Water Requirements and Impacts Associated with Alternative Energy Sources

D.L. Marrin

ABSTRACT

The global switch to energy sources that are more sustainable and less polluting (particularly with respect to carbon dioxide emissions) seems to be inevitable given the current world situation. This switch is both dependent upon and will have a profound impact on local water resources and on the global water cycle. Most notably, hydrogen gas is produced from methane by reacting steam with natural gas. This process is not only energy intensive and dependent on both water and fossil fuels, it produces carbon dioxide as a byproduct. Alternative energy sources like wind, solar, and fuel cells (hydrogen/oxygen) pose the least water demands, whereas nuclear, fossil, and biomass fuels pose the greatest demands. Similarly, technologies designed to obtain more usable water (e.g., desalination, wastewater reclamation) are dependent on fossil fuels or other energy sources that require substantial amounts of high quality water.

Keywords: *water, alternative, energy, biofuels, hydrogen, solar, desalination, cycles.*

INTRODUCTION

As domestic prices for gasoline soar and the Middle East conflicts continue to elude resolution, our switching to a less fossil fuel-dependent economy is at the forefront of political and technical agendas. In keeping with this trend, we are bombarded with claims of a "green revolution" with respect to everything from hydrogen- and solar-powered generators to automobiles that run on ethanol or seawater. The truth is that few of these proposed energy alternatives are actually "green" in terms of their sustainability, independence from fossil fuels, or environmental pollution. In the winter 2001 issue of *Whole Earth Magazine*, editor Peter Warshall wrote an article outlining the interdependency of water, energy, and money in our postmodern world that he describes as the "unholy triumvirate." He notes that, "All fuels (biomass, geothermal, hydrogen, uranium, coal, natural gas, petroleum) that convert water to steam to drive turbines and create power survive by water." Whether obtaining, refining, transporting, growing, or disposing of the fuels used to run our present-day world, water is integral to producing power and cleaning-up the mess created by its production. Warshall noted that either increasing the amount of water available to us or cleaning-up the water we have polluted in garnering our needed energy requires power. Thus, we currently exist within a positive feedback loop whereby ever more water and power are demanded that, in turn, require ever more money to obtain.

Fossil fuel demands are predicted to rise almost 60% by the year 2030, which includes corrections for the probable effects of rising oil prices and alternative energy sources. By the same date, more than 60% of the world's population is predicted to be living under conditions of water stress or scarcity, which is attributed predominantly to climate change and to urban population growth in arid regions. In fact, Australia is now experiencing severe drought as a result of weather patterns, population increases, and a high per capita water use (Novak, 2007). So, as we embark on a switch from fossil fuels to alternative energy sources, we must keep in mind that the quantity, distribution, and quality of water available to support such a switch may prove to be the limiting factor. Conventional coal-, nuclear-, and oil-powered plants that generate electricity require enormous volumes of cooling water, and even the so-called dry cooling plants consume only slightly less water per kilowatt because they are less efficient in generating electricity. Let's take a look at some specific alternative energy sources and their consumption and/or production of water.


Petroleum Refining: on the increase or decrease? (ClipArt)

WATER AND BIOFUELS

Whereas converting the unusable byproducts of conventional agriculture into so-called *cellulosic* ethanol constitutes a green technology, its fuel yield is relatively low compared to converting sugar-rich food crops. Nearly all of the *bioethanol* that is advertised as rescuing the world from oil dependence represents the antithesis of a green product. The cultivation of corn, beets, sugarcane, and other starchy crops for the sole purpose of producing ethanol has the same irrigation (water) demands as growing them for food, has already been linked to global food shortages, and has continued to pollute surface and ground waters with pesticides, herbicides, and fertilizers. Our switching to bioethanol as a major fuel source requires either a conversion of food to energy crops (diminishing the global food supply) or an expansion of the cultivated land under corporate agriculture (escalating the demand for and pollution of water). Moreover, the considerable volume of water utilized for milling, hydrolyzing, fermenting, and distilling ethanol from either sugar-rich foods or fiber-rich plant material must be treated as an aqueous waste stream before it reenters the natural environment.

Besides the issue water pollution, there is an ongoing debate as to whether the total energy required to produce and transport bioethanol—let alone to properly deal with its resulting pollutants—exceeds that gained from burning it in automobiles. Ethanol is a less efficient fuel than is gasoline (on a volumetric or "per liter" basis) and produces as much atmospheric CO_2 when burned. On the positive side, ethanol generates fewer air pollutants than does gasoline, and the carbon present in ethanol is derived from existing atmospheric CO_2, rather than from ancient petroleum deposits that contribute "new" CO_2 to the atmosphere. Some analysts have suggested that bioethanol may be more valuable as a feedstock for chemical processes, such as those producing hydrogen gas or organic acids, than as a fuel (Demirbas, 2007).

The term *biodiesel* refers to vegetable oils or, less frequently, to animal fats that are either blended with petroleum diesel to create a mixed fuel or chemically modified to serve as a stand-alone fuel. The chemical modification of natural oils requires a catalyst and/or heating, which transform the large, highly-branched molecules of the oils into smaller, straight-chain molecules that are optimal for diesel engines. While biodiesel is generally considered to be more environmentally friendly than is bioethanol (in terms of its production processes and contribution to global warming), it is a less efficient fuel than petroleum diesel and requires the cultivation of crops (not necessarily major food staples) such as soybeans, rapeseeds, palms, or sunflowers from which the oils are separated.

Oil separation and other preparatory processes for biodiesel require water, although not as much as the processes identified for bioethanol. Biodiesel may also be produced from used cooking oils; however, the presence of particulates and free fatty acids requires a filtering step and generally produces an even lower quality fuel. Finally, certain species of freshwater microalgae produce oils appropriate for biodiesel, and the water in which they grow is suitable for multiple uses without any treatment. In addition to using these oils for biodiesel, they can be used as a feedstock to produce hydrogen gas according to a process known as *flash volatilization*. This process rapidly converts certain components of the oils to hydrogen (and other gases) by dropping them onto a heated catalyst, which requires a significant amount of energy but very little water (Salge et al., 2006). A comparison of major energy sources and their estimated water demands are shown on Figure 1.

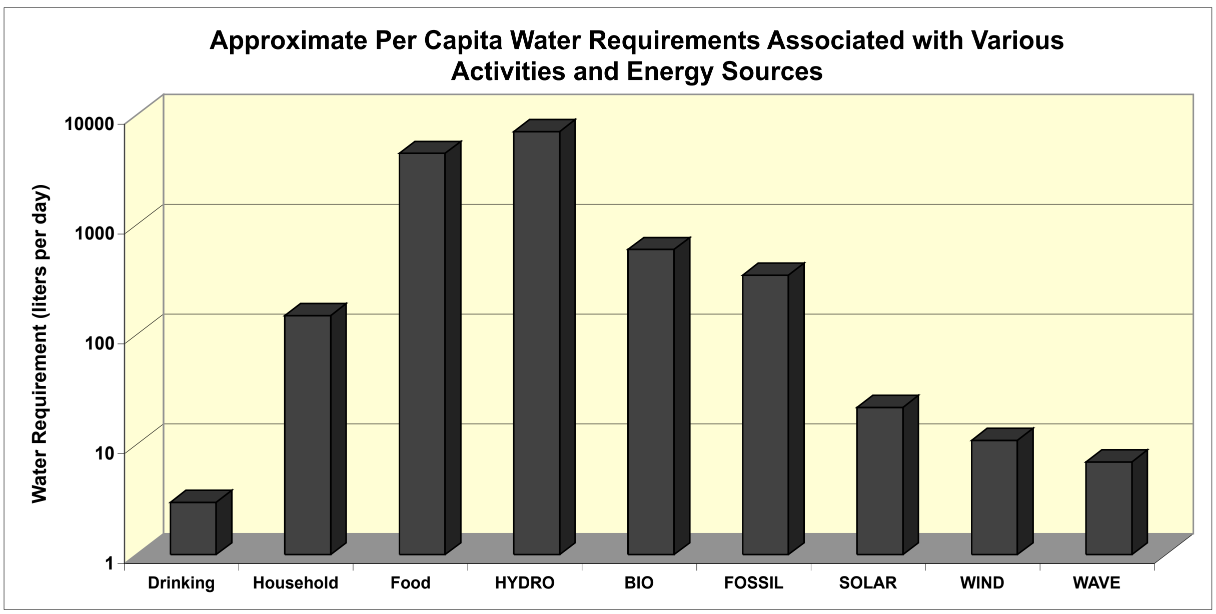

Figure 1. Per capita water requirements associated with common activities and needs (drinking, household uses, and food production) and with the production of energy (hydroelectric, biofuels, fossil fuels, solar, wind, and wave power). These values represent approximations for purposes of gross comparison and are based on data provided by Varis (2007), USDOE (2006), and others. Most of the water used for hydroelectric is not consumed or degraded in the same manner as it is for the other energy sources. Also, the water requirements for fossil fuels and biofuels include a number of subcategories, each of which possess substantially different water requirements. Finally, these estimates do not necessarily include the water requirements for dealing with any associated pollutants.

Hydrogen gas is perhaps the most highly-touted of the alternative energy sources because it is a very efficient fuel and produces only water vapor (i.e., no CO_2) when burned. In fact, much has been written about the global hydrogen economy supplanting the soon-to-be-obsolete petroleum economy in the upcoming decades. Economics notwithstanding, there still seem to be technical issues related to the storage and transport of hydrogen gas. In addition, not all hydrogen gas is created equally—at least in terms of sustainability and efficiency. The biological production of hydrogen is inherent in a variety of natural processes; however, setting up the appropriate environmental conditions and capturing the hydrogen gas can be somewhat tricky. Biomass gasification is a process whereby unused plant material is heated, thus producing a mixture called *bio-syngas* that must be reformed with steam (heated water) to produce hydrogen. The term "syngas" refers to the fact that the gas is synthesized under artificial or man-made, as opposed to natural or environmental, conditions. As previously noted, hydrogen can be produced by flash volatilization using far less water than that required for bio-syngas.

Interestingly, hydrogen can be produced by green algae and by the combined efforts of two different types of bacteria that can also generate some of the nutrients and precursors required for their continued hydrogen production, serving as an example of micro-scale sustainability in the production of a renewable fuel. Photosynthetic green algae produce hydrogen gas using the visible portion of the solar spectrum, while certain photosynthetic bacteria simultaneously produce hydrogen gas using the near infrared portion of the spectrum. The cell biomass that accumulates during the course of this photosynthetic activity is then fermented by anaerobic bacteria that produce even more hydrogen gas, as well as short-chain organic acids that serve as substrates for the photosynthetic bacteria and algae (Melis and Melnicki, 2006). Reported by U.C. Berkeley scientists, the process is not quite as simple as it first appears because microbes must be switched between light and dark phases and the accumulation or depletion of certain gases and ions (salts) in the water can influence the entire process. Nonetheless, it stands as one of the most innovative, sustainable, and non-polluting techniques for producing hydrogen gas.

SOLAR AND WATER POWER

Besides hydrogen power, solar power is probably the most frequently suggested (and refuted) alternative energy source for the upcoming decades. Other than geothermal energy, which is dependent on the radioactive decay of elements far beneath the planet's surface, sunlight is the ultimate source of all energy on Earth. Interestingly, it is water's phase changes (e.g., among its solid, liquid, and vapor states) that are instrumental in distributing solar energy around the globe. Furthermore, it is the hydrogen and oxygen atoms derived from water that are combined with the carbon atoms from CO_2 during the solar-powered process of photosynthesis—thus creating the biomass that was discussed in the previous section. Hence, it is argued that tapping directly into sunlight would constitute the most logical and efficient means of garnering more energy.

The counter argument has been that our technological ability to capture, store, and transform solar energy into the electricity that powers most man-made systems is quite limited. This argument is weakening as more efficient solar panels and conversion units are developed. But how might a burgeoning solar economy affect the water demand? Surprisingly, the answer seems to be that the greatest use of water for solar power (at least on a small-scale basis) is in manufacturing the hardware components. Some solar technologies (e.g., passive hot water heaters) depend on the direct heating of water, thus eliminating the water needed for power generation. Another major challenge to the universal application solar power relates to differences in the amount of sunlight (mostly seasonally) reaching various parts of the globe.

One solution to the unequal distribution of solar radiation on Earth (both spatially and temporally) is to utilize wind, wave, and tidal energies that are ultimately derived from the interaction of the entire planet with the moon and/or sun. Whereas all three of these energy sources are dependent on global water dynamics, their demands on water in the conventional sense are actually quite minimal. Wind farms produce both clean and renewable energy (meeting about 1% of the world's power needs); however, the issues of aesthetics (particularly noise) and of bird and bat mortality remain a concern. Ultimately, our solving these wind power issues may prove to be easier than solving issues related to other alternative energy sources. Wave energy would seem to be a viable alternative for coastal regions and islands; however, the actual structures and equipment/instrumentation must be designed to withstand the battering of large storms. Although concerns about construction costs and energy conversion efficiencies have been raised, there is potential in ocean waves that represent a legitimate alternative source.

Hydroelectric Power: a common form of water power. (ClipArt)

When the subject of water power is raised, people commonly picture endless reservoirs and massive hydroelectric turbines being turned by cascading water. Almost a century of experience with such facilities has demonstrated that the energy generated has much higher costs than those incurred for just construction, operation, and maintenance. The destruction of terrestrial and aquatic ecosystems, the impacts to human communities and hydrologic regimes, the tremendous loss of water due to evaporation, and a paucity of additional dam sites are predicted to reduce the viability of hydroelectric as a significant growth sector for power production.

CAPTURING AND TRANSFORMING WATER

Water is unmistakably a major consideration in developing and implementing any form of alternative energy. As such, the question is often asked as to whether we can simply produce more water to meet our needs. The answer depends on what exactly one means by "producing" more water. Obviously, there is plenty of oxygen gas in the atmosphere to create more water; however, the problematic component is hydrogen gas because it is not readily available in our environment—at least not in the required concentrations and locations. Hence, we are left to produce more usable freshwater either from unusable freshwater (e.g., currently inaccessible or polluted) or from seawater. A major difficulty with both of these options is that they require a tremendous amount of energy. Hence, our making more water in order to make more energy is generally a losing proposition—sometimes referred to as unsustainable. Let's consider seawater and polluted freshwater as potential sources of usable water.

Seawater desalination is being heralded as the eventual, and perhaps ultimate, answer to worldwide water shortages because of seawater's almost infinite availability and because much of world's population lives near the coast. However, not unlike the previously described biofuels, desalination is accompanied by some formidable challenges. Perhaps the two most obvious are the pollutants created by desalination, including brine (a very concentrated salt solution) and an array of chemicals (e.g., anti-scaling and anti-microbial agents, acid-base adjustors, corrosion inhibitors, surfactants) used to prevent the fouling of pipes and RO membranes. The term *RO* refers to "reverse osmosis," a process that forces water through synthetic membranes possessing pores small enough to pass water, but not salts or pollutants. The power demands of forcing water through RO membranes have traditionally been considered too costly for most water uses; however, the advent of more efficient membranes and the use of solar energy to remove salts from seawater by thermal (*humidification-dehumidification*) and mechanical (*electrodialysis*) methods have served to reduce the power demands of desalination (Mathioulakis et al., 2007).


The Oceans: a source of power and water. (ArtToday)

In addition to solar energy, wind and wave energies have been suggested as powering coastal desalination plants. A novel chemical process reported by McCutcheon et al. (2005) actually uses CO_2 to draw the salts out of water; however, considerable energy is required to produce the reactants (ammonia and carbon dioxide) and to deal with the waste products (e.g., soda ash). As much as one liter of brine is generated for every two liters of freshwater, and no disposal option averts the negative impacts on marine or terrestrial environments. The brine not only contains high concentrations of salts (up to 5-fold greater than those in seawater), it also contains wastes such as heavy metals, organic pollutants, and excess heat. While some impacts of brine disposal are seemingly confined to the designated disposal sites within oceans or soils, others are not.

The reuse of polluted waters or municipal wastewater is another potential source of clean freshwater that is predicted to serve as the analogue for desalination in areas located far from the ocean. The conventional treatment of wastewater to drinking water standards can be moderately to highly energy- and water-intensive (depending on several factors), qualifying it as an option for producing water under some conditions. Constructed wetlands, *living machines* (wetland-like systems), and various types of treatment lagoons that utilize aquatic plants or microalgae to remove pollutants from wastewater streams are significantly more efficient than are conventional facilities, but they do not produce a high enough quality water for drinking. On the other hand, they do produce water suitable for irrigating crops, which can benefit from the organic carbon and nutrients (e.g., nitrogen and phosphorus) that would otherwise require removal. Because agriculture represents the largest user and polluter of water resources, wastewater reuse or recycling could reduce the volume of high quality water currently used to irrigate crops. Unlike desalination, small-scale systems (i.e., appropriate for individual households) that produce high quality water by treating wastewater are not yet practical. A comparison of the common impacts associated with producing or delivering more water is shown on Figure 2.

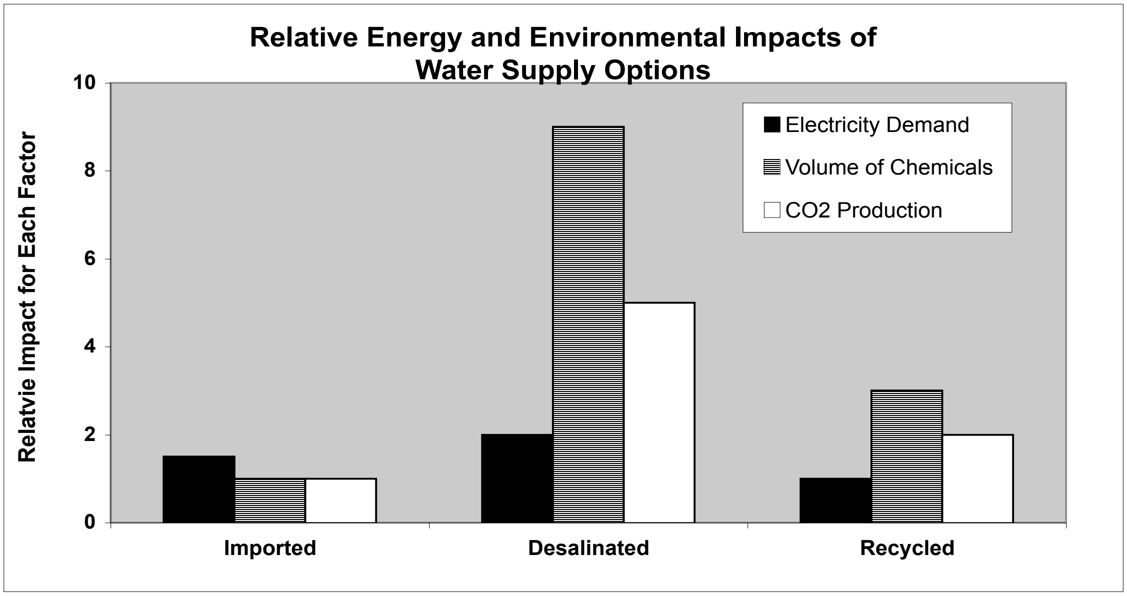

Figure 2. The relative energy and environmental impacts (based on the three factors of electricity demanded, volume of chemicals required, and mass of carbon dioxide produced) for various water supply options. Imported water is transported from outside the watershed, whereas desalinated and recycled water are produced from non-potable water. Based on data from Stokes and Horvath (2006) for a water purveyor in Northern California.

There are a number of other techniques available for capturing currently inaccessible water (Jenerette and Larsen, 2006). Condensation is a method of converting water vapor into liquid water by cooling humid air present in the atmosphere or the pore spaces of shallow soil. Similar to other methods of water production, the cooling process requires energy that, in turn, requires additional water. Artificial recharge is a means of transferring treated or captured surface waters (e.g., urban runoff, agricultural return flows) to groundwater aquifers. Storing water in aquifers averts the evaporative losses associated with storing it in surface impoundments; however, pumping groundwater requires additional power. A variation on this underground theme entails the construction of earthen dams to capture and recharge seasonal runoff beneath intermittent stream channels or the use of groundwater dams to augment recharge in specific locations. The latter techniques normally require less power and infrastructure than do the former because of their smaller scale and fewer potential pollutants.

Expanding on this small-scale theme, practices such as permaculture, gray water usage, and rainwater harvesting have a tremendous potential to maximize our water efficiency and, at the same time, to return us to a more hands-on relationship with water that was sacrificed for the convenience of corporations or public utilities supplying our water (Lancaster, 2006). Finally, there are myriad water conservation techniques for decreasing our water demand that would diminish the need to increase our water production. Whereas each household can monitor and reduce its "visible" water use, a substantial portion of a household's total water consumption is hidden in the form of products and services. Although rarely listed under the heading of water conservation, practices such as reducing our electricity and gasoline bills, eating more locally-grown and organic foods, switching to a diet that includes less meat, building with recycled materials, and using fewer paper products all contribute to the quantity and quality of water.

CONCLUSION

The selection of alternative energy sources that finally gain widespread acceptance and use will probably depend, in large measure, on costs that have been skewed by subsidies, very short-term projections, and little or no consideration of environmental and health impacts. This is precisely the formula that has encouraged our clinging to an antiquated fossil fuel-based economy well into the twenty-first century. In regards to our selecting alternative energy sources, the current water crises will ensure that water has a substantially greater influence that it did in our selecting energy sources a century ago. Many of the water crises we face today stem from the collective belief that we can manipulate the planetary water cycle so that it conforms to our dictates—no matter how contrary to the patterns and rhythms of the natural world. I refer to water *crises*, rather than to water *shortages*, because the volume of fresh water on Earth's surface is not significantly different than it was thousand years ago. What have changed are the number of people (particularly those living in places with limited local water resources), the widespread relocation and degradation of water, and the perception of water as a right to be demanded, rather than as a resource (or even a gift) for which to be thankful.

REFERENCES

Ayhan Demirbas. "Progress and recent trends in biofuels," *Progress in Energy and Combustion Science* **33** (2007): 1–18.

Darrel Jenerette and Larissa Larsen. "A global perspective on changing sustainable urban water supplies," *Global and Planetary Change* **50** (2006): 202–211.

Brad Lancaster. *Rainwater Harvesting for Drylands, Volume 1*. Tucson, AZ: Rainsource Press, 2006.

E. Mathioulakis, V. Belessiotis, and E. Delyannis. "Desalination by using alternative energy: review and state-of-the-art," *Desalination* **203** (2007): 346–365.

Jeffrey McCutcheon, Robert McGinnis, and Menachem Elimelech. "A novel ammonia-carbon dioxide forward (direct) osmosis desalination process," *Desalination* **174** (2005): 1–11.

Anastasios Melis and Matthew Melnicki. "Integrated biological hydrogen production," *International Journal of Hydrogen Energy* **31** (2006): 1563 –1573.

Rachel Nowak. "The continent that ran dry," *New Scientist* (16 June 2007): 8-11.

Lori Pottinger. *River Keepers Handbook: A Guide to Protecting Rivers and Catchments in Southern Africa*. Berkeley, CA: International Rivers Network, 1999.

J. R. Salge, B. J. Dreyer, P. J. Dauenhauer, and L. D. Schmidt. "Renewable hydrogen from nonvolatile fuels by reactive flash volatilization," *Science* **314** (2006): 801–804.

Jennifer Stokes and Arpad Horvath. "Life cycle energy assessment of alternative water supply systems," *International Journal of Life Cycle Analysis* **11** (2006): 335 – 343.

U.S. Department of Energy. *Energy Demands on Water Resources*. Washington, DC: Report to Congress, December 2006.

Olli Varis. “Water demands for bioenergy production,” *Water Resources Development* **23** (2007): 519-535.

Peter Warshall. “The unholy triumvirate,” *Whole Earth Magazine* (Winter 2001): 8 pp.