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Bibliographic Addendum*

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Water Demand for Biofuels Production

Feedstock Production and Fuel Processing

Fuel Type and Conversion Process	Biomass Feedstock	Processing Water Use Intensity (gal H_2O/gal fuel)		Feedstock Water Use Intensity		
		Process Water Use	Process Water Consumption	Feedstock Water Demand Ac-ft / Acre	Biofuel Yield gal fuel / Acre	Feedstock Water Consumption[d] gal H_2O/gal fuel
Ethanol, Starch or sugar-based Wet mill or Dry mill	Corn	~ 2 - 6	~ 4	~ 1.2	400	980
	Sorghum			~ 1.0	170	1900
	Sugar Cane			~ 2.0	560	1160
	Sugar Beets			~ 2.3	550	1360
Ethanol, Cellulose-based[a] Biochem or Thermochem	Switchgrass	~ 3 – 12 [e] estimate	~ 2 - 6 [e] estimate	~ 2.3	500 - 800 (700 estimated)[b]	Rain-fed
	Woody biomass			~ 2.5	500 – 800	Rain-fed
Biodiesel from Oil Extraction and Trans-Esterification	Soybeans	~ 0.3 - 3	~ 1	~ 0.8	40	6500
	Sunflower			~ 1.5	80	6100
	Oil Palm			≥ 2.5	510	Rain-fed
	Algae	~ 0.3 - 3	~ 1	Not determined [f]	3,000 - 15,000 [c] (5000 estimated)	Not determined [f]

[a] Cellulose-based ethanol yields of 100 gal/dry ton based on laboratory data, processes are still experimental
[b] Switchgrass yields have exceeded 10 dry tons/acre experimentally, but more routinely range from 3 to 7 dry tons/acre
[c] Algal-based biodiesel production estimates based on laboratory and small scale test data; viable high-yield scale-up still uncertain
[d] Water consumption with irrigated feedstock production at per-acre water demand and per-acre biofuel yield levels shown
[e] Estimates based on unvalidated projections for commercial processing; [f] Non-fresh water used; losses mainly from evaporation

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Assumptions, references, and other basis for information provided in table

All quantitative water use shown in the table for biofuel feedstock production and processing are intended to be representative with reasonable accuracy, based on available information.

Ranges for many of the entries in the table are also presented in tables shown and documented in the Energy-Water Report to Congress published in December 2006 and available at http://www.sandia.gov/energy-water/congress_report.htm

Water consumption in ethanol processing plants was found in the following:

- "Water Use by Ethanol Plants: Potential Challenges", Institute for Agriculture and Trade Policy, October 2006
- Personal communications with Andy Aden, biofuel processing engineer at the National Renewable Energy Laboratory (NREL), Golden, CO, during the 2006-2007 time frame
- Andy Aden, "Water Usage for Current and Future Ethanol Production", Southwest Hydrology, September/October 2007.

Assumptions, references, and other basis for information provided in table

Crop yields and water use for irrigation of corn, soy, and sugar beets was based on calculations using average national yields and average irrigation water use available through:

•USDA 2002 census data and the USDA 2003 Farm and Ranch Irrigation Survey.

For sugar crop based ethanol production, yields of sugar production and ethanol production for cane and beet were found in:

•Shapouri, Hossein, and Michael Salassi, “The Economic Feasibility of Ethanol Production from Sugar in the United States, report done through a cooperative agreement between the Office of Energy Policy and New Uses (OEPNU), Office of the Chief Economist (OCE), U.S. Department of Agriculture (USDA), and Louisiana State University (LSU), July 2006.

For oil crop yields, data was found on-line at http://journeytoforever.org/biodiesel_yield.html#ascend#ascend

Yield for conversion of vegetable oil to biodiesel fuel is roughly 0.8 * Oil Crop Yield

Assumptions, references, and other basis for information provided in table

Information on oil palm was also found at
http://www.uga.edu/fruit/oilpalm.html#TAXONOMY#TAXONOMY
From which estimates of yield and water requirements for crop production were made

Information on algae oil production potential were obtained from

•Sheehan, John, et.al., “A Look Back at the U.S. Department of Energy’s Aquatic Species Program: Biodiesel from Algae, NREL/TP-580-24190, July 1998.

Water use for algae production was not estimated, due to heavy dependency on the specific location and cultivation system configuration and processes used.

Assumptions, references, and other basis for information provided in table

Water use for switchgrass is found in:

•McLaughlin, Samuel, et.al., “Projecting Yield and Utilization Potential of Switchgrass as an Energy Crop, Advances in Agronomy, v. 90, pp. 267-297, 2006.

Water use in perennial woody biomass crops is generally equal or higher than herbaceous perennials like switchgrass, as noted in:

•Stephens, William, et al. (2001). “Review of the Effects of Energy Crops on Hydrology.” Institute of Water and Environment, Cranfield University. Silsoe, Bedford MK45 4DT, 15. February 2001. http://www.silsoe.cranfield.ac.uk/iwe/documents/src_hydrology.pdf#search=%22bioenergy%20impacts%20on%20hydrologic%20flows%22