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# Energy and Water


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## ABSTRACT

*We use water in generating electricity and producing fuels for transportation. Energy producers already compete with farmers, manufacturers, and families who need water, and as we look at ways to increase our supply of energy while reducing the impact on the environment, we are encountering the ironies of history: in many cases, the new technologies that can provide better, cleaner energy will soak up more water than the dirty old technologies. There is no silver bullet. Any technological solution for energy may raise critical questions about the impact on our supply of fresh water. Additionally, as we look to new sources of water, through the treatment of brackish resources, seawater desalination, water reuse and recycling, further energy demands will be placed on our resources beyond that of today's traditional water treatment technologies.*

*This paper considers the water challenges involved in generating electricity and producing fuels for transportation in the future. We consider the tradeoffs involved in the cooling processes used in different types of plants generating electricity, with various levels of water withdrawal and consumption, and note that new systems that withdraw less water actually consume more than the older ones did. Similarly, when we consider alternative ways of producing fuel for transportation, we see immense demands for water as part of the price for reduced reliance on fossil fuels. The future transportation fuels portfolio for this country is uncertain and there are significant uncertainties about the impact on already constrained water resources. As an example, irrigating crops for biofuels could put great stress on water resources. We show water withdrawals and consumption rates for electricity generation and a range of transportation fuel types and processes. The future is uncertain and constrained and therefore, there is a potential for conflict.*



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## Overview

Energy and water are inextricably linked. We need water for energy production and we require energy for water pumping, treatment and distribution. Without access to water resources our energy production capabilities are threatened. Without sufficient energy resources our ability to manage water supplies is also threatened. When sites for new electricity generation plants are chosen, there are four major considerations, fuel supply, air supply, water supply and transmission capacity. As we look to the future of electricity generation there are uncertainties around resource requirements, transmission systems, two way power and information flow on the electric grid to name a few. Transportation fuels require water and potential alternatives to traditional oil and gas refining will require more water resources, how much is uncertain.

The tug of war between energy and water, and the challenges of balancing those needs, will generate a lot of business for attorneys. Legal tussles over water rights already keep municipal, county, and state governments at loggerheads, with plenty of friends of the court, such as nongovernmental organizations contributing their own briefs. Government agencies at every level will need legal advice on new policies, regulations, and statutes. And, with the critical demand for more energy, and more clean water, businesses are springing up everywhere, hoping to capitalize on new technologies, with the aid of imaginative legal talent.

## Generating electricity

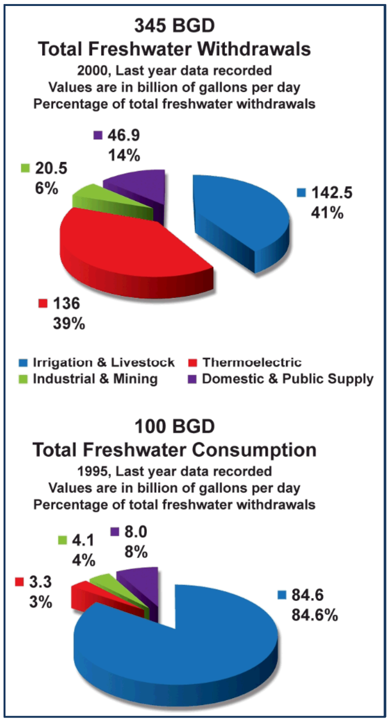
In the United States, we generate almost all our electric power with thermoelectric power plants using fossil fuels—coal (335,830 MW), natural gas (442,945 MW), petroleum (64,318 MW), or nuclear energy (105,585 MW), with smaller contributions from hydroelectric (77,419 MW), biomass, wind, geothermal, and solar (photovoltaic and thermal) energy (26,470 MW).[1] All thermoelectric plants need some form of cooling to dissipate waste heat, to prevent mechanical failure, and to operate efficiently.

The most common cooling systems depend on water. The open-loop or once-through system, withdraws water, passes it through the plant, and returns it at a higher temperature to the original body of water. The closed-loop or recirculating system withdraws much less, but evaporates most of what it withdraws. Cooling ponds can be employed as a source of cooling water and transfer waste heat from the plant by evaporation. Dry cooling reduces water requirements but can restrict plant operability when the cooling capacity of the air is insufficient.

Thermoelectric generation systems withdraw 39% of all fresh water withdrawn in 2000, or about 136 billion gallons a day. Seawater contributes another 59 billion gallons per day. Some of that water is consumed, or lost through evaporation and no longer available for beneficial use by others. Thermoelectric generation represents roughly 3.3% of the total consumption of water or 3.3 billion gallons per day in 1995 which was the last time that consumption data was gathered and reported. This is shown in the figure below. (Excerpted from forthcoming publication)



[1] EIA 2006.




The industry has been shifting to closed-loop cooling systems in new plants, sharply reducing the amount of water withdrawn. But despite withdrawing less than earlier plants, these new plants consume more, sometimes a lot more. These plants withdraw just 2 to 5% of the volume of water withdrawn by the once-through systems, but almost all the water withdrawn is evaporated, so the overall rate of consumption has gone up from 200 to 400 gallons per Megawatt hour to 300 to 700 gallons per Megawatt hour. That's the kind of tradeoff that gives with one hand and takes with the other. It's typical of the kind of ironies we see throughout the relationship between energy and water. (Figure excerpted from forthcoming publication)

**Table 1-1. Electric Power Generation Water Use**

(Table excerpted from forthcoming publication)

| Plant Type | Cooling Process | Water Use Intensity (gal/$MWh_e$) | | |
|---|---|---|---|---|
| | | Steam Condensing[2] | | Other Uses[3] |
| | | Withdrawal | Consumption | Consumption |
| Fossil or biomass steam turbine[4,5,6] | Open-loop | 20,000–50,000[4] | ~200–300[4] | 15–36 |
| | Closed-loop | 300–900[4] | 300–714[4,5] | |
| | Pond | 300–600[4] | ~480[4] | |
| | Dry | 0 | 0 | |
| Nuclear steam turbine[4] | Open-loop | 25,000–60,000[4] | ~400[4] | 36 |
| | Closed-loop | 800–1,100[4] | ~720[4] | |
| | Pond | 500–1,100[4] | 400–720[4] | |
| | Dry | 0 | 0 | |
| Natural Gas Combined-Cycle[4,5,6,7] | Open-loop | 7,500–20,000[4] | 100[4] | 10–20[7] |
| | Closed-loop | 150–400[5,6,7] | 130–400[5,6,7] | |
| | Dry | 0[7] | 0[7] | |

2 Values are included for a range of plant designs, cooling water temperatures, and locations.
3 Includes water for equipment washing, air emissions control, restrooms, and other water uses. Sometimes these uses are called "hotel loads."
4 EPRI 2002.
5 NETL 2007.
6 NREL 2006.
7 CEC 2002.

| | | | | |
|---|---|---|---|---|
| Coal Integrated Gasification Combined-Cycle[4,8] | Closed-loop | 360–540[8] | ~200–510[4,5] | 130[4] |
| | Dry | 0 | 0 | 130[4] |
| Geothermal Steam[9] | Closed-loop | 2,190[9] | 1,640–1,750[9] | NA |
| Air Cooled Geothermal[10] | Dry | 0 | 0 | NA |
| Concentrating Solar[6,11,12] | Closed-loop | 850–1,125[11] | 750–920[6,12] | 10–53[11] |
| | Dry | 0 | 0 | ~4.4–8[12] |
| Hydroelectric[12,13] | N/A | 10,200[14] | 0 | 4,500[13] – 18,000[15] |

### *Electric Vehicles*

To cut down on carbon dioxide emissions, some people hope to turn to electric vehicles, particularly as gasoline prices have increased, and batteries improved, so they cost less, take up less space, and hold a charge longer. But if plug-in cars become popular, we have to face some questions:

> How can we generate this much additional electricity, if we continue to rely on coal-fired generation plants?
>
> Where can we get the additional water needed for the process of generating power?
>
> How can we modify the existing grid to distribute additional power from alternative, intermittent, distributed sources of renewable energy?

Here's another gotcha. If we switched the entire fleet of American vehicles to electricity, we would reduce car emissions, but probably expand emissions from coal-fired plants to produce the electricity, and consume a lot more water. One study compared the use of water per mile of transportation, and found that switching to electricity would more than double the amount of water needed, if we use traditional power plants. If we move to carbon sequestration, roughly 25% more power is required, and hence an increase in the amount of water required, for capturing and sequestering the carbon dioxide. There will be difficulty in balancing these competing demands—and the likely growth of legal work at the intersection of energy and water.

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8 NETL 2002.

9 Grande 2008a. The numbers shown in the above table are from the Geysers power plant.

10 Kutscher and Costenaro 2002.

11 Cohen et al. 1999.

12 Leitner 2002.

13 Gleick 1994.

14 Hydroelectric power generation does not use steam condensing. The water flows through to the turbine, and then back into the river or stream, consuming nothing. Solley et al. 1998.

15 Although this is not an "other use" based on the definition in footnote 3, the amount of water evaporated from reservoirs used for electric power generation is substantial and is placed here for comparison purposes. Note that these reservoirs also provide irrigation, recreation, and support for the ecology, so the amount of evaporation due just to hydropower is substantially less than 18,000 gal/MWh.

## Producing fuels for transportation

### *Why water is critical in producing fuel*

We use a lot of water in extracting resources and refining those resources for transportation fuels. The easiest way to reduce the amount of water we need during production would be to improve the efficiency of our vehicles, and reduce demand. But we can also improve the efficiency with which we withdraw and consume water when producing:

Conventional petroleum fuels (oil and gas)

Unconventional fossil fuels like Compressed Natural Gas (CNG), coal-to-liquids, gas-to-liquids, and oil from shale and tar sands

Alternative fuels such as biofuels

Crude oil supplies 95% of the energy used for transportation. As prices rise for crude, alternative fuels begin to look attractive. But, ironically, traditional processes for extracting and refining oil require less water than needed for most alternative fuels.

Drilling for crude withdraws water along with oil. The water is usually impaired in some way, typically with salt. Most of this brackish water is reinjected into the wells, to create new fractures in the rock, and to drive oil toward the well. Overall, to get a gallon of gasoline, we consume only about 3.2 gallons of impaired water, and almost no fresh water. Refining crude oil into usable fuel consumes from 1 to 2.5 gallons per gallon of gas, depending on the amount of water used for cooling, and the type of products being produced.

By contrast, extracting and refining crude oil from oil sands consumes between 2.7 and 6.9 gallons of water per gallon of gas. And further refining this crude can consume almost twice as much water as needed for conventional crude oil.

Here's the irony: yes, oil sands and oil shale contain a lot of petroleum, but to get that into usable form we must use up far more water than for conventional oil. At what point does the value of the new source of oil cross the cost of using up fresh water?

What of other fossil fuels? Converting gas to liquids, or coal to liquid, consumes slightly more fresh water than used in extracting and refining crude oil. But coal mining uses about 0.3 to 0.8 gallons of water for the equivalent of a gallon of gasoline, and concerns about the environmental impact on local water supplies still linger in some peoples' minds.

Extracting natural gas (methane) consumes almost no fresh water, and refining it consumes less than a third of a gallon for the equivalent of a gallon of gasoline. Natural gas, then, has less impact on the water supply than any other fossil fuel. New gas supplies are being discovered and exploited with the tight shale formations across the country. Some people are concerned about the impact of hydrofracture of these formations and the impact on local water supplies.

### *Biofuels*

We are becoming more sophisticated and efficient at producing fuels from biological material—biomass—made up of grains, oil crops such as palm and soy, waste vegetable oil, animal fat, trap grease, wood, grasses, the non-edible parts of vegetables, and starchy plants. But growing any biofeedstock requires water. If the crops can get by with rainwater, cultivation withdraws no water from lakes and rivers. But if we must irrigate crops to have a dependable supply, we may require several acre-feet of water per acre per year. And increasing irrigation to grow more grain, sugar, and oil commodity crops for biofuels, or to increase the yield on the biomass, could require an additional several billion gallons of water per day or up to 320 gallons of water per gallon of gasoline equivalent just to produce the biomass resource.

Refining biomass into fuel uses biochemical or thermochemical processes, most of which consume water. Water consumption ranges from less than one gallon to almost 10 gallons of water to get the equivalent of one gallon of gasoline.

Of all the biofuels being explored today, growing algae to make biodiesel fuel consumes the least water during growth, and only 1.8 gallons of water for each gallon of gasoline, in refining. Plus, algae can take up a lot of $CO_2$ from streams of concentrated waste. But this technology is still so new that we do not yet know how best to handle the trade-off between the cost of water lost to evaporation in inexpensive open ponds, compared to the cost of closed systems that make more efficient use of water.

**Table 1-2. Water Withdrawals and Consumption for Several Transportation Fuel Alternatives.**

(Table excerpted from forthcoming publication)

| | | Energy Resource Production | | Energy Resource Refining | |
|---|---|---|---|---|---|
| **Fuel Type** | **Process** | **Water Withdrawals (Gal Water/ Gal Gasoline Equivalent)** | **Water Consumption (Gal Water/ Gal Gasoline Equivalent)** | **Water Withdrawals (Gal Water/Gal Gasoline Equivalent)** | **Water Consumption (Gal Water/Gal Gasoline Equivalent)** |
| Crude oil/ LP-Gas | Oil and gas refining (traditional) | negligible | negligible | 12[16] | 1.0 – 2.5[16] |
| | Oil refining (reforming and hydrogenation) | negligible | negligible | 12[16] | 2.3 – 4.6[16] |
| Natural gas/LNG/CNG | Extraction/ processing | negligible | negligible | | 0.3[16,17] |
| Gas-to-liquids: natural gas and biogas | Reforming and refining | | negligible | <0.9 – 2.7[17,18] | < 0.9 – 2.7[17] |
| Coal-to-liquids | Gasification/ liquefaction and refining | | 0.3 – 0.8[17] | 0.9 – 2.7[17] | 0.9 – 1.1[19]<br>1.4 – 2.7[16] |
| Synthetic crude | Ex situ retort | | 2.1 – 5.2[20] | 12[16] | 1.0 – 4.6[16, 21] |

16 Gleick 1994.
17 King and Webber 2008.
18 Water use estimates are assumed to be less than the coal-to-liquid process because in coal-to-liquids the extraction of methane uses water. In gas-to-liquids, this step is nonexistent.
19 Boardman 2007.

| | | | | | |
|---|---|---|---|---|---|
| oil from oil shale | | | 3.8[16] | | |
| | In situ retort | | 1.2 – 2.3[16] | 12[16] | 1.0 – 4.6[16,21] |
| Crude bitumen from oil sands | Extraction and refining | | 2.7 – 6.9[16] | 12[16] | 1.0 – 4.6[16, 21] |
| Ethanol: starch or sugar based | Dry grind | 10 – 450 [22]<br>(94 weighted average) [22]<br>1165 [23]<br>7.5 – 3200 [24] | 7 – 320 [22]<br>67 (weighted Average) [22]<br>247 – 329 [25] | 3 – 7 [22,26,27] | 3 – 7 [26,27]<br>4.5 [22] |
| Ethanol: cellulose-based | Thermochemical and biochemical refining | | ~200[25] | <1 – 9.8 | <1 – 9.8[26,27] |
| Biodiesel (soybean) | Transesterfication | | ~760[25] | 2 – 7.5 | 0[28]<br>2 – 7.5[29] |
| Biodiesel (Algae) | Transesterfication | | ~38[25] | 0.9 – 2.7 | ~1.8 |
| Hydrogen | Natural gas steam reforming | negligible | negligible | 5.58[30] – 6.4[31] | 5.58[30] – 6.4[31] |
| | Thermoelectric electrolysis | | | 1,335[30] | 32[30] |
| | Solar or wind electrolysis | | | ~3[32] | ~3[32] |

### *Treatment of impaired waters*

Traditionally, industry has used fresh water for many industrial processes, but in many areas there is a decline in the quantity and quality of fresh water for drinking, so alternatives are being considered. Treatment of non-traditional, impaired water sources, such as seawater and brackish water desalination and water reuse are being considered. There are uncertainties in the future of our water supplies. There are questions about the impact of climate change, the public acceptance of treatment options and even the ownership of these non-traditional water resources.

20 Bartis et al. 2005.
21 AICHE-CWRT 2003.
22 ANL 2009a.
23 NRC 2008.
24 Chiu 2009.
25 Kreider and Curtiss 2007.
26 NREL 2007.
27 Aden 2007.
28 Some biodiesel refineries claim to use no water in the production process due to new proprietary technologies that take the place of the "washing" step at the end of the refining process. Greenline Industries 2008.
29 Pienkos 2007.
30 Webber 2007.
31 Spath and Mann 2001.
32 Kroposki et al. 2006.

There is a need to develop a better census of non-traditional waters, develop better technologies for treatment, lower the cost of treatment and the energy requirements for treatment, and develop materials that can manage the treatment waste streams. We will also need clarity with respect to policy and regulatory issues.

## Conclusions

The more we explore alternate sources of energy, the more we discover that our traditional ways of producing electricity and transportation fuels withdraw and consume a lot of water, but many new technologies require even more. We are looking at multiple ironies. When we reduce carbon dioxide emissions, we may be inadvertently stressing your water supplies, or fouling the environment in some other way. When we find new ways to produce energy, we may end up depriving farmers, businesses, and families of fresh water.

These conflicting demands, the push and pull of economic, social, and political forces, will become more intense as we crave more energy, and need more water. There is no magic solution and there is considerable uncertainty. Society will need legal help in resolving disputes over water and energy, formulating policy, and helping entrepreneurs contribute. That's one last irony: what's a really difficult challenge for our nation could turn out to be good business for many attorneys.

## Bibliography


Aden, Water Usage for Current and Future Ethanol Production, *Southwest Hydrology*, Sept/Oct, p. 22-23, 2007.

American Institute of Chemical Engineers Center for Waste Reduction Technologies (AICHE-CWRT), Industrial Water Management: A Systems Approach, 2nd edition. CH2M Hill, Englewood, CO, 2003.

Argonne National Laboratory (ANL), *Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline*, ANL/ESD/09-1, Argonne, IL, January/2009a.

Bartis, J. T., LaTourrette, T., Dixon, L., Peterson, D. J., and Cecchine, G., Oil Shale Development in the United States: Prospects and Policy Issues, Rand Corporation Canada's Oil Sands – Opportunities and Challenges to 2015: An Update, NREL/DOE-MG-414, Rand Infrastructure, Safety, And Environment, 2005.

Boardman, R., Gasification and Water Nexus, Idaho National Laboratory, Workshop on Gasification Technologies, Denver, CO, March 14, 2007.

California Energy Commission (CEC), *Comparison of Alternate Cooling Technologies for California Power Plants: Economic, Environmental and Other Tradeoffs.* Report # 500-02-079F. PIER Energy-Related Environmental Research, Electric Power Research Institute (EPRI), Palo Alto, CA, Feb/2002.

Chiu, Y., Walseth, B., and Suh, S., Chiu, EST, Water Embodied in Bioethanol in the United States, *Environmental Science Technology*, 2002 in print, web published March 10, 2009.

Cohen, G., Kearney, D., and Kolb, G., *Final Report on the Operation and Maintenance Improvement Program for Concentrating Solar Power Plants*, Report # SAND99-1290. Sandia National Laboratories, Albuquerque, NM, Jun/1999.

Electric Power Research Institute (EPRI), Water and Sustainability (Volume 3): U. S. Water Consumption for Power Production—The Next Half Century, Report # 1006786. EPRI, Palo Alto, CA, Mar/2002.

Energy Information Administration (EIA), *Annual Energy Review 2005*, Report # EIA/DOE-0383. EIA/DOE, Washington, DC, Oct/2006.

Gleick, P., Water and Energy, in *Annual Review of Energy and Environment, 1994*, vol. 19, p. 267-299, 1994.

Grande, M., Phone and e-mail communication with Murray Grande, Geothermal Facility Manager for the Northern California Power Authority (NCPA), 2008.

Hutson, S., Barber, N., Kenny, J., Linsey, K., Lumia, D., and Maupin, M., Estimated Use of Water in the United States In 2000, *USGS Circular1268,* Mar/2004.

King, C., and Webber, M., Water Intensity of Transportation, *Environmental Science & Technology*, vol. 42, no. 21, p.7866-7872, 2008.

Kreider, J., and Curtiss, P., Comprehensive Evaluation of Impacts from Potential, Future Automotive Fuel Replacements, in *Energy Sustainability 2007*, held in Long Beach, CA, June 27-30, 2007. American Society of Mechanical Engineers (ASME), Report # ES2007-36234. New York, NY, 2007.

Kroposki, B., Levene, J., Harrison, K., Sen, P., and Novachek, F., Electrolysis: Information and Opportunities for Electric Power Utilities, Report # NREL/TP-581-40605. National Renewable Energy Laboratory, Golden, CO, Sep/2006.

Kutscher, C., Costenaro, D., Assessment of Evaporative Cooling Enhancement Methods for Air-Cooled Geothermal Power Plants. National Renewable Energy Laboratory (NREL)**,** Report # NREL/CP-550-32394. *Geothermal Resources Council (GRC) Annual Meeting*, Reno, NV, Sep 22-25, 2002.

Leitner, A., RDI Consulting, Fuel from the Sky: Solar Power's Potential for Western Energy Supply, National Renewable Energy Laboratory (NREL)**,** NREL/SR-550-32160. Washington, DC, Jul/2002.

National Energy Technology Laboratory (NETL), *Cost and Performance Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity*, Research and Development Solutions, LLC (RDS), Final Report DOE/NETL Report # 2007/1281. NETL, Pittsburgh, PA, May/2007, revised Aug/2007.

National Energy Technology Laboratory (NETL), *Major Environmental Aspects of Gasification-Based Power Generation Technologies*, Science Applications International Corporation (SAIC), DOE/NETL, Washington, DC, Dec/2002a.

National Energy Technology Laboratory (NETL), *Produced Water Fact Sheet*, US DOE/NETL, Pittsburgh, PA, 2002b.

National Renewable Energy Laboratory (NREL), Cooling for Parabolic Trough Power Plants, presented at the *2006 Parabolic Trough Technology Workshop*, Incline Village, NV, Feb 14-16, 2006, Report # NREL-PR-550-40025, US DOE, Washington, DC, Feb/2006.

National Renewable Energy Laboratory (NREL)**,** Thermochemical Ethanol via Indirect Gasification and Mixed Alcohol Synthesis of Lignocellulosic Biomass, Report 3 NREL/TP-510-41168. Golden, CO, Apr/2007.

National Research Council (NRC), *Water Implications of Biofuels Production in the United States*, National Academies Press, Washington, DC, pp. 19-25, 2008.

Pienkos, P., The *Potential for Biofuels from Algae*, Report # NREL/PR-510-42414. National Renewable Energy Laboratory (NREL), Washington, DC, Nov/2007.

Solley, W. B., Pierce, R. R., and Perlman, H., *Estimated Use of Water in the United States in 1995*, in U.S. Department of the Interior, USGS Circular 1200, location, vol. 71, 1998.

Spath, P., and Mann, M., *Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming,* Report # NREL/TP-570-27637, NREL/DOE, Golden, CO, Feb/2001.

Webber, M., The Water Intensity of the Transitional Hydrogen Economy, *Environmental Research Letters 2*, 034007 (7 pp.), doi:10.1088/1748-9326/2/3/034007, Sep/2007.