Integrating Water Sustainability into the Low Carbon Fuel Standard

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Executive Summary

The "water footprint" or "embedded water" of a product is seen as the amount of water consumed during its life cycle (Chapagain and Hoekstra, 2004). As the State of California implements the Low Carbon Fuel Standard (LCFS), a more complete view of environmental and social sustainability demands consideration be given to the effects that various pathways would have on water resources.

While the role of biofuels in a climate protection strategy is unclear owing to the global warming consequences of both direct and indirect land-use, water use remains another central issue and could be, in the words of a recent report, the "Achilles heel" of biofuel production (Keeney, 2006). This study projects the effects on California water resources from some scenarios of in-state feedstock and fuel production.

Many analyses of the water implications of bioenergy only take into account consumption by biorefineries. Because the feedstock cultivation phase of the biofuel production process is by far the most water-intensive part of the bioenergy life cycle, our analysis quantifies these consumptions as well. We find that on average over 1500 gallons of water are consumed (i.e. removed from productive use for a given hydrologic cycle – see Box 1) in the production of a single gallon of corn ethanol in California – with feedstock cultivation accounting for more than 99% of this use. In comparison, the amount of water required to produce the average daily diet in North America is 1330 gallons, the average in Western Europe is 1240 gallons, while in Sub-Saharan Africa, this figure is less than 500 gallons (Serageldin, 2001).

In some scenarios, the cultivation of biofuel feedstocks could serve to *reduce* the strain on California water resources insofar as thirstier crops are displaced by energy feedstocks. Often, however, a tradeoff exists between minimizing greenhouse gas (GHG) emissions and avoiding effects on a variety of other environmental criteria (Zah, Boni *et al*., 2007; Spatari *et al*., 2008). For example, developing understandings of indirect land-use change may bring increasing incentives not to displace current cultivation for bioenergy production (Delucchi, 2002, Searchinger *et al.,* 2008, Jones *et al*., 2008). This could bring about extensification of agriculture onto currently uncultivated lands, which would mean applying irrigation water where none was required before, and so offsetting none of the new water consumption with reductions from displaced crops.

Our research shows that biofuel production in California could either increase or decrease the sustainability of the state's water resource use. It also makes clear the feasibility and

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importance of estimating the water consumed in production of fuels from various feedstocks grown in different regions of the state. We suggest that rule-making under the LCFS consider water resources in hopes of pursuing a broader sustainable fuel system for California. We further suggest the incorporation of water sustainability as a task under the Alternative and Renewable Fuel and Vehicle Technology Program (AB 118) and other relevant renewable fuel legislation. Options available to the Air Resources Board in incorporating water sustainability into LCFS policies include:

(a) Ignore water resources, delegating this consideration to water programs
(b) Determine a "price" for water in Global Warming (GW) units and add it to Average Fuel Carbon Intensity (AFCI)
(c) Charge a tax on water use for biofuel production
(d) Establish a go/no-go rule for maximum water consumption per MJ of all fuels allowed under the LCFS
(e) Categorize counties/regions in California based upon water scarcity, establishing go/no-go rules for each county/region.

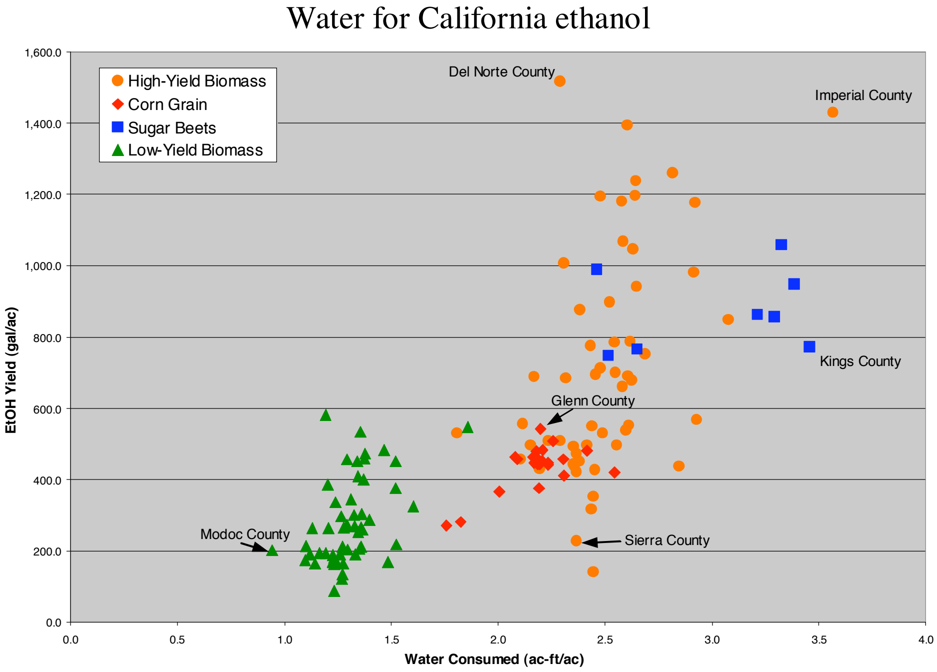


Figure 1: Variation in water consumed and fuel produced among the different counties and the potential feedstocks for biofuel production in California.

1. Introduction

Motivated by rising petroleum prices, security concerns, and intention to reduce greenhouse gas (GHG) emissions, policies promoting biofuel production are becoming increasingly common. One such policy is California's Executive Order S-01-07, the Low Carbon Fuel Standard (LCFS). In implementing this standard, the California Air Resources Board must consider the non-climate implications of its policy options. Expansion of biofuel production in the state could have a significant effect on water resources.

The initial LCFS technical and policy documents (Brandt, *et al*., 2007; Arons, *et al*., 2007) are explicit about their exclusive concern for fuel's GHG profile. The technical analysis, part I states:

> *This report addresses only the climate change impacts of fuels, and does not address other public health and environmental impacts…Many of these issues will become more important if biofuel production and use expand, and they are critical to the long-term viability of all energy resources.*

In this report we detail our research into the effect on California water resources of increased ethanol production under the Low Carbon Fuel Standard (LCFS). We provide context through some background on California agriculture and water resources, and develop a methodology for estimating water consumption in California biofuel production. We then project the water resource implications of some scenarios for biofuel production under the LCFS and conclude with policy recommendations for the Air Resources Board in implementing the standard with consideration for water sustainability.

2. Background – Water Resources

2.1 California water resources:

California receives about 200 million acre-feet of precipitation and in-flow in the average year, which makes up the state "water budget." However, this flow varies greatly from year to year (DWR, 2005).

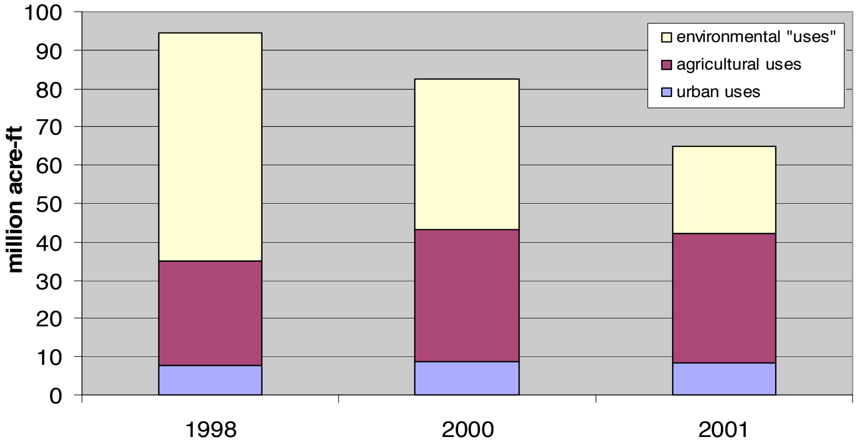


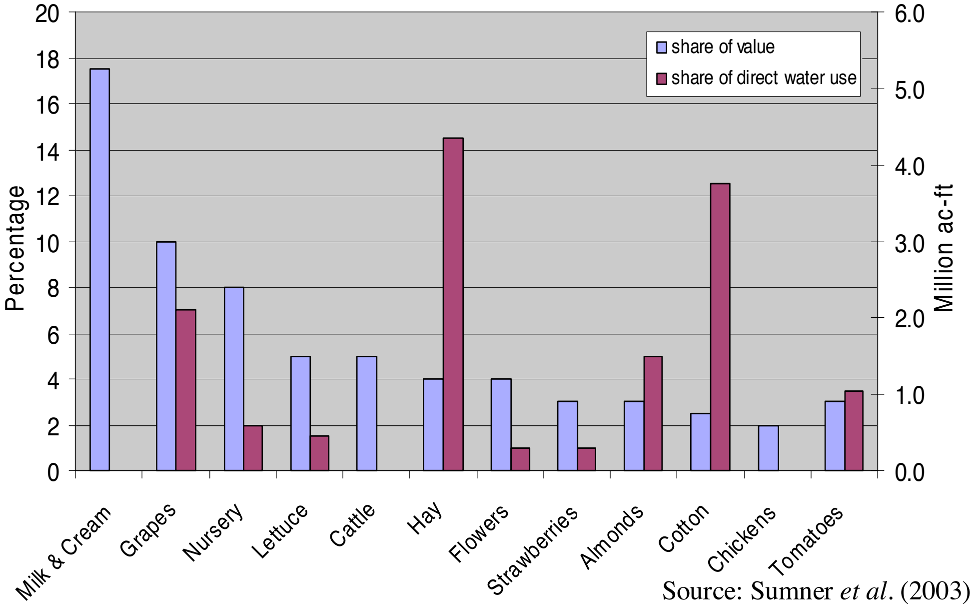
Figure 2: Use of California dedicated water supply in varying rainfall conditions (data from California Department of Water Resources)

Figure 1 presents the uses of water in wet, average and dry years. During the three years shown, the state received 171%, 98% and 72% of average rainfall respectively (DWR, 2005). While urban water use remained largely stable, agricultural diversions rose both in real and relative terms when water was more scarce, presumably because reduced rainwater meant increased need for irrigation.

On average, water use in California results in an annual 1.6 million acre-ft[1] budget shortfall. This shortage is made up largely through overdraft of groundwater, a resource that provides 30% of annual water consumption (Howitt and Sunding 2003; Sumner, Bervejillo *et al.*, 2003).

2.2 Water and California agriculture

California's large agriculture sector is entirely dependent upon the availability of water, either through rainfall on fields or through irrigation. As a result, 84% of the developed water in the state is used to irrigate its 9.68 million acres of agricultural land. (Howitt and Sunding 2003)



Source: Sumner *et al*. (2003)

Figure 3: Water use in some California agricultural production

Owing to variation in plant physiology and cultivation practices, cultivation of different crops requires different amounts of water (Fig 3). Furthermore, water required to grow the same crop in different climates also varies. For example, water applied to alfalfa ranges from 2.7 ac-ft per year in the Placer County in the Sierra-Nevada Mountains to 6.6 ac-ft per year in the Imperial Valley at the Southeast corner of the state.

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[1] An acre-ft is a volumetric measure equal to the amount of water required to cover an acre of land at a depth of one foot. (1af = 325,851.43gal. = 1,233,482.1 L.)

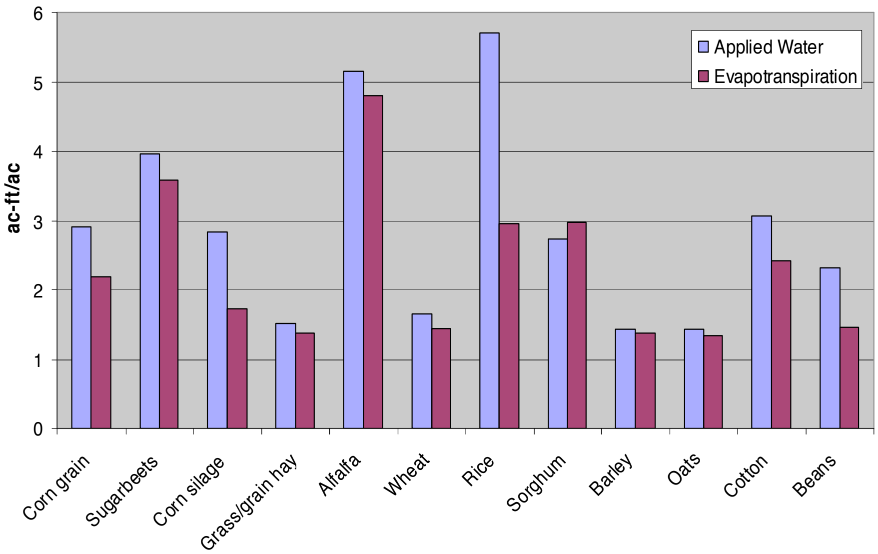

Figure 4: Water consumption by major California field crops

2.3 Water use in biofuel production

Production of biofuels in California, especially from agricultural feedstocks, would inevitably affect the state's water resources. It may increase consumption in some areas while decreasing it in others if it replaced other, greater water consumptions. It would also have a similar effect on water pollution, which can occur at numerous points along the biofuel production chain.

Water is consumed at multiple links in the biofuel supply chain. Figure 5 shows the major uses of water necessary for the agricultural and industrial phases of biofuel production.

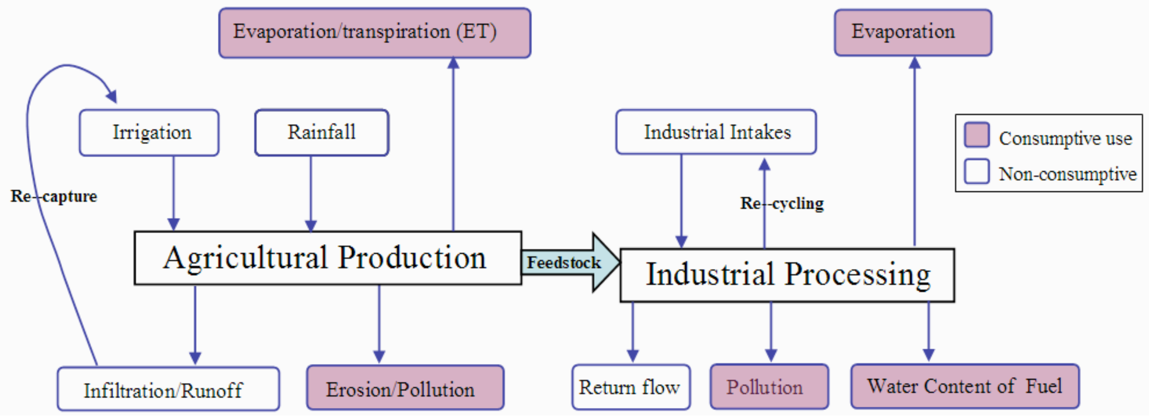

Figure 5: Schematic of water uses in biofuel production

Different measures of consumption will be important in different contexts. For example, the "embedded water" (see Box 1) in a given biofuel can be estimated in terms of gallons of water per unit of energy (e.g. megajoule or gasoline gallon equivalent). In answering questions of sustainability, however, we may be more concerned with ascertaining what volume of water is consumed per *acre* used to grow feedstock. Furthermore, these numbers will be most useful insofar as they can be considered in relation to water availability in the particular region where the biofuel was produced.

Box 1: Water consumption – some background and terminology

The term “***applied water***” refers to all water that is provided to an agricultural field through irrigation. Unlike some other materials, which are irretrievably consumed when they are used, water used in agriculture can often be recaptured through a variety of pathways. Water that is inefficiently applied to a farm, for example, will run off or percolate down to the water table where it can often be recaptured for later use. The amount of water applied, therefore, may differ from the amount consumed. Further complicating matters is the fact that even when it has evaporated, water is not destroyed but will instead make its way back to the beginning of the cycle as rain. Since there is no way to know, let alone to control, where evaporated water will fall next, this analysis uses a common definition of ***water consumption***. Water is considered consumed if it is removed from potential further use for the remainder of the hydrologic cycle.

Another useful concept that will be employed in this analysis is that of ***embedded water***. Water consumed in the production of a given good can be said to be “embedded” in that good, while the actual amount of water actually contained in the good itself may be minimal or zero.

Three types of consumption are relevant to this analysis:

Evapotranspiration

The largest consumptions of water on the planet are evaporation and transpiration (essentially productive evaporation through plant tissues) – collectively termed evapotranspiration (ET).

Industrial/biorefinery consumptions –

Water is consumed in industrial processes through uses such as cooling and incorporation into finished products.

Pollution –

Pollution can be considered a consumptive use of water, since it removes a certain volume of water from being later utilized productively.

2.4 Evapotranspiration

Cropping systems vaporize water in two ways: through evaporation from the soil surface and through transpiration, evaporation of water through plant tissues. These two processes are collectively referred to as evapotranspiration (ET). Nearly all agricultural production in California is fed by irrigation, and demand for irrigation water is largely responsible for water budget shortfalls the resulting drawdown of the state’s groundwater tables.

2.5 Industrial/biorefinery consumptions

Most of the water consumed in the industrial processing phase of the biofuel supply chain is lost to evaporation during cooling. Approximately 4 gallons of water are consumed in the production of a gallon of ethanol from conventional feedstocks (Keeney and Muller 2006). Cellulosic plants currently have a larger water footprint – closer to 9.5 gallons of water per gallon of ethanol produced – but this may fall in the near future (National Research Council 2007).

In comparison, production of a gallon of gasoline requires from 3.4 gallons of water (Gleick, 1994) to over 60 gallons for processing of tar sands or oil shale (Davis and Velikanov, 1979). These figures, however, reflect almost the entirety of the life-cycle water use for petroleum whereas they are a small portion of the consumption for biofuels.

2.6 Pollutive consumption

Pollution is another important anthropogenic consumption of water. It can be considered consumptive since it removes water from productive use. Biofuel feedstocks are often cultivated using input-intensive agricultural methods. The degree to which agrichemical inputs are used varies by crop, location, and cultivation methods employed. A study of nitrate runoff from farmland under corn-soy rotation found that increasing nitrogen input to the soil by 20% and 40% increased the nitrogen load in runoff water by 25% and 49% respectively (Chaplot, Saleh *et al*., 2004).

Beyond intensifying current production, expansion of feedstock cultivation into regions that are not presently cultivated, could cause erosion. Land may be removed from the Conservation Reserve Program (CRP), which preserves sensitive and erosion-prone land. The USDA anticipates that farmers will return 4.6 million acres of CRP land to active cropping when their current contracts expire (USDA, 2007).

The industrial portion of the ethanol production process also poses water pollution concerns. Salt buildups in the cooling towers and brine byproduct from water purification must both be periodically discharged (Berndes, 2002; Keeney and Muller, 2006). Also, biodiesel plants can release environmentally harmful levels of glycerin (Goodman, 2008).

3. Methods

Water applied to agricultural fields but not consumed by the crops is later available elsewhere and is therefore not included in our calculations of biofuel embedded water. There is some precedent for the quantification of embedded water in conventional agricultural commodities (Chapagain and Hoekstra 2004; Hoekstra and Chapagain 2007). These studies use models of crop ET to determine how much water has been consumed in growing a given crop or the crop constituents of a processed product. These models are based upon the Penman-Montieth equations (see Box 2) which calculate crop ET per acre from climatic and crop physiological data (Allen, Pereira *et al*., 1998).

Box 2: Crop ET – The Penman-Montieth Equation

Developed at the UN Food and Agriculture Organization, the Penman-Monteith model is the standard instrument for estimating crop ET. The model calculates ET using a combination of climatic data and crop physiology (Allen, Pereira *et al*. 1998).

$$ET_c[c] = K_c[c] \times ET_0$$

C = crop

K_c = physiological crop coefficient

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}$$

ET_0 = reference crop evapotranspiration [mm/day],

Δ = slope of the vapour pressure curve [kPa/°C]

T = average air temperature [°C]

γ = psychrometric constant [kPa/°C]

e_s = saturation vapour pressure [kPa]

R_n = net radiation at the crop surface [MJ/m^2/day]

G = soil heat flux [MJ/m^2/day]

U_2 = wind speed measured at 2 m height [m/s],

e_a = actual vapour pressure [kPa],

e_s-e_a = vapour pressure deficit [kPa].

Researchers at the California Department of Water Resources have parameterized and refined the Penman-Monteith model for the California context, producing the Consumptive Use Program (CUP), which was used in this study. The model has been validated using nine years of calculated ET data from the instrumentation network of the California Irrigation Management Information System. (Orang, Snyder *et al.*, 2005).

3.7 LCFS production targets/scenarios

The UC-LCFS study (Brandt, *et al.*, 2007; Arons, *et al.*, 2007) projects scenarios for meeting and surpassing the GHG reduction targets set by executive order S-1-07. For the purposes of this study, we consider those scenarios that meet (as opposed to exceed) the 10% reduction goal using the biofuel-intensive (G10) case. The other assumption central to this analysis is that 40% of the biofuel consumed under the scenarios is produced from feedstocks grown inside California in accordance with the 2020 target set by Executive Order S-06-06. Based upon these figures, this analysis assumes 830.4 million gasoline gallon equivalent (GGE) in-state ethanol production.

Biodiesel is not considered in this analysis for a number of reasons. First, it plays a much smaller role in state transport fuel projections than does ethanol. Second, at this point California does not produce potential biodiesel feedstocks in appreciable quantities. Both soybeans and canola, the two major agricultural feedstocks for biodiesel, are grown in such small quantities and on so few farms that their acreage is not reported in the USDA agricultural census, which redacts data that may be traceable to individual farmers. Even if biodiesel feedstocks can profitably be grown in California, there are not now sufficient data as to where they would be grown and what would be their water consumption characteristics.

Increased biofuel production could be met in a variety of ways. Conventional energy crops commonly grown in California include corn, other grains, and sugar beets. Beyond these conventional biofuel feedstocks, there are the “second generation” feedstocks, such as biomass from agricultural waste, municipal solid waste, and dedicated biomass energy crops such as switchgrass and miscanthus. Development of these feedstocks and production pathways would have distinct implications for California water resources.

3.8 Conventional feedstocks

This analysis attempts, wherever possible, to draw upon existing California agricultural data in projecting future production scenarios. It therefore preferentially considers crops that are currently grown in the state – projecting an increase in their cultivation – over those that are hypothetical or experimental in their application to the California context.

Corn grain is the primary feedstock for biofuel production in the United States. While mostly grown in the Midwest, corn production in California has been expanding rapidly – with plantings rising almost 25% between 2006 and 2007 to over 600,000 acres. The majority of this acreage is planted to corn grown for forage and silage to supply the state’s livestock operations. Yields consistently equal or exceed Midwestern production, but this high productivity comes at the cost of elevated irrigation and chemical inputs.

Sugar beets are another major potential feedstock for California. Though they were grown on only 40,000 acres in 2007, they could easily expand above their historical high of over 300,000 acres in the late 1960s and early 1970s. Furthermore, California sugar beet cultivation produces among the highest yields on the planet (Kaffka and Hills, 2007). In the spectrum of California field crops, sugar beets are water-intensive (see figure 3), require moderate fertilizer input, high pesticide use, and create substantial erosion.

Sugarcane, while a major feedstock for ethanol production globally, is not grown widely in California and is therefore not included in this analysis.

3.9 Cellulosic feedstocks

According to the UC-LCFS study, California could have sufficient feedstocks for production of over 1 billion gallons of lignocellulosic biofuel per year by 2020. This would constitute a large proportion of the 16.5 to 17 billion gallons of total fuel demand projected for light duty vehicles by that year (Brandt, *et al*., 2007; Arons, *et al*., 2007). While production at this scale depends upon development and commercialization of technologies that are largely still experimental, lignocellulosic biofuels are likely to play a role in the low-carbon energy future of California.

The two broad categories of biomass feedstock for lignocellulosic ethanol production are purpose-grown *feedstock crops* and agricultural, forestry, industrial, or municipal *waste materials*. Table 1 presents some published estimates of potential production capacity from a variety of feedstocks.

Table 1: Potential lignocellulosic ethanol production in California

	Potential Yields	
Biomass Source	**Feedstock (million dry ton/yr)**	**Ethanol (million gge/yr)**
Field and seed	2.3	105
Orchard/vine	1.8	83
Landfilled mixed paper	4	213
Landfilled wood & green waste	2.7	144
Forest thinnings	14.2	660
Totals	**24.9**	**1205**

Source: Williams (2006)

2.3.1 Dedicated feedstock crops

Productive perennial grasses such as miscanthus and switchgrass, as well as the low-input high-diversity managed grasslands investigated by Tilman *et al*., (2006) and short-rotation woody crops (SWRC) are all potential feedstock crops for lignocellulosic ethanol production in California. Some have been shown to provide environmental and economic benefits such as sequestering carbon in soil (Tilman *et al*., 2006), improving marginal lands, providing buffer strips to reduce erosion and chemical runoff, and habitat creation (Koo-Oshima, 2007; Mann and Tolbert 2000; Helmers *et al*., 2006). They are also usually grown with lower rates of fertilizer and pesticide input (McLaughlin and Walsh, 1998).

Water productivity data have not yet been gathered for cellulosic feedstocks, but according to the National Research Council (2007), they are far more productive per unit of water consumed than are conventional feedstocks. However, it is also worth noting that while there is very little irrigation of such crops today, this could change were biomass fuels to become competitive and higher yields profitable.

At the time of this writing, there have been no comprehensive or even sufficiently broad field tests of these crops in the California context. Furthermore, the existing crop evapotranspiration models are calibrated for current crop systems and have not yet been applied to most biomass crops. As a result, this analysis uses two hypothetical biomass crop feedstocks – one low-yield and one high-yield – using outside data to project biomass yield, water consumption, and ethanol productivity.

The low-yield biomass (LYB) crop is modeled here on grassy fodder crops (hay and haylage) currently grown in the state. Similar to lignocellulosic feedstock crops, fodders have been bred and cultivated to maximize total plant biomass rather than one specific plant product as is the goal with most crops. The productivity of these crops on average is approximately 375 gallons of ethanol per acre annually – similar to the yields anticipated from the low-input high-density grasslands studied by Tilman *et al.,* (2006).

High-yield biomass (HYB) crops in this analysis are modeled as producing 9 dry tons of biomass per acre on average annually after Williams (2006) with the relative yields in various California regions modeled on common biomass crops currently grown in the state. The water consumption dynamics of these hypothetical HYB crops are modeled after Berndes (1999).

2.3.2 Waste materials

The estimated 33.6 million tons of crop and forestry residues, municipal solid waste, and industrial byproducts that could be collected annually and converted to liquid fuels may play a part in building California's low-carbon energy system (CA Biomass Collaborative, 2005).

Quantifying the embedded water in fuels made from these residues raises the difficult question of how to apportion the water consumed (e.g. is it reasonable to assert that all of the water used to grow corn is embedded in the grains themselves and none in the stover?). Various methods of apportioning these effects, such as by mass fraction or by economic value fraction, have been used in studies of GHGs and embodied energy. For the purposes of this study, however, the embedded water in these waste streams is considered to be zero because it is assumed that they are truly agricultural, municipal, or industrial *wastes* and that therefore cropping and production decisions are not influenced by the consumption of these residues.

Production of ethanol from waste biomass feedstock might cause significant pollution. Some of the processes for converting municipal and industrial waste to fuel can generate waste streams contaminated with toxic pollutants such as dioxin and furans. Also, the removal of too much of the crop residues from the field could be expected to harm soil structure and exacerbate erosion problems (National Research Council 2007).

3.10 Production scenarios

We considered three scenarios of ethanol feedstock mix for California transportation fuel: *conventional feedstocks*, *cellulosic energy crop development*, and *waste utilization* (table 2).

Table 2: Production Scenarios

1	***Conventional Feedstocks:***	
	Production using common, currently available agricultural feedstocks and technologies.	- 50% corn grain - 50% sugar beets
2	***Cellulosic Crop Development:***	
	Assumes development of biomass energy cropping and lignocellulosic ethanol production.	- 25% corn - 25% sugar beets. - 25% low-yield biomass crops - 25% high-yield biomass crops
3	***Waste Utilization:***	
	Incorporation of waste-stream feedstocks using lignocellulosic ethanol technologies.	- 25% low-yield biomass crops - 25% high-yield biomass crops - 25% agriculture/forestry residues - 25% industrial/municipal wastes

Each of these scenarios has a gross water footprint dependent upon the feedstock mix and where it was grown. However, the net water resource implications also depend upon what land use is displaced for feedstock cultivation.

We assume that crops displaced for feedstock production will be field crops – specifically corn, sugar beets, wheat, rice, sorghum, barley, oats, cotton, beans, and fodder crops. These are low-value crops, and are therefore more likely to be abandoned in favor of biofuel feedstocks than are higher value crops such as fruits and vegetables. Furthermore, these field crops are annuals, so the land is available the next year at no loss as opposed to being tied up in a long-term investment such as a fruit or nut orchard. We used four scenarios to investigate the implications of displacement for water resources: *average field crops, thirstiest crops, least thirsty crops, and grasslands* (Table 3).

Table 3: Displacement scenarios

A	***Average Field Crops:*** Cultivation of ethanol feedstocks is modeled to displace the average field crop acreage in a region.
B	***Thirstiest Crops:*** Best-case displacement - ethanol feedstocks preferentially displace crops, such as rice and alfalfa, with unusually high water demand.
C	***Least Thirsty Crops:*** Worst-case scenario displacement wherein cultivation of ethanol feedstocks replaces those crops with the lowest water demand.
D	***Grassland - Extensification:*** Production of ethanol feedstocks is modeled to result in extensification of California agriculture - occurring solely on currently uncultivated land.

The combination of the above three feedstock mixes and four displacement types generated twelve distinct scenarios for this analysis. These scenarios are not meant to represent or recommend probable future feedstock/displacement mixes, but simply to project the water resource implications of some potential pathways.

The analyses were carried out at a county level. For simplicity, we assumed that crops are currently being grown in places to which they are well suited and that increases in production would occur in proportion to current regional output. Similarly, land area employed in achieving these outputs was determined based upon each county's crop productivity. In order to better understand this system, more sophisticated analysis is needed and planned, applying economic models to project the probable locations of biofuel feedstock expansion in California.

Agricultural productivity data used in this model are drawn from the Agricultural census conducted by the USDA National Agricultural Statistics Service. Agricultural inputs are modeled after estimates published by the University of California Cooperative Extension service. Data on refining processes and outputs are drawn from the EBAMM model (Farrell *et al*., 2006), the GREET model (Wang, 2007), and the NREL model biorefinery (Wooley *et al*., 1999).

3.11 Leakage and indirect effects

Beyond water embedded in the fuels themselves, biofuel production under LCFS policies might affect water resources in two ways. First, this analysis only accounts for a 40% in-state share of the projected biofuel production. The remaining 60% of necessary feedstock is assumed to be produced outside California. Responsible policy-making requires that we consider the effect of our consumption patterns on resources elsewhere, as well as those within the state.

Second, by removing land from current cultivation, biofuel production will perturb international commodity markets, causing alterations in land and resource use globally (Delucchi, 2002; Searchinger, 2008). The effect of this indirect land use change, and its attendant implications for water resources, are not captured in this analysis because the focus of this research is on California water resources. The effect of indirect land-use change on water resources is fundamentally different from its effect on climate change, however. Use of water has very different implications in contexts with varying water availability, whereas GHGs have essentially the same effect wherever they are produced.

4. Results:

4.1 Water consumption

Our analysis shows a clear difference in fuel embedded water amongst the feedstocks modeled. Figure 5 shows the average embedded water in ethanol from each of the feedstock crops. Biorefinery consumptions are included separately in this figure, but represent less than 1% of the embedded water shown here.

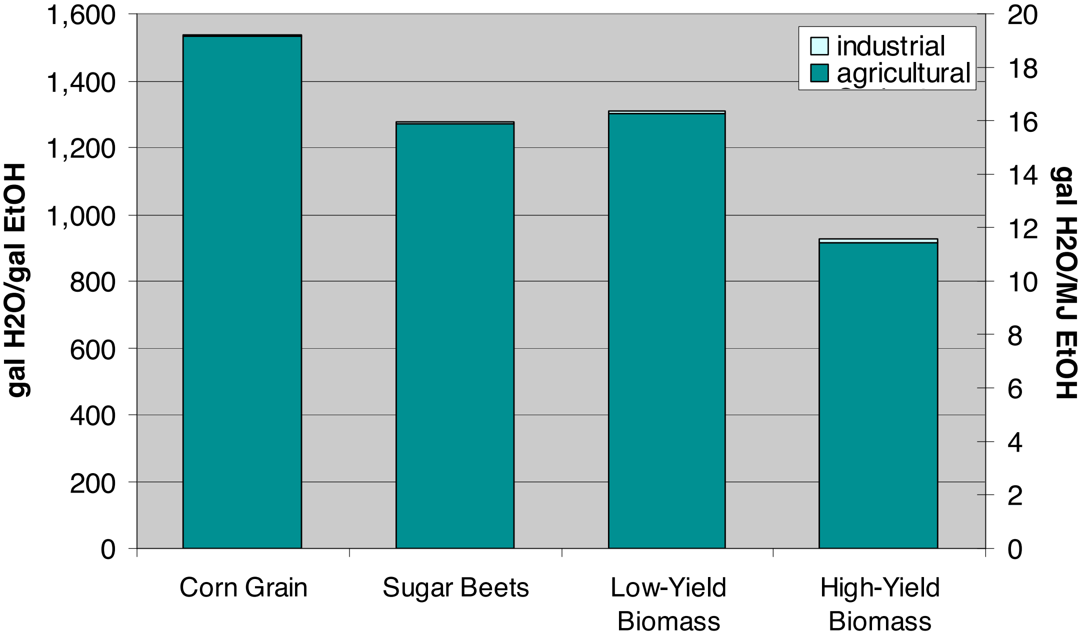

Figure 6: Embedded water (gal ET/gal ethanol) – statewide weighted average

The average embedded water in ethanol from these feedstocks across California ranges from 920 to 1,500 gallons of water per gallon of ethanol. In comparison, production of a comparable (by energy content) volume of petroleum fuel requires from 2.2 gallons of water (Gleick, 1994) to over 39 gallons for fuel from tar sands or oil shale (Davis and Velikanov, 1979). Nearly all of the water embedded in these petroleum fuels is consumed in industrial processing whereas the vast majority of biofuel embedded water is taken up by ET in the fields.

The values for embedded water in figure 5 are weighted averages for each feedstock across the state, and so do not reveal the heterogeneity in both yield and crop ET amongst counties in California. Figure 6 indicates the breadth of values seen for these crop characteristics. The data points in this figure each represent a county in which the crop feedstock in question is commonly grown.

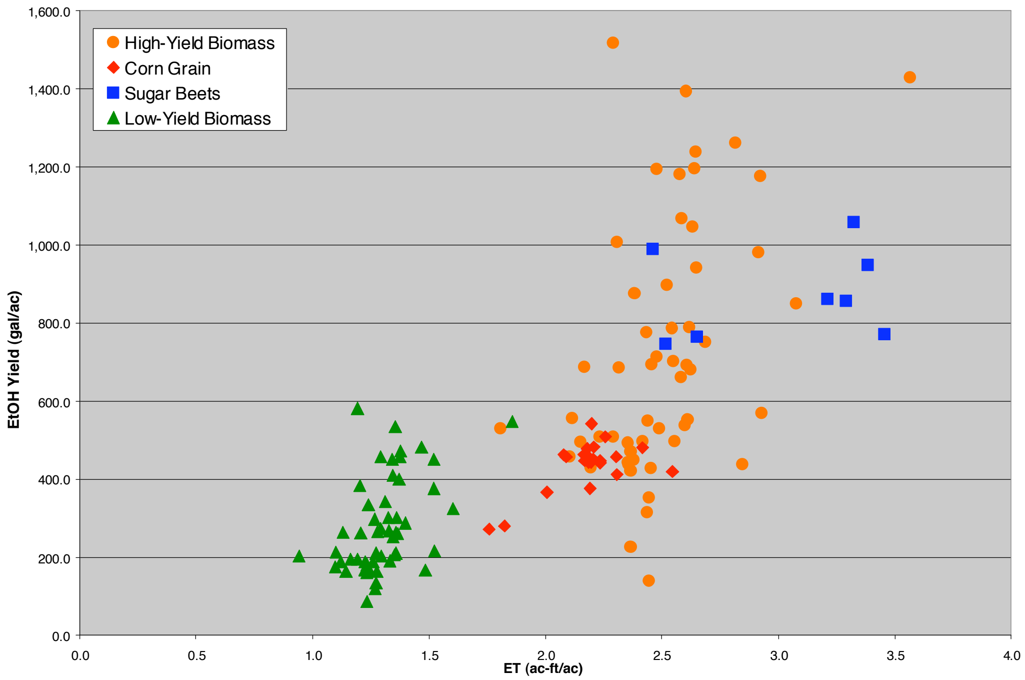

Figure 7: ET and yield by county

Presented differently, this variation in yield and ET among counties reveals different information. Figures 7 and 8 focus on the low-yield biomass feedstock. Figure 7 presents the water consumed per *gallon* of fuel from each of these places, while Figure 8 shows the amount consumed per *acre* cultivated. The contrasting patterns of these two maps show that while more water is consumed in cultivation of this crop in the southern reaches of the state, those areas are also more productive per unit consumption.

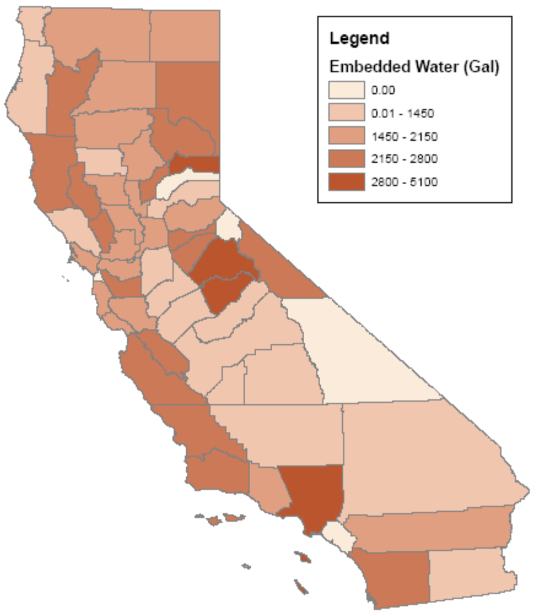

Figure 8: Embedded water in ethanol from low-yield biomass feedstock

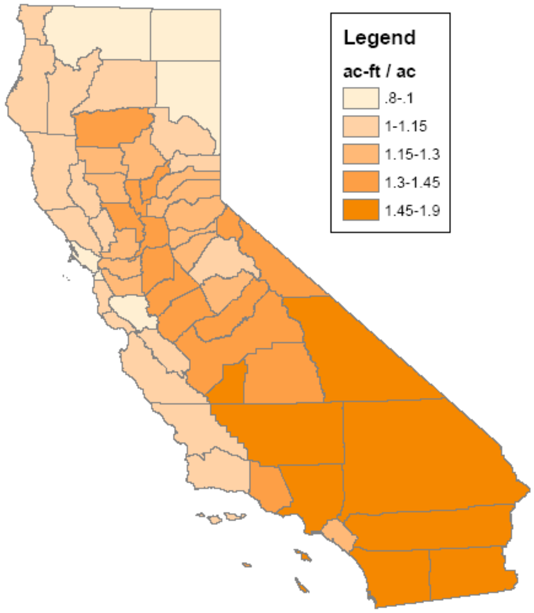

Figure 9: Water consumed in annual cultivation of low-yield biomass

This is of particular interest in light of the fact that more than 70% of average runoff occurs north of Sacramento while the southern part of the state accounts for over 75% of demand (Sumner, Bervejillo *et al*., 2003).

We found water resource requirements for biofuel expansion under the LCFS to vary greatly across the scenarios investigated. Table 4 lays out some of these projected consumptions as compared to current average supply.

Table 4: Net water consumption (ET) relative to total supply

Scenario	Consumption (ac-ft/ac)	Total consumption (million ac-ft)	% of average irrigation	% of average total supply
1	2.54	5.47	16.0%	2.7%
2	2.12	5.26	15.4%	2.6%
3	1.68	2.21	6.5%	1.1%

Biofuel production under these scenarios requires large inputs of water, but in some cases, other heavily consumptive activities are displaced by the introduction of bioenergy cropping. Figure 9 shows the effect that the twelves scenarios investigated would have on California irrigation resources. This figure presents net affect on applied water since ET is not known for native grasslands across the state, making a comparison with energy cropping infeasible.

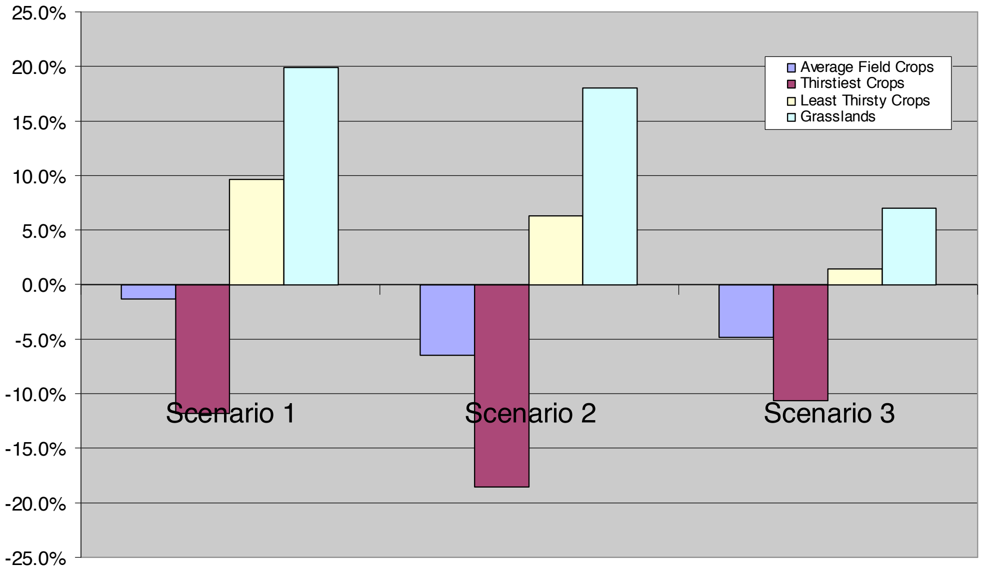

Figure 10: Percent change in applied water per acre

If regional average field crops were displaced by biofuel feedstocks, each of the scenarios would see a decrease in total irrigation water demand statewide, since some of those displacements would occur on land previously occupied by very heavily irrigated crops such as rice and alfalfa. If these heavily irrigated crops were *preferentially* displaced, the water savings would be significant. However, if instead crops which do not require a great deal of irrigation were displaced, there would be a net increase in irrigation demand.

Finally, if the bioenergy targets were met through extensification of cropland onto native grassland habitats, the net increase in water demand would be far more substantial

4.2 Pollution

The application of chemical fertilizers and pesticides is a major component of most agriculture in California. A shift in cultivation patterns, such as the one that would result from the large-scale production of biofuels in California would be expected to affect the rate and location of these chemical applications. Figures 10 and 11 detail the projected net effect on agrichemical application in California from the scenarios studied.

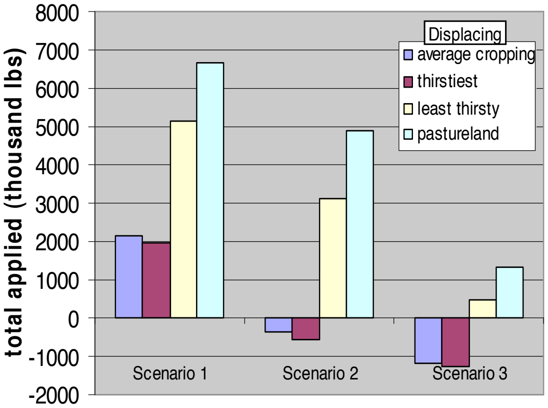

Figure 21: Change in pesticide input from bioenergy production scenarios

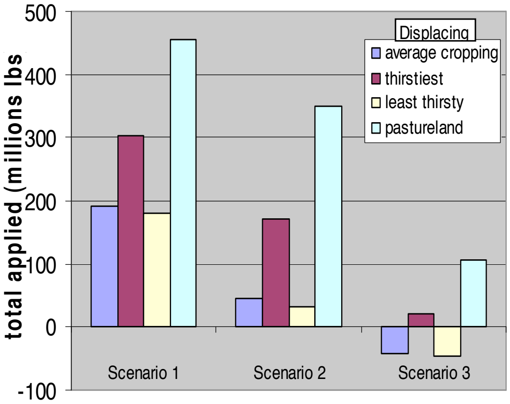

Figure 32: Change in N Fertilizer inputs from bioenergy production scenarios

5 Discussion and Recommendations:

Efforts to mitigate greenhouse gas emissions should not leave other problems in their wake. At times the achievement of climate goals and the preservation of water resources may be at odds. For example, concerns about indirect land-use change could lead to extensification of agriculture into uncultivated grasslands so as not to displace current production. This would be the most water-intensive course of action as no existing agricultural water demand would be displaced to offset the increases in consumption for bioenergy.

Water resource implications of LCFS policies should be considered in the rule-making process to ensure that the standard does not drive an unsustainable consumption of the state's water resources. We recommend the following considerations:

- **Implement a water accounting system.** Our analysis shows the feasibility of calculating the water embedded in biofuels from different feedstocks grown in various California regions. Alongside life-cycle GHG accounting, CARB should implement a water accounting system. Some potential features of such a system might be:
    - Default values for crop water consumption and the ability to opt-in to proving lower consumption for producers who are improving efficiency. This system could also be designed to incorporate tradable permits for water pollution.

  - Performance subsidies to encourage Best Management Practices and to minimize loading of sediments and chemicals into waterways. Such incentives have been successful federally in the Conservation Reserve Program – reducing cropland erosion by over 40% between 1982 and 2003 (National Academies, 2007).

- **Establish water impact regulations for Low-Carbon Fuels.** Calculated or reported water consumption for biofuel production should be applied in a regulatory framework. Options available to the Air Resources Board in incorporating water sustainability into LCFS policies include:
  - Ignore water resources, delegating this consideration to water programs (not recommended)
  - Determine a "price" for water in Global Warming (GW) units and add it to Average Fuel Carbon Intensity (AFCI)
  - Charge a tax on water use for biofuel production
  - Establish a go/no-go rule for maximum water consumption per MJ of all fuels allowed under the LCFS
  - Categorize counties/regions in California based upon their scarcity of water, establishing go/no-go rules for each county/region.

- **Look beyond embedded water.** Water consumption represented by leaching of agrichemicals into a watershed might be quantified through a regulatory system, but that system will also need to consider the human and ecological health effects of regional and temporal spikes in pollutant concentration.

- **Look beyond California.** Consumption of imported fuel as well as economic effects of shifting cropping systems here will cause alterations in agricultural systems outside the state. Water is a scarce resource in many locales, with 1/3 of the planet's less developed countries predicted to have insufficient water resources to meet their needs by the year 2025 (Seckler, Molden *et al.*, 2003) and with agriculture consuming up to 90% of withdrawn water in some places (Postel 2006).

  While it may not be CARB's, or the CA Department of Water Resources' mandate to guarantee sustainable use of water resources abroad, it is certainly our ethical obligation to do what we can to ensure that our consumption habits do not put undue strain on people and ecologies across the planet.

- **Regulate siting and design of biorefineries.** While water consumption by biorefineries is a relatively small portion of total crop embedded water, it may have a large local effect. For each 1 million gallons per year of production capacity, corn ethanol plants use enough water to support a town of approximately 5,000 people (Keeney and Muller, 2006). Careful siting and design of biorefineries will minimize conflicts between different water uses as well as ensuring that the waste streams from plants cause the least possible harm to the environment and human health. Furthermore, consumption can be reduced through mandated use of technologies for recycling much of the water now lost from cooling towers. Co-location with wastewater treatment facilities allows biorefineries to use degraded effluents. Co-location with livestock operations allows for cycling of water and waste products between the two processes, including the efficient use of wet distiller's grains as cattle feed.

- **Legislative incorporation.** Water sustainability should be incorporated as a task under the Alternative and Renewable Fuel and Vehicle Technology Program (AB 118) and other relevant renewable fuel legislation.
- **Future research:** Further research is necessary in order to effectively manage and minimize the negative water resource effects of California's low carbon transportation system. The research reported here would be made more robust through the incorporation of economic modeling in order to refine the scenarios with projections of probable feedstock production locations. Also, research into biomass crops as well as waste biomass collection and processing systems appropriate to the California context should be a major priority in the state's bioenergy plan.

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