Supporting Information

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The Water Footprint of Biofuels: A Drink or Drive Issue?

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A) Water (ET and Irrigation) and land requirements in the U.S. for ethanol produced from different crops (Figure 1 in paper)

To estimate water requirements, distinguishing between withdrawals and consumptive use is important, the former meaning the overall amount of water diverted from a water body for a particular use (*e.g.,* irrigation) regardless of whether it is returned or not, and the later meaning the water not directly returned to the system but consumed during the process, (*e.g.,* evapotranspiration).

To calculate the consumptive water use of biofuels in the U.S. for selected crops, we used the virtual water content of crops grown in the U.S. from the UNESCO's report "The Water Footprint of Nations" 2004 [1]. Cellulosic crops used as biofuel feedstocks (*e.g.,* switchgrass) were not included in the report, and consequently its evapotranspiration requirement was obtained from a combination of studies across the U.S. geography [2-4] (Table S1)

ET values were converted to water consumed per liter of biofuel produced by factoring in ethanol conversion yields for the respecting crops (Table S2), which were obtained from industry statistics or pilot scale tests when possible. When such statistics were nonexistent, such as with cellulosic feedstocks, we assumed an efficiency of 80% of the theoretical ethanol yield according to NREL. This assumption was made on the basis that the actual corn ethanol yield [5] is about 80% of the theoretical [6].

Table S 1. Virtual water content and average yields of selected crops in the U.S and calculated values for an ethanol volume basis

	Virtual Water Content	***Water footprint based on ET***
	m^3/tonne	***L water/ L ethanol***
Maize	489	1,262
Potatoes	105	777
Sugar cane	103	1,266
Sugar beet	84	812
Sorghum	782	2,018
*Soybean**	1,870	4,185
Switchgrass	N/A	1,401

* Soybean is used to produced biodiesel rather than ethanol, and this value represents energy-equivalent liters of ethanol (obtained by multiplying by 0.64, which is the ratio of energy content of ethanol to that of biodiesel if using 6.18 KWh per liter of ethanol and 9.58 KWh per liter of biodiesel as provided by Oak Ridge National Laboratory (ORNL) quick-reference list of conversion factors[5])

Table S 2. **Ethanol yields**

Crop	*L/tonne harvested*	*Source*
Sugar cane	81	The Feasibility of Ethanol Production from Sugar cane in the U.S. [7]
Potatoes	135	Ethanol Production for Automotive fuel Usage [8]
Sugar beet	103	The Feasibility of Ethanol Production from Sugar cane in the U.S. [7]
Corn grain	387	NREL average yield (not theoretical) [9]
Sorghum grain	387	The Feasibility of Ethanol Production from Sugar cane in the U.S. [7]
Switchgrass	311	80% of theoretical ethanol yield calculator DOE [6]
Poplar tree	294	80% of theoretical ethanol yield calculator DOE [6]
Soybean	447	Biodiesel and Petroleum Diesel Life Cycles [10]

Estimation of overall water withdrawals (*i.e.,* irrigation) for different crops used statistics on irrigation from different regions of the U.S., thus taking into account the regional variability. We estimated how many of liters of irrigation water are needed to produce one liter of ethanol from seven different crops, for each of the major producing states (which altogether accounted for 80% or more of the total U.S. production for that crop), and calculated a weighted average with the following formula:

$$x^j = \frac{x_1^j w_1^j + x_2^j w_2^j + \ldots. + x_n^j w_n^j}{w_1^j + w_2^j + \ldots. + w_n^j}$$

Where:

x^j is the U.S.-weighted average of irrigation water requirements of ethanol for crop *j* (L irrigation water/ L irrigated ethanol);

x_i^j is irrigation requirement per liter of ethanol for crop *j* in state *i* (L irrigation water/ L irrigated ethanol); and

w_i^j is the weight of the state-specific value, (*i.e.,* the percentage of U.S. production of a particular crop *j* attributable to state *i*)

n is the number of states accounting for ≥ 80% of the total U.S. production for that crop.

Rankings of top producing states [11] for each crop were obtained from the National Agricultural Statistics Service (NASS) of the USDA for the year 2003 to match the 2003 Farm and Ranch Irrigation Survey (FRIS) by the USDA [12], the latest available, from which irrigation water uses for each crop, and irrigated harvest yield for traditional crops used as feedstocks were obtained. Data on irrigation of sugar cane was not available through the FRIS 2003 and we used personal communications from faculty at the University of Florida [13] and Louisiana State University [14]. Irrigation data for switchgrass was not available and harvest yields were obtained from the same experiments from which ET data were found (Table S1) Since no irrigation water was applied to cellulosic feedstocks in those experiments, no irrigation was assumed in this study, but we acknowledge that irrigation might happen in the future if they are grown as fuel crops.

The estimation of the x^j (U.S. weighted average) and x_i^j (state specific) values required factoring in ethanol conversion yields (Table S2), feedstock harvest yields, irrigation water requirements and fertilizer application rates. Land requirements were estimated using the same method and dataset used for water irrigation requirements.

A summary of all required agricultural input data and results by state and as a weighted national average can be found in Tables S7 and S8 for traditional crops. The standard deviations depicted as error bars in Figure 1 were calculated from the pool of state-specific x_i^j values for each crop.

B) Nitrogen and pesticide requirements for producing one liter of ethanol from different crops (Figure 2 in paper)

Nitrogen requirements were estimated using the same method used for water irrigation and land requirements. Error bars correspond to the standard deviation of the pool of results for the states considered. The latest available fertilizer (nitrogen) application rates (Tables S7 and S8 were obtained from the 2000 and 2003 Field Crops Agricultural Chemical Usage database from NASS [15] for all crops except for potatoes and sugar cane, which were not available. A national average for potato fertilizer application rate was obtained from an Economic Research Service (ERS) of the USDA [16] while nitrogen data for sugar cane were obtained from independent sources for each of the major producing states [17-22] Fertilizer use of cellulosic feedstocks (Table S10) was inferred from the same sources from which irrigation and harvest yields data were obtained (see above).

Pesticide data were obtained from the USDA NASS agrichemical usage data, which provides total pesticide usage for the Nation and total harvest mass for specific crops [15]. The most recent data set for most of the crops (corn, potatoes, soybeans) was available for 2005. The most recent sorghum values were from 2003. Switchgrass data was from Pimentel & Patzek, who suggest that 3 kg/ha pesticide used [23]. This application is typically only in the first year and so the normalization to the ethanol volume produced assumed one year of pesticide application for eight years of switchgrass harvest. No data were available for the sugar crops. Pesticide use data were normalized to liters of ethanol (or ethanol equivalents) using the method described above.

Table S 3. Pesticide use data

Crop	*Year of data*	*Harvested area (1000 ha)*	*Total U.S. Pesticide Use*				*Pesticide Application*	
			herbicide (tonne)	*insecticide (tonne)*	*fungicide (tonne)*	*other (tonne)*	*application (kg pest./ha)*	*g pest./ L e*
Corn	2005	30,947	71,625	2,204	42	0	2.39	0.66
Potatoes	2005	342	634	445	2,515	30,923	100.94	15.29
Soybeans	2005	26,237	35,085	1,086	87	0	1.38	2.57
Sorghum	2003	3,426	6,995	120	0	0	2.08	1.24
Switchgrass	--	--	--	--	--	--	3.00	0.08

* assumed 3 kg/ha pesticide in first year, averaged over total 8-year harvest

The pesticide data show the sum of herbicides, insecticides and fungicides (Table S3).

The high application value for potatoes is largely due to the use of sulfuric acid at harvest time to kill plant shoots to make the harvest easier. Other common pesticides include atrazine and alachlor for corn and glyphosphate, used primarily on soybeans. The use of glyphosphate on corn is growing rapidly due to the switch to over 50% of corn acreage being planted with “Roundup Ready” corn [24]. Note that glyphosphate is the active ingredient in this commercial herbicide.

The estimated pesticide application for switchgrass assumes 3 kg/ha of broadleaf herbicides (e.g., atrazine and 2,4-D) used in the first year only for switchgrass establishment. The impact of these agricultural pesticides on water quality continues to be studied and is often hotly debated. For example, in a study in 2003, atrazine was implicated as an endocrine disruptor contributing to mutations in frogs even at very low concentrations [25]. More recent studies, however, have shown this to not be the case [26].

C) Water uses of various energy-related processes (Table 1 in paper)

Water is needed to produce energy. In Table 1 (in manuscript) we show water uses of various processes related to electricity production and oil extraction and refinement, which were obtained from the DOE Report to Congress “Energy Demands on Water Resources” [27] and “The Water and Energy Nexus” article [28]. We added to this list the irrigation water requirements of corn ethanol and soybean biodiesel obtained in this study (Table S11 or Figure 1 in paper). We converted the data given in different units to liters per Mega-Watt-hour (L/MWh) for easy comparison. We assumed energy contents of 1,700 KWh per barrel of petroleum, 6.18 KWh per liter of ethanol and 9.58 KWh per liter of biodiesel, and that a barrel of oil is contains 42 U.S. gallons as provided by Oak Ridge National Laboratory (ORNL) quick-reference list of conversion factors [5].

Table S 4. Water uses of other energy related processes

Process	***gal/MWh***	***L/MWh***
Petroleum extraction	3-10	10-40
Oil refining	20-40	80-150
Oil shale surface retort	45-180	170-681
NGCC* power plant, closed loop cooling	60-8,000	227-30,300
Coal Integrated Gasification Combined-Cycle	~230	~900
Nuclear power plant, closed loop cooling	~250	~950
Geothermal power plant, closed loop tower	500-1,100	1,900-4,200
Enhanced Oil Recovery	~2,000	~7,600
NGCC*, open loop cooling	7,500-20,000	28,400-75,700
Nuclear power plant, open loop cooling	25,000-60,000	94,600-227,100
Irrigated corn ethanol**		2,270,000 - 8,670,000
Irrigated soybean biodiesel**		13,900,000 - 27,900,000

* Natural gas combined cycle

** From data in Table S8 and Figure 1 in paper

D) What it will take to make enough corn ethanol to meet the EISA mandate?

In order to obtain water, land and nitrogen requirements of the 57 billion liters of ethanol (15 billion gallons per year), we multiplied this value for the weighted averages of this requirement calculated on a liter-of-biofuel basis from Table S11 (also in Figure 1 in paper). S11 weighted averages are calculated from 2003 agricultural statistics, and current industry ethanol yields (table S2) as found in the literature.

Table S 5. Footprint of 15 BGY.

Metric	*Quantity*	*Benchmark for Comparison*
Fuel Requirement	56 Billion Liters Ethanol (15 BGY)	7% of 2006 annual gasoline consumption
Amount of feedstock	143 Million tonnes (5.8 Billion bushels)	44 % of the 2007 U.S. corn production
Land	16 Million ha (39 Million ac)	9% U.S Cropland
Irrigation water*	6×10^{12} L (1.6×10^{12} gallons)	3.23 % of current irrigation water use in the U.S. (Compare to 1.23 Trillion gallons withdrawn per year in Iowa for all uses)
Nitrogen fertilizer	2.5 million tonnes (5.5×10^{12} lbs)	19% of the N fertilizer used for all crops in the U.S. (~$2.2 billion)

*Assuming 19% of corn is irrigated

Alternatively, we can calculate the footprint associated the additional expansion from 2007 baseline, which would be of 9.5 BGY instead of 15BGY if we consider that 5.5 BGY were produced in 2007. We obtain the 2007 baseline value as follows: The Renewable Fuel Association (RFA) (http://www.ethanolrfa.org/industry/statistics/) reports two values of ethanol production for the year 2007: 6.5 BGY (Historic US Ethanol Production), and 5.5 BGY (Energy Industry Overview). If we take that 2,117 million bushels were used to produce ethanol in 206-2007 (USDA long term projections at http://www.ers.usda.gov/publications/oce081/) and factor in the conversion yield of ethanol (2.53 gal/bu, or 387 L/tonne, Table S2), we obtain 5.4 BGY. For our calculations we assumed 5.5 BGY were produced in 2007 per the RFA Energy Industry Overview, resulting in an additional 9.5 BGY needed to meet the 15 BGY mandate by 2015.

Table S 6. Footprint of 9,5 BGY.

Metric	*Quantity*	*Benchmark for Comparison*
Fuel Requirement	36 Billion Liters Ethanol (9.5 BGY)	4.5% of 2006 annual gasoline consumption
Amount of feedstock	93 Million tonnes (3.6 Billion bushels)	28 % of the 2007 U.S. corn production
Land	10.3 Million ha (25 Million ac)	5.7% U.S Cropland
Irrigation water*	3.8×10^{12} L (1×10^{12} gallons)	2 % of current irrigation water use in the U.S. (Compare to 1.23 Trillion gallons withdrawn per year in Iowa for all uses)
Nitrogen fertilizer	1.5 million tonnes (3.5×10^{12} lbs)	12% of the N fertilizer used for all crops in the U.S. (~$2.2 billion)

*Assuming 19% of corn is irrigated.

The results shown in both tables S5 and S6 assume current trends in harvest and fermentation yields, as well as irrigation rates and irrigation acreages. While alternative scenarios can be built using projected increases in agricultural and industrial yields; this scenario can be considered as a baseline for comparisons.

Table S 7. Summary of U.S. agricultural statistics for non-leguminous crops.

From NASS 2003, FRIS 2003 (Table 27), Field Crops Agricultural Chemical Usage 2000 and 2003, 2002 Census of Agriculture (Volume 1, Chapter 2, Table 24), and other pertinent sources [11-14, 16-22, 29] necessary to obtain the following statistics: % of U.S. production, % of irrigated area, % area fertilized with nitrogen, Irrigated Yield (Yirr), Ratio irrigated to non-irrigated yield (Yirr/Ynon-irr), Irrigation rate (I-rate), Nitrogen application rate (N-rate). The environmental footprint results are presented as: Liters of water per liter of irrigated ethanol *(Lw/Lie)*, land used per liter of ethanol *(m^2/Le)*, and grams of Nitrogen fertilizer used per Liter of fertilized ethanol *(gN/Lfe)*.

	US prod. [1]	*Irrig. Area* [2]	*Fert. Area* [3]	*Yirr* [4]	*Yirr/ Ynon-irr* [4]	*I-rate* [5]	*N-rate* [5]	*Water* [6]	*Land* [7]	*Nitrogen* [8]
CORN	*(%)*	*(%)*	*(%)*	*(bu/ac)*		*(ac-ft/ac irrigated)*	*(lb/ac fertilized)*	*(Lw/Lie)*	*(m^2/Le)*	*(g N/Lfe)*
Iowa	19	1	93	171	1.17	0.5	133	367	2.62	39.0
Illinois	18	2	98	174	1.07	0.6	161	432	2.51	45.3
Nebraska	11	61	95	186	2.14	1.2	130	809	2.82	41.0
Minnesota	10	3	95	169	1.30	0.6	122	445	2.82	38.5
Indiana	8	4	99	169	1.18	0.5	154	371	2.82	48.6
Ohio	5	0.12	100	143	1.02	1.6	164	1,402	2.64	48.5
South Dakota	4	4	92	169	1.52	1.0	98	742	3.70	40.7
Wisconsin	4	3	99	171	1.50	0.7	102	513	3.19	36.4
Missouri	3	9	99	158	1.39	0.6	169	476	3.81	72.1
Kansas	3	54	99	178	3.12	1.4	133	986	3.43	51.1
Michigan	3	9	99	165	1.35	0.5	123	380	3.21	44.3
Texas	2	36	98	184	3.61	1.6	146	1,090	3.49	57.0
US		19	96							
						U.S. Weighted average		***566***	***2.85***	***44.0***
						Standard deviation		***340***	***0.45***	***9.9***
SORGHUM	*(%)*	*(%)*	*(%)*	*(bu/ac)*		*(ac-ft/ac irrigated)*	*(lb/ac fertilized)*	*(Lw/Lie)*	*(m^2/Le)*	*(g N/Lfe)*
Texas	37	16	63	68	N/A	1	90	1,843	7.62	61.0
Kansas	32	6	97	93	N/A	0.9	76	1,213	9.14	37.7
Nebraska	8	5	99	113	N/A	1.3	86	1,442	6.63	35.1
Arkansas	4	27	N/A	90	N/A	0.6	N/A	836	5.02	N/A
US		11	82							
						U.S. Weighted average		***1,523***	***8.08***	***49.2***
						Standard deviation		***422***	***1.73***	***14.3***
SUGAR CANE	*(%)*	*(%)*	*(%)*	*(Tonnes/ha)*		*(in)*	*(Kg N/ha fertilized)*	*(Lw/Lie)*	*(m^2/Le)*	*(g N/Lfe)*
Florida	52	98	N/A	88	N/A	44.75	163	1,684	1.40	22.7
Louisiana	37	0	N/A	59	N/A	N/A	112	N/A	2.09	23.4
US		48	N/A							

						U.S. Weighted average		***1,684***	***1.70***	***23.1***
						Standard deviation		***N/A***	***0.49***	***0.5***
SUGAR BEET	***(%)***	***(%)***	***(%)***	***(Ton/ac)***		***(ac-ft/ac irrigated)***	***(Kg N/ha fertilized)***	***(Lw/Lie)***	***(m^2/Le)***	***(g N/Lfe)***
Minnesota	33	1	100	24	N/A	-	135	N/A	2.09	19.5
Idaho	20	100	97	29	N/A	2.7	224	1,224	1.48	24.3
North Dakota	17	6	94	20	N/A	2.2	146	1,417	2.11	17.1
Michigan	11	N/A	100	21	N/A	0.5	105	313	2.26	34.4
US		24	98							
						U.S. Weighted average		***1,081***	***1.97***	***22.2***
						Standard deviation		***590***	***0.35***	***7.7***
POTATOES	***(%)***	***(%)***	***(%)***	***(CWT/ac)***		***(ac-ft/ac irrigated)***	***(Kg N/ha fertilized)***	***(Lw/Lie)***	***(m2/Le)***	***(g N/Lfe)***
Alaska	37	100	N/A	109	3.63	0.50	N/A	923	3.14	N/A
Idaho	27	100	N/A	349	N/A	2.10	N/A	1,211	1.92	N/A
Washington	20	95	N/A	535	1.54	2.30	N/A	865	1.15	N/A
US		96	100							
						U.S. Weighted average		***1,051***	***2.38***	***58.8***
						Standard deviation		***185***	***1.01***	***N/A***

[1] See sample calculation 1.
[2] See sample calculation 2.
[3] See sample calculation 3.
[4] See sample calculation 4 (find % irrigated corn area for all states in table S9).
[5] See sample calculation 5.
[6] See sample calculation 6.
[7] See sample calculation 7.
[8] See sample calculation 8.

Table S 8. Summary of U.S. agricultural statistics for soybean (a leguminous crop that is not frequently fertilized with N

From NASS 2003, FRIS 2003 (Table 27), Field Crops Agricultural Chemical Usage 2000 and 2003, 2002 Census of Agriculture (Volume 1, Chapter 2, Table 24), and other pertinent sources [11-14, 16-22, 29] necessary to obtain the following statistics: % of U.S. production, % of irrigated area, % area fertilized with nitrogen, Irrigated Yield (Yirr), Ratio irrigated to non-irrigated yield (Yirr/Ynon-irr), Irrigation rate (I-rate), Nitrogen application rate (N-rate). The environmental footprint results are presented as: Liters of water per liter of irrigated ethanol *(Lw/Lie)*, land used per liter of ethanol *(m^2/Le)*, and grams of Nitrogen fertilizer used per Liter of fertilized ethanol *(gN/Lfe).*

	US prod. (%)	***Irrig. Area (%)***	***Fert. Area (%)***	***Yirr (bu/ac)***	***Yirr/ Ynon-irr***	***I-rate (ac-ft/ ac irrigated)***	***N-rate (lb/ac fertilized)***	***Water (Lw/Lie)***	***Land (m2/Le)***	***Nitrogen (g N/Lfe)***
Illinois	15	2	11	46	1.24	0.6	15	2,038	13.86	14.9
Iowa	14	0	15	42	1.24	0.4	49	1,488	15.77	55.4
Minnesota	10	1	8	43	1.43	0.6	17	2,180	16.02	19.5
Indiana	8	1	7	43	1.16	0.4	29	1,454	13.49	28.1
Nebraska	7	42	32	55	1.72	1	14	2,841	12.66	12.7
Ohio	7	0	19	53	1.29	-	20	N/A	13.32	19.1
Missouri	6	7	12	43	1.30	0.5	26	1,817	17.38	32.4

South Dakota	5	2	29	43	1.54	0.8	14	2,907	18.64	18.7
Arkansas	5	58	3	43	1.39	0.8	61	2,907	13.32	58.3
North Dakota	4	1	43	38	1.27	0.7	32	2,878	17.68	40.6
US	-	7	18							
						U.S. Weighted average		***1,935***	***12.42***	***29.3***
						Standard deviation		***618***	***2.16***	***16.5***

Table S 9. Percentage irrigation acreage of corn.

	Total harvested acres 2002	*Harvested acres irrigated 2002*	*% irrigated 2002*[1]
Alabama	176,122	11,990	6.81%
Alaska	N/A		
Arizona	27,838	27,838	100.00%
Arkansas	238,554	145,351	60.93%
California	168,354	168,192	99.90%
Colorado	708,197	634,015	89.53%
Connecticut	3,010	(N/A)	
Delaware	161,421	43,747	27.10%
Florida	26,790	9,404	35.10%
Georgia	252,176	99,179	39.33%
Hawaii	4,383	4,383	100.00%
Idaho	42,209	(N/A)	
Illinois	10,742,787	211,167	1.97%
Indiana	5,123,291	180,305	3.52%
Iowa	11,761,392	86,261	0.73%
Kansas	2,494,179	1,346,807	54.00%
Kentucky	1,043,990	8,195	0.78%
Louisiana	461,782	130,968	28.36%
Maine	2,660	(N/A)	
Maryland	406,841	31,940	7.85%
Massachusetts	2,573	(N/A)	
Michigan	2,007,021	180,261	8.98%
Minnesota	6,556,082	178,457	2.72%
Mississippi	496,219	123,232	24.83%
Missouri	2,677,491	246,315	9.20%
Montana	11,642	11,642	100.00%
Nebraska	7,344,715	4,505,579	61.34%
Nevada	7,344,715	4,505,579	61.34%
New Hampshire	880	(N/A)	
New Jersey	66,128	4,465	6.75%
New Mexico	48,096	47,904	99.60%
New York	450,664	4,262	0.95%
North Carolina	700,045	23,716	3.39%
North Dakota	991,390	54,445	5.49%
Ohio	2,869,951	3,387	0.12%
Oklahoma	182,777	99,457	54.41%
Oregon	19,308	19,116	99.01%
Pennsylvania	790,111	3,277	0.41%
Rhode Island	41	-	
South Carolina	240,085	14,932	6.22%
South Dakota	3,165,190	123,229	3.89%
Tennessee	593,564	7,286	1.23%
Texas	1,815,560	658,177	36.25%
Utah	14,999	14,999	100.00%
Vermont	5,130	(N/A)	
Virginia	335,692	12,953	3.86%
Washington	73,703	73,038	99.10%
West Virginia	29,123	(N/A)	
Wisconsin	2,862,031	83,602	2.92%
Wyoming	34,095	33,507	98.28%
United States	**75,574,997**	**14,172,559**	**18.75%**

[1] See sample calculation 2.

Table S 10. Yields, evapotranspiration, land and fertilizer requirements for Switchgrass.

Location	*ET (m^3/ha)*	*Y (Tonne/ha)*	*N-rate (KgN/ha)*	*ET Water (Lw/Le)*	*Land (m^2/Le)*	*Nitrogen (g N/Lfe)*
West Nevada		10	56		*3.29*	18.4
Knoxville, TN		16	110		*2.01*	22.1
Stephenville, TX	6,564	14	200	*1,517*	*2.31*	46.2
Hope, Arkansas	5,962	17	200	*1,161*	*1.95*	38.9
Ames, Iowa	7,622	13	200	*1,943*	*2.55*	51.0
Clinton, Louisiana	8,540	26	200	*1,041*	*1.22*	24.4
Columbia, Missouri	7,702	13	200	*1,910*	*2.48*	49.6
Florence, SC	8,539	22	200	*1,239*	*1.45*	29.0
Beeville, TX	6,386	21	200	1,000	1.57	31.3
Average				***1,401***	***2.09***	***34.6***
Standard deviation				***396***	***0.93***	***10.6***

Table S 11. Irrigation, land, and nitrogen requirement for biofuel production in the U.S. from different crops.

	Land Use		***Water Use***		***Fertilizer Use***	
	m^2 land /Le	**STDEV**	**L irrigation water/ L irrigated ethanol produced**	**STDEV**	**g N/L fertilized ethanol**	**STDEV**
Corn grain	2.8	0.45	566	340	44.0	9.9
Potatoes	2.4	1.01	1,051	185	58.8	N/A
Sugar cane	1.7	0.49	1,684	N/A	23.1	0.5
Sugar beet	2.0	0.35	1,081	590	22.2	7.7
Sorghum	8.1	1.73	1,523	422	49.2	14.3
Soybean*	8.1	1.40	1,256	401	29.7	16.5
Switchgrass	2.1	0.93	N/A	N/A	34.6	10.6

* As energy-equivalent liters of ethanol (i.e., multiplied values per L biodiesel by 0.62)

E) Sample data and calculations for table S8

1. Percentage of U.S. corn production attributable to Iowa in 2003.

We obtained the 2003 harvested corn acreage from "US & State Data– Crops", for all states available at http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/index.asp, and then divided the Iowa harvested corn acreage by the total US harvested corn acreage.

State	Harvested (1,000 ac)	% US Production
Iowa	11,900	19
United States	70,944	100

2. Percentage of irrigated cropland for each crop.

we obtained % of irrigated acreage for each crop using data from Volume 1, Chapter 2, table 24 (http://www.agcensus.usda.gov/Publications/2002/Volume_1,_Chapter_2_US_State_Level/index.asp) from the 2002 Census of Agriculture for each crop and for each state.
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State	Total harvested acres 2002	Harvested acres irrigated 2002	% Irrigated 2002
Iowa	11,761,392	86,261	0.73%

3. Percentage of area fertilized with nitrogen fertilizer.

We obtained fertilizer application areas from the 2000 and 2003 Field Crops Summary. .Agricultural Chemical Usage database (corresponding to year 2003) from NASS available at http://usda.mannlib.cornell.edu/usda/nass/AgriChemUsFC/2000s/

State	*Percent of acres fertilized with N fertilizer (%)*	*Rate of application (lbs/ac.year)*
Iowa	7	27

4. Irrigated corn yield (Yirr) and Ratio of irrigated to non-irrigated corn yield (Yirr/Ynon-irr).

We obtained data from Table 27 of the FRIS 2003, downloadable from the 2002 Census menu at http://www.nass.usda.gov/Quick_Stats/ or at http://www.agcensus.usda.gov/Publications/2002/FRIS/index.asp.
In Iowa, the average irrigated corn yield was 171 bu/ac while the average non-irrigated corn yield was 146, which results in a ratio of 1.17.

State	*Yirr (bu/ac)*	*Y nonirr (bu/ac)*	*Yirr/Ynonirr*
Iowa	171	146	1.17

5. Irrigation and nitrogen application rates and percentages of area irrigated/fertilized.

We obtained irrigation rates from Table 27 of FRIS 2003, and fertilizer application rates from the 2000 and 2003 Field Crops Agricultural Chemical Usage database available at http://www.agcensus.usda.gov/Publications/2002/FRIS/index.asp, and http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1001, respectively.

State	*I-rate (ac-ft/ac irrigated)*	*% irrigated*	*N-rate (lb/ac fertilized)*	*% fertilized*
Iowa	0.5	1	133	93

6. Water footprint of biofuels based on irrigation.

2003 Irrigation rates (ac-ft/ac) were divided by 2003 irrigated yields (bu/ac). Ethanol conversion efficiencies were factored in and unit conversions performed to finally obtain the water footprint based on irrigation (Lw/Le). The example below shows data for ethanol from corn grown in Iowa.

State	*Water applied (ac-ft/ac irrigated)*	*Irrigated yield (bu/ac)*	*Ethanol conversion efficiency (L ethanol/Tonne grain)*	*Irrigation water footprint (Lw/Lie)*
Iowa	0.5	171	387	367

7. Land footprint of biofuels.

Ethanol conversion efficiencies were factored in with 2003 corn yields to obtain the land footprint of biofuels (m^2/Le). The example below shows data for ethanol from corn grown in Iowa.

State	*2003 Average yield (bu/ac)*	*Ethanol conversion efficiency (L ethanol/Tonne grain)*	*Land footprint (m^2/Le)*
Iowa	157	387	2.69

8. Nitrogen footprint of biofuel.

2003 Nitrogen application rates (lb N/ac fertilized) were divided by 2003 fertilized yields (bu/ac). Ethanol conversion efficiencies were factored in and unit conversions performed to finally obtain the grams of nitrogen per liter of ethanol from fertilized land (gN/Lfe).

State	*Average N-application rate (lb/ac fertilized)*	*Average yield (bu/ac)*	*Ethanol conversion efficiency (L ethanol/Tonne grain)*	*Nitrogen footprint (gN/Lfe)*
Iowa	133	171	387	39.04

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