Organizing Committee Perspectives on Energy and Water Sustainability through the 21st Century

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Water sustains all life on earth; energy sustains human society.

Introduction

Sustainability of energy and water through the 21st century was the daunting topic for an invited group of 25 experts gathered at the Arbor Day Farm, Nebraska City, Nebraska, October 8–11, 2000. Sustainability of what? for whom? at what rate of consumption? of what quality? and for how long? were questions raised in every discussion. Eventually, the participants selected 10 policy recommendations by a cumulative voting process from more than 30 suggested for each resource. However, the selected policy recommendations do not reflect the full spectrum of the discussions.

Therefore the conclusions of the Conference are synthesized and supplement the policy recommendations with information presented by keynoters and developed during the discussions and consensus-building exercises. The reader is referred to reports of two conferences on resources, environment, and society that preceded this meeting (Gerhard et al., 1996; Gerhard, 1999) for additional background.

Energy Sustainability

The world is consuming around 27 billion barrels of oil per year. Reserve additions, including discoveries of new oil resources, are significantly less than that, about 10 billion barrels in 1998 (Energy Information Administration, 2000). The disparity between additions and consumption is the *petroleum deficit*.

Recognizing that exploration and development of petroleum have been hampered in recent years by low prices, these numbers are not a real indicator of the potential for future petroleum production throughout the world. Nonetheless, these numbers do suggest that there is a long-term shortfall between production and discoveries, one that will likely increase with time.

As Downey (this volume) points out, "We didn't leave the Stone Age because we ran out of stones." There is more oil to be discovered in the world, and many regions have not been adequately explored by the drill. There are many very large known petroleum resources that we have not yet exploited because of price and technology. This argues that there is a lot of oil yet to be discovered and produced in the world.

Edwards (this volume) suggests that by 2050 supply will be less than demand, and that other energy resources will be required. Edwards argues that petroleum is a finite resource, soon to be scarce. These two papers illustrate the disparate views in the current debate on future petroleum energy supply and demand.

Petroleum is very price sensitive. Increasing global demand with a constrained supply simply increases price, whether the constraints are natural or artificial. If this is correct, when demand finally exceeds supply, the price will rise until demand is suppressed. The period of time during which petroleum can be used for low-cost personal transportation and inexpensive disposable plastic products may come to an end sooner than many of us might wish. Under one extreme scenario, if oil becomes scarce enough for the price to rise to $500 per barrel, there would still be a pharmaceutical industry, because the value of medicines from petrochemicals is not very dependent on the value of the feedstock. However, at that price it is doubtful that society will be driving many automobiles or disposing of plastic trash bags in the manner done today.

The amount of residual oil in abandoned shallow oil fields and in tar sands is sufficient to meet any expected need for pharmaceuticals. If the price is allowed to reach demand-discouraging high levels, the supply of petroleum essentially becomes inexhaustible.

Alternative and renewable energy sources continue to receive much attention from the mass media. Unfortunately, media coverage provides limited information and demonstrates little knowledge of total global energy use and production. Wind, solar, biomass, geothermal, and ocean tides seem to promise essentially limitless "free" energy, but barriers to their use are legion. Despite billions of dollars invested over decades, none of these sources has yet been able to supply significant amounts of useful energy. Some, such as grain alcohol currently require more energy to produce than they can deliver as fuel (Younquist, this volume).

For example, replacing one 24-megawatt electric-generating plant in Kansas would require constructing and operating 24,000 wind turbines, 24 hours a day, 365 days a year, unlikely even in western Kansas. Evenly distributed, each of the 105 Kansas counties would have about 229 turbines, but because not all counties have good wind sources, there would be uneven distribution of the towers.

In order to gain the efficiency of the single fossil-fueled plant, there would have to be about four times the number of turbines (more than 800 per county), because the wind does not blow constantly enough throughout the state. In addition, the wind-turbine fields would require batteries that could store the power, and so on. Coal remains the fuel of choice for electrical generation in the near future (Sondreal, this volume).

Excepting hydroelectric facilities, traditional renewable-energy sources are primarily useful for local and limited applications. Solar power has supplanted wind power on many ranches for pumping remote water supplies. While these remote and local applications of alternative nontraditional energy sources are useful, efficient, and deserve further development, they will not power large cities. There is potential for wider application of solar-energy conversion if efficiencies can be improved.

Unconventional fossil-energy resources may hold the key to supplying the world with energy over the next century or two (see Downey, this volume). However, the implied caveat for using unconventional fuels is development of cost-efficient and environmentally benign technology to extract, refine, and use those fuels.

Tar sands, oil shale, and tight gas sands all contain huge amounts of petroleum. The tradeoff for access is disturbance of the land, modification of the landscape, and the need to dispose of the waste products of production.

The costs of the new technology required to use these fuels is such that they can become part of the fuel mix only after the price of conventional petroleum, coal, and natural gas become high enough to make investments in the unconventional fuels economically attractive. Use of these unconventional fuels can extend the energy supply at current levels of consumption for additional decades. The price to be paid is the increasing input energy required to produce the present level of energy output.

One potential bright spot in the energy-supply picture is the possibility of accessing natural gas hydrates from the deep ocean and from Arctic permafrost zones. Estimates of potential recovery of methane (natural gas) range from extremely large to small (Kvenvolden et al., 1993; W. Harrison, personal communication, 2000). Most estimates are quite large.

One of the unique characteristics of natural gas hydrates is that they are an apparently renewable resource, even on human time scales. Exploitation problems involve actually locating mineable deposits, and developing the technology to safely extract and expand them from their "natural" crystalline state to a useable fuel gas. Under surface pressure and temperature conditions, they expand explosively.

The potential for a significant amount of energy from natural gas hydrates is high, but the time frame for development is likely to be decades. Natural gas hydrates will not be a low-cost resource no matter how much becomes available because of the harsh and challenging environments in which it occurs and from which it must be extracted.

In the next twenty years it is anticipated that fuel cells, fueled by natural gas, may be the first replacement for petroleum products in transportation. Already in use in space, fuel cells have potential to become the first practical alternative to petroleum transportation fuels, as part of the trend toward higher hydrogen-content fuels (Fisher, 1999).

Fisher (his figure 3) demonstrates that the hydrogen content of fuels has increased over time in a natural progression. Wood ($H/C = 0.1$) was the energy base until major utilization of coal ($H/C = 1$), then oil ($H/C = 2$). Now, and in and immediate future, natural gas (fossil methane, $H/C = 4$) will be the fuel of choice. The midpoint and turning point for decreased carbon and increased hydrogen content is about 1935, when the petroleum economy was established. Fisher projects that there will be a nonfossil hydrogen economy starting in about 2025, established by 2050, and by 2150, a full hydrogen economy. The U.S. DOE is sponsoring a demonstration fuel-cell electrical-generating station for the U.S. EPA Environmental Science Laboratory at Ft. Meade, Maryland (U. S. Department of Energy, 2000).

Natural gas is touted as an environmentally benign boiler fuel for making electricity, but the demand for natural gas is rising in many other sectors. The major constraint on natural gas is simply access to the resource base (National Petroleum Council, 1999). Aesthetic and scenic vista restrictions on access to the near-offshore coastal waters and the Rocky Mountains have greatly curtailed the potential for natural gas production in the United States, even as the Federal government encourages a switch from coal and petroleum to natural gas. As this is written, the nation reached its historic high natural gas price.

Nuclear power may again become acceptable in the United States when the cost of petroleum becomes high enough to seriously affect the average citizen and when the Federal government can credibly assure the public that high-level long-lived radioactive waste can be safely disposed of and contained. Electric-power generation from nuclear fuels is the single clear technologic and practical solution to significantly increasing the supply of electricity to the nation without using larger amounts of coal.

The long-term solution to creating a sustainable-energy supply lies in new and unconventional thinking. Almost all the debate on energy sustainability involves using known fuels and energy resources.

Schmitt (this volume) proposes a radically different alternative—mining Helium 3 (He^3) from the moon, transporting it back to Earth, and using its fusion energy to generate electric power. While the business plan for that proposal requires access to some advanced technology and may take many years to mature, it demonstrates the thinking that is necessary to solve many human problems throughout the world.

We need new ideas and new paradigms. Unconventional thinking is necessary to solve our conventional problems.

Other factors beyond supply affect sustainability. Global-population growth has been exponential, and does not yet show signs of abating (fig. 1). With present technology and at present use levels, the supply of cheap petroleum to sustain present levels of consumption will not likely be sustainable through the end of the 21st century, no matter how much more is discovered, unless global population is stabilized.

No other single factor is as important in assessing energy sustainability as global population. This question has not been addressed in the United Nations and appears to be beyond direct political action by any individual country. Education appears to be a key element to resolving this problem. Religious beliefs that favor unrestricted reproduction and national economic policies that favor large families over small are significant factors in the seemingly inexorable increase of global population. Sustainable energy for a 6-billion-person world is a significantly more tractable problem than assuring sustainable energy for a 10-billion-person world in 2050.

A very different issue but no less important in consideration of a globally sustainable energy supply is the equitable distribution of energy to all the people of the world. Much of the world's population has limited access to the energy needed for development of their society and maintenance of their culture.

If we are to bring the world standard of living up to United States levels, sustainability of current energy supplies is suspect in this century. There is little likelihood that North America and Europe will voluntarily decrease their standard of living.

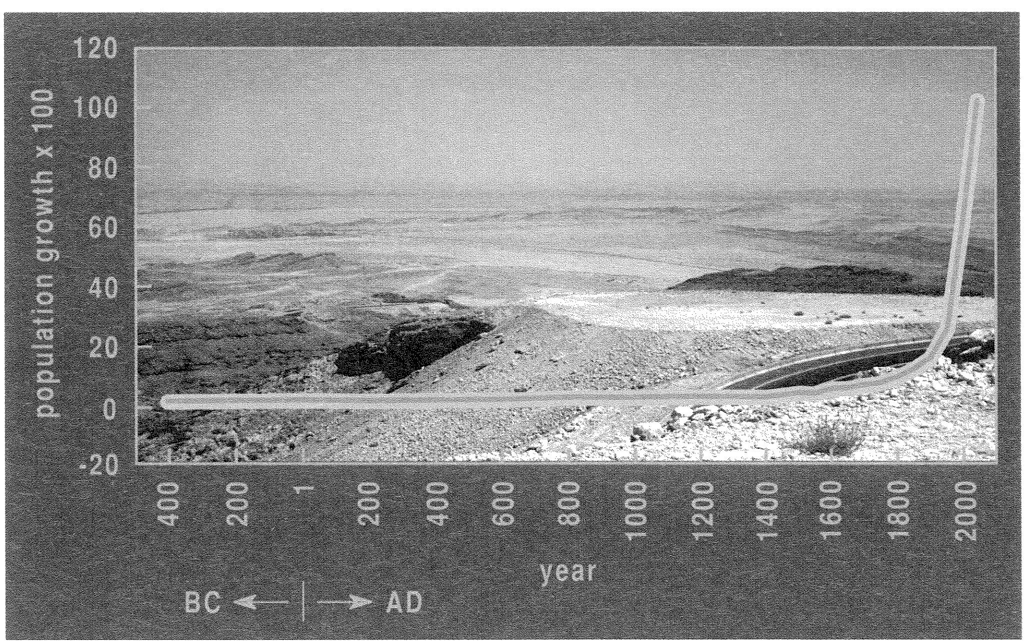

FIGURE 1—Global population curve.

Water Sustainability

The issues surrounding sustainable water are very different from those surrounding sustainable energy. There is sufficient water on and in the Earth to sustain global population for centuries to come, regardless of forecast global population increases. However, 97% of the Earth's water is not potable. Human beings and most other animals cannot drink it.

Oceans are saline, and most of the underground water contained in continental rocks is saline, often more salty than the oceans. Therefore, we must evaluate the availability of freshwaters developed during the hydrologic cycle (fig. 2), some of which is now (presently) fossil water, that is, water that was emplaced during the last glacial stage.

Freshwaters from the hydrologic cycle occur as streams, lakes, and ground water. They are subject to the variations of the hydrologic cycle and changes in climate. They can be made useless by contamination or depleted by excessive use; or, they can be protected, managed, and sustain the human species as well as the diverse populations of plants and animals upon which human civilization depends (Kreitler, this volume; Alley, this volume).

Three major factors determine water sustainability:

- Freshwater does not occur evenly over the planet. The unequal distribution of freshwater means that some societies have an abundance of high-quality freshwater, while others suffer greatly from having a small amount of not very good water.
- Freshwater is subject to an infinite variety of contamination. It dissolves many compounds and transports others easily. Maintaining water quality consistent with human consumption is not easy even in natural settings. Large concentrations of human beings inevitably exacerbate the problem.
- Water is required to maintain many natural ecosystems (Triplett, this volume). Overuse of the water resource harms such ecosystems, but we have not yet been able to quantify those effects on the human standard of living.

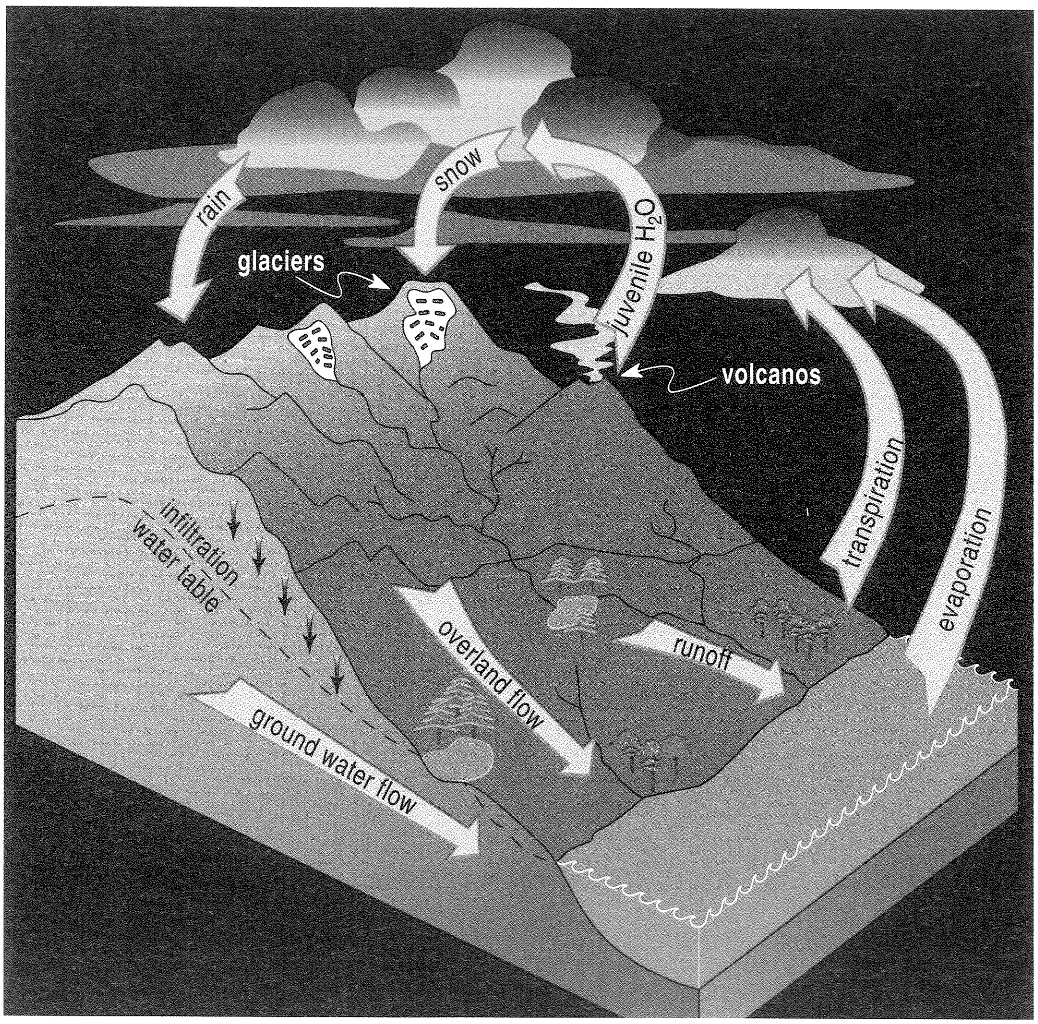

FIGURE 2—Hydrologic cycle.

Water, unlike oil, has a high "place" value and a low "unit" value. That is, one doesn't normally pay a lot for water, but it has to be found near where it is used, as it costs a lot to move it from one place to another, like sand and gravel. Oil has a high unit value, and a corresponding low place value. Oil is sufficiently valuable and energy dense to make it profitable to move it from where it is found to where it is used, like most metals. *It is that difference that makes sustainable water a local issue rather than a global issue. The global nature of the hydrologic cycle, however, adds a global dimension even to the most local consideration of freshwater as a sustainable resource.*

For instance, in eastern Kansas, municipal water is taken from both surface reservoirs and rivers, and from ground-water wells. There is abundant water, rainfall approaches more than 40 inches per year, and there is no water-supply problem. In western Kansas, there is no surface water available to municipalities. They are completely dependent on ground water.

In western Kansas, the City of Hays has inadequate well supply from its major stream aquifer, and has been supplementing its supply with brackish water from the Dakota Formation. Some of the ground water that is available has been inadvertently polluted in former years, and remediation is underway, but the pollution restricts the water supply even further. The city has purchased water rights from a ranch in another drainage. The costs to move the water, even if approval for an interbasin transfer is gained, will be in the tens of millions of dollars.

Hays has less than 25,000 residents, but has been on water rationing for more than 10 years. They do not have a sustainable water supply, unlike much of the more populous eastern portion of the state. Appropriate management of water resources can mitigate many problems, but there are trade-offs that must be made (Gerhard, this volume).

Some of the western Kansas water-supply problem is the result of depletion of the High Plains aquifer, so that surface springs that once fed the rivers no longer provide water. In addition, modern agricultural practices attempt to keep all precipitation on the land on which it falls, permitting as little run-off as possible. Both of these practices have decreased the surface flow of streams, reduced the quantity of water available to the associated stream aquifers, and negatively impacted stream ecology.

Internationally, the problems are more severe. Much of central Africa, Australia, and the Middle East are desert. Nationalistic fervor, cultural differences, geographically small nations, the need for agriculture, and limited surface waters have made this issue a military one in some cases. The potential for additional military action over water supply is high. Today, irrigated agriculture is a mainstay of the global food supply. There is not a sustainable water resource in much of the global desert. Population growth tends to be very high in those regions, creating further problems.

Along some of the world's largest rivers, where water is plentiful, contamination from human activity has extensively degraded water quality. Long-term human settlement in the major river valleys has made the water difficult and expensive to treat. Among those rivers are the Mississippi, the Ganges, the lower Nile, the Mekong, and the Rhine.

There is a false perception that only Third World nations have mistreated their water supplies. In America, 30 years ago water could be directly imbibed from glacial lakes and high-country streams, but no longer. In the last few decades a micro-organism, *Giardia lambia,* apparently carried by recreational hikers, has contaminated these waters and made them undrinkable without filtering.

In major U.S. urban corridors, massive population growth has overtaxed water resources, so that increased population or significant drought causes water shortages. On Long Island, New York, overbuilding on ground-water-recharge areas along with concurrent rapid population growth is overtaxing the sole-source aquifer that holds the ground water on which the people of the island subsist. There is no alternate potable water resource, but no regional water-management system is yet in place (Yannacone, personal communication, 2000). Artificial-recharge and conjunctive-use strategies will become more important issues in the future.

Desalinization through artificial evaporation is a standard potable-water-recovery process along desert coastlines, but it is very expensive and energy intensive. In addition, the distilled water requires mineral supplements before it can be used as drinking water. In U. S. funds, such desalinized water costs cents per gallon, as compared to gallons per cent for normal treated municipal water in the freshwater-rich areas of the world.

Where water is brackish, reverse osmosis can be used, but that process also is expensive, and the systems take much maintenance.

The most important municipal and irrigation water-supply additions today are made by diversions of water. Unintended consequences of water diversions, including those of "safe yield" (Sophocleous, 2000), can have major environmental and supply impacts, such as has happened in the Aral Sea, where diversion for agriculture dried up an important fishing industry and polluted the remaining water, and created health problems.

Denver, Colorado, receives a significant part of its water supply from a western slope Rocky Mountain interbasin transfer, and one result is Mexico getting less than its adjudicated water supply from the Colorado River. Any interference in a stable natural system usually drives the system into instability. Every drop of water diverted from the natural system has an effect on all downstream society. Some of these effects such as flood control may be seen as good, but others such as reduction of streamflow, loss of needed water supplies, loss of wetlands, are not.

Recently, the State of Kansas successfully litigated against Colorado for taking water adjudicated to Kansas by compact from the Arkansas River. Agriculture in Colorado had grown at the expense of agriculture and municipal water supplies in Kansas. The United States Supreme Court decided the matter. Planning for the consequences of interference in natural systems is a basic requirement of any water policy.

The sustainable water question must resolve the issue of determining priority of water use. Competition for water resources is increasing and will increase between user groups as well as between nations, as global population continues its exponential growth. There are some clear choices to be made.

As cities expand, they demand more water, and the only resource left in many places, like southern California, is to take the water from agriculture. Water for direct human use takes precedence over water for indirect human use (agriculture, hydroelectric power generation) in the United States. However, there are costs associated with that precedence.

Colorado Springs and Denver have been purchasing water rights in the mountain valleys above them for a number of years. The land that was irrigated grass pasture no longer supports large-scale grazing or hay harvest, and many of the ranches that were dependent on the irrigated meadows have been subdivided into 35 acre "ranchettes" for urban recreational homes. Urban sprawl exacerbates urban water demands.

Agricultural use of water is very high. Over 83% of the water used in Kansas in 1995 was for irrigation, nearly 3.5 million acre feet (Gerhard, this volume). The green revolution that feeds large portions of the world requires massive amounts of water. As population grows, municipal water demand grows, water is diverted from agriculture, and agricultural productivity drops. Food supply can then become the problem. A sustainable water policy requires balancing of competing needs: for human consumption, industry, agriculture, and natural ecosystems.

Summary

In summary, there are sufficient fossil-energy resources and other conventional fuels, as well as nuclear-energy resources for the next few decades, despite an increasing global population. In the short term, energy is sustainable.

Although oil and natural gas prices are high by modern standards, they are not high in a historical context. Some of the high oil price is in the products from petroleum rather than the crude supply. Refining capacity in America is working at nearly 97% of capacity, allowing for no safety margin. Whenever a major refinery must shut down for maintenance, supply of products drops below demand. Fewer refineries exist today (159) than 20 years ago (324). Capacity has been reduced by more than three million barrels per day (Gold, 2000). Transportation of large amounts of crude oil or petroleum products to the points of ultimate consumption by ship is becoming increasingly costly. Transportation margins appear to be thin enough to discourage investment in new capacity. These issues affect the energy-supply outlook.

In the mid-term, out 50–100 years, there is concern that technological innovation will not keep pace with energy demand on a global basis. There is no consensus as to when the global petroleum supply will have peaked, although many, including Edwards (this volume), believe that it will occur in the next 50 years. With projected population of 10 billion by 2050, there is cause for concern.

Natural gas is a huge global resource, some of which is wasted by oil production in remote areas. As the resource gains value and desirability, more will be captured and transported to regions of high demand. The technology to capture and transport natural gas is constantly improving, and we can expect to see significantly more gas on the market by the time it is needed.

Unconventional resources and energy conservation will be required to maintain the flow of energy to the expanding population. Whether fuel cells and gas hydrates or tar sands and oil shale, there does not appear to be a good mid-term solution to the energy fuel mix other than greatly expanded use of nuclear energy. There appears to be a shortfall developing in sustainability of conventional energy resources in the mid-term.

A domestic and eventually an international energy policy is necessary by the United States to sustain the nation's energy supply. Without technological advances to increase energy supply, the remaining petroleum resources will be competitively sought, and it is extremely likely that wars will be fought over the remaining resources. There seems to be little hope that equity issues involving energy supply will be addressed during this period of potentially increasing conflict.

For the long term, there is no question that unconventional thinking and unconventional resources will be necessary to sustain the world's energy supply. If there is to be any equity in the distribution of energy and energy resources among the societies of the Earth, it must come through invention of cheap and transportable energy resources not now well-known.

Schmitt (this volume) has outlined one such approach. Lunar energy supplies perhaps could solve the energy-sustainability problem for generations to come, but to develop the moon as an element of the energy supply for the Earth requires bold and creative approaches—thinking "outside the box." Political decisions must be made for time scales far longer than the months or years to the next election. We must do better than we have.

Setting priorities for water use to sustain freshwater supply will not be easy. Already, agriculture and natural ecosystems are in political conflict. Waterfowl and wildlife refuges are claiming water farmers consider necessary for irrigation. Minimum streamflows, Federal regulations on "swimmable waters," wetlands-preservation laws, and attempts at restoration of habitat to pre-development conditions have greatly increased water demand without any comparable increase in water supply. Restoration of the Florida Everglades is one such attempt (Scott and Schmidt, this volume).

A sustainable-water policy means providing potable water in perpetuity, for whatever size global population materializes. While there is sufficient water on Earth to accomplish that goal, there is insufficient wealth among many nations who need more water for their people at places the water does not naturally occur in sufficient quantity or quality. Transporting water is very expensive and has many unintended consequences downstream from the diversion. Desalinization of ocean waters and pumping of deep fossil waters requires prodigious amounts of energy, further adding to costs and adding to energy demands.

One approach to developing a sound sustainable-water policy is to value water appropriately, using the full cost approach. This requires that the consequences of diversion and of depletion be fully accounted for, and that the value of natural ecosystems, particularly watersheds and groundwater-recharge areas be quantified along with agricultural, industrial, and municipal consumption. Because sustainable water is a local problem in a regional context, an integrated watershed/recharge planning system is required, rather than one limited by unnatural geopolitical boundaries.

There is sufficient potable water on Earth for its inhabitants. Getting adequate quantities of appropriate-quality water to the right places at the right time is the problem.

Intersection of Energy- and Water-sustainability Issues: Epilog

Considering both sustainable energy and sustainable water as the joint conference topics was based on a belief that these two resources are very closely linked and are destined to be the commodities over which armed conflicts are likely during the remainder of this century. Water and energy sustain agriculture. We need energy to have water in today's world.

A case in point is the use of water from the High Plains aquifer of western Kansas. The original water column exceeded 600 feet in parts of southwestern Kansas, but depletion by pumping for irrigation has dropped water levels more than 170 feet in specific locations, as natural recharge is slow and uncertain (Gerhard, this volume). Much of the water is considered to be fossil water, that is, water that was emplaced during the last glacial stage. Total depth to the base of the saturated zone is over 600 feet in some places, and some wells now pump water up over 450 feet.

The energy to pump the water has come from natural gas, owing to the fortuitous overlap of the High Plains aquifer and the Hugoton Natural Gas Area, a world-class giant gas field. Mineral owners in the region took their natural gas royalty in kind, accessing natural gas at the wellhead to operate their pumps. A prosperous farm economy was developed on this apparently free energy and free water. It operated well for 50 years, but reality has finally set in.

Increased natural gas production, rising because of increased demand, has caused the natural gas reserves and field pressures to drop. Consequently, the wells are now on vacuum, and gas is routed to large compressor stations to be re-pressurized and put into the pipeline for eastern markets. Gas is no longer available to the farmer at the well head, and farmers have had to establish their own local gas utility to move sufficient gas from the large compressor stations back to run water pumps. At the same time, pumping-energy requirements have soared, by virtue of the lowering of the water table, so that an additional 150 feet of lifting is necessary.

Farm prices have decreased, not increased, with time and inflation. There is serious question as to how long the irrigated agriculture of southwestern Kansas will survive, because dry-land farming may not provide a livelihood for most of the farms.

There is linkage between energy and water. Moving water, desalinization, driving water-treatment plants, all require large amounts of energy. If the cost of energy goes up, the cost of water will also. If the supply of energy goes down, the amount of water available for use where it is needed will also go down. Sustainable energy is required for sustainable water. The United States has had an energy and food policy for centuries: "Cheap food and cheap energy . . . at any cost."

This approach will be untenable through the 21st century. A more realistic and informed public policy for water and energy is required. Earth scientists and life scientists must work together to bring about the necessary changes in public policy.

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