

WATER AND ENERGY SECURITY

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ABSTRACT

The energy security goals of the United States are inextricably linked with our nation's water resources. Greater energy security will require additional water resources, and the growing imbalance of domestic water supply and demand will require the more efficient use of energy in water and wastewater technologies. Conventional and unconventional domestic production of oil depend on water for extraction and refining. Hydropower is being challenged by competing water uses and water quality issues. Inland waterway transport, which is more energy efficient than alternative modes, and water for cooling conventional power plants are competing with environmental and recreational goals. Revolutionary energy technologies, such as a hydrogen-based economy and Freedom CAR, will transform the domestic production, transport, and use of energy, with unknown water implications. Current technologies to process and transport water and wastewater are very energy intensive. Desalination, which many argue will be required to meet the needs of a growing world population, can be made more viable by reducing the energy intensity of current desalination technologies.

Although cursory evidence points to an impending collision between energy security and water, our assessment capabilities – e.g., data, models, and analysis tools – are woefully lacking. It is currently impossible to be very specific about the magnitude of the problems or to develop roadmaps to achieve both national goals simultaneously. And the uncertainty is compounded by a lack of understanding of the implications of climate change on energy and water cycles.

Technology improvements must be complemented by incentive structures to use energy and water most efficiently. We argue that the incentive structures that are now being discussed, and in some cases implemented, to use our water more efficiently (while addressing equity concerns) have a direct link and similarity to the energy incentive structures that were put in place in the 1970s and 1980s to improve our nation's energy security.

Finally, we argue that if the nation is to achieve our energy security and water goals, the federal government and its agencies must play a greater role in science, research and development, legislation, and regulation. The long history of leaving water issues to state and local governments must be challenged if these competing goals are to be realized.

INTRODUCTION

The energy security goals of the United States cannot be met without simultaneously addressing the water resource constraints facing our nation. In fact, energy security and water resources are inextricably linked. Increased energy security will result from:

1. Greater domestic production of clean energy;
2. Further reductions in the intensity¹ of U.S. energy use;
3. Actions to make all energy supplies, both domestic and foreign, more reliable and less subject to disruption;
4. A better understanding of the science, technology, and socioeconomic factors that determine energy supply and demand; and
5. Proper incentive structures to use energy most efficiently, while addressing equity concerns.

Likewise, our freshwater resource problems can be addressed via:

1. Further advances to reduce the intensity of U.S. water consumption;
2. New technologies to improve the quality of our freshwater resources;
3. Improved water management practices to increase the availability and improve the quality of freshwater supplies;
4. Production of additional freshwater supplies – e.g., desalination;
5. A better understanding of the science, technology, and socioeconomic factors that determine water supply and demand; and
6. Proper incentive structures to use water most efficiently, while addressing equity concerns.

Each of these technical approaches to improve energy security has a direct link to water. Each of these technical approaches to address our water resource problems has a direct link to energy. A better understanding of the science, technology, and socioeconomic factors that determine our energy production and use has a direct link to water. Also, water use can be relatively energy intensive, (i.e., ground water pumping). Even the incentive structures that are now being discussed, and in some cases implemented, to use our water more efficiently (while addressing equity concerns) have a direct link and similarity to the energy incentive structures that were put in place in the 1970s and 1980s to improve our nation's energy security.

This paper provides an overview of the intricate and critical dependence of energy security on adequate supplies of freshwater, both domestically and internationally. This paper also argues that there is an urgent need for the Federal government and its agencies to place the energy-water

¹Energy intensity refers to the quantity of energy required to produce a given level of economic output. Engineering efficiency refers to the quantity of energy required to produce a given level of physical output. Economic efficiency in the production of goods requires that for a given production of y , the output of x should be the maximum possible. Efficient production also requires that the production of one product cannot be expanded without reducing the production of another good.

nexus among its highest priorities. As energy security became a national priority in the 1970s, water resources will become a national priority in the coming decades.²

BACKGROUND

The energy price shocks of the 1970s and 1980s resulted in reductions in energy intensity such that today it takes only about 56 percent of the energy required in 1970 to produce a dollar of GNP. Energy intensity is expected to continue to decline by 1.6 percent a year out through 2020. U.S. production of most energy forms, including coal, natural gas, nuclear energy, and renewables has increased substantially in the past two decades. Unfortunately, the increases have been largely offset by decreases in domestic oil production. U.S. energy consumption is projected to increase by 32 percent by 2020, totaling some 127 quadrillion Btus (quads). However, domestic production is projected to increase by only 86 quads, leaving a difference between domestic energy supply and demand at about 50%. Balancing our future energy supply and demand will require even further improvements in energy intensity, increased domestic energy production, and increased energy imports.

Electricity demand, in particular, is projected to increase by 1.8% per year over the next two decades; and the United States is projected to need about 393,000 megawatts of new generating capacity by 2020. To meet this demand, the United States must build between 1,300 and 1,900 new power plants, or an average of 60 to 90 new plants per year. Another key example of our growing energy challenge is oil for transportation. In 2000 the United States consumed an average of 19.5 million barrels of oil per day, with about two thirds of that going to transportation. The U.S. Department of Energy (DOE) projects that under current policies, the share of U.S. oil consumption met by net imports will increase from 52 percent in 2000 to 64 percent by 2020. These projections come at a time when the future political stability of our international oil suppliers is questionable. The National Economic Development Group projects that over the next 20 years, U.S. oil consumption will increase by 33 percent and natural gas by over 50 percent. Our energy infrastructure must be expanded and made more reliable, including the addition of about 38,000 miles of new gas pipelines and some 255,000 miles of electricity distribution lines. (See National Energy Policy Development Group.)

Trends in the availability and consumption of freshwater are equally troubling. Of all the water resources on earth, more than 97 percent are in the form of saltwater. The largest portion of freshwater is in the form of glaciers and permanent snow cover. Only 0.76 percent is in the form of groundwater, 0.007 percent in freshwater lakes, and 0.0002 percent in rivers. The United States has 8% of the world's fresh water, yet even our eastern states are beginning to suffer water quantity and quality problems. On both coasts, the United States is reaching the end of the era in which we could always expand water supply (Mehan).

One need not look further than your local newspaper to understand our growing water resource problems. Atlanta is a prime example. Atlanta and its swelling suburbs rely for nearly all their water on the Chattahoochee River, which is the smallest waterway to supply so large of an

²The U.S. Department of Interior's Water 2025 Initiative is one example of our nation's growing concern about, and commitment to, water resources.

American city. Groundwater resources are essentially non-existent. Georgia officials project that Atlanta's water consumption will keep rising to 705 million gallons a day by 2030, a point that even they describe as the maximum possible, given other demands on the river, including hydropower, reservoir-based recreation, and the need to sustain ecosystems downstream. The problems are further complicated by interstate conflicts. Georgia, Florida, and Alabama are involved in an unresolved dispute over the Apalachicola-Chattahoochee-Flint basin because of water reallocation and environmental concerns. (See, for example, *New York Times*, 2002a.)

In eastern states such as North Carolina groundwater is being exhausted. In some counties the primary aquifers have been dropping as the demand for water increased. And in some places, sea water has been drawn in, contaminating the aquifers' freshwater. (See *New York Times*, 2002e.) By 2050 the population of Texas is expected to double, while the available water there is projected to drop by a fifth (*New York Times*, 2002d).

On the demand side, some states and localities require offsetting cuts in water consumption before further economic development can take place. Some state and local rules, especially in western states, require that developers show there is adequate water before new housing is built. In many places where growth has outstripped supplies, demonstrating adequate water supply is becoming a significant hurdle. In one case, developers must pay for the installation of water-conserving toilets in existing homes to reduce local water consumption to balance the water-consumption increases that will result from new development (*New York Times*, 2002g).

Obviously, water resource problems extend beyond our borders. The *New York Times* (2002d) reported recently that 40% of the world's population lives in countries where it is difficult or impossible to get enough water to satisfy basic needs. The freshwater that is available is often shared by many countries with conflicting needs and goals. On a world scale, for example, nineteen watersheds are shared by five or more nations. The Danube River tops the list with 17 nations. Of equal or greater consequence are the water problems of the Middle East, where the threat of war is based in part over water supplies (Gleick).

ENERGY SECURITY AND WATER

Energy Security and Water – Water and Energy Security: Energy analysts have typically ignored the water requirements of their proposed measures to meet stated energy security goals. Water analysts have typically ignored the energy requirements to meet stated water goals. In many cases, this has led to proposals, on both the energy and water sides, that have explicit or implicit assumptions about the availability of the other resource – assumptions that in some cases appear to be unrealistic and other cases await serious analysis to show that the assumptions are valid.

In this section of the paper, we examine various energy futures – futures that have been forecasted by DOE under existing technology and policy conditions -- and also futures that require radical technological change – technological change that is consistent with stated goals of the current Administration. In both cases we identify the explicit and/or implicit assumption about water that these futures contain, and we ask if these assumptions are reasonable. The cursory evidence that is available – and only cursory evidence is available at this time, which is a

problem within itself – suggests that these desirable energy futures will not be realized without significant improvements in the management and use of our domestic freshwater supplies.

Conventional Oil Production and Water

Let us begin with a couple of examples that demonstrate the conflict between energy and water in today's markets. We will later move to the more daunting barriers that water presents as we move toward our nation's energy security goals.

The current energy sector is dependent on water inputs. For example, water plays a critical role in oil production, both in extracting oil from conventional wells and in extracting unconventional sources of petroleum that are now starting to enter the market. In conventional oil production, water is often injected into an oil reserve to provide extra pressure to push more oil to the surface. And as domestic oil reserves are depleted, additional water will be needed to pump oil via what is called "enhanced recovery."

In the case of some unconventional oil technologies, such as oil sands, huge quantities of water are injected in the bitumen (from which oil is extracted) to heat and soften it, and thus making it easier to extract. Depending on the process, one to ten barrels of water can be required to produce each barrel of oil from this particular extraction method. The oil industry has countered their critics by arguing that a rising portion of their water consumption is salty, brackish water taken from deep underground aquifers, which is often of no use to cities and farmers. Some industry representatives argue that conventional and unconventional oil production can be increased with little impacts on our freshwater supplies. Critics counter these arguments by stating that "the addition of chemicals to water used in oil recovery and the fact that much of the recycled water ends up in deep underground reservoirs (means) that "ultimately," it is lost from the normal water cycle." (New York Times, 2002c).

In areas where these technologies have penetrated the market, such as Alberta, Canada, there is a major debate over competing water uses. If these new oil production techniques are to be economically, and maybe more importantly socially, viable, water resources will play a critical role (*New York Times*, 2002c).

MTBE and Water Quality

Methyl Tertiary-Butyl Ether (MTBE) is a gasoline additive that has been linked to the contamination of many thousands of drinking water supplies around the country. Made from methanol and a by-product of the oil refining process, MTBE was added to gasoline starting in 1979 to replace lead and to increase octane. More recently, MTBE has been added to "reformulated gasoline" to help meet air pollution goals in ozone non-attainment areas. Other oxygenated compounds -- for example alkyl ethers, ethanol, or methanol – can be substituted; but industry has been reluctant to move to these alternatives.

A major setback to the oil and chemical industries took place in July of 1999 when an EPA panel recommended that MTBE be reduced in use as a gasoline additive because of the toxic hazards that MTBE poses to drinking water supplies throughout the United States. MTBE is a known

animal carcinogen and possible human carcinogen. When MTBE is released into the environment via transport accidents, leaking tanks, or simple over-filling at gas stations, MTBE can travel great distances underground to the water table. It is established that MTBE concentrations at or below five parts per billion can give otherwise pure water a distressing turpentine-like taste and odor -- often rendering it unfit for consumption. Studies have shown that MTBE does not readily bind to soil particles and it resists natural degradation (American Petroleum Institute). According to Hadder, a ban on MTBE would result in a two to six cent per gallon refining cost increase. Using ethanol, one of the alternatives oxygenates, would further increase prices by about one additional cent per gallon. (Also see National Governors Association.)

MTBE is an example of how water and energy are connected in today's energy markets. Water quality goals are in limited conflict with our goal to produce domestic fuels at the lowest possible price and to fully utilize our existing refining capacity. Although not a severe constraint in comparison to issues discussed below, MTBE (energy vs. water) is on the national agenda.

Hydropower

We now move to a more significant area of conflict between energy and water. Hydropower produces about 7 to 10 percent of the electricity used in the United States, depending on water availability, and is the fourth largest U.S. source of generation. In some regions of the country, such as New York and the northwestern states, the contribution is much larger.

There are numerous technical issues that are currently being researched to improve the efficiency of hydropower, including more efficient and environmentally friendly turbines. For example, the DOE's Hydropower Program works in collaboration with industry to improve the technical, societal, and environmental benefits of hydropower. Nevertheless, hydropower generation and plant factors are dropping due to environmental and regulatory pressures.

The principal advantage of hydropower is its large renewable domestic resource base, the absence of polluting emissions during operation, its capability in some cases to respond quickly to utility load demands, and its very low operating costs. But there are disadvantages and tradeoffs to be considered. Disadvantages can include high initial capital cost and potential environmental impacts. Potential environmental impacts of hydropower projects include altered flow regimes below storage reservoirs or within diverted stream reaches, water quality degradation, mortality of fish that pass through hydroelectric turbines, blockage of upstream fish migration, and flooding of terrestrial ecosystems by new impoundments. However, in many cases, proper design and operation of hydropower projects can mitigate these impacts. Hydroelectric projects also include beneficial effects such as reservoir recreation, water supply, flood control, etc.

The competing uses of dams, locks, and reservoirs have water, energy, and environmental tradeoffs. These tradeoffs are best explained by recent events. For example, during the California energy crisis of 2001, hydroelectric facilities in the northwest states were asked to provide needed electricity to California. Although the Pacific Northwest was experiencing a drought, regulators allowed increased production of hydropower to help meet California's needs.

Unfortunately, the result was the highest number of salmon ever killed in one year in the Columbia River. (e.g., *Seattle Times*).

A second example is the Tennessee Valley Authority's (TVA) current Reservoir Operations Study (ROS). The ROS is a two-year study to evaluate if the operation of the Tennessee River System can be changed to provide greater "overall value to the public." TVA states that the Tennessee River System is operated to "provide multiple benefits, including navigation; flood control; low-cost, reliable electricity, water quality and water supply; sustainable economic development; and recreation." Some of the tradeoffs being considered in the study, including maintaining higher lake levels throughout the year for recreational and tourism purposes, could detract from the hydropower potential of the river. "TVA reservoir operating policies guide decisions about when and how much reservoir levels rise and fall, the amount and timing of water released downstream at different times of the year, and how that water should be released." (Tennessee Valley Authority, July 2002, page 1). Debates about water levels for recreation and tourism objectives, environmental concerns, and hydropower optimization will continue to be one very visible joining of the energy and water debates. These debates within the TVA region are very representative of other situations around the United States.

Inland Waterway Navigation

Inland waterway navigation may not be immediately recognized as a clash between energy and water goals; but in fact it is. Inland waterways carry massive amounts of bulk freight, about 15 percent of the nation's freight by volume. And our waterways carry this freight at a much lower energy intensity per ton than the alternatives of rail and, especially, truck.

A fully loaded barge with 1500 tons is the equivalent of taking 58 trucks off the highways. So the 620 million tons of cargo on inland and intracostal waterways is the equivalent of taking 24 million trucks off U.S. highways (Navigation Data Center). If competing water uses result in the unavailability of inland navigation, the total consumption of energy required to move our nation's freight will increase and work against our energy security goals.

Inland waterway navigation requires construction of dams and locks and maintenance of river channels. This job falls to the U.S. Army Corps of Engineers (Corps), which began its mission in 1824 when the Corps was authorized to improve safety on the Ohio and Mississippi Rivers. Today, the Corps maintains more than 12,000 miles of inland waterways and operates 235 locks. Freight that travels by river can cost about 50 percent per ton-mile as that of rail or about 10 percent that of trucks. In the case of the Tennessee Valley Authority's reservoir system, navigation benefits are estimated to be more than twice as high as that system's flood control benefits. Most of these benefits relate to transportation of coal, petrochemicals, and other petroleum products.

Building larger locks to accommodate additional traffic and maintaining channels at specified depths and widths by dredging and other means poses environmental questions. Thus, as with hydropower, there are tradeoffs to consider between the benefits our inland waterway system provides in terms of navigation and other externalities, such as river erosion and maintenance of a diversified and thriving aquatic system. For example, some environmental groups have

proposed that the depth of some pools (i.e., the areas of water between dams) on the Upper Mississippi River be lowered periodically to promote a more robust aquatic system. These drawdowns, however, would effectively close the river for navigation for periods of months. During these closures, traffic would have to be diverted to other modes (e.g., rail and truck), which consume more energy per ton mile and have more emissions of atmospheric pollutants. This is yet another neglected and not fully considered example of the conflict between water and energy goals.

The Future of Electric Power

The examples of the conflicts between our energy security and water goals presented up to this point are certainly of concern and merit attention. However, in the scope of our overall goal of secure energy supplies and in light of other significant challenges facing our nation, these problems may not be viewed as critical at this time.

We now turn to future energy scenarios and future visions of how our energy security can be enhanced. Each of these futures, under a continuance of current policies and evolutionary technologies and under more ambitious and radical policies and technologies, poses serious water issues. The saying you sometimes hear when asking for driving directions, “You just can’t get there from here” is an accurate and appropriate characterization of the impending clash between our energy security and water goals.

First consider our electric power future under current policies and only evolutionary technological progress. As stated earlier, the DOE predicts that the United States will need about 393,000 MW of new generating capacity by 2020. To meet this demand, the United States must build between 1,300 and 1,900 new power plants, or an average of 60 to 90 new plants per year. Where will this capacity come from? What sources of energy will be used? What water resources will be required, and can those demands be met when other demands for our dwindling water resources are growing at rapid rates?

Some additional background is needed. The United States in the year 2000 obtained its electricity from the following fuel types: coal (52 percent), nuclear (20 percent), natural gas (16 percent), hydropower (7 percent), oil (3 percent), and other renewables (2 percent). The DOE projects that in the near term as much as 90 percent of new capacity will rely on natural gas. Natural gas is a relatively plentiful energy resource, and natural gas technologies are highly efficient and relatively low polluting means to generate electricity. These supplies are, however, not limitless; and as we will discuss in a latter section of this paper, our nation has “its eyes” on natural gas for another very important energy security initiative.

Coal is by far the most plentiful energy resource in the United States. The United States has a 250 year supply of coal, and most energy analysts look to coal as a necessary part of any energy future for the United States. The growing electricity demands our nation faces will require that we utilize our hydropower to the fullest extent (given other water goals); increase our production of natural gas; push the frontiers of renewables such as wind, solar and biomass; and continue to develop and adopt more efficient end-use technologies. One is hard pressed, however, to see a

future in which coal is not a “major player.” Nuclear power may also play a role, especially if public concerns about safety and waste disposal can be addressed satisfactorily.

If coal and nuclear power are major parts of the electric power equation, and evolutionary technology is used, water will be a major input and constraint. In fact, as we stated earlier, “you may not be able to get there from here.”

The key problem is water for cooling. (A secondary problem is water for new scrubbing technologies to limit air emissions.) As of today, about 40 percent of our freshwater use in the United States is for power plant cooling. This is close to the quantity of water used for irrigation and other agricultural uses (about 42 percent). Although water use for cooling is mostly non-consumptive, it does have both water quality and consumptive use impacts.

Again, the severity of the problem may best be shown by example. In many river basins, water temperatures are limiting the expansion of our generating capacity. For example, former Governor Don Sundquist of Tennessee imposed a moratorium in 2002 on the installation of new “merchant” power plants because of cooling constraints. These high-efficiency, natural-gas-fired turbines require large quantities of water for cooling. With current technology, water cannot be made available for cooling without imposing unacceptable damages to our aquatic systems. Similar moratoriums have occurred in Pennsylvania, Washington, and Idaho. Idaho recently ruled that two large power plants proposed for the Washington-Idaho border should be denied water rights for cooling. The plants would evaporate nearly four billion gallons each year, or enough freshwater for about 100,000 U.S. citizens with typical usage.

Consider another example. The Tennessee River runs relatively shallow and warm at Muscle Shoals, Alabama, where the TVA’s Browns Ferry Nuclear Power Plant is located. Under current conditions it is not unusual for the temperature of the intake water at Browns Ferry to be equal to the plant’s thermal discharge limits. This situation could become worse in the future with more energy production in the basin and climate change.

Innovative and affordable cooling technologies could, and should, be developed. These new technologies will hopefully reduce or eliminate the need for water cooling. In fact, cooling technologies already exist that do not require water, but they are much less energy efficient than water cooled systems. Thus, even more new power plants would have to be constructed to meet our nation’s growing electricity demand if these existing technologies were used.

Our nation’s electricity demand is expected to grow significantly, even with the adoption of new energy efficient technologies. Additional generating capacity must be constructed to meet growing demand and to support economic development. And whether it is based on coal, natural gas (merchant plants), or even nuclear, additional water supplies will be needed for cooling. But will that water be available? Will the water be available in the locations where the power plants should be constructed? If power plants are constructed where the water is available, will there be sufficient transmission and wheeling capacity to move the electricity to the regions of demand? The argument that our energy security and water goals will soon clash has become more compelling.

The Hydrogen Economy

The conflict between energy security and water resources becomes more uncertain and almost certainly more severe as we move to future scenarios that assume revolutionary technological change.

An interesting future is painted by Rifkin. He argues that the fossil fuel era is passing, primarily because fossil fuels are being exhausted and the associated emissions are unacceptable. Rifkin states:

“If the fossil-fuel era is passing, what can replace it? A new energy regime lies before us whose nature and character are as different from that of fossil fuels as the latter was different from the wood-burning energy that preceded it...Hydrogen is the lightest and most ubiquitous element found in the universe. When harnessed as a form of energy, it becomes “the forever fuel”.” (Rifkin, Page 8)

In the future that Rifkin describes – a future to which many, including the President, subscribe – the world undergoes a technological, regulatory, and social revolution in the way that electricity is produced, transmitted, and consumed. Some additional background is needed.

First, hydrogen is not an energy form in itself, because it is not naturally available on Earth. Like electricity, hydrogen is an energy carrier. It is a secondary man-made form of energy that must be produced from some primary energy form, whether it be coal, oil, natural gas, nuclear, or renewables. In the future, hydrogen could be produced at a large scale facility and transmitted to the site of consumption. Alternatively, the primary fuel could be transmitted to the site of consumption (or produced on site) and used to produce hydrogen. Hydrogen, once produced, is envisioned to be used in fuel cells, which directly convert hydrogen to electricity.

“There are a number of ways to produce hydrogen. Today, nearly half of the hydrogen produced in the world is derived from natural gas via a steam-reforming process. The natural gas reacts with steam in a catalytic converter. The process strips away the hydrogen atoms, leaving carbon dioxide as the by-product. Coal can also be reformed through gasification to produce hydrogen, but this is more expensive than using natural gas. Hydrogen can also be processed from oil or gasified biomass.” (Rifkin, Page 185)

Hydrogen can, of course, be produced by electrolysis, and industrial electrolysis plants exist in numerous countries. However, hydrolysis is not used to produce a large percentage of hydrogen. Only about 4 percent of hydrogen produced in the United States is produced by electrolysis because, according to Rifkin, the cost of electrolysis is much higher than the natural gas steam-reforming process.

In the long term, natural gas supplies are unlikely to be sufficient to sustain a hydrogen economy. Coal, our nation’s most abundant energy resource, could be used. Of course climate change concerns about carbon dioxide accumulating in the atmosphere will likely require that the CO₂

be captured and stored. One advantage of producing hydrogen from coal is that an integrated treatment system for carbon dioxide and other emission may be more effective than with systems that have to treat coal combustion emissions.

In an utopian world, all of our nation's energy supplies would come from renewable and carbon-free forms of energy, such as photovoltaics, wind, hydro, biomass, and geothermal. These renewables would be used to generate electricity that is used in an electrolysis process to split water into hydrogen and oxygen atoms. The Institute of Gas Technology reports that industrial electrolysis processes exist today that have electricity-to-hydrogen engineering efficiencies of above 75 percent (Rifkin). Most energy analysts, including the current authors, do not believe that our nation can fully transition to renewables within the next several decades. Thus, a transition to hydrogen will be fueled by conventional fossil fuels, in combination with a growing percentage of renewables.

A key component of a move to a hydrogen economy may be distributed generation. Distributed generation refers to integrated or stand-alone small electricity generating power plants that are located at or near the site of the end users. These small-scale facilities, which will likely be powered by natural gas and possibly some renewables, would be located near factories, neighborhoods, and commercial buildings. They also would be integrated within the electricity grid so that excess electricity could be sold over the grid.

Fuel cells may play a key role in the move to a hydrogen economy. In some scenarios, hydrogen is produced and stored on site. When electricity is needed, hydrogen would be used in fuel cells to produce electricity for the site. Hydrogen and fuel cells are seen as one method to essentially store electricity on site. Electricity from fuel cells is currently much more expensive than conventional generation. According to Rifkin, electricity from fuel cells currently costs between \$3,000 to \$4,000 per kilowatt, while electricity from a state-of-the-art gas-fired central power plant is between \$500 to \$1,000 per kilowatt.

But what about water? Rifkin and other advocates of a hydrogen economy, to the best of the current authors' knowledge, have not addressed the water requirements for a transition to a hydrogen economy. If conventional fossil fuels are used as the primary fuel, there are obvious water issues. Even if renewables, such as biomass and geothermal, are used, water questions abound. For example, biomass production may require much more irrigation. If a transition to a hydrogen economy is a legitimate option, the viability of our freshwater resources to support this transition must first be demonstrated.

Freedom CAR

President George Bush in his January 28, 2003 State of the Union Address proposed "\$1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-powered automobiles." The President went on to state that "our scientists and engineers will overcome obstacles to taking these cars from laboratory to showroom so that the first car driven by a child born today could be powered by hydrogen, and pollution-free." The Department of Energy estimates that Freedom CAR may reduce our imports of oil by more than 11 million barrels per day by the year 2040. Over the next five years, the President has proposed \$720

million to develop hydrogen-powered fuel cells, hydrogen infrastructure, and advanced automotive technologies.

To move toward the President's vision, DOE recently announced plans for the "Freedom CAR (Cooperative Automotive Research)," which replaces the previous DOE/Big Three consortium, The Partnership for a New Generation of Vehicles (PNGV). PNGV's stated goal was to develop and introduce a family car with three times the fuel efficiency of the current family sedan. According to DOE, Freedom CAR has an even more ambitious goal – the development of a mass-produced vehicle powered by a fuel cell. Fuel cell technology and mass production of vehicles powered by hydrogen produced domestically from renewable sources will be the main focus of Freedom CAR research. In addition to producing a more fuel efficient vehicle, a major objective of Freedom CAR is to move away from vulnerable oil imports to more secure domestic resources.

As is the case with the earlier discussion of the hydrogen economy, the key question is how our nation can produce hydrogen in sufficient quantities to make Freedom CAR a reality. It is unrealistic to believe that renewable sources alone will be sufficient. There are fuel reformers that can convert natural gas and liquid fuels into hydrogen. However, these systems form a hydrogen gas stream that includes carbon and sulfur containing molecules that must be removed before the hydrogen can be used in a fuel cell. Also, these contaminants must be exhausted somehow, which reduces the environmentally friendly aspect of the fuel cell.

A back-of-the-envelope calculation illustrates the magnitude of the water resource requirements to move to a hydrogen based transportation system. If the United States were to replace all petroleum imports currently used for transportation (some 10 million barrels per day) and conventional electrolysis were used to produce the hydrogen required, the United States would roughly have to triple our domestic electric generation capacity. Obviously, not all hydrogen for Freedom CAR would come from conventional hydrolysis using conventional electricity generation technology. But under any reasonable scenario, water resources for cooling and other needs (yet to be identified, studied, and estimated) could be a potential "show stopper."

WATER AND ENERGY

Up to this point, the focus has been on the water requirements to meet our energy security goals. We now turn to the connection between energy and our water goals.

Water, Wastewater, and Energy

There is growing interest in understanding and promoting energy efficiency in the water and wastewater industries. Water and wastewater technologies are energy intensive. It is estimated that about 55 billion kilowatt hours of electricity is used in the United States each year for water and wastewater treatment. This is about 35 percent of the total energy used by municipalities. More than 95 percent of the energy used in these facilities is for motor-driven pump and aeration systems. Experts estimate that as much as 15 percent of this energy could be saved by implementing state-of-the-art technologies (CEE Market Transformer News). R&D is needed to reduce the energy required to treat, pump, and distribute freshwater. Other new technologies

could be focused on reducing the energy required for irrigation, mining, industrial, commercial, and residential purposes.

Clearly, to the extent that the energy intensity of our water and wastewater industries can be reduced, our energy security is enhanced. Unfortunately, there is little evidence that these opportunities are being pursued by industry or federally funded research and development.

Desalination

One of the ways to achieve our water goals is to produce more fresh water. Desalination is a process to remove salt and other minerals from seawater, brackish water, or wastewater. A number of technologies have been developed for desalination: reverse osmosis, electro dialysis, vacuum freezing, distillation, and capacitive deionization (Hoffman).

While much can be done to improve the management of existing water supplies, there is broad agreement that extensive use of desalination will be required to meet the water needs of a growing world population. Energy costs are the principal barrier to greater use of desalination technologies. In fact, there is no shortage of water. Rather, there is a shortage of cheap energy to convert saltwater to freshwater and transport that water to the point of need.

New technology has driven down the cost of producing freshwater. For example, the costs of desalination using reverse osmosis has fallen from about \$23 per 1,000 gallons in 1978 to about \$2 in 2001. And energy accounts for about 41 percent of the total cost of this process (Hoffman).

Desalination is one means to address our nation's water resource problems. Some communities have already moved in this direction. For example, Tampa has installed desalination facilities to produce 35 million cubic meters of freshwater per day (Hoffman).

Affordable and low-energy-intensive desalination technologies could also play a role in improving the stability of the Middle East and major oil producing nations. Many public figures have stated that future wars in the Middle East could be over freshwater supplies. To the extent that desalination and other technologies can alleviate water problems in these nations, our nation's energy security is enhanced.

Helping Balance the Water Equation

Our energy security goals will inevitably require additional freshwater supplies. A strong case can, therefore, be made that our nation has a responsibility to help balance the water equation by supporting research and development to lower the water intensity of our industrial, commercial, agricultural, and residential sectors, including the energy sector. This has been recognized in part by the U.S. Department of Interior's recently announced Water 2025. However, that initiative is targeted at western states and does not pay sufficient attention to the energy sector.

The DOE in collaboration with industry has made great strides to improve the nation's energy intensity over the past three decades. Home refrigerators now use about one third less energy than in 1972; new commercial fluorescent lighting systems use less than half the energy they did

during the 1980s; industrial energy used per unit of output declined by 25% from 1980 to 1999; and the chemical industry's energy use per unit of output has declined by about 40% in the past 25 years. Despite the improvements, problems persist. In recent Congressional testimony, Paul Dean, North American manufacturing director for Dow Chemical said that "his company realized three years ago that water is a resource that can no longer be taken for granted. In 2000, a drought forced many of Dow's plants to reduce water use, and in some cases plants came within just a few days of running out of water." (*Environment and Energy Daily*).

A similar effort is needed by DOE and/or other federal agencies to support research and development during the coming decades to make similar progress in the water area. Fewer demands for water in the industrial, agricultural, commercial, and residential sectors could effectively counter increased demands for water to meet our growing energy needs. In the past, DOE has supported effective programs with industry to target energy efficiency goals. Programs such as Industries of the Future leveraged its R&D investments through collaborative R&D partnerships in nine vital industries – i.e., agriculture, aluminum, chemicals, forest products, glass, metal casting, mining, petroleum, and steel. A program targeted at water efficiency in the energy and other sectors could be patterned after this program. A useful starting point would be to assess the demands for water within the different sectors and to develop a roadmap to achieve improved water efficiency within each sector.

THE LACK OF MODELS AND DATA

The arguments made up to this point are based on sketchy information. Although we believe these arguments are compelling, our assessment capabilities – e.g., data, models, and analysis tools – are woefully lacking, because the water-energy nexus has been neglected.

Water Supply and Demand

Although much general information on water supply and demand is available, our knowledge of the use of water for specific energy related purposes is very limited, as is our knowledge of local water supplies and demands. Regional patterns are difficult to predict, and opportunities for efficiency improvements in our use of water go unrealized. In addition, we lack a data system and model to track the flows of water among natural and engineered systems.

One of the most troubling aspects is the lack of information about current and projected water supplies and water demands. Gleick (page 39) states that

“...various projections and estimates of future freshwater demands have been made over the past half century, some extending out as much as 60 or 70 years. These projections have invariably turned out to be wrong.”

Our current capabilities to forecast water supply and demand, especially on a regional basis, are grossly insufficient. Gleick (page 43) reports that past efforts to predict freshwater withdrawals have been highly inaccurate. Existing forecasts agree that water withdrawals and consumptive use will increase significantly in coming years, but specifics vary considerably. For example, Shiklomanov (1998) forecasts that the consumptive use of water world wide will increase from

2,329 km³/year in 2000 to 2,818 km³/year by 2025. One of the key factors to influence the future withdrawal of freshwater is industrial use. Shiklomanov (1998) projects that world-wide water withdrawal for industrial uses will increase from 768 km³/year in 2000 to 1,121 km³/year in 2025. Falkenmark and Lindh (1974) projected 2015 total world water withdrawal under a base-case, no-industrial-water-reuse assumption. They concluded that domestic uses would account for 890 km³/year (8.2 percent), agricultural uses at 5,850 km³/year (54.0 percent), and industrial uses at 4,100 km³/year (37.8 percent). The authors include an alternative scenario in which 90 percent of industrial water use is recycled, reducing the projected industrial water consumption to 1,145 km³/year (14.5 percent of the revised total water consumption). (See Glick for reviews of these past studies.)

Significant improvements in data on how water is used are very much needed. Better and more detailed data would allow the development of input/output tables to relate specific industrial, commercial, agricultural, and residential uses to specific water requirements. This worthwhile first step would help guide future R&D to reduce the consumption of water in all sectors.

In addition, efforts, such as DOE's Office of Science's proposed Global Water Cycle (GWC) Program, could employ advanced computer capabilities, improved and more detailed data, and new sophisticated methodologies to improve our understanding of trends in the global water cycle. More specifically, GWC could help improve our understanding of the intensity, location, and duration of hydrologic events; enhance our capabilities to predict variations in the water cycle; and quantify interactions between the global water cycle and atmospheric composition, climate, land use, biogeochemical cycles and ecological processes. Unfortunately, at this time DOE has not made a firm commitment to pursue this program.

Climate Change

Climate change could have a huge impact on the availability of freshwater on a regional basis, which will have an impact on the amount and timing of water inflows to our reservoirs. For example, recently in the mountainous areas of the U.S. western states, there has been more rain and the snowpack has declined. Recent predictions of global change by Japanese show the southeastern United States among the regions at most risk of decreasing water supplies." (Oki).

Additional work is needed to link existing climate models with projected regional demands for water for energy purposes. This linkage could provide crucial information in our studies of hydropower, inland waterway navigation, conventional electricity generation, the viability of Freedom CAR and the hydrogen economy, and the need for and viability of desalination.

INCENTIVE STRUCTURES AND REGULATORY REFORM

We began this paper by stating that both our energy security and water resource goals can be addressed by putting in place the "proper incentive structures to use energy and water most efficiently, while addressing equity concerns." We also stated that "the incentive structures that are now being discussed, and in some cases implemented, to use our water more efficiently (while addressing equity concerns) have a direct link and similarity to the energy incentive structures that were put in place in the 1970s and 1980s to improve our nation's energy security."

“Too cheap to meter,” a phase once taken seriously in the energy sector, has been replaced by concerns over energy security, environmental emissions, and global climate change. As a result, energy policies that in the 1970s subsidized domestic oil drilling and fixed prices below market-based levels have been replaced with policies that allow prices to increase so that the price of energy reflects the cost of production. Other policy initiatives include “full costs pricing,” which calls for the costs of environmental damages and energy vulnerability to be included in the price of energy. Yet for all practical purposes, water, a resource with equal importance for economic development, energy provision, and environmental quality, is still treated in many places as “too cheap to meter.” And in those cases where water is metered and purchased by quantity, there is strong evidence that prices do not reflect total (or full) cost of production.

As a result, we have water markets that are not allowed to reach equilibrium. Artificially low water prices cause a disconnect between the quantity of water produced and the quantity of water demanded. Allocation systems (other than price) must, therefore, be imposed to allocate water in various ways, depending on the specific region, state, and municipality. Existing water laws and institutions are a significant barrier to achieving a balance between water supply and demand.

Some communities have implemented voluntary restrictions as a means of balancing supply and demand. Unfortunately, these restrictions are not very effective. For example *The Daily Camera* states that:

“Water restrictions can be an effective way to reduce water use, but only if the restrictions are mandatory, according to a new study done by University of Colorado researchers...Not surprisingly, water use dropped, by as much as 56 percent, when cities instituted mandatory restrictions...But voluntary watering restrictions, by and large, aren’t very helpful...In fact (in some areas) total water use actually increased when those cities asked residents to conserve voluntarily.”

Mehan argues that “Properly valuing our water resources strikes me as a threshold issue, one that defines how we deal with water issues.” (Page 3) In other words, when the severity of our water problems reaches some threshold, there will be increasing pressures to adopt market measures to allocate water. The growing global trend to privatize water supplies is one indication that some people recognize water’s growing scarcity and rising value.

The production, use, and allocation of water in the coming decades may follow transitions similar to those in energy markets that began in the 1970’s. Changes in energy markets, including the way energy resources were priced, resulted in large price jumps. While costly at the time, the energy price shocks of the 1970s and 1980s, in combination with ambitious R&D programs within DOE and industry, resulted in reductions in energy intensity such that today it takes only about 56 percent of the energy required in 1970 to produce a dollar of GNP. Similar opportunities likely exist in the ways we utilize our water resources, but those opportunities will not be realized without major changes in the way water is allocated and without major R&D programs targeted at increasing water efficiency.

If water moves toward market allocation, our nation will face major changes in how freshwater is produced, allocated, and used. Current uses that are based on historical allocation methods may give way to higher valued uses. These changes could have significant impacts on the availability of water for energy production and use, inland waterway transportation, hydropower, the viability of desalination, and the future of electric power.

Also, legal and regulatory issues abound. The differences between western appropriation doctrine and eastern riparian doctrine are well known (Cummings, Norton, and Norton, 2001a). Questions have been raised about the ability of local and state governments to effectively deal with in-stream flow problems during periods of drought. Cummings, Norton, and Norton (2001a, Page 1) have asked “Under conditions where “new” users cannot acquire access to water supplies how does a region grow, take advantage of economic development opportunities, and avoid conditions leading to a stagnant economy?” As water constraints become more severe, new approaches, likely based on market principles, will have to be implemented to allow for the transfer of rights to use water. Unfortunately, in many states relevant regulatory provisions are unclear and/or ambiguous about the state’s ability to implement such changes. Nonetheless, as demands for water increase, new allocation mechanisms will have to be developed if regional and national needs – including our energy security goals – are to be met.

One of the arguments made against the market allocation of water is equity. In other words, everyone has a basic right to water. Water should not be sold in a market. This is, of course, a compelling argument. But once again, we can look to historic transitions in energy markets for solutions. Programs such as DOE’s Weatherization Assistance Program and the Low Income Home Energy Assistance Program (LIHEAP) provide subsidies to low-income individuals who cannot pay market prices for energy. If water is eventually sold within markets, similar programs could be developed and adopted.

Another important argument against market allocation of water is environmental protection. Water markets will require some degree of regulation to insure that instream flows are sufficient to preserve ecosystems.

THE INSTITUTIONAL ISSUE: WHOES PROBLEM IS IT ANYWAY?

Any debate over the allocation and use of water resources must be conditioned by the unique circumstances that govern current water allocations. Water is currently seen as a state and local issue. Water comes under state and local discretion. With few exceptions state policy sets water policy, and state policy is entrenched in judicial decisions. Currently, there is little incentive for water rich, or even water-balanced states to agree to long-term interstate transfers. Without federal leadership, change will be piecemeal and inefficient.³

We hope that our examples have outlined the importance of energy and water and illustrated the need for federal agencies and the nation as a whole to address these issues. Unfortunately, there is no specific agency within the Federal government that has sole responsibility for water; and it

³Interstate water compacts are one exception where the federal government plays a significant role.

is widely acknowledged that leadership is needed to bring focus to the growing water problems we face. There are several agencies with unique roles. DOE has several Offices currently addressing water issues. DOE's (EERE) Hydropower Program is the most obvious and of direct relevance. The Office of Science is taking the DOE lead on the important Global Water Cycle Program. The Office of Fossil Energy has programs that indirectly address issues related to water quality at power plants. And, of course, the Office of Nuclear Energy would play a key role in desalination and also as a future user of water.

The Environmental Protection Agency has responsibilities for monitoring and addressing water quality. The U.S. Army Corps of Engineers has extensive expertise and laboratories to address a wide variety of water issues. Unfortunately, the Corps is not specifically addressing the intersection of energy and water.

The Office of Science and Technology Policy (OSTP) has formed a new Subcommittee on Water Availability and Quality, which includes the DOE. Legislation has been offered in Congress to form a new National Water Policy Commission, which is being proposed by Rep. John Linder of Georgia and Rep. John Duncan of Tennessee. In recent hearings, Rep. John Duncan stated:

"The scarcity of water is increasingly causing water to be viewed as a finite commodity, and even a market good, rather than a ubiquitous common resource or free good...Many municipalities, businesses and land developers are scrambling to secure water rights to help ensure they have adequate supplies of water for now and into the future." (Environment and Energy Daily).

The federal government and its agencies are beginning to recognize the importance of understanding and addressing water resources. And our nation now has a long history of addressing energy security. Unfortunately, the nexus of the two remains largely untouched. If the nation is to reach its energy security and water resource goals, the two issues must be joined.

CONCLUSIONS

The energy security goals of the United States are inextricably linked with our nation's water resources, because energy production has consumptive and non-consumptive water demands and energy production affects water supplies. Greater energy security will require additional water resources, and the growing imbalance of domestic water supply and demand will require the more efficient use of energy in water and wastewater technologies. Conventional and unconventional domestic production of oil depend on water for extraction and refining. Hydropower is being challenged by competing water uses and water quality issues. Inland waterway transport, which is more energy efficient than alternative modes, and water for cooling conventional power plants are competing with environmental and recreational goals. Revolutionary energy technologies, such as a hydrogen-based economy and Freedom CAR, will transform the domestic production, transport, and use of energy, with unknown water implications. Current technologies to process and transport water and wastewater are very energy intensive. Desalination, which many argue will be required to meet the needs of a growing world population, can be made more viable by reducing the energy intensity of current desalination technologies.

Although cursory evidence points to an impending collision between energy security and water, our assessment capabilities – e.g., data, models, and analysis tools – are woefully lacking. It is currently impossible to be very specific about the magnitude of the problems or to develop roadmaps to achieve both national goals simultaneously. And the uncertainty is compounded by a lack of understanding the energy and water implications of climate change.

Technology improvements must be complemented by incentive structures to use energy and water most efficiently. The incentive structures that are now being discussed, and in some cases implemented, to use our water more efficiently (while addressing equity concerns) have a direct link and similarity to the energy incentive structures that were put in place in the 1970s and 1980s to improve our nation’s energy security. Our nation can learn from what our nation has done well and poorly as we have worked toward greater energy security during the past three decades.

If the nation is to achieve our energy security and water goals, the federal government and its agencies must play a greater role in science, research and development, legislation, and regulation. The long history of leaving water issues to state and local governments must be challenged if these competing goals are to be realized.

Until the diverse and, too often, dysfunctional set of federal agencies that have water responsibilities are reorganized, consolidated, or show they can coordinate effectively, individual agencies will have to do the best they can to avoid aggravating energy and water conflicts. DOE can make important contributions in the water arena.

DOE should increase its R&D investments associated with the water-energy nexus in three areas: 1) integrated planning models and supporting information that can be used on a regional basis to identify water constraints on sustainable energy development, 2) large-scale studies of the global water cycle as it is influenced by climate change and other socio-economic trends, and 3) technology development that will decrease the water-use intensity of all types of energy production, enable new water supplies available for energy production, and reduce the energy use by the water sector. The first of these areas should be used to support strategic planning in each of DOE’s Offices, to ensure that new energy development is compatible with existing water uses in all regions of the U.S. The second area is basic research that should focus on large, regional testbeds (i.e., large river basins) and link watershed-scale hydrologic process studies to global change modeling. The third area should be tailored to technology opportunities in each DOE’s different Offices that concentrate on different subsectors: Fossil Energy, Nuclear Energy, Energy Efficiency and Renewables, etc.

No single approach, scientific answer, R&D program, or policy will supply the information and technologies needed to address water and energy security in a systematic manner, but neither will separate and diverse approaches that are prepared from inconsistent assumptions and to support local agendas alone. There is an opportunity for a single federal agency or group of agencies to offer an integrated approach, even while recognizing the regional specifics that must be addressed. As there was a need for strong federal leadership in the 1970s to address what was viewed as an “energy crisis,” there is now an equal need for strong federal leadership to address

the water issues that threaten our energy security and the water problems that will, unchecked, threaten our economic growth and ultimately our national security.

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