KEYNOTE ADDRESS

WATER DEMANDS FOR EXPANDING ENERGY DEVELOPMENT

George H. Davis

Introduction - Much concern has been expressed recently as to whether water supplies will be sufficient to support accelerated energy development foreseen in Project Independence. Taking the U.S. as a whole, water supplies are ample for energy growth, but locally, as in the Colorado Basin, limited supplies will dictate economies in water consumption and will affect plant siting.

The objective of this presentation is to put water demands for energy growth in proper perspective. The energy processes under discussion exhibit wide demand flexibility depending upon cost of water, and exhibit marked flexibility regarding siting. It will be important to take maximum advantage of economic trade offs in order to avoid serious conflicts with competing water uses.

Water is required in most aspects of energy production -- mining and reclamation of mined lands, on-site processing, transportation, refining, and conversion to other forms of energy. Water supply is generally adequate for energy growth in the East, the South, and along the seacoasts. Most water-supply problems will be in the arid parts of the West, and especially in areas

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George H. Davis is a member of the United States Geological Survey, Water Resources Division, National Center, Reston, Virginia.

where annual rainfall is less than 10 inches -- the lower limit for establishing vegetation without irrigation.

Extraction -- Coal mining demands are generally modest and include water for dust control, fire protection, and coal washing. In most locals these demands are nominal and quality is not a serious limiting factor. The U.S. Bureau of Mines (PIB) recently estimated average water use at 15 GPT in underground mining, compared to 4 GPT in surface mining, and 8 GPT for waste disposal in each. The greater water requirement for underground mining relates to greater need for dust control below ground, and higher demand for washing in the East where underground mining predominates. Little of the water used in coal mining would return to surface streams except a part of the waste disposal requirements. Using a current approximation of 600,000,000 tons annual production of which 50% is surface mined, we arrive at annual water demand nation-wide of 21,000 acre-feet for underground mining and 11,000 acre-feet for surface mining. In addition, in arid areas we must also count water required for revegetation of surface-mine waste. A NAS-NAE study group considering this problem concluded that application of 1/2 to 3/4 of an acre-foot per acre should be sufficient to establish seedlings that would survive without further irrigation. Of course, the area disturbed per ton of coal produced varies greatly with the thickness of the bed mined. Thick beds in Wyoming yield as much as 80,000 tons per acre. In comparable deposits the water needed for revegetation would amount to 2 to 3 gallons per ton over and above other requirements. Of course, the average thickness of stripable coals is less and the water requirements for revegetation are proportionately higher. Dreyfus estimates that at 500MT per year production the water requirement for Western revegetation would not exceed 24,000 acre-feet per year, or about 16 gallons per ton. This water must be of reasonably good quality (say less than 2,000mgl) to sustain plant growth. In most places these demands would be rated as small, but in parts of the arid zone of the Southwest even these nominal amounts of water raise serious questions as to plant siting and the practicability of mining.

Slide 1 shows the Colstrip Mine in E. Mountana production (A) 5,000,000 tons per year. Note regrading of waste. Rainfall here generally is sufficient to grow grass without irrigation, although it is the practice here to give the grass a single irrigation to assure a good start.

Uranimum mining has similar water needs to coal mining for dust control, ore beneficiation, and revegetation as appropriate. However, because the energy production from uranium is orders of magnitude greater than a comparable weight of coal, the use of water on-site is only about 1/10 that of coal for comparable energy yield. The AEC estimates that annualized uranium mining to supply a 1,000 mw Nuclear Reactor would disturb only 17 acres. Water used at the mine site is modest and is mostly consumed as evaporation from mill tailings ponds. Indeed, at the Highland Mine in the Powder River Basin in Wyoming (precipitation @ 14 inches) drainage from the open pit mine supplies water demand of the mine and mill except in dry summer months.

Oil-shale mining is expected to become a major industry in several areas underlain by the Green River Formation in Colorado, Utah, and Wyoming. Shale will be extracted by surface mining, underground mining, and as an adjunct to in-situ underground retorting. Retorting of extracted shale will be done on or near the mine site, because of the low oil content (20-40 gallons per ton), and large volumes of loose burnt shale will be produced. Indeed, one of the largest water demands in the entire process is for compaction and revegetation of retort plant waste, which comprises 40% of the total water use. This water is consumed by evaporation or is permanently bound with the waste, which sets up like a low-grade concrete. Estimates of water needs of an oil-shale industry range from 121,000 to 189,000 af/yr at a production level of 1,000,000 bbls/day or 2-1/2 to 4 gallons of water per gallon of oil produced. When considering a production level of 1,000,000 bbls/day it should be kept in mind that this would require mining 1,000,000 tons/day of high-grade shale -- a rate equal to more than 1/2 the tonnage of coal presently mined in the U.S. -- so it will not come about suddenly.

Petroleum production is the other energy extraction activity using significant amounts of water. Drilling currently requires about 50,000 af/yr (16 X 10^9 gallons) nation-wide, but as this is distributed over a wide area and is a single-time use, supply poses no serious problem. Where water flooding is enployed for secondary recovery larger volumes of water are needed. Salt water is used as available, but is supplemented with fresh water as needed. The nation-wide fresh water demand for this use is estimated at 175,000 af/yr currently (57 X 10^9 gallons).

<u>Transport</u> -- Turning now to transport, the main water demand in this field is for coal slurry lines, which is one of the economic trade offs rapidly coming to the fore. The outstanding operating example is the 278-mile line from the Black Mesa Mine in N.E. Arizona to the Mojave Power Plant on the Colorado River in Nevada. This line moves 4.8 million tons of coal in a 48% water slurry to supply a 1,500 MW Power Plant. The 3,200 acre-feet annual water requirement is mined from a deep aquifer system that should support this pumpage for the life of the coal resource. The slurry line supply is only 1/7 the cooling water requirement of the plant and the slurry water is largely reclaimed for power plant use. As the weight of water used in cooling is 3 times the total weight of water and coal moved in the slurry, the advantage clearly lies in transporting fuel rather than water in most cases.

Slide 2 shows the Mojave Plant. The main water consumption is by the 6 banks of forced draft cooling towers extending to the right of the plant. The prominent evaporation ponds dispose of plant blowdown, normally about 20% of make-up water supply, which is too poor in quality to return to the Colorado River.

Slide 3 shows the route and profile of the Mojave slurry line. In this case a slurry pipeline was preferred over rail transport because of the rugged terrain to be crossed. This is a good example of the option of siting a power plant where water is available rather than at the mine or the load center.

The total water consumption of the plant is 23,000 af/yr of which the slurry line furnishes one-seventh. A much larger slurry line (ETSI) is in planning stages to carry 25 million tons of coal per year from E. Wyoming 1,000 miles to Little Rock, Arkansas. This 48-inch pipeline would require some 15,000 acre-feet of water annually. Large scale lines such as this pose some difficult institutional problems, however, because they commonly involve interstate export of water from deficient areas to places where disposal of the waste water poses problems.

Refining - Energy fuel refining processes of particular interest with respect to water consumption are oil refining and uranium processing.

Oil refining, which consumes water mainly in cooling processes, requires about 10 gallons of water per gallon of oil processed. Of this, from 1 to 2 1/2 gallons is consumed, the higher figure applying to the more modern complex processes. It is estimated that consumptive use in oil refining is currently 740 thousand af/yr (241 X 10^9 gallons) (PIB est.). As this use is mainly in established industrial areas and is partly met by saline estuarine waters, it does not pose a major supply problem.

If we look now at the annualized uranium fuel cycle of a 1,000 MW nuclear Plant, we find a total consumption of 500 af/yr (165 X 10^6 gallons). As noted earlier 40% (65 mg) of this was used around the mine and mill. 90 mg (55%) is used for cooling at the uranium enrichment plant. An additional 8 mg is used mainly in uranium hexafluoride production and fuel-rod processing. To round out the total picture, we should add another 500 acre-feet of water consumed by power plants supplying electricity for the enrichment plant. If this sounds like a lot of water and energy for a 1,000 MW Plant, keep in mind that the energy produced is 22 times the energy consumed to produce the nuclear fuel.

Conversion - Having examined extraction, transport, and refining, lets look now at the really big consumers of water in the energy industry--conversion processes. Of special importance in the drive for self-sufficiency are coal gasification, coal liquefaction, oil shale retorting, use of geothermal energy for electric generation, and increased use of coal burning and nuclear reactors for electric generation. In each mode considerable flexibility is possible in process employed, plant design, location of processing facility with respect to extraction site, source and use of water, and location of market. With such flexibility it is impossible to assign rigid water requirements to any single development, but ranges of water demand are a useful first approximation for planning purposes. Moreover, in steam-electric power plant operation the economic need for high fuel efficiency generally dictates water use within close limits, hence unit values of water consumption can be estimated with considerable confidence.

Steam Electric Generation -- The most efficient method of meeting large steady electric demand (base load) is by use of a steam turbine to drive a generator. The steam may be produced from geothermal wells, by burning coal, oil, or gas, or by heat given off by nuclear fission. The power output of a steam turbine is greatly increased by reducing the pressure on the outlet side of the turbine. This is done by use of a condenser, which lowers the temperature of the exhaust steam, causing condensation and thus significantly reducing the pressure. The cooling capacity needed for the condensation phase accounts for the greatest consumption of water in the entire energy-production process.

Various systems are used for condenser cooling--once-through circulation, cooling ponds, sprayers, wet cooling towers, dry cooling towers, and combinations of the preceding systems. Once-through cooling commonly is used where the plant is near an abundant source of water, such as the sea, a large lake, or large river. As the name suggests, water from an infinite (for practical purposes) source is circulated through the condenser and carries the waste heat away to a point of discharge elsewhere on the water body. The heat is dissipated mainly through increased evaporation from the slightly warmer water body and by conduction to the atmosphere.

Where no large water body is available a natural or artifical pond may be used for storage and as a heat sink. In this mode, heat is dissipated mainly through surface evaporation from the warmed pond. Where the cooling capacity of the pond is inadequate, sprayers may be used to increase evaporation. Sprayers may also be used together with canals in once-through-systems to reduce the impact of heated discharge on fish and other aquatic biota.

Slide 4 shows the San Onofre Nuclear Power Plant, S. California. Rated at 700 MW. Cooling water is withdrawn from and returned to the Pacific Ocean.

Slide 5 shows the Rancho Seco Nuclear Power Plant near Sacramento, California. Rated at 2000 MW. A closed cycle cooling system obtains makeup from the Folsom South Canal of USBR. Condenser cooling is provided by the two natural draft hyperbolic towers. At 40 stories height they are the tallest structures in the Central Valley.

Where water is in short supply or discharge of heated water is unacceptable, and ponds are not practicable, cooling towers generally are employed. In wet cooling towers some of the warm water evaporates through contact with an air draft, either naturally induced or driven by fans, thus cooling the remaining water. Dry cooling towers dissipate heat directly to an air draft in a fashion similar to an automobile radiator. Although dry cooling towers are effective in reducing water consumption, their capital cost greatly exceeds that of wet cooling processes, and their use results in a loss of thermal efficiency as well. They find their greatest use in cold climates and to date have seen little use in the United States in steam-electric power generation.

Various combinations of these cooling techniques are applied to achieve maximum economy in combination with acceptable environmental effects. The cooling system is quite independent of the type of fuel; rather, it depends mainly on local factors such as availability of water, terrain features, and potential environmental impacts.

Slide 6 shows the heat and water balance of a typical 1,000 MW coal-fueled electric plant. Of the 9×10^9 btu/hr (billion) energy fuel input, 10% leaves as waste heat thru the stack, 5% is accounted for as miscellaneous in-plant losses, 38% leaves as electric energy, and the remaining 47% waste heat from the condenser circuit, must be disposed of through the evaporative cooling tower shown on the right. This particular plant operating 80% of the time would consume 15,000 af/yr (4.8×10^9 gallons) or as much water each year as would be used in mining 400,000,000 tons of coal from surface mines-- more than the present U.S. production. If wet flue gas scrubbers are required to meet air quality regulations on sulfur emissions, an additional consumptive use of 3,000 af/yr must be accommodated.

Considerably more detail is given in USGS Cir. 703, so I will not go into the reasons for variation in water consumption, which is closely rated to thermal efficiency of the process employed. In general the most water-thrifty systems of steam-electric generation are fossil-fueled plants at @ 40% TE, followed by nuclear plants at about 31% TE, and geothermal at 14% TE. Water consumption is roughly in inverse proportion to efficiency as will be shown on a slide later. The evaporative consumptive demand in gallons per Kwh is 0.5 for fossil-fuel, 0.8 for nuclear, and 1.8 for geothermal. This poor water efficiency for geothermal is due to inherently low temperature and pressure of natural fluids which precludes high thermal efficiency.

In terms of water withdrawals, steam-electric power is now the largest single use of water in the U.S. having passed irrigation withdrawals in 1965.

Slide 7 illustrates the rapid growth of withdrawals for thermal electric power in recent years (in billions of gallons per day). In comparing power with irrigation, it should be remembered that the power withdrawals are mainly for once-through cooling systems which consume much less of the water than do irrigation withdrawals.

Slide 8 shows annual withdrawal of water in acre-feet vs. power generated in Kwh $\times 10^9$. Mean annual discharge of the Mississippi at St. Louis is shown for a yardstick. The flattening of the curve in recent years is due to increasing thermal efficiency and greater use of closed cooling systems.

<u>Coal Gasification</u> -- As there are no modern-design coal-gasification plants of commercial scale in the United States, estimates of water demand must be based on research operations, foreign experience, and design data of projected plants. One of the chief sources of information is an engineering report of the El Paso Natural Gas Co. Burnham I Coal Gasification Complex planned for a site near Farmington, New Mexico. The processes being considered for that complex, designed to produce 288 million scp (standard cubic feet) per day of pipeline-quality gas (954 Btu per ft^3), include coal gasification by the Lurgi process followed by shift conversion, gas cooling, gas purification, and methane synthesis. In simple terms, the Lurgi Process produces a low Btu product (about 400 Btu per ft^3) which is upgraded by methane synthesis to pipeline quality. In various stages water is consumed in the chemical reaction; cooling requirements contribute additionally to the overall water demand. Because water is scarce in the region of the plant, recycling will be used to the maximum, and air cooling will be used insofar as practicable. The water input will consist of about 7,000 gpm divided from the San Juan River plus 765 gpm of moisture in the coal input, and 630 gpm produced by the

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Slide 9 is a highly simplified diagram of the water flow to the Burnham Complex. Places where water enters the process are identified in blue, while water consumptions are identified in red. The colored figures represent percentages of inflows and consumption.

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methane-synthesis reaction. Of this total input, some 26% will react to form gas, 17% will be piped to the coal mine and other offsite users, 11% will evaporate from waste ponds, 2% will leave as wet ash, and 35% will evaporate in the cooling system. This represents an extreme case of water conservation as the plant is engineered so that only 15% of gross cooling requirement is met by evaporative cooling. In other areas and under other conditions, water consumption might be considerably higher. In terms of annual consumption at an assumed load factor of 91%, the above estimates indicate total water consumption of 14,000 acre-feet per year of which about 2,500 is supplied to the mine and other offsite uses, leaving a consumptive demand for the plant of about 11,500 acre-feet per year.

To summarize, water consumption in coal gasification plants producing pipeline gas of 250 million scf per day capacity can be expected to range from about 10,000 acre-feet per year where water is at a premium to 45,000 acre-feet per year where abundant but poor-quality water is used for cooling. The principal differences are in evaporative cooling requirement and relate to the extent to which air cooling is employed and greater waste-water disposal where input water is of low quality.

Production of low Btu gas for power-plant consumption onsite rather than high Btu pipeline-quality gas is considered feasible in many situations. This can be accomplished in essentially the way planned at the Burnham Complex except that the methane-synthesis process is omitted. As the methane synthesis does not play a major role in water consumption, it appears that this alternative mode of gas production would have little bearing on consumptive demand for comparable Btu outputs.

Coal Liquefaction -- Water demand in coal liquefaction processes is poorly known because there are no commercial plants operating and numerous rival processes are presently under study. Unit water consumption estimates range from 0.2 to 1.3 acre-feet/year/bpd capacity. Until better data becomes available, projecting water requirements has little meaning.

Slide 10 is a synthesis of unit values of water consumption in the main water-consuming energy processes expressed in common units of gallons of water consumed per million Btu energy output. In the three upper bars for steam-electric power and the two bottom bars both refining, average values are shown because variability is small. On the other three processess, none of which are yet commercial, maximum and minimum values are shown as a measure of our ignorance. Other water uses described were too low to plot. It can readily be seen that steam-electric generation far exceeds other energy processes in terms of unit water use.

Using average values of unit consumptive use we have plotted net water consumption of the several processes in 1970 and as projected by AEC to 1985 under the assumption of energy self-sufficiency. Some other scenarios would show greater growth of coal electric power relative to nuclear. but otherwise the totals differ only slightly.

Slide 11 shows growth of water consumption in various classes of electric generation from about 2-1/4 million acre-feet in 1970 to about 6 million acre-feet in 1985. Projections for coal gasification indicate consumption by coal gasification of about 500,000 acre-feet by 1985. Recent deferrals of construction programs in the current capital crunch will have the effect of stretching out these projections, but more authoritative forecasts are not yet available.

Now then what does all this mean in terms of water demand for energy development in the West. There has been considerable concern expressed, especially on the banks of the Potomac, as to whether sufficient water is available for projected western energy development. Regretably, much discussion has been ill-informed. A common source of confusion is failure to distinguish between withdrawal and consumption of water. Still another is the tacit assumption that energy development necessarily involves large water consumption at the site of extraction. This latter, of course, overlooks the alternative of transporting the energy fuel off-site for conversion.

Slide 12 - let us look at current and future energy diagrams. On the left are energy fuel sources with amounts normalized to BOPDE X 10^6. Domestic oil and gas production are the largest sources of energy. The largest use group is industrial (9.9 BPOE) followed closely by transportation, residential and commercial, and electric generation. On the right is shown used vs. lost energy indicating about 50% overall thermal efficiency. It is noteworthy that electric generation and transport constitute most of the waste because of inherent low thermal efficiencies of steam turbines and internal combustion engines.

Slide 13 - If we turn now to a "business-as-usual" projection for 1990, we find significant trends that will have major impacts in the West. We find a threefold increase in electric generation supplied almost wholly by nuclear and coal. The increased coal and uranium production to accomodate this would be largely from western mines. Gas and oil go to their highest economic uses for space and process heat, and transportation. The high ratio of imported oil has implications that have received much attention in the past 1-1/2 years. A notable feature of this projection is that accompanying a more than doubling of energy consumption is a slippage in thermal efficiency from 50.5% to 44% due to proportionally larger increases in low-thermal efficiency electric generation and transport. Keep in mind that this picture is only one of many projections and much current legislation aims to correct the big oil import deficiency. Presumably this would be accomplished by reducing demand for oil and by substitution of coal insofar as possible.

Now lets examine the implications with respect to water use in the West.

1. Nuclear power represents a large consumptive use of water. By far the greatest consumptive use is for evaporative cooling at the nuclear power plant. For the forseeable future we can expect power plants to be sited close to major power markets in the Eastern states and water supply will dictate the specific plant location in most cases. In any event, the impact on water deficient areas in the West should be limited to the increased water demand related to mining except for power plants serving markets in the West, such as in Central Arizona, Central California, and Southern California.

2. Domestic natural gas production is shown as declining somewhat so one would not expect an additional impact of water supplies in the area. In any event water consumption in natural gas processing is a rather small demand.

3. Increased coal production is shown as going largely to electric production, which will represent a large water consumption at the power plant. However, it does not follow that this consumption necessarily will be in the coal producing areas. Currently, much western coal is going by rail to power plants at Midwestern electric load centers, and the economic realities will dictate that much future generating capacity be sited near load centers.

Indeed, minemouth plants such as the Four Corners and San Juan Plants are the exceptions rather than the rule, and are economically desirable because they can serve several widely separated load centers through interties. Indeed, if coal slurry transportation can overcome legal and institutional constraints that presently obstruct development, this may become the preferred method of conveying large amounts of energy over long distances to meet large electrical demands.

In the area of coal gasification the preferred sites are at mine mouth due to the low cost of gas transmission by pipeline, however, there appears to be some flexibility in plant siting through moving the fuel to a source of water via rail or slurry. Moreover, in the projection shown only 0.9 MBPOE of coal gasification is envisioned for 1990, a relatively small portion of the total.

4. In the oil sector we find a small decline in domestic production and a huge increase in imports. Presumably on-site water demand for water flooding would change very little; water demand for refining would increase in proportion to total production, but as at present this would be concentrated chiefly in Gulf Coast and Eastern refining centers.

   Water demand for oil shale production is tied to the mine site because the large volumes of material handled require retorting close to the mine and much of the water demand is for disposal of the waste shale. The projection for 1990 is 0.8 MBPOE, all in the Upper Colorado Basin. However, this is within water rights available to the states involved -- Colorado and Utah.

Summarizing, the major consumption of water in energy production is and will continue to be for steam-electric condenser cooling. The approximately 8 million acre-feet of water to be consumed nation-wide in energy processes under self-sufficiency assumptions is about the annual flow of the Colorado River thru Grand Canyon or about 1/15 of the annual flow of the Mississippi at St. Louis. Thus, at the national level there is no reason to suggest that water would be a limiting factor in energy development. Even in water deficient areas of the West the provision of water for energy development is simply a planning problem. Where costs or social or legal constraints prove insurmountable for mine mouth development, in most energy fuels, transportation of fuel to point of use generally provides a ready alternative.