional Water Supply

## Objectives

This report includes an analysis of crops that can be grown to generate energy as a primary or a secondary product. This energy production is compared with energy use required to create potable water in coastal urban areas from ocean and other saline or degraded waters. The use of these local resources eliminates the energy demand for moving surface water over high elevations and long distances. The bioenergy alternatives described here serve to create a system by which electricity transfers are substituted for direct water transfers.

As a case study, the transfer of electricity generated using bioenergy crops from the Imperial Valley to the San Diego metropolitan area for the purposes of producing potable water is evaluated in comparison to the current plan of continuing to supply Colorado River water through the QSA.

The Imperial Irrigation District has finalized the QSA with other agencies located in Southern California to sell water. In order to meet the growing water requirements from these communities, Imperial County growers and the IID may be influenced both economically as well as politically to transfer larger quantities of water in future years. The question is whether a sufficient amount of water with feasible price and acceptable quality and environmental impact can be provided in the coastal area by desalination using energy generated in the Imperial Valley. The analysis of the latter is conducted assuming an annual water use of 303,000 acre-feet for crop production that otherwise would be transferred for municipal supply.

## Bioenergy Crops

### Sugarcane

Sugarcane is a tropical crop that throughout the world is processed into raw sugar and molasses. In the United States, sugarcane is planted and harvested in primarily in Hawaii, Florida, Louisiana, and Texas[8]. Sugarcane has been grown in Imperial County since 1950's, but has never been a major crop. It requires good sun and warm temperatures during the growing season as well as fairly large amounts of water. Imperial County receives sustained and intense sunlight to support sugarcane growth.

[8] USDA The economic feasibility of ethanol production from sugar in the United States. July 2006.

Even though the county has low precipitation, irrigation water from the Colorado River via the All-American Canal is supplied for agricultural purposes and could be used for sugarcane production as one bioenergy crop.

Sugarcane production in California has the potential to produce both a cash crop for farmers and substantial amounts of ethanol and electricity. There has been increasing interest in Imperial County over the possibility of sugarcane production, although a number of concerns have developed including whether cane-derived ethanol would be suitably credited under the state's low carbon fuel standard. A meeting organized in 2006 as a preliminary step for the present study between representatives of the California Department of Agriculture and local growers was well attended by growers, the Farm Bureau, representatives of the Imperial Irrigation District, and a local sugarcane growers interest group. Representatives of the Imperial Irrigation District, the Farm Bureau, and farmers agreed to help serve as an advisory committee for future studies on ethanol production.[9]

## Sugarcane Production

Although generally associated with tropical climates, sugarcane has been a major cash crop in the United States for decades and has been cultivated in areas of the United States since before the American Revolution. In 2005 there were over 900,000 acres of sugarcane under cultivation in the United States.[10]

Sugarcane is a perennial crop that can be harvested 4 to 5 times before reseeding. Traditionally suited to growth in hot humid areas, principal US production areas are in Florida, Louisiana, Texas and Hawaii. Yields vary among the states. On average, an annual harvested acre of sugarcane yields 3.55 tons of sugar. The average recovery rate, that is the quantity of sugar as a percentage of total cane, is 12.33 percent.[11]

Sugarcane has been grown in Imperial County since at least the 1950's. It has never been a major cash crop; rather, it has been grown primarily in small plots for pasture and research. Imperial County's long, sunny growing season provides for excellent sugarcane development. The area's lack of natural rainfall, less than 3 inches a year, is made up for by its abundant supply of irrigation water from the Colorado River via the All-American Canal. In 1997 the University of California, Davis Research and Extension Center (DREC) began a study on sugarcane's growth capabilities in Imperial County, studying twenty-two commercially available sugarcane varietals. Farm trials began the following year for 11 varietals with promising results.

## Sugarcane Production Yields Across the United States

Production yields for sugarcane vary widely in the United States among producing regions. Three important factors are typically used in assessing the quantity and quality of sugarcane produced: the sugarcane yield-per-acre, the average recovery rate, and the sugar yield-per-acre. The recovery rate is the amount of sugar present in the

[9] Notes on file with the principal author
[10] USDA The Economic Feasibility of Ethanol Production From Sugar in the United States, pg 16. July 2006
[11] USDA The Economic Feasibility of Ethanol Production From Sugar in the United States, pg 16. July 2006.

sugarcane itself. This number varies between growing zones and even between growing years depending on growing conditions. The recovery rate and the cane yield-per-acre establish the sugar yield-per-acre.

Hawaii is by far the best growing region within the United States. There the recovery rate is often over 12% and exceed 14.5% in 2005 and 2006.[12] Sugarcane yield-per-acre in Hawaii is often double what it is in other sugarcane producing states. Per-acre yields exceed 80 tons per year.[13] Greater cane yield coupled with higher sugar content lead directly to sugar yields-per-acre double or triple what they are in other producing states.

Despite Hawaii's impressive ability to grow sugarcane, its total acreage dedicated to cane production fell from a high of 104,800 acres in 1981-1982 to 24,200 acres in 2005.[14] This drop in production acreage is due primarily to conversion of agricultural lands to residential and tourist development.

Sugarcane has been expanding in less productive areas such as Louisiana. Louisiana's cultivated acreage grew from 247,000 acres in 1981 to 420,000 acres in 2005.[15] Louisiana's sugarcane yield per acre, however, is of the order of 25 tons per acre -- less than one-third that of Hawaii's, and sugar yield per acre is about one-third that of Hawaii's at approximately 3 tons per acre.

Louisiana and Hawaii are the two extremes of sugarcane cultivation in the United States. Florida and Texas, the other producing states, tend to have slightly higher yields than Louisiana, but considerably below the yields found in Hawaii. On average, Texas has a 40 ton per acre sugarcane yield and recovery rate of around 10.5%.[16] Florida's sugarcane yields average about 37 tons per acre with recovery rates usually about 12%,[17] for an average sugar yield about 6% higher than that of Texas.

**Capacity and Quality of Cane Production in Imperial County**

No large-scale production of sugarcane exists in Imperial County. In addition to the DREC studies mentioned above, the Imperial County Sugarcane Growers association has also been conducting its own long term studies on growth. The DREC results indicated good growth potential in the Imperial County, second to Hawaii in terms of production yields (Table 3).

DREC's initial sugarcane study averaged 67.9 tons of sugarcane per acre. Across 22 different sugarcane varieties, yields ranged from 47.5 tons/acre-year for variety HOCP

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[12] USDA The Economic Feasibility of Ethanol Production From Sugar in the United States, pg 47. July 2006.
[13] USDA The Economic Feasibility of Ethanol Production From Sugar in the United States, pg 47. July 2006
[14] USDA The Economic Feasibility of Ethanol Production From Sugar in the United States, pg 47. July 2006
[15] USDA The Economic Feasibility of Ethanol Production From Sugar in the United States, pg 48. July 2006
[16] USDA The Economic Feasibility of Ethanol Production From Sugar in the United States, pg 47. July 2006
[17] USDA The Economic Feasibility of Ethanol Production From Sugar in the United States, pg 48. July 2006

88-739, to 84.5 tons/acre-year for variety CP 48-103.[18] After its positive initial results, the DREC joined with local growers and initiated farm trials of eleven of the most promising sugarcane varieties in 1998. These varieties yielded an annual average of 65.7 tons of sugarcane per acre leading to 10.2 tons of sugar per acre.[19]

Based on these results, an acre of sugarcane in Imperial Valley might commercially produce in excess of 10 tons of sugar per acre with sugar yields ranging from 10.6% to 18% depending on the sugarcane varietal cultivated.[20] This is approximately double what the Southeast region of the United States produces.

These figures are all based on the use of currently existing seed stock. No seed variety has been developed to specifically take advantage of the unique conditions in Imperial County. This report uses conservative estimates of output in Imperial County, but future developments might realize higher yields.

Carson Kalin of Kalin Farms in Imperial County has been experimenting with different seed combinations for the last 6 years. Kalin claims yields significantly higher in sugar content and yield per acre.[21] Kalin was not willing to share his figures at this time, however, due to the proprietary nature of his seed hybrids.

Table 3. Average cane and sugar yields by producing state.[22]

| State / Region | Sugarcane Yield (tons/ac-y) | Sugar Recovery Rate (%) | Sugar Yield (tons/ac-y) |
|---|---|---|---|
| Imperial County | 65.7 | 10.6 – 18 (avg. 15.4) | 10.1 |
| Hawaii | 93.5 | 12.9 | 12.1 |
| Florida | 37.0 | 12.1 | 4.7 |
| Louisiana | 27.4 | 11.4 | 3.1 |
| Texas | 39.4 | 10.5 | 4.1 |

**Water Requirements for Sugarcane Production in Imperial County.**

Imperial County's potential to grow sugarcane effectively is based not only on soil and climate conditions, but on the ability of growers in Imperial County to irrigate in an efficient and timely manner. Most sugarcane growing regions rely on natural precipitation. The ability to irrigate on an as-needed basis will provide a significant advantage to Imperial County Growers.

[18] UCR Forecasting Center And UC Desert Research & Extension Center, On the Economic Feasibility of Sugar Cane-to-Ethanol Operations in the Imperial Valley, Preliminary Draft, 10/8/01.
[19] UCR Forecasting Center And UC Desert Research & Extension Center, On the Economic Feasibility of Sugar Cane-to-Ethanol Operations in the Imperial Valley, Preliminary Draft, 10/8/01.
[20] UCR Forecasting Center And UC Desert Research & Extension Center, On the Economic Feasibility of Sugar Cane-to-Ethanol Operations in the Imperial Valley, Preliminary Draft, 10/8/01.
[21] Phone Interview Carson Kalin July 27, 2007, notes on file with principal author.
[22] Based on UCR Forecasting Center And UC Desert Research & Extension Center, On the Economic Feasibility of Sugar Cane-to-Ethanol Operations in the Imperial Valley, Preliminary Draft, 10/8/01 and USDA The Economic Feasibility of Ethanol Production From Sugar in the United States 2000- 2004 averages. July 2006

Growing sugarcane in Imperial County will be a water intensive process. Sugarcane requires about 78 inches of water, or 6.5 acre-feet, for each cultivated acre per growing cycle.[23] There is one growing cycle per year.

This water usage, though heavy, is not necessarily unusual. Alfalfa is a major cash crop in Imperial County that also requires approximately 6.5 acre-feet of water per growing cycle.[24] The economic success of sugarcane in Imperial County is dependent on a stable and relatively cheap water supply.

Imperial County's water is drawn from the Colorado River via the All-American Canal. The Imperial Irrigation District (IID) manages the water supply and oversees over 3,000 miles of canals and drains. The Colorado River supplies irrigation to over 450,000 acres of agricultural land and 135,000 residential and commercial customers in California's Imperial Valley.[25]

Imperial County's abundant water has become a highly valued commodity. The IID has recently finalized the QSA to sell water to other agencies such as those in San Diego County, Los Angeles County, Ventura County, and Riverside County. According to the QSA, the IID "will transfer to SDCWA up to 200,000 AFY and CVWD and MWD combined up to 103,000 Acre Feet per Year (AFY) of water conserved from delivery system improvements and on-farm efficiency improvements, all in return for payments totaling billions of dollars."[26]

Any future compact will look to the 303,000 AFY already traded as a benchmark. Based upon the annual 6.5 acre-feet per acre water demand, this 303,000 AFY translates to 46,600 acres of sugarcane that could be produced with the water Imperial Valley is willing to trade at present.

Given the continuing growth of the urban and suburban communities in Southern California, and the growing water requirements of these communities, there will be continued economic and political pressure on Imperial County growers and the IID to transfer larger quantities of water in the years to come. There is no question Imperial Valley has the water resources necessary for sugarcane growing. The real question is whether enough water can be recovered in a city hundreds of miles away by the process suggested in this report in a cost-effective manner. It remains to be seen whether 46,600 acres of sugarcane can generate 303,000 AFY water in Los Angeles or San Diego at a price that is competitive with physically transporting the water.

**Ethanol Production from Sugarcane**

The profitability and thus feasibility of growing sugarcane is tied directly to the price and quantity of ethanol that can be produced. Theoretical ethanol yield is 163 gallons per ton of sucrose. Under commercial operations the yield is generally lower, typically

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[23] UCR Forecasting Center And UC Desert Research & Extension Center, On the Economic Feasibility of Sugar Cane-to-Ethanol Operations in the Imperial Valley, Preliminary Draft, 10/8/01. pg 35

[24] http://alfalfa.ucdavis.edu/symposium/2004/talks/20041214_WasteW_Poole.pdf

[25] www.iid.com

[26] http://www.iid.com/Water_Index.php?pid=61

around 141 gallons of ethanol per ton of sucrose,[27] although yields around 124 gallons/ton are also reported. Assuming an average yield of 10 tons of sugar per acre per year, ethanol production per acre would average over 1,400 gallons.

No sugarcane-to-ethanol facilities exist in the United States. The technology to operate ethanol plants exists and is currently being used on a large scale in Brazil. In Brazil, many plants have a dual capacity.[28] Sugarcane is cut, crushed, and processed to produce molasses and sugar. Ethanol is produced by fermenting sugar. Quoting from the 2001 DREC report on a possible sugarcane processing facility, "[s]uch a plant will consist of a station separating cane residue (or leaf) from millable cane, a station separating millable cane into sugar juice and bagasse components, a fermentation station transforming sucrose into ethanol and $CO_2$, conveyors transporting residue and bagasse to storage, and boiler-generators for electric power." There will also be facilities for extraction of molasses and other materials from residue and bagasse, for preparation of ethanol and $CO_2$ for shipment and sale, and for processing and handling of other by-products.

**Sweet Sorghum**

With funding provided by the California Energy Commission, the California Department of Food and Agriculture sponsored demonstration plantings of sweet sorghum throughout the state in 1990 – 1992. Twelve different farmers, in eight different counties in California ranging from the southern San Joaquin Valley to the central coast, to the northern Sacramento Valley, to the high plains of Lassen County in the northeast corner of the State grew nine different cultivars including seven hybrids and three open-pollinated varieties. Project area ranged from 0.2 to 20 ac (0.1 to 8 ha) planted. Total biomass yield ranged from 1.6 to 13.5 dry tons/ac, (3.6 to 30.3 Mg/ha) with an average of 7.6 dry tons/ac (17 Mg/ha) for all projects over all three years.

Cost of production up to harvest ranged from $32 to $82/dry ton ($35 to $90/Mg) including both fixed costs and operating costs, with ultimate biomass yield a primary factor in determining the cost of production. Costs associated with specific activities varied widely depending on site-specific circumstances. Field preparation costs ranged from $6.25/ac ($15.45/ha) for 20 ac (8 ha) of sandy-loam soil previously in oat hay, to $163/ac ($403/ha) for a 10 ac (4 ha) field with heavy clay soil which previously had been in sugar beets. The cost of irrigation ranged from $44 to $100/ac ($110 to $250/ha) for the water and its application. Weed control costs ranged from zero to $50/ac (0 - $125/ha). Production costs up to harvest ranged from $338 to $514/ac ($835 to $1,270/ha).

The energy potential of the crop can be considered in a variety of processing scenarios, including sugar conversion to ethanol and bagasse combustion for electricity generation (coproduction), sugar and cellulose and hemicellulose conversion to ethanol, and combustion only for electricity generation. Energy potential calculations were made based upon the following assumptions: a higher heating value for sweet sorghum of 7,500 Btu/lb (17.5 MJ/kg), and an overall conversion efficiency of 20% for biomass

[27] USDA The Economic Feasibility of Ethanol Production From Sugar in the United States, 18, Appendix pg 46. July 2006
[28] USDA The Economic Feasibility of Ethanol Production From Sugar in the United States, pg 47. July 2006

combustion power plants; a theoretical ethanol yield of one gal/14 lb sugar (142 gallons/ton or 0.6 L/kg), a 90% sugar recovery rate from sweet sorghum, and a 95% fermentation efficiency; total potential fermentables from sweet sorghum sugar and lignocellulosic material were assumed to be 73% of dry matter. Based on yield data and laboratory analyses, the energy potential of the crop for these three scenarios was: an average of 355 gal/ac (3,319 L/ha) ethanol, 4,100 kWh/ac (10,130 kWh/ha) electricity for coproduction and an average of 7,060 kWh/ac (17,450 kWh/ha) for electricity production only.

The energy costs of producing the crop appear to be quite favorable, however, a complete systems analysis including growing the crop, harvesting, hauling, and processing remains to be performed. It is useful to perform a brief comparison of the input requirements between growing corn (the predominant ethanol feedstock), and sweet sorghum. Sweet sorghum has required no more than 100 lbs/ac (112 kg/ha) of nitrogen as fertilizer, no pesticides, very limited use of herbicides (one of fourteen projects), and about half the irrigation water that corn requires under similar growing conditions. An analysis of energy requirements in California agriculture (Cervinka, et al., 1981), shows that energy inputs to grow, harvest, and transport corn are $11.5\times10^6$ Btu/ac (30 GJ/ha) or $2.55\times10^6$ Btu/ton (3 GJ/t), given current average corn yields of 4.5 ton/ac (10 t/ha). Assuming a 90 gal/ton (375 L/t) ethanol conversion rate results in an ethanol yield of 405 gal/ac (3,789 L/ha) energy cost of 28,400 Btu/gal (7,915 kJ/L) ethanol. Sweet sorghum has energy requirements of about $11.3\times10^6$ Btu/ac (29.4 GJ/ha), including growing, harvesting, and transporting the crop. Based on an average biomass yield of 7.6 ton/ac (17 t/ha) with 73% of the biomass convertible to ethanol, and an overall conversion efficiency of 85%, and 14 lb sugar/gal ethanol, results in an ethanol yield of 690 gal/ac (6,451 L/ha), at an energy cost of 16,350 Btu/gal (4,554 kJ/L) ethanol. The higher heating value of ethanol is 83,670 Btu/gal (23,340 kJ/L). The feedstock energy costs of corn and sweet sorghum are 34% and 20% of heating value, respectively.

**Sugar beets**

Imperial County is the largest sugar beet growing region in California, with about 25,000 acres planted each year. The planting season begins in September and continues until mid-October. Harvest starts roughly April 15 and usually ends by August 1. There are several sugar beet varieties approved by a seed evaluation committee for use in Imperial Valley. “Phoenix” performs well for early plantings and “Beta 4430” is commonly planted for the remainder of the season. Irrigation requirements average about 5.5 ac-ft per acre per year.

Average yields range from 37 to 42 wet tons per acre resulting in about 5.5 to 6 tons of sugar, and about 3 tons of non-sugar solids. Production costs average about $1,400 per acre, while crop value is about $1,800 per acre. Highest recorded yield is nearly 70 tons per acre, at 15% sugar, resulting in 10.5 tons of sugar per acre.

## The Price of Ethanol Needed for Sustainable Refining

Ethanol is mainly valued as an alternative fuel or fuel additive. As such, its price is tied directly to the price of gasoline. The higher the price of gasoline the greater the demand and thus price for ethanol. In 2006 the USDA estimated that, given all tax incentives, a standalone ethanol production plant would require a consistent ethanol price between $2.10 and $2.20 per gallon. The price of ethanol over the second half of 2006 was consistently over $2.20 a gallon,[29] declining through late 2009 to below $1.25/gallon as gasoline blendstock in California.[30]

The USDA made its cost/benefit calculations based strictly on a sugarcane-to-ethanol model. However, ethanol production is not the only energy or profit center embodied in sugarcane. In 2001 the DREC conducted a study factoring in ethanol production as well as the sale of sugarcane byproducts such as bagasse-derived energy and $CO_2$.

The process for producing ethanol is nearly identical to that of creating pure grain alcohol, for example. By taking into consideration other profit generating aspects of sugarcane production, the DREC report concluded that a profit could be made for both farmers and plant operators at ethanol prices of $1.40/gallon (2001 unadjusted dollars).[31] Ethanol price in California has fluctuated from below this price to well above it, but remains volatile.

## Electricity Generation and Revenue from an Ethanol Refinery

Bagasse is the biomass residue left over after all of the available juice has been removed from the sugarcane plant. Bagasse accounts for approximately 15 to 20% of sugarcane weight and contains approximately 8,000 Btu per dry pound.[32] In the Imperial Valley, with 303,000 AFY of water available for trade, a sugarcane yield of 65.7 tons/ac-year across 46,600 acres, and an average bagasse fraction of 15%, annual bagasse production would total 459,200 tons. At 25% conversion efficiency, this would in turn yield 538 GWh of electricity, which for a baseload operation at 85% availability is the equivalent of 72 $MW_e$ capacity.

A single Imperial County ethanol refinery is expected to power, at the minimum, a 50 MWe generator – about 70% of the potential. The ethanol refinery itself requires 10 MWe of capacity during the processing season. This leaves 40 MWe available for wheeling over the grid.[33]

A cogeneration plant in Imperial Valley would be eligible for a production tax credit (PTC) of 1.9 cents per kWh under the closed loop biomass classification. The PTC was renewed under emergency legislation in October 2008 and extended until the end of 2010. The future of the PTC beyond then is uncertain. A representative from IID stated

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[29] http://www.boston.com/business/articles/2006/10/19/market_spotlight_ethanol_in_a_pinch/
[30] http://energyalmanac.ca.gov/gasoline/graphs/component_prices.html, 11 January 2009.
[31] UCR Forecasting Center And UC Desert Research & Extension Center, On the Economic Feasibility of Sugar Cane-to-Ethanol Operations in the Imperial Valley, Preliminary Draft, 10/8/01.
[32] USDA The Economic Feasibility of Ethanol Production From Sugar in the United States, pg 38. July 2006. Conversion of 7000-8000 BTU to KWh provided by http://www.onlineconversion.com.
[33] UCR Forecasting Center And UC Desert Research & Extension Center, On the Economic Feasibility of Sugar Cane-to-Ethanol Operations in the Imperial Valley, Preliminary Draft, 10/8/01.

that a biomass facility would likely be able to sell power at $67.50 per MWh, or 6.75 cents per kWh.[34] According to the DREC, the generator would operate for 230 days out of the year for an availability of 63%, generating from 40 MWe net capacity a total of 221 GWh of electricity worth $14.9 million wholesale with a PTC worth $4.2 million.

# Water and Energy – The Nexus

An October 2003 report prepared by the California Department of Water Resources investigated the state of the art of water desalination[35]. The report made the following findings and recommendations.

Water desalination technology is well proven and its energy and cost efficiency continues to improve. It can be an effective strategy for providing new water supplies. While desalination is energy intensive, providing substantial urban water supplies would result in a relatively small increment in overall statewide electricity demand. Depending on the quality of the source water, treatment plant technology and capacity, about 1.3 to 3.3 MWh of electricity would be required to produce one ac-ft of potable water at a cost of $130 to $1,250 from brackish water sources. For estuarine and sea water, approximately 3.3 to 4.9 MWh of electricity would be required to produce an ac-ft of potable water at a cost of $700 to $1,200 per ac-ft based on the price of electricity of 5 - 11 cents per kWh. Lastly, the report estimated that seawater desalination would require, on average, 30% more energy than existing interbasin supply systems such as the State Water Project or Colorado River supplies to coastal urban southern California.

This estimate was also corroborated by an MWD engineer. Without factoring in the immense cost of expanding the current aqueduct system, it already costs the Metropolitan Water District about 2 MWh of energy per ac-ft of water to power pumping stations that ship water from the Colorado River to the Southern California basin.[36] Given the massive water needs of the Los Angeles and San Diego counties this constitutes an immense amount of energy lost due to the cost of transportation alone. This does not factor in water losses incurred during conveyance and storage of water from remote sources.

# Policy and Institutional Issues

The Imperial Valley and southeastern California have been identified as potential sources for significant amounts of renewable electricity from various sources, including solar, geothermal, and biomass. New electricity transmission capacity is recognized as needed to bring this power to it points of consumption in coastal urban southern California. Projects such as the three IID sponsored Green Path transmission projects and the Sunrise Powerlink project are under development.

Coastal urban communities and their water suppliers are increasingly recognizing the need to improve local water self-reliance through all strategies and technologies. Many

[34] Bob Fuett, IID Energy Aug, 2006 meeting, notes on file with the principal author.
[35] Water Desalination – Findings and Recommendations. California Department of Water Resources. October 2003.
[36] Phone Interview with California Water Engineer John Scott, December 18, 2006. Notes on file with author. According to Mr. Scott this number is not published in any Metropolitan publication.

of these, including water treatment will require additional energy, but that energy may at least be partially offset by energy saved in not conveying water over long distances. The Water Energy Climate Action Team (WETCAT) recently proposed several measures to improve California's water/energy efficiency as a greenhouse gas reduction strategy. Measures included water treatment and recycling at urban waste water treatment plants. It noted that water supply and conveyance of water from northern to southern California consumes an estimated 3.2 MWh per acre-foot (MWh/AF). In sharp contrast, the estimated cost to recycle wastewater is approximately 0.7 MWh/AF. As a result, the potential energy savings that could be realized through water recycling is estimated as 2.5 MWh/AF for southern California communities that import water. It went on to estimate that as much as 23% of municipal wastewater flows could be recycled.

# Biomass-Water Treatment Substitution Scenarios for Urban Water Supply

## Land Requirements under constant irrigation rate and variable water-treatment energy demand

Land requirements for biomass production in providing energy for desalination in substitution of direct water transport were compared under different yield scenarios. Three cases representing low, average, and high biomass and desalination water yield conditions were evaluated for substitution potential (Table 4).

Table 4. Biomass and desalination water yield scenarios.

| | | Yield Scenario | | |
|---|---|---|---|---|
| Parameter | Units | Low | Average | High |
| Sugarcane yield | tons/ac-y | 40 | 65 | 95 |
| Sugar yield | % | 7 | 15 | 23 |
| Ethanol yield | gals/ton sugar | 141 | 147 | 154 |
| Bagasse yield | % | 15 | 18 | 18 |
| Power generation efficiency | % | 20 | 25 | 30 |
| Refinery parasitic demand | % | 20 | 20 | 20 |
| RO energy demand | MWh/ac-ft | 6.5 | 3.3 | 1.3 |
| Water demand | ac-ft/y | 303,000 | 303,000 | 303,000 |
| Irrigation requirement | ft of water | 6.5 | 6.5 | 6.5 |
| Pumping energy savings | MWh/ac-y | 0 | 2 | 3 |
| Electricity transmission loss | % | 10 | 10 | 10 |
| Land required | ac | 373,340 | 58,564 | 11,238 |

In order to meet the water supply requirement of 303,000 ac-ft/y, the average yield assumptions would require 58,564 acres of sugarcane production, about 25% more than the land capability when irrigating with 6.5 ac-ft/ac-y. To satisfy the desalination water requirement, irrigation efficiency would have to be improved under these assumptions so that water demand was reduced to 5.2 ac-ft/ac-y. The low yield scenario fails substantially to provide sufficient energy for desalination, whereas under the high yield scenario less than a quarter of land capability would be needed. The response under each scenario for variable desalination energy demands ranging up to 8 MWh/ac-ft of water and with only bagasse used for power generation is shown in Figure 2. Urban water production per acre of crop production is shown in Figure 3 for varying

desalination rates, assuming average yield values only and that only bagasse is used for electricity generation. The urban water production increases if the ethanol produced from sugar is also used for electricity generation (Figure 4), but the economic impacts of this would need further inspection.

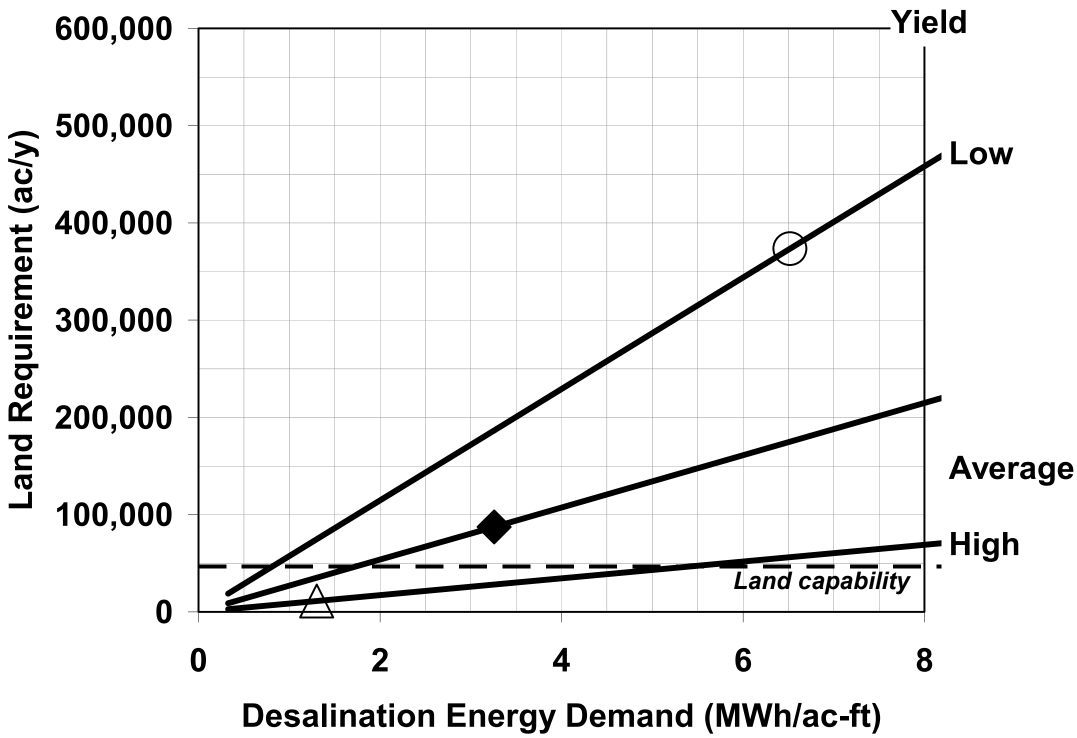


Figure 2. Land required for sugarcane production in substituting for direct water transfers for three biomass and desalination water yield scenarios and variable desalination energy demands. Assumes only bagasse is used for electricity generation. Symbols mark reference points from Table 4. Dashed line indicates land capability using 303,000 ac-ft/y of water with an application rate of 6.5 ac-ft/ac-y.

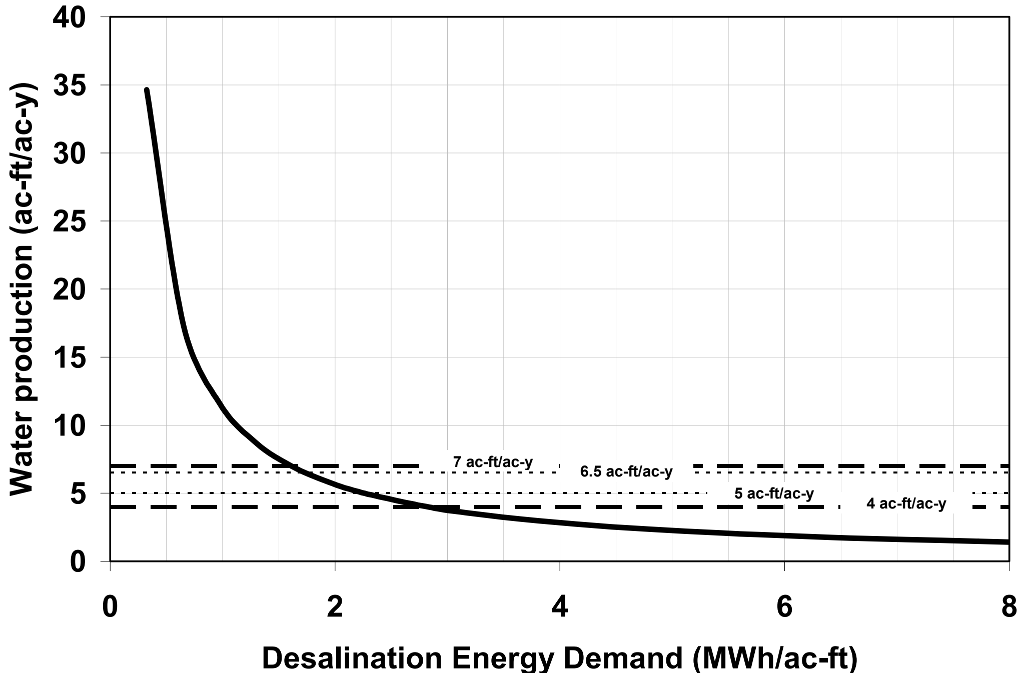


Figure 3. Urban water production by desalination for average sugarcane and bagasse yields and variable desalination energy demand. Irrigation application rates of 4 to 7 ac-ft/ac-y shown for comparison, indicating breakeven desalination energy requirements in the range of 2.8 to 1.6 MWh/ac-ft of water produced. Assumes only bagasse is used for electricity generation.

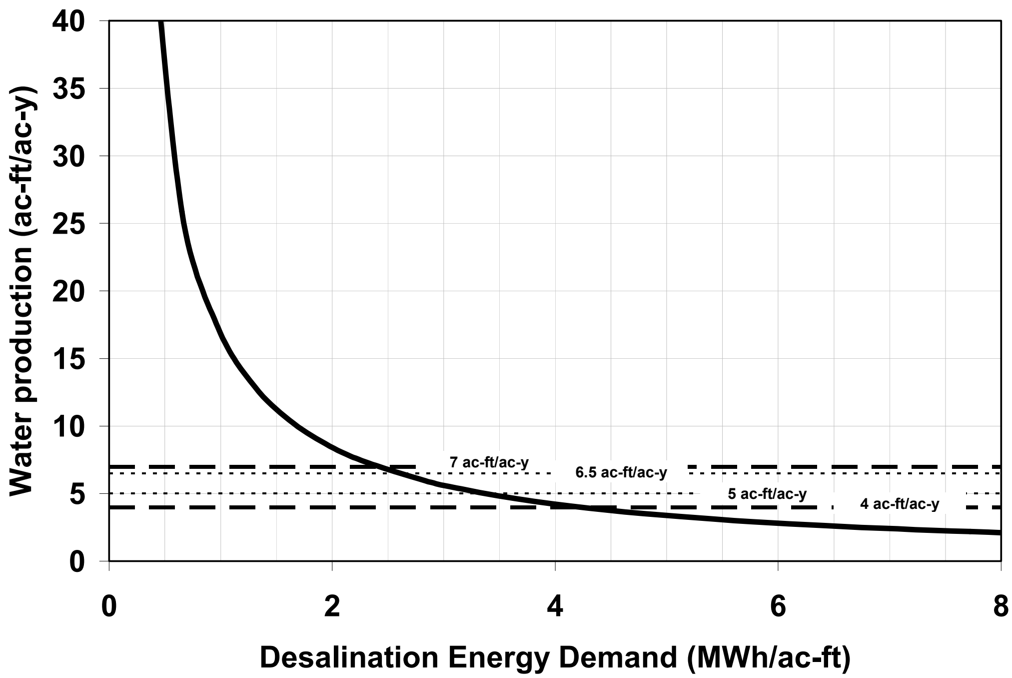


Figure 4. Same as Figure 3 but assuming both ethanol and bagasse from sugarcane are used for electricity generation. Maximum breakeven desalination energy requirement in the range of 4.2 to 2.4 MWh/ac-ft of water produced.

## Urban water production under variable crop yield, irrigation rate, and water-treatment energy demand

Five alternative scenarios were analyzed varying the amount of applied water for crop irrigation in addition to varying crop yield and the energy intensity of water treatment. This approach shows the expected range for urban water supply yields per acre of land used to produce the energy crop (sugar cane) compared to the amount of applied water per acre of energy cropland. This approach allows a unit comparison. If net "virtual water" results, then the amount of land dedicated to energy crops can vary, depending on the amount of "virtual water" demand.

The following scenarios were analyzed:

- Worst case - High irrigation water requirement/low crop yield/high water treatment energy requirement
- Best case - Low irrigation water requirement/high crop yield/low water treatment energy requirement
- Existing Conditions – Current sugar cane crop production and water treatment knowledge and estimated technology mix
- Existing Conditions with current ocean desalination energy requirement
- Likely Optimized System – predicted five year progress in sugar cane production and water treatment.

Assumptions for these five scenarios are summarized in Table 5, with results shown in Table 6.

Table 5. Alternative crop production and water-treatment scenarios.

| | Worst | Existing | Ocean Desal | Optimized | Best |
|---|---|---|---|---|---|
| | | | | | |
| Crop Yield[1] | 40 | 55 | 55 | 70 | 95 |
| Sugar % | 12 | 15 | 15 | 18 | 20 |
| Dry Matter % | 15 | 15 | 15 | 18 | 20 |
| Heating Value[2] | 17 (7325) | 18 (7500) | 18 (7500) | 18 (7500) | 18.9 (8122) |
| Conversion Rate | 20 | 23 | 23 | 25 | 30 |
| Applied Water[3] | 7 | 6.5 | 6.5 | 6 | 5 |
| Line Losses % | 10 | 10 | 10 | 8 | 5 |
| Electricity Use[4] | 6.1 | 4.0 | 5.1 | 3.3 | 1.3 |
| Electricity Use[5] | 0 | 2 | 2 | 2.3 | 3 |
| Ethanol Yield[6] | 141 | 147 | 147 | 147 | 154 |

1. Wet tons per acre acre-feet/acre
2. MJ/kg (Btu/lb)
3. Acre-feet per acre (ac-ft/ac)
4. MWh/ac-ft for water treatment and/or local management
5. Mwh/ac-ft to convey water
6. Gallons/ton of sugar

Table 6. Summary results for alternative scenarios.

| | Worst | Existing | Ocean Desal | Optimized | Best |
|---|---|---|---|---|---|
| | | | | | |
| Crop Yield[1] | 40 | 55 | 55 | 70 | 95 |
| Applied Water[2] | 7 | 6.5 | 6.5 | 6 | 5 |
| Electricity Use[3] | 6.1 | 4.0 | 5.1 | 3.3 | 1.3 |
| | | | | | |
| Water Yield[4] | 0.8 | 1.9 | 1.7 | 4.4 | 21.8 |
| Ethanol Production[5] | 677 | 1213 | 1213 | 1852 | 2633 |

1. Wet tons per acre
2. Acre-ft/acre
3. MWh/ac-ft for water treatment and/or local management
4. Ac-ft/ac of municipal water supply
5. Gallons/acre

The above analyses assume electricity is produced only from the bagasse fraction of sugarcane. Electricity can also be generated from the fuel ethanol made from the sugar fraction, providing additional virtual water (Table 7).

Table 7. Additional virtual water produced by generating electricity from both bagasse and fuel ethanol. Assumes 4.57 kWh of electricity generated per gallon of ethanol.

| | Ethanol yield (gal/ac) | Urban water treatment energy demand (MWh/ac-ft) | Additional virtual water yield (ac-ft/ac-y) |
|---|---|---|---|
| Worst | 677 | 6.1 | 0.5 |
| Existing | 1213 | 4.0 | 1.4 |
| Ocean Desalination | 1213 | 5.1 | 1.1 |
| Optimized | 1852 | 3.3 | 2.6 |
| Best | 2633 | 1.3 | 9.3 |

Capacity for producing urban water is shown for varying irrigation water demand and crop yield in Figure 5 assuming only bagasse is used for electricity generation and an optimized energy demand (3.3 MWh/ac-ft) for water treatment. Crop yields approaching 100 tons/ac-y with 5 ft of water applied could meet the need for 303,000 ac-ft/y of urban water supply. If the water treatment energy demand is substantially reduced and ethanol is also used for power generation, the urban water supply capability is about four times greater (Figure 6), indicating a significant potential associated with the approach.

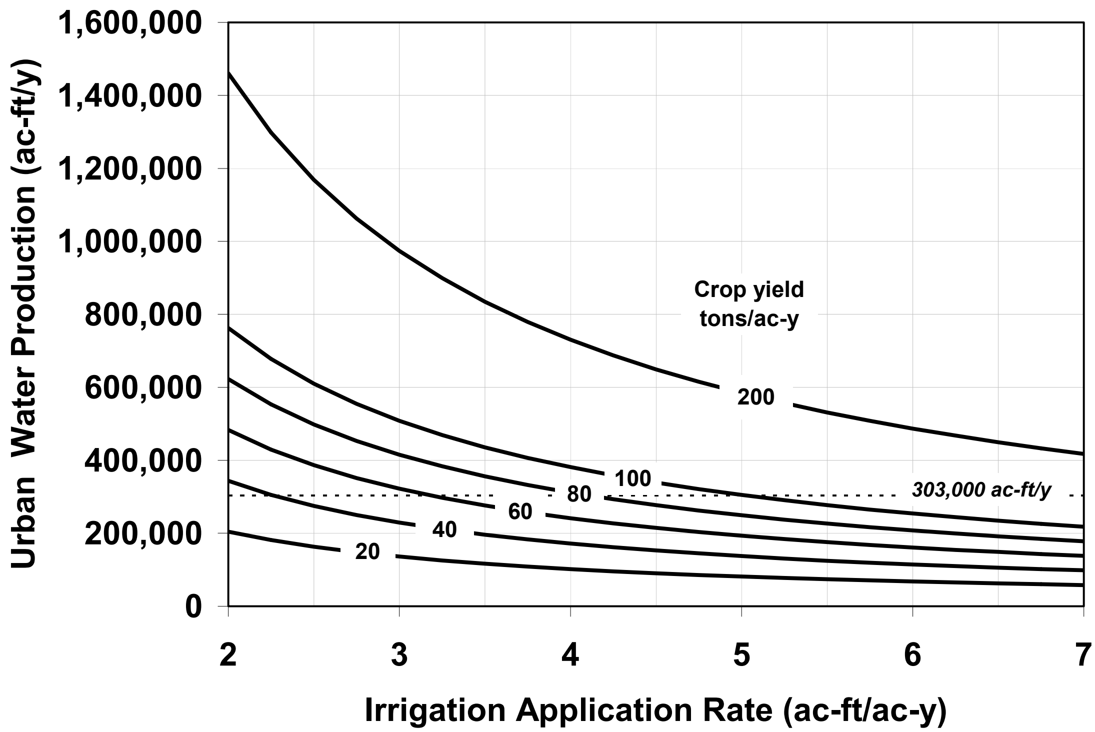


Figure 5. Urban water production by water treatment for varying irrigation water demand and sugarcane crop yield. Assumes only bagasse is used for electricity generation and 3.3 MWh/ac-ft water-treatment energy demand.

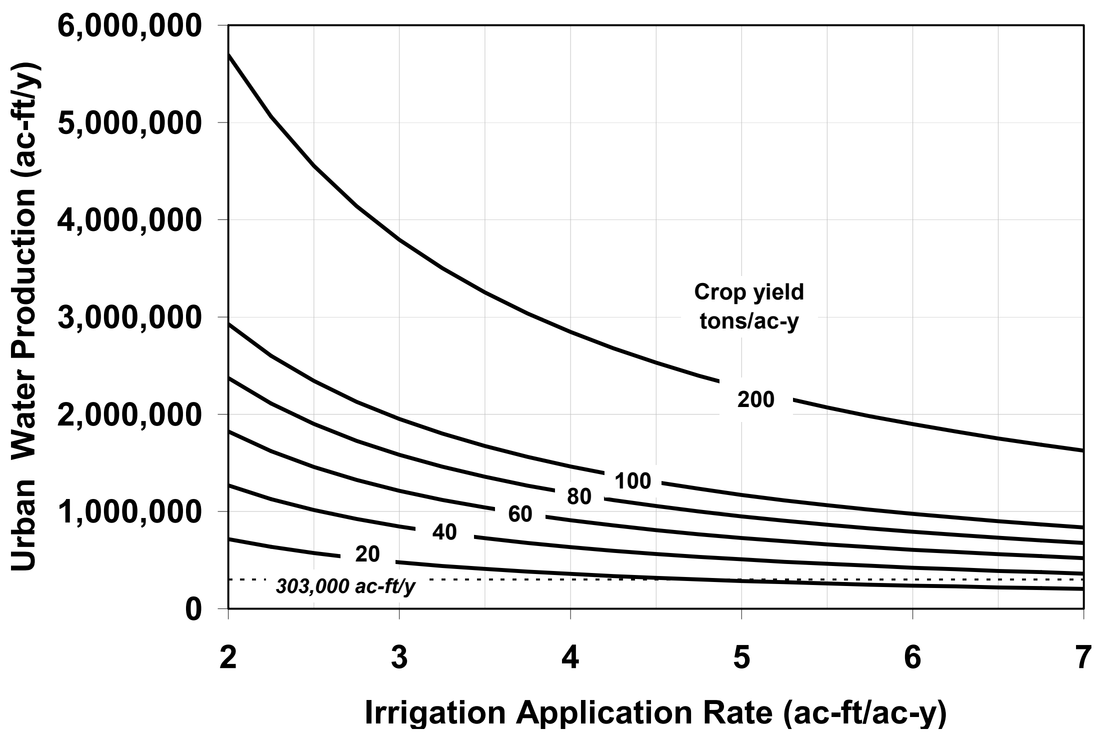


Figure 6. Same as Figure 5 but assuming both fuel ethanol and bagasse are used for electricity generation and 1.3 MWh/ac-ft water-treatment energy demand.

# Discussion and Conclusions

As coastal urban populations continue to grow, urban water supply reliability will increasingly depend on greatly expanding water recycling, reuse and treatment of existing water supplies conveyed from remote sources using existing infrastructure and from the ocean. This water supply reliability strategy will depend on additional electricity to provide the energy needed to process the water to domestic and industrial water quality standards.

This preliminary analysis of producing high yield biomass energy crops by using irrigation water that would otherwise be conveyed to coastal urban areas suggests that providing "virtual water" in the form of electricity for desalination and other forms of water treatment may under some conditions prove at least technically feasible. Full economic analyses are required to investigate the economic potential of growing bioenergy crops in substitution of direct water transfers to meet urban demand.

The "virtual water" system presented here proposes a water-energy system that is more closely linked. Such a system may provide for increased water supply reliability for coastal urban areas, as well as current areas of origin. The system may also provide for a less carbon intensive water supply that reduces the need to physically move more water over great distances, and uses biomass (and other renewable sources of energy) for water treatment and management at the local level.

A number of other issues remain to be addressed, including lifecycle assessments of virtual water supply systems, means to secure electricity savings credits when reducing direct water pumping requirements, net energy analyses comparing local water management options with virtual water supply concepts, and potential reliability impacts due to weather and crop production uncertainties. Although uncertainties associated with the assumptions used are for the most part high, sufficient potential exists to warrant a more comprehensive assessment of this approach for sustained agricultural production and urban water supply.

While this paper has shown that the prospect of technical feasibility is worthy of further investigation, as briefly discussed, other institutional and infrastructure barriers also need to be addressed. These issues are far beyond the scope of this initial analysis, but it may be helpful to identify them for consideration as further analysis is conducted. Issues that could impact the technical and economic feasibility of the proposed "virtual water" system include:

- Constructing and operating electrical transmission from areas such as the Imperial Valley producers to coastal urban consumers.
- Transparent accounting of the carbon intensity of existing and future water supplies.
- Overcoming public perception of the suitability of water for domestic uses from recycle and reuse sources.
- Developing appropriate market mechanisms to ensure access to electricity and water markets from environmentally superior sources based on a life cycle analysis approach to water supplies using a strong energy/carbon/water system analysis.

- Continuous improvement of biomass energy systems from biomass feedstock production and acquisition, through conversion to various forms of renewable energy.
- Continuous improvement of water treatment, storage, conveyance and distribution systems, as well as water conservation and water use efficiency methods to improve energy efficiency.

Many of these issues are being addressed by various levels of government and interested stakeholders. It is important that they be addressed in an integrated, comprehensive and systematic approach that can anticipate new systems such as the one presented.